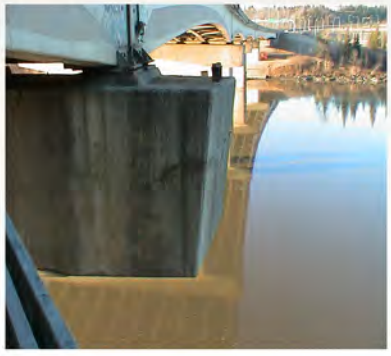

Adapting to Climate Change

Canada's First National Engineering Vulnerability Assessment

of

Public Infrastructure

April 2008

Appendix B-2
Town of Placentia, Newfoundland

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Water Resources Public Infrastructure Vulnerability Assessment for Placentia, Newfoundland

Newfoundland Labrador

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Public Infrastructure Engineering Vulnerability Committee (PIEVC) Engineering Protocol Applications

Placentia NL Case Study Application of a Climate Change – Infrastructure Vulnerability Protocol

01 Breakwater
02 Flood Wall
03 Flood Plain (Placentia Town Hall)
04 Roads and Culverts (Route 100 - Dunville)

March 25, 2008

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- John Morrissey, Ken Powers and Derrick Petten of NL Transportation and Works
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- Tammy Keats of NL Environment and Conservation

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Executive Summary – Newfoundland and Labrador

Four public infrastructures in the Town of Placentia, NL were assessed to determine if they could withstand the additional loads to be placed on them by changing climatic events. The assessment forecasted to year 2050. The Engineering Protocol of the Public Infrastructure Engineering Vulnerability Committee (PIEVC, October 2007 Version) was used. The Placentia evaluation is one of a series of case study evaluations of infrastructure located across Canada.

Infrastructure and local information was gathered from a variety of sources including NL Transportation and Works, NL Municipal Affairs, NL Environment and Conservation, and the Town of Placentia. The project team gathered data and information on specific survey elevations; analysis of climate, climate change and variability; Quaternary and surficial geology; and previously researched discussions of the natural environment and Town of Placentia. Consultations were held with the owner / operators of the Infrastructure of Interest, NL Transportation and Works and the Town of Placentia.

The project considered several relationships between climate and climate-related changes and infrastructure performance to year 2050. The relationships focused on the possibility of flooding in specific areas of the Town of Placentia based on past occurrences. These included:

- The effect of a combined sea level rise and storm surge height to 7.4 m above sea level on the stone and timber Breakwater along Placentia Beach;
- The performance of the sheet steel pile Flood Wall situated along the lagoon margin to a combined increase of sea level and maximum storm surge to 5.3 m above sea level;
- For the downtown flood plain area, the Town Hall was used as an example location. Sea level rise by 0.15m and a 12% increase in rainfall intensity would have a combined increase on the groundwater table elevation by 0.45 m from the current value of 0 m during intense rainfalls;
- The main highway road and culverts system that runs through the town could experience a 40% increase in water runoff with a 12% increase in rainfall if current land clearing practices continue.

The potential infrastructure performance considerations included structural integrity; capacity to function as intended; foundation stability; maintenance; operations and monitoring; emergency contingency planning; property damage and protection; policies and procedures; and lifecycle asset management decision making.

Following consultations with the Town of Placentia, NL Transportation and Works and the project team, assessments were made on likelihood of the combination of climate and other changes having an impact on the infrastructure performance and the severity of those impacts. High scores, indicating significant impacts on infrastructure, were further evaluated. A Vulnerability Ratio is based on the capacity of the infrastructure to meet its performance goals based on the loads being placed on it. The Adaptive Capacity indicates if and how the capacity over time can withstand the changing loads or stresses being placed on the infrastructure performance. All of these results influence the conclusions and recommendations that are made.

The most significant Breakwater recommendations are:

- Establish a baseline of wave activity, this may be achieved through the "SmartBay" system operating within the Placentia Bay;
- Demonstrate if an erosion trend exists in the beach region, in comparison to previously collected data
- Demonstrate performance trends by using, reporting, and regularly reviewing anecdotes, photographs, observations, and measurements.

The most significant Flood Wall recommendations are:

- Establish baseline monitoring of inner bay high wave events that makes use of NL Transportation personnel permanently on duty at local lift bridge. This could be enhanced with the use of passive, low maintenance, solar powered instruments
- Demonstrate a baseline splash zone corrosion rate in the steel wall
- Use life cycle asset management activities to plan for the eventual renewal or replacement of the infrastructure by 2050.

The most significant downtown Flood Plain (Town Hall) recommendations are:

- Consider higher groundwater elevations in new storm sewer pipe designs
- Any case for development in flood risk areas should consider that the indicated climate change for this area includes: 1) a 12% increase in rainfall intensity that may result in a 0.30 m increase in groundwater elevation, and, 2) a 0.15 m rise in mean sea level.

During the August 2007 tropical storm event, the NL Transportation Route 100 road and culvert system through the Dunville community section of the Town of Placentia, experienced complete failure at multiple locations. The disaster response for this specific public infrastructure in Dunville was about $500,000.00. The initial disaster response in Dunville by NL Transportation and Works was part of a multi-million dollar regional effort.

For the Dunville road and culvert system, the evaluations and recommendations were driven by a predicted 12% increase in rainfall, and a potential 40% increase in storm water runoff rates. The actual amount will depend upon changes to the vegetation cover on the steep sloped, thin soil, and shallow bedrock land directly upslope from Route 100.

The most significant Road and Culvert recommendations are:

- Future use of the Placentia IDF curve information in local designs
- Adjust the runoff coefficient value and associated travel times, for the steep sloped, thin soil, shallow bedrock proportion of the total area draining into the culvert being designed
- Account for the reduced effective flow rate and potential debris accumulation for culverts with installed end screens
- Increase the available maintenance resources, and efficiency of communication between NL Transportation and the Town of Placentia
- Adjust the mandate for designers in accordance with the anticipated changes.

A legacy of this case study is the development of Placentia specific Intensity-Duration-Frequency (IDF) curves for current and 2050 conditions.

Executive Summary – PIEVC

A climate change-infrastructure vulnerability evaluation was made of specific public infrastructure in the Town of Placentia NL. The methodology used was the October 2007 version of the Engineering Protocol of the Public Infrastructure Engineering Vulnerability Committee (PIEVC). The Placentia evaluation is one of a series of case study evaluations of infrastructure located across Canada.

The project team developed climate and other change working assumptions for 2050, regarding sea level, storm surge waves, rainfall (IDF curve format) and storm water runoff coefficient based on evolving changes in land use (particularly vegetation) cover. A PIEVC commissioned Ouranos report in January supplemented the the project teams work.

The Protocol was applied to a stone Breakwater, a steel sheet pile Flood Wall, a downtown Flood Plain (using the Town Hall as an example building location), and a road and culvert system that has failed on several occasions, most recently in 2007. The changes used in the evaluation included sea level elevation; potential wind assisted storm surge wave height; rainfall as presented in an Intensity-Duration-Frequency (IDF) curve format; storm water runoff coefficient based on land use, topographic, vegetative, and subsurface soil and bedrock conditions.

A legacy of this case study is the development of Placentia specific Intensity-Duration-Frequency (IDF) curves for current and 2050 conditions. These may be useful for a variety of public and private sector designers.

There is a reasonable expectation that the recommendations of this case study will influence the design calculations for the post-2007 tropical storm replacement culverts in the Dunville area. These are being designed and constructed in 2008.

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1.0 Climate Change Overview

The International Panel for Climate Change (IPCC) have concluded that

> "Warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level."

Impacts around the world and across Canada will vary. The newly released national assessment, ***From Impacts to Adaptation: Canada in a Changing Climate 2007***, provides a review of the current knowledge around climate change for Canada and by region and can assist in efforts to adapt the predicted changes. The regional study for Atlantic Canada (Vasseur and Catto 2007) was used in the compilation of this report.

2.0 PIEVC Protocol Overview

2.1 Introduction

With the increasing amount of research into climate change, there is a better understanding of what can be expected in terms of the effects of extreme weather events in specific regions of Canada (e.g. Vasseur and Catto 2007). With this comes a recognition that many examples of critical infrastructure were not built to withstand either repeated extreme events at current magnitudes, or the anticipated future events. Infrastructure failure could result in increased risk to public safety and large financial loses.

Natural Resources Canada and Engineers Canada established the Public Infrastructure Engineering Vulnerability Committee (PIEVC) to develop and oversee the implementation of a national scale assessment of the vulnerability of public infrastructure to the predicted impacts of climate change and variation. This proactive approach can help identify weaknesses in existing infrastructure and highlight adaptive capacity needs.

Four priority areas were identified: Buildings; Roads and Associated Structures; Storm water and Wastewater Systems; and Water Resources.

Seven pilot and case studies were conducted across Canada to test and refine the protocol.

2.2 PIEVC Engineering Protocol (Steps 1-5)

The PIEVC Engineering Protocol outlines a step-by-step procedure using a combination of basic risk assessment procedures, pre-designed worksheets, expert consultations, assessment matrix and an experts-operators' workshop. The protocol can be applied to a wide array of infrastructures and infrastructure components.

The protocol is divided into 5 steps. Pre-designed Worksheets guides the entire process. These can be found in Appendices.

Step 1. Project Definition
Step 2. Data Gathering and Sufficiency
Step 3. Vulnerability Assessment
Step 4. Indicators Analysis
Step 5. Recommendations

Step 1. Project Definition (Worksheet 1)

This steps provides an overview of what infrastructure(s) will be assessed and why.

Step 2. Data Gathering and Sufficiency (Worksheet 2)

Step 2 further defines exactly what will be assessed. It may be the entire infrastructure as a single unit or it may be more useful to divide the structure into components and assess them individually. Detailed information on the engineering of the infrastructure is gathered including the extreme climate events and loading assumptions made during the design and construction of the infrastructure, its age relative to the expected lifetime of the structure, and the maintenance, as well as management and lifecycle plans.

This is also where the specific climate and climate-related factors of concern are determined; data sources are identified and data is collected. This must include projections at and beyond the expected lifetime of infrastructure.

This step involves consultations with a large range of experts including the design, construction and maintenance engineers and other personnel; as well as climatologists and climate change experts.

Step 3. Vulnerability Assessment (Worksheet 3)

Step 3 brings together the information gathered in Step 2. Relationships between the infrastructure components and climate and climate-related factors are thorough explored to highlight vulnerabilities in the infrastructure.

During this step, data gaps are identified. Steps 1 and 2 may be revisited and additional work may be required to fill the gaps to ensure the data is sufficient to conduct the assessment.

Worksheet 3 provides assessment scales to help quantify vulnerability as the probability of a climate or climate-related event impacting the infrastructure or component and the severity of that impact. A matrix format is provided to aid this work as it can be a large task depending on the number of infrastructure components and climate factors identified. It is also important to assess the infrastructure for cumulative climate effects. For example, the cumulative impact of increased sea level, intense rainfall and storm surge on coastal infrastructure.

Pilot testing of the protocol stresses the great value in completing the assessment matrix as a workshop exercise involving both those with the expertise and those with the practical knowledge of the infrastructure being assessed. The workshop provides an opportunity for detailed discussion and increased understanding of the infrastructure, predicted changes in climatic events and vulnerabilities to those events. The workshop has the added benefit of bringing together individuals that generally would not get together for an in-depth discussion on the climate-infrastructure interactions.

The probability and severity scales rate interactions from 0 to 7, resulting in vulnerability scores from 0 to 49. The protocol provides prioritization methodology to assist with sorting and identifying critical climate-infrastructure interactions. This methodology breaks the climate-infrastructure interactions into three categories: those with high vulnerability scores that can be directly considered under Step 5 where recommendations on actions that should be taken are made; those with low vulnerability scores that do not need further action; and those in between that require further assessment under Step 4 to determine if action is required.

Step 4. Indicators Analysis (Worksheet 4)

Step 4 focuses on structural engineering to determine if the infrastructure or its components has the capacity to withstand the increased load that will be place on it.

Vulnerability exists when the infrastructure has insufficient capacity to withstand the predicted loads that will be placed on it. **Load > Capacity –** It is often represented as Load/Capacity > 1.

> Where Vulnerability exits, the Load/Capacity score is >1. Additional analysis and discussion are provided. Where Vulnerability is not considered to exist, no additional analysis is made.

Adaptive Capacity exists when the infrastructure has sufficient capacity to withstand increasing loads from climate change effects. Adaptive Capacity is the opposite of vulnerability. **Load < Capacity –** It is often represented as Capacity/Load >1.

> Where Adaptive Capacity exists, the Capacity/Load score is > 1. Discussion and Recommendations are based on making adaptations. Where Adaptive Capacity is not exist, vulnerability does, and recommendations are based on taking new initiatives.

Capacity Deficiency is the amount of capacity that must be added to the infrastructure to address the vulnerability identified. Capacity Deficiency can be calculated as Load – Capacity if sufficient data exists.

The data required for the indicator analysis may not be readily available. These data gaps may simply require additional data gathering at Steps 1 and 2 before Step 4 can proceed. However, it is possible that work required to collect the necessary data is beyond the scope of the project. In these cases, recommendations under Step 5 must identify what data are required and make suggestions on how best to collect the data.

The possibility exists that the data required for the indicator analysis is very difficult to acquire. In this case, a multi-disciplinary professional judgement using all available expertise can be made on the capacity of the infrastructure to withstand the predicted loads.

Step 5. Recommendations (Worksheet 5)

Step 5 provides recommendations based on work completed in Steps 1 through 4. These will generally fall into five categories: remedial action to upgrade the infrastructure or component; management action to account for changes in infrastructure capacity; development of or improvements to existing monitoring protocols for future assessments; Identification of data gaps and processes to fill the gaps; and no action required.

3.0 Placentia Project Site Description

For the Town of Placentia project, this section provides the information gathered under Steps 1 and 2. Background is provided on the Town of Placentia, historical climate events and efforts to protect the town's low lying areas, briefly discusses the infrastructure to be assessed and reviews the predicted changing in climate for the region.

3.1 Town of Placentia

The community of Placentia is one of the oldest in Newfoundland, with successive occupation by Beothuk, Basque, French, and English/Irish settlers. The broad gravel flats provided an ideal location for drying cod for export. The amalgamated town of Placentia includes the communities of Placentia, Dunville, Jerseyside, Freshwater (resettled residents of Argentia), and Argentia. The total population in 2006 was approximately 3,800 (Statistics Canada). The historical core of the community is located on the mid-bay barachoix, a mixed pebble-cobble, gravel-and-sand feature. An overview of the environmental setting can be conveniently obtained from Castle Hill National Historic Park, north of the harbour.

Placentia (from the Basque town of Plentzia, "a harbor within hills", changed by the French to Plaisance) was initially used by the Basques *ca.* 1540, and was founded as a French community *ca*. 1660. The oldest tombstone in the Anglican Church cemetery, being the Basque epitaph, "*Here lies having died on May 1st, 1676, John de Sale Cesana, son of the House of Sweetest Odor*", was relocated to Castle Hill Historic Park in 1985.

Unlike the English colonies, Plaisance was always intended primarily as a military base, rather than a fishing port or colonial venture. The inhabitants, however, persisted in conducting themselves in non-military ways, including fishing and commercial occupations, and even traded with the 'enemy' in St. John's and New England. Although under the Mercantile System, French vessels licensed by Louis XIV were supposed to have a monopoly on trade, in practice Plaisance merchants traded primarily with Québec and Boston. New England merchants visited several times annually, bringing less expensive and higher quality goods than the French monopolists, and receiving fish in return. Trade was extensive between 1676 and 1710. The 1713 Treaty of Utrecht confirmed English

possession of the Avalon Peninsula, forcing the French to relocate to Louisbourg in Cape Breton. Although residents were given the option of remaining and declaring allegiance to the British, only four men did so, all of whom were deeply involved in the trade with New England.

The development of the community on the bar has proceeded largely for historical reasons. Drowned forests and peat at Ship Harbour (north of Placentia) indicate that sea levels have risen in the past 1000 years. Building foundations uncovered by archaeological excavations at the site of Fort Frederick, adjacent to the lift bridge at Placentia, suggest that sea level may have been ± 3 m lower than present in the early 1600's. Evidence of enhanced erosion along many Placentia Bay beaches indicates that transgression is currently occurring.

Much of Placentia town now lies very near sea level, and the foundations of all structures are below the marine limit. Salt-water infiltration is an ongoing problem, as is flooding. Deposition has continued on the landward side of the barrier into the lagoon, following the pattern indicated by the 17 relict beach ridges on the landward side of the gravel flat, identified by Don Forbes of the Atlantic Geosciences Centre, Bedford, Nova Scotia.

Placentia has been flooded many times. A letter from the British garrison officers to the Royal Engineers in St. John's, in 1775 reported a depth of up to four feet of water in "every house in this place". More than 10 floods have occurred in the past 100 years. Northeast winds travel from landward in the Placentia region, and hence seldom cause coastal modification. Southwesterly winds, especially during August and September, are more effective agents of geomorphology.

Following flooding event in 1960, the original breakwater was built. Flooding occurred again in the 1970s and early 1980s. The 1960 structure was replaced in the 1980s with creosote – stone wall. Flooding during storm events continued as waters travelling through the channel under the lift bridge, and then washing over the community from the lagoon. In 1992 and 1993, Government extended the breakwater and installed a steel rampart (backside flood wall) around the southeast side of the community.

Floods can pose a significant threat to property and public safety. The purpose of the breakwater and the backside flood wall was to protect the existing infrastructure built on the flood plain and residences living there. The flood plain is still considered at risk to flooding and as such the Province of Newfoundland and Labrador discourages the construction of new buildings and structures within the risk area.

3.2 Infrastructure to be assessed

3.2.1 Breakwater

The Breakwater is constructed of a heavy timber cribbing network filled with stone. The heavy timber includes creosoted wood in the original section and green pressure treated wood in the part constructed in 1993. The breakwater is parallel to the main beach along Placentia Roads. It separates the active beach from Beach Road, which forms the western

limit of development for the downtown peninsula section of the Town of Placentia. The breakwater is capped by a publicly accessible boardwalk, built and maintained for resident and tourist use.

Owned and operated by the Town of Placentia, the Breakwater was originally built with Government of Canada resources in the early 1990s. Construction was a response to flooding between 1960 and 1989. There has been no flooding of downtown Placentia since the breakwater was built.

3.2.2 Flood Wall

The Flood Wall is essentially constructed of steel sheet pile wall, and was constructed in 1993. The Flood Wall breakwater is parallel to and between the main beach and a road on the downtown peninsula portion of the Town of Placentia. A publicly accessible and maintained boardwalk exists along the top of it.

Owned and operated by the Town of Placentia, the Flood Wall was originally built in the early 1990s with Government of Canada resources. This was a response to flooding between 1960 and 1989. There has been no flooding of Downtown Placentia since it was built.

3.2.3 Placentia Town Hall (Flood Plain)

The buildings on the downtown Placentia Flood plain, as represented by the Town Hall as an example property, relates primarily to the estimated 1:20 year and 1:100 year flood plain footprint areas. These areas are presented in mapping developed through the Canada - Newfoundland Agreement on Flood Damage Reduction.

These areas were derived from technical work in the late 1980s and early 1990s, prior to the construction of the current Breakwater and Flood Wall. They were a part of the technical justification for the Breakwater and Flood Plain design and construction.

If circumstances are acceptable for the Town Hall, they may be representative of other downtown flood plain building locations as well. A storm water sewer line is planned in front of the building. A sanitary sewer line runs from the downtown to the treatment plant by the Breakwater.

3.2.4 Roads and Culverts System (Dunville)

Route 100 highway from St. John's to Placentia runs through the Dunville portion of the Town of Placentia municipal unit. Uphill on the north side is a steep slope with some residences, small evergreen trees on minimal soil cover, and outcrops of bedrock. There are some barren patches within the tree cover. The forest is not logged at present, but was in the past, and when the exposed soil eroded, barren patches without tree cover were the result. The south (lower) side of the road slopes steeply towards the water, where there are more residential homes. Route 100 is at right angles to the water runoff route from north to south.

Flooding problems have involved rainfall events, partially and temporarily blocked culverts, water building up at places along the upslope of the road, water punching through culvert and road locations, and water overtopping the road and causing rapid erosion. The results have included washouts of portions of the road, replacements of road and culvert sections, the flooding of residential homes, and the temporary isolation of portions of the community.

In August 2007 rainfall from Tropical Storm Chantal resulted in extensive road and culvert damage in the area, and too many homes and private properties. The initial disaster response in Dunville by NL Transportation and Works was part of a multimillion dollar regional effort. Previous storm events have also caused road damage throughout the Cape Shore area.

4.0 Protocol Application

This section provides a general overview of climate and climate-related parameters, performance measures and adaptive capacity decision making that are applied to all four infrastructures assessed.

4.1 Climate and climate-related parameters

4.1.1 Present Climate

The climate of Eastern Newfoundland is classified as mid-boreal (Köppen-Geiger Dfb), marked by relatively cool conditions and seasonally consistent precipitation, with humid and perhumid moisture regimes. Newfoundland lies within the Boreal Ecoclimatic Province of Canada. The climate is controlled by the dominant westerly winds of the mid-latitude Northern Hemisphere, and the proximity of the relatively cold waters of the Labrador Current system of the Atlantic Ocean. Mean February sea surface temperatures are less than 0°C along the majority of the coastline. Local factors, such as topography and the prevalence of onshore and offshore breezes, create distinct mesoclimatic and microclimatic regimes in many locations.

Within the Avalon Peninsula, summers are short, cool, and wet (normally, the driest and hottest month is August). Winters are moderately mild and wet. Long springs (March through June) and relatively short autumns (September through mid-October) are normal. The Avalon zone, influenced by southwesterly winds blowing landward, is considered to be the area of Newfoundland showing the most marked maritime influence. At shoreline sites, daily mean temperatures in February vary from -2.5°C to -6°C. Interior areas are 1-2 C° colder than adjacent coastal sites.

August daily mean temperatures vary from 14°C to 16°C, with sites exposed to maritime conditions associated with southwesterly winds being cooler than sites on the northeast coast. On local scales, summer temperature values vary with aspect. Sites in these areas that are exposed to direct southwesterly winds are somewhat more variable in temperature than are sheltered areas. Freeze-thaw cycles are generally numerous from mid-December

to early April, and frost events may occur at any time from early September to June. In exposed coastal headlands, several freeze-thaw cycles may occur daily during the early and late winter.

The mean annual precipitation throughout the Avalon varies from 1500 to 1650 mm. Local variations between adjacent stations indicate that wind effects are significant in causing the amount of precipitation to be under-estimated. Individual storms (notably Gabrielle in September 2001) may bring more than 100 mm of rainfall within 24 hours. Some northeast-facing slopes on the northeast Avalon received more than 200 mm of rain during Gabrielle.

Additional variations are due to aspect and differences in the proportion of precipitation types. Areas marked by larger proportions or amounts of snowfall also generally receive less total precipitation. Shoreline areas receive less snowfall and more freezing rain and drizzle than do interior locations, although rainfall events in coastal areas may be associated with freezing precipitation events inland.

In coastal sites, typically 15-25 % of the precipitation falls as snow, although in exposed regions subject to onshore winds the proportion of snowfall may be less than 10%. Large annual variations are common.

Fog is common along the Placentia Bay shore. Argentia, the foggiest weather station in Canada, averages 206 days with at least 1 hour of fog.

Ice foot development is commonly a major factor in the geomorphic development of the Conception Bay shoreline north of Spaniards Bay, and along the Trinity Bay shoreline. Formation of an ice foot largely precludes winter erosion of beach sediments. The southerly extent of persistent ice foot development coincides with the position of the -0.5° C February SST isotherm, confining the phenomenon to the northern and central parts of the shoreline surrounding the Avalon Peninsula. Ice foot development is less common along Placentia Bay than along Trinity and Conception Bays, and is generally associated with strong positive NAO conditions.

Wind patterns vary seasonally, and local topographical effects are extremely significant in many embayments. Westerly and southwesterly winds are more prevalent throughout the year, although winds may originate from any point of the compass at any time of the year. The southwesterly winds generally bring warm, moist air to the region from the warmer ocean surface waters south of the Burin Peninsula.

Along the open shorelines of Placentia Bay, the extensive fetch allows the southwesterly winds to be effective agents driving the evolution of coastal geomorphology. Strong southwesterly winds are associated with many of the major storms and hurricanes during the summer and autumn, which generally pass over the region from southwest to northeast. Wind patterns show some seasonal variation, with easterly and southwesterly winds alternating during the summer, and southwesterlies dominating during the winter. Diurnal onshore and offshore winds are common in most embayments.

Strong southerly winds associated with late autumn and winter storms also are effective agents at modifying coastlines, if they arrive prior to the formation of pack or landfast ice.

4.1.2 Changes

Throughout Newfoundland & Labrador, natural climate change and variation can be observed since deglaciation. Ecosystems have proven to be highly resilient when influenced by previous changes in climate, but these previous events occurred over longer periods of time, and were not compounded by additional stresses imposed by human activities.

Climate change and variation operate simultaneously on different time scales. Change is recognizable from comparison of meteorological statistics from two or more periods (at a minimum of 30 years in duration), which may be consecutive sequences, periods including overlap, or multiple periods extending over longer times. Climate variation is defined as a recognizable shift or oscillation in meteorological conditions occurs over periods of one to several years, but which does not necessarily involve a change in climate over longer periods.

Climate variation regularly results in the production of different weather regimes in consecutive years (alternating dry and wet summers, yearly variations in snowfall). A changed climate regime can result in increased variation: alternation between much drier and much wetter summers can occur, without affecting the mean summer precipitation calculated over a 30-year period. Thus, increased variation can occur, without resulting in a change of the established trend in the overall mean. Although this may be considered as 'climate variation' rather than 'climate change', the effects of year-to-year variations on infrastructure may be more significant than a change spread over several decades.

Although climate change and variation are frequently considered at broad, regional scales, significant local differences exist in processes and impacts. As an example, the cyclic North Atlantic Oscillation (NAO) influences many coastal communities. The NAO is a measure of the difference in winter atmospheric pressure regime between the Icelandic Low pressure system and the Azores High pressure system. A 'positive' NAO phase occurs when the pressure differential between the Icelandic Low and the Azores High is at maximum. The effects of a positive NAO phase are most pronounced in the winter months. A 'negative' NAO phase occurs when the pressure differential between the Azores High and the Icelandic Low is reduced.

A strongly positive NAO phase results in colder temperatures in coastal Labrador, and in temperatures at or slightly below average along the eastern coastline of Newfoundland (Catto *et al.*, 2003). In these areas, positive NAO phases are marked by strong northerly winds, increased wave activity, low winter sea surface temperatures, and extended areas and durations of sea ice. Strongly positive NAO phase years (or periods within winters) result in increased snowfall in the Avalon Peninsula (Catto *et al.,* 2003; Catto, 2006a, 2006b).

The negative NAO phase produces the opposite effects, resulting in warmer, drier winters, particularly with reduced snow cover, to coastal Labrador and eastern Newfoundland.

Southwesterly winds are dominant, sea ice is reduced or restricted, and ice foot development does not occur on southern Newfoundland beaches. The strongest negative NAO effects occur in conjunction with El Niño conditions (Catto *et al.,* 2003). The available data suggest that the influence of the NAO is most significant along the coast of Labrador and northern and eastern Newfoundland. As the Avalon Peninsula is flanked by large embayments and the open Atlantic Ocean, the NAO effects are significant there.

Climate change and variation since ca. 1850 have resulted from a combination of natural and human-induced causes, with warming in North America since 1845. However, the pattern of temperature change in Atlantic Canada does not follow the general trend for interior North America, with cycles of warming and cooling and local variation. Overall, between 1948 and 2005, Atlantic Canada has warmed by approximately 0.3°C (Vasseur and Catto, 2007). Precipitation has also increased. These overall values, however, include much variation locally, and coastal areas subject to NAO influences differ substantially from interior areas.

For eastern NL, future climate change scenarios differ, due to the influence of the Labrador Current and the NAO. Limited warming of the Labrador Sea influences temperatures and precipitation, producing cooler (locally wetter) winters, and warmer, drier summers, as noted recently (e.g. Jacobs and Banfield, 2000; Catto and Hickman, 2004; Vasseur and Catto, 2007). Future climate change is anticipated to represent continuation of these trends.

4.1.3 Projections to Year 2050

The changing climate will bring increased pressure upon the coastline and onshore infrastructure through coastal erosion, increased frequency and magnitude of storm events, storm surges, decreased nearshore /coastal ice, and sea level rise. Climate changes impacts were considered, to the year 2050.

4.1.4 Sea Level Elevation

A rise in mean sea level by 0.15 m from the current value of 0 m to 0.15 m is used in this case study. This combined experience and judgement of project team members resulted in working assumption that is used in this evaluation. Ouranos report (Appendix 7) predicted a similar increase.

4.1.5 Storm Surge Wave Elevation

A rise in a potential wind assisted storm surge wave elevation by 0.25 m from the current potential wave height elevation of 7.00 m to 7.25 m is used for the Breakwater in this case study. A similar smaller value was used for the Floodwall evaluation. Catto *et.al.* (2003) comments on a maximum potential wave height for the Placentia area of 6.9 m. This is the mean significant wave height under current conditions offshore of the Avalon Peninsula, and has been used in the assessment of coastal sensitivity to sea level rise along the Placentia Bay shoreline. Catto *et al*. (2003) and Catto 2006a discusses the relationship between wind speed, duration, and incremental increase in wave height - above tidal and storm surge elevations. This combined with the experience and judgement of project team members resulted in working assumption that is used in this evaluation. A 5% increase was similar to what was presented in the Ouranos report (Appendix 7) on the upper end of range of changing wind speeds.

4.1.6 Rainfall

A rise in rainfall intensity by 12% as applied to the storm water runoff calculations and the local Intensity-Duration-Frequency (IDF) curve, is used in this case study evaluation. It is a threshold value between today and 2050. Overlaying the local medium term influence of the rise and fall of the North Atlantic Oscillation, onto a longer range but less certain climate change trend, results in a 12 % rise and then a reduction before 2050 (Appendix 8, Appendix 9). The combined experience and judgement of project team members resulted in working assumption that is used in this evaluation. From this, and the existing patterns of rainfall at different stations, were used the basis for the IDF curves developed in this case study for Placentia and again in 2050 (Appendix 8).

4.1.7 Land Use Storm Water Runoff Coefficient

The storm water runoff coefficient for steep sloped land, with very shallow bedrock close to surface, rises from 0.5 for current and very local conditions to a potential, plausible, future value of 0.7 (+40%) depending on patterns, trends and changes in land use. These values relate to a change from a thinly forested area on steep land overlying shallow bedrock (0.5), to where tree cutting results in open fields (0.7). This is for the steep slopes directly upslope from Route 100. Elsewhere in the water shed draining into the culvert, other values may be appropriate. A 0.35 value seems reasonable for forested areas, on flatter land, and more significant soil depths than those immediately adjacent to Route 100 (Appendix 8). This as well as other information sources, and the experience and judgement of project team members resulted in working assumption that is used in this evaluation.

4.1.8 Cumulative Change

Sea level rise plus the wind assisted storm surge elevation are used in the evaluations for the Breakwater and the Flood Wall. Sea level rise and increased rainfall are used in the evaluation of the Flood Plain (Town Hall building location), where the general groundwater and sea level elevations are the same. Rainfall in an IDF curve format, and land use storm water runoff coefficient used in peak flow calculations for culvert designs, are used in this evaluation for the Route 100 Dunville road and culverts. This area was damaged by the August 2007 tropical storm Chantal.

4.2 Project Performance Measures

This evaluation considered the relative influence of the predicted climate and other changes, on the following types of infrastructure performance:

- Strength
- Capacity
- Stability
- Maintenance, Operations and Monitoring
- Emergency Planning
- Property Protection (Insurance)
- Policy and Procedures
- Lifecycle Planning

The result is the following list of types of performance, prioritized in the order in which the greatest relative changes are anticipated from current circumstances, practices, and procedures. This is also a prioritized list for order in which the potential performance vulnerabilities are analyzed.

4.3 Vulnerability and Adaptive Capacity

For Strength, Capacity and Stability, the data required for the indicator analysis is not readily available. Additional work beyond the scope of the project is required to collect the necessary data.

For Maintenance, Operations and Monitoring; Emergency Planning; Property Protection (Insurance); Policy and Procedures; and Lifecycle Planning, the data required for the indicator analysis is very difficult to acquire. A multi-disciplinary professional judgement using available expertise can be made on the capacity of the infrastructure to withstand the predicted loads.

The following four sections provide information for each of the four infrastructures, lists the specific climate parameter values used, and presents the vulnerability assessment and other results.

5.0 Breakwater Infrastructure

5.1 Description

The Breakwater is constructed of a heavy timber cribbing network filled with stone. The heavy timber includes creosoted wood in the original section (1982 construction) and CCA pressure treated wood in the part constructed in 1993. The breakwater is parallel to the main beach along Placentia Roads. It separates the active beach from Beach Road, which forms the western limit of development for the downtown peninsula section of the Town of Placentia. The breakwater is capped by a publicly accessible boardwalk, built and maintained for resident and tourist use. The Breakwater is owned and maintained by the Town of Placentia. Construction was in a response to repeated flooding between 1960 and 1989. There has been no flooding of downtown Placentia since the breakwater was built.

Some relevant measurements, dimensions, and elevations are:

- 0 m is mean sea level and 0 m is used as a geodetic elevation
- 1.2 m is the typical high tide level (1992) under calm conditions. Similar tidal ranges are indicated by the available data from Argentia*
- 2.2 m: This is the typical elevation above sea level of pebble and cobble gravel accumulated by wave action at the base of the Breakwater. However, the amount of sediment varies both along the length of the Breakwater and over time. The typical

* Data from Argentia, Station 835, http://www.meds-sdmm.dfo-mpo.gc.ca/MEDS/Databases

elevation of exposed beach sand at the toe is 2.6 m. Along the breakwater, beach sand typically reaches elevations of 3.2 m
- 4.1 – 4.4 m is the typical elevation of stone on the beach side of the Breakwater
- 5.8 m is a typical top elevation of a typical Breakwater section.

Under normal circumstances, the top of the breakwater is between 2 and 4 m above the height of the beach sediment on the seaward side. However, beach profiling since the construction of the breakwater, along with numerous observations, indicates that the elevation of the sediment varies considerably. On some occasions, sediment ramparts have reached to the level of the boardwalk, indicating transport and deposition by storm waves. In other instances, erosion has removed sediment, leaving the uppermost deposits less than 2 m above mean sea level.

Current regular maintenance and monitoring efforts are minimal. The structure receives continuous wave action. Occasional waves currently overtop the Breakwater. The potential exists for erosion to compromise the breakwater in both a functional and physical way.

A catastrophic failure of this Breakwater would flood most of the downtown portion of the Town of Placentia.

5.2 Climate and Climate-related Projections

Climate Event for Breakwater	Current levels	Predicted for 2050	Predicted Change
Sea Level Elevation	0m	0.15m	+ 0.15m
Storm Surge Wave Elevation	7.00m	7.25m	+ 0.25
Sea Level Elevation and Storm Surge	7.00m	7.40m	+ 0.40m

5.3 Breakwater Performance Measures

Performance Measure	Current Status
Maintenance, Operations and Monitoring	Specific maintenance, operations, and monitoring activities currently consist of an annual inspection of the boardwalk for public use and safety.
Stability	Other Breakwater structures around the Avalon and Burin Peninsulas have failed when wave action has eroded and undermined the foundations of the structures. The resulting instability caused other structures to collapse due to gravity.
Capacity	The capacity of the structure is its ability to function as a barrier to flooding by seawater. The amount of seawater overtopping the breakwater has remained within acceptable limits, although spray and slosh have reached Beach Road.
Strength	The structural integrity of the Breakwater is the ability to maintain itself and withstand the forces being placed on it by natural and human activities.
Lifecycle Planning	Infrastructure asset lifecycle planning does not currently include the Breakwater.
Property Protection (Insurance)	Since the construction of the Breakwater (and Flood Wall), no significant road and property damage has occurred on the downtown Placentia side of the structure
Policies and Procedures	
Emergency Planning	Emergency Planning procedures are based in part on the scenario of major downtown flooding event, which might be due to a failure in Breakwater performance.

5.4 Results: Step 3 Vulnerability Assessment

Table below presents the climate-infrastructure interactions vulnerability scores for the Breakwater. The PIEVC protocol suggests further analyses under Step 4 for vulnerability scores between 12 and 36.

Breakwater Performance Measures	Climate Parameter	Vulnerability
Maintenance	Sea Level/Storm Surge	25
Stability	Sea Level/Storm Surge	25
Capacity	Sea Level/Storm Surge	24
Maintenance	Sea Level	20
Capacity	Storm Surge	16
Stability	Sea Level	16
Lifecycle Planning	Sea Level/Storm Surge	15
Stability	Storm Surge	15
Strength	Sea Level/Storm Surge	15
Lifecycle Planning	Sea Level	10
Lifecycle Planning	Storm Surge	10
Strength	Storm Surge	10
Insurance / Protection	Sea Level/Storm Surge	9
Capacity	Sea Level	6
Insurance / Protection	Storm Surge	6
Maintenance	Storm Surge	6
Policy and Procedures	Sea Level	6
Policy and Procedures	Sea Level/Storm Surge	6
Policy and Procedures	Storm Surge	4
Emergency Planning	Sea Level/Storm Surge	3
Emergency Planning	Storm Surge	3
Emergency Planning	Sea Level	2
Strength	Sea Level	2
Insurance / Protection	Sea Level	1

5.5 Results: Indicator Analysis

Further analyses were conducted on Maintenance, Stability, Capacity, Lifecycle Planning and Strength. Listed in order of priority based on the Vulnerability scores above.

5.5.1 Maintenance, Operations and Monitoring

Prudent ownership and responsibility provides a requirement to reduce information uncertainties where possible and demonstrate the validity of currently perceived trends and expectations regarding the Breakwater. In our opinion, the resources (human, equipment, time, opportunity and financial) currently being applied are insufficient for that purpose.

Therefore, a vulnerability is considered to exist, and the score is >1.

Reducing the uncertainties through monitoring may result in a changed score.

With respect to the currently available resources and mandate, Adaptive Capacity is not perceived to exist, the score is < 1.

New initiatives are recommended.

5.5.2 Stability

There is no current monitoring information that can be used to conclude if the potential for erosion exists, how it would change in the future, and what the anticipated effect would be in undermining and compromising the Breakwater foundation stability for the structure. The concern is for this form of instability, rather than cracking, deformation, and sliding.

The available data based on beach profiling since 1980 indicates that the beach sediment is highly mobile. There is no preferential area of accumulation of sediment. Although there is a net trend of sediment movement from south to north (towards the lift bridge), this pattern is inconsistent and subject to change. Southwesterly and westerly winds generally result in northward movement of sediment along the beach, but northeasterly winds cause sediment to move in the opposite direction. The overall balance of transport favours northerly movement.

The alternation of erosion and deposition recorded by beach profiling indicates erosion at the base of the breakwater along its length. Deposition by wave action that forms ramps of sediment that can be exploited by waves to overtop the barrier can also occur along the breakwater. Most accumulations of sediment ramps have been observed in the central and north-central segments of the breakwater.

Deposition and erosion can change rapidly during individual storm events. At Placentia, as elsewhere on the Avalon Peninsula, changes in sediment level in excess of 1.5 m (both increases and decreases) have been observed adjacent to breakwaters and fixed structures.

Given what has happened with other breakwater structures, and the consequences of this type of performance failure, prudent ownership and responsibility encourages a better understanding of the current and changing erosion potential.

In our opinion, the resources (human, equipment, time, opportunity and financial) currently being applied are insufficient for that purpose.

In this sense a vulnerability is considered to exist, the score is >1.

Reducing the uncertainties through monitoring may result in a changed score.

With respect to the current resources and mandate, Adaptive Capacity is not perceived to exist, the score is < 1.

New initiatives are recommended.

5.5.3 Capacity

Currently the potential exists for a wave with a height of 7 m (or about 1.2 m higher than the top of the Breakwater) to roll up against the infrastructure. Currently, the potential exists for wave action to pass water over the top of the Breakwater by overwashing. Observations of overwashing that did not result in significant damage to the breakwater could only be made during the height of storm events. Waves of similar heights have impacted other Cape Shore Beaches, such as Ship Cove, Big Barachoix, and Gooseberry Cove, on several occasions since 1990. The infrastructure owner does not perceive that an unacceptable quantity of sea water has overtopped or overwashed the Placentia Breakwater. The current capacity, based on the first fifteen years of operation, appears to be sufficient.

An incremental 10% increase due to climate change, in the unknown quantity of water that currently or has the potential to pass over the Breakwater, is not perceived to present an unacceptable performance result.

However, there is insufficient available information regarding wave heights that make it to the breakwater wall, to make better conclusions regarding this type of infrastructure performance. In general, waves and their energy appear to be substantially absorbed by the sand and gravel on the sea side of the Breakwater.

Therefore a vulnerability is considered to exist, and the score is >1.

Reducing the uncertainties regarding wave height frequency and the volume of sea water passing over the Breakwater through monitoring may result in a changed score.

With respect to the currently available resources and mandate, Adaptive Capacity is not perceived to exist, the score is < 1.

New initiatives are recommended.

5.5.4 Lifecycle Planning

Prudent ownership and responsibility provides a requirement to better prepare for the long term understand the current and changing erosion potential.

The resources (human, equipment, time, opportunity and financial) currently being applied are insufficient.

In this sense a vulnerability is considered to exist, the score is >1.

Reducing the uncertainties through monitoring may result in a changed score.

With respect to the current resources and mandate, Adaptive Capacity is perceived to exist, and the score is > 1.

Adaptation management measures are recommended.

5.5.5 Strength

Prudent ownership and responsibility encourages one to have continued confidence in the structural integrity of the Breakwater. The resources (human, equipment, time, opportunity and financial) currently being applied for this purpose are insufficient.

In this sense vulnerability is considered to exist, the score is >1.

This is based in part on no deterioration of the condition of the heavy timber used in the crib works.

With respect to the current resources and mandate, Adaptive Capacity is perceived to exist, and the score is > 1.

Adaptation management measures are recommended.

5.6 Recommendations

New initiatives associated with Stability, Capacity, Strength and Lifecycle Planning performance measures are recommended.

5.6.1 Stability

- Determine if an erosion trend exists that could undermine the structure, or that eroded material is being deposited on the beach side of the structure, or that the total volume of

sand and gravel on the beach side of the structure is fairly consistent but is moving around due to wave action*.
- Collect anecdotal information from Town residents and staff regarding exposed sand, stone cover, and potential of erosion to Breakwater. Maintain this on file with the Town of Placentia for future reference.
- Review stone cover beach profiles made at time of construction
- Maintain a regularly updated photographic record of sand and stone conditions on the sea side of the Breakwater, first at monthly intervals and changing to seasonal, annual, and multi-year intervals as trends become established.
- Conduct an intensive "beach profile" using surveyor total station equipment or functionally similar equipment. Document the exposed sand and stone conditions on the sea side of the Breakwater. Use the data to calculate a stone and sand volume with respect to the geodetic elevation of 0 m. Successive beach profiles have been made since about 1980. The data is held by Don Forbes of GSC Atlantic. Most recent profiles have used total station survey equipment. Compare results with interpretation of original beach profiles. Have an appropriate professional review the accumulated information and provide an opinion on an appropriate time interval range for further "beach profile" efforts.
- Engineering review of stability issues in 2018 and at approximately 10 year intervals.

5.6.2 Capacity

- Consider utilizing Smartbay to monitor wave action and tides at Point Verde.
- Have a regular report made of the relevant SmartBay results and copied to the Town of Placentia for future reference.
- At regular intervals, such as five years, collect anecdotal information from Town residents and staff regarding wave action over the Breakwater. Maintain this on file with the Town of Placentia for future reference.
- If concerns grow regarding wave action over the Breakwater, consider adding passive splash monitor(s) and documenting the results.

5.6.3 Strength

Adaptation management measures are recommended.
- Perform regular reported inspections by the Town Works Chief / designate
- Conduct an engineering inspection in 2018, and at approximately 10 year intervals.

5.6.4 Lifecycle Planning

Adaptation management measures are recommended.
- Have the Breakwater included in Town of Placentia asset management
- Anticipate and financially prepare for a major renewal, renovation, or replacement of the infrastructure by 2050

* Substantial data exists as held by the Geological Survey of Canada, Atlantic, in addition to that available to the consultant team.

6.0 Backside Flood Wall

6.1 Description

The Flood Wall is essentially constructed of steel sheet pile wall, constructed in 1993. The Flood Wall breakwater is parallel to and between the main beach and a road on the downtown peninsula portion of the Town of Placentia. A publicly accessible and maintained boardwalk exists along the top of it.

Owned and operated by the Town of Placentia, the Flood Wall was originally built in the early 1990s with Government of Canada resources. This was a response to flooding between 1960 and 1989. There has been no flooding of Downtown Placentia since it was built.

Some relevant measurements, dimensions, and elevations are:
- 0 m is the mean sea level and is taken as a geodetic elevation of 0 m
- 1.2 m is typical high tide (1992) under calm conditions
- 2.2 m is the typical Flood Wall section top elevation

Current regular maintenance and monitoring efforts are minimal. The structure receives continuous wave and tidal action. Waves are not known to currently overtop the Flood Wall, although occasional wind spray does occur.

The potential exists for corrosion to compromise Flood Wall performance.

A catastrophic failure of this Flood Wall with respect to sea water would result in the flooding of much of downtown Placentia.

6.2 Climate and Climate-related Projections

Climate Event for Flood Wall	Current levels	Predicted for 2050	Predicted Change
Sea Level Elevation	0m	0.15m	+ 0.15m
Storm Surge Wave Elevation	5.00m	5.15m	+ 0.15m
Sea Level Elevation and Storm Surge	5.00m	5.30m	+ 0.30m

6.3 Flood Wall Performance Measures

Performance Measure	Current Status
Maintenance, Operations and Monitoring	Specific maintenance, operations, and monitoring activities do not exist.
Stability	Steel sheet pile walls, driven down and founded on to good soil and bedrock material, and when the unbalanced, uneven, exposed surface loading from soil and water is reasonable, have good stability characteristics.
Capacity	For the infrastructure owner, the quantity of sea water passing over the Flood Wall, onto the road or property on the other side, has no reached unacceptable levels. There has been no unacceptable flooding event in downtown Placentia since the Flood Wall and Breakwater have been constructed.
Strength	The most likely challenge to the structural integrity of the Flood Wall is from corrosion in the wet / dry tidal splash zone. The Town of Placentia has proposed addition of a $300,000 cathodic protection system, with funding from other sources.
Lifecycle Planning	Infrastructure asset lifecycle planning by the Town of Placentia does not currently include the Flood Wall.
Property Protection (Insurance)	Since the construction of the Flood Wall (and Breakwater), no further road and property damage has occurred on the downtown Placentia side of the structure.
Policies and Procedures	Aside from what is indicated with other Performance Measures, there are no other policies and procedures of the Town of Placentia relating to the Flood wall infrastructure.
Emergency Planning	The Town of Placentia has established Emergency Planning procedures that are based in part on the scenario of major downtown flooding event, which might be due to a failure in Flood Wall performance.

6.4 Results: Step 3 Vulnerability Assessment

Table below presents the climate-infrastructure interactions vulnerability scores for the Backside Flood Wall. The PIEVC protocol suggests further analyses under Step 4 for vulnerability scores between 12 and 36.

Backside Flood Wall Performance Measures	Climate Parameter	Vulnerability
Maintenance	Sea Level/Storm Surge	24
Maintenance	Storm Surge	20
Capacity	Sea Level/Storm Surge	18
Lifecycle Planning	Sea Level/Storm Surge	15
Capacity	Storm Surge	12
Maintenance	Sea Level	12
Lifecycle Planning	Sea Level	10
Lifecycle Planning	Storm Surge	10
Capacity	Sea Level	9
Strength	Sea Level/Storm Surge	9
Stability	Sea Level	6
Stability	Sea Level/Storm Surge	6
Stability	Storm Surge	4
Strength	Storm Surge	4
Insurance / Protection	Sea Level/Storm Surge	3
Policy and Procedures	Sea Level/Storm Surge	3
Emergency Planning	Sea Level/Storm Surge	2
Emergency Planning	Storm Surge	2
Insurance / Protection	Sea Level	2
Insurance / Protection	Storm Surge	2
Policy and Procedures	Sea Level	2
Policy and Procedures	Storm Surge	2
Emergency Planning	Sea Level	1
Strength	Sea Level	1

6.5 Results: Indicator Analysis

Further analyses were conducted on Lifecycle Planning, Maintenance, Capacity, and Stability. Listed in order of priority based on the Vulnerability scores above.

6.5.1 Maintenance, Operations and Monitoring

Prudent ownership and responsibility provides a requirement to reduce some information uncertainties and demonstrate the validity of some currently perceived trends and expectations regarding the Breakwater.

The resources (human, equipment, time, opportunity and financial) currently being applied are insufficient.

In this sense a vulnerability is considered to exist, the score is >1.

Reducing the uncertainties through monitoring may result in a changed score.

With respect to the currently available resources and mandate, Adaptive Capacity is not perceived to exist, the score is < 1.

New initiatives are recommended.

6.5.2 Capacity

Currently the potential exists for a wave with a height of 5 m (or about 3 m higher than the top of the Flood Wall) to roll up against the infrastructure. Anecdotal information suggests that sea waves lose significant energy while moving through the inlet spanned by the Lift Bridge. The result is not unobstructed wave action against the wall, but what infrequently appears as a very high tide.

Currently the potential exists for wave action to pass water over the top of the Flood Wall. That may not have happened yet since the breakwater construction, but the potential exists. The infrastructure owner does not perceive that an unacceptable quantity of sea water has overtopped or overwashed the Flood Wall. The current capacity, based on the first fifteen years of operation, appears to be sufficient.

An incremental 10% increase due to climate change, in the unknown quantity of water that currently or has the potential to pass over the Breakwater, is not perceived to present an unacceptable performance result.

However, there is insufficient available information regarding wave heights reach the Flood Wall, to make better conclusions regarding this type of infrastructure performance. In general, waves and their energy appear to be substantially absorbed by moving through the inlet spanned by the lift bridge.

In this sense a vulnerability is considered to exist, the score is >1.

Reducing the uncertainties regarding wave height frequency and the volume of sea water passing over the Flood Wall through monitoring may result in a changed score.

With respect to the currently available resources and mandate, Adaptive Capacity is not perceived to exist, the score is < 1.

New initiatives are recommended.

6.5.3 Lifecycle Planning

Prudent ownership and responsibility provides a requirement to better prepare for the long term understand the current and changing erosion potential.

The resources (human, equipment, time, opportunity and financial) currently being applied are insufficient.

In this sense a vulnerability is considered to exist, the score is >1.

Reducing the uncertainties through monitoring may result in a changed score.

With respect to the current resources and mandate, Adaptive Capacity is perceived to exist, and the score is >1.

Adaptation management measures are recommended.

6.5.4 Strength

Visual discolouration was noted in the splash zone. However, the degree and rate of corrosion has not been quantitatively demonstrated. The resources (human, equipment, time, opportunity and financial) currently being applied for this purpose are insufficient.

In this sense a vulnerability is considered to exist, the score is >1.

With respect to the currently available resources and mandate, Adaptive Capacity is not perceived to exist, the score is < 1.

New initiatives are recommended.

6.6 Recommendations

New initiatives are recommended.
Those associated with Capacity, Life Cycle Planning, and Strength performance objectives

6.6.1 Capacity

New initiatives are recommended.

- Seek to have water level observation information recorded by the NL Transportation and Works Placentia Lift Bridge staff (manned 24 / 7)
- Seek to have water level information maintained by Town of Placentia for future reference.
- Seek to have high / low or yes / no water level information collected and maintained for the top meter of the Flood Wall at a high wall elevation, relatively close to the Lift Bridge
- Have a Professional Review of the accumulating water level information and have an opinion provided on the frequency and duration that the water level rises to within 1 m of the top of the Flood Wall at the measuring point.
- Add a new buoy to the Smartbay.ca network to monitor wave action and tides at Point Verde
- Have a regular report made of the relevant SmartBay.ca results and copied to the Town of Placentia for future reference
- At regular intervals, such as five years, collect anecdotal information from Town residents and staff regarding wave action over the Flood Wall. Maintain this on file with the Town of Placentia for future reference.
- If concerns grow regarding wave action over the Flood Wall, consider adding passive splash monitor(s) and documenting the results.

6.6.2 Lifecycle Planning

Adaptation management measures are recommended.

- Have the Flood Wall included in Town of Placentia asset management
- Anticipate and financially prepare for a major renewal, renovation, or replacement of the infrastructure by 2050
- Perform regular reported inspections by the Town Works Chief / designate

6.6.3 Strength

Adaptation management measures are recommended.

- Have a professional opinion on the degree and rate of corrosion, especially in the wet / dry splash zone.
- Have a professional opinion on a cost effective set of measures such that corrosion does not compromise the strength of the steel sheet pile wall or the capacity to keep water on the salt water side of the wall.

7.0 Town Hall / Flood Plain

7.1 Description

The buildings on the downtown Placentia Flood plain, as represented by the Town Hall as an example property, relates primarily to the estimated 1:20 year and 1:100 year flood plain footprint areas. These areas are presented in mapping developed through the Canada - Newfoundland Agreement on Flood Damage Reduction.

These areas were derived from technical work in the late 1980s and early 1990s, prior to the construction of the current Breakwater and Flood Wall. They were a part of the technical justification for the Breakwater and Flood Plain design and construction.

If circumstances are acceptable for the Town Hall, they may be representative of other downtown flood plain building locations as well. A storm water sewer line is planned in front of the building. A sanitary sewer line runs from the downtown to the treatment plant by the Breakwater. Originally storm water drainage was directly discharged into the infiltration capacity of the porous, coarse, marine washed, surface soil material.

The flooding in downtown Placentia that occurred in the 1960s, 1970s and 1980s did not happen again after the construction of the Breakwater and Flood Wall. Downtown Placentia did not experience any flooding during the August 2007 post-tropical storm event , which resulted in flooding in Dunville.

If the Breakwater, Flood Wall, and Lift Bridge operate in the future as intended, the current flood risk to the Town Hall could be impacted by a combination of increased rainfall, and a decreased capacity of the ground to absorb storm water due to either higher groundwater (or tidal) elevations.

Some relevant measurements, dimensions, and elevations are:

- 0 m is mean sea level and 0 m is used as a geodetic elevation
- 0.45 m is the anticipated upper future mean groundwater elevation
- 0.55 m is the approximate bottom of the foundation footings
- 1.75 m is the floor elevation for the Town Hall, and
- 2.2 m is the typical top elevation of the Flood Wall.

7.2 Climate and Climate-related Projections

Climate Event for Town Hall/Flood Plain	Current levels	Predicted for 2050	Predicted Change
Sea Level Elevation	0m	0.15m	+ 0.15m
Storm Surge Wave Elevation	7.00m	7.25m	+ 0.25m
Sea Level Elevation and Storm Surge	7.00m	7.40m	+ 0.40m
Rainfall		+0.30m	12%
Sea Level Elevation and Rainfall	0m	0.45	+ 0.45m

Sea Level Rise and Rainfall
Storm water rainfall intensity increases by 12% as applied to the storm water runoff calculations and the local Intensity-Duration-Frequency (IDF) curve. If all the rain goes into beach wash soil having an effective porosity of 0.33, it is assumed that a 0.30 m change in groundwater elevation would occur from time to time. A rise in the combination of mean sea level and rainfall percolating into the beach wash surface material is 0.45 m (0.15 m + 0.30 m) from the current groundwater elevation of effectively mean sea level.

7.3 Town Hall/Flood Plain Performance Measures

Performance Measure	Current Status
Maintenance, Operations and Monitoring	Specific maintenance, operations, and monitoring activities would support the Flood Plain Town Hall building capacity to function and perform as desired.
Stability	The relatively small, single story, slab on grade Town Hall building in the downtown Flood Plain, has a perimeter concrete foundation wall. The current groundwater table is not above the foundation footing elevation.
Capacity	The Town Council perceives that the Town Hall building has an uninterrupted capacity to function as the administrative and executive centre for the Town of Placentia municipal government.
Strength	The structural integrity of the Town Hall building is the ability to maintain itself and withstand the flood plain forces being placed on it by natural and human activities (i.e. wind, rain, rising groundwater levels, flooding). The most likely challenge to the structural integrity of the Town Hall building would be if flooding were occurring above the floor elevation.

Performance Measure	Current Status
Lifecycle Planning	Infrastructure asset lifecycle planning does not currently include the Town Hall/Flood Plain
Property Protection (Insurance)	Since the construction of the Breakwater (and Flood Wall), no significant road and property damage has occurred on the downtown Placentia side of the structure
Policies and Procedures	A flood plain development policy exists for much of this area.
Emergency Planning	Emergency Planning procedures are based in part on the scenario of major downtown flooding event.

7.4 Results: Step 3 Vulnerability Assessment

Table below presents the climate-infrastructure interactions vulnerability scores for the Town Hall/ Flood Plain. The PIEVC protocol suggests further analyses under Step 4 for vulnerability scores between 12 and 36.

Town Hall/Flood Plain Performance Measures	Climate Parameter	Vulnerability
Policy and Procedures	Sea Level/Rainfall	15
Lifecycle Planning	Rainfall	10
Lifecycle Planning	Sea Level/Rainfall	10
Insurance / Protection	Sea Level/Rainfall	9
Maintenance	Sea Level/Rainfall	9
Capacity	Sea Level/Rainfall	8
Insurance / Protection	Rainfall	8
Policy and Procedures	Rainfall	8
Policy and Procedures	Sea Level	8
Capacity	Rainfall	6
Maintenance	Rainfall	6
Lifecycle Planning	Sea Level	5
Capacity	Sea Level	2
Emergency Planning	Rainfall	2
Emergency Planning	Sea Level/Rainfall	2
Maintenance	Sea Level	2
Stability	Rainfall	2

Stability	Sea Level/Rainfall	2
Emergency Planning	Sea Level	1
Insurance / Protection	Sea Level	1
Stability	Sea Level	1
Strength	Rainfall	1
Strength	Sea Level	1
Strength	Sea Level/Rainfall	1

7.5 Results: Indicator Analysis

Further analyses were conducted on Lifecycle Planning, Policy and Procedures, and Capacity. Listed in order of priority based on the Vulnerability scores above.

7.5.1 Policy and Procedures

The need to update the applicable current policies and procedures associated with the flood plain, are anticipated to increase in response to proposals for development. Any case for changing the applicable policies and procedures associated development in flood risk areas should consider that the indicated climate change for this area includes: 1) a 12% increase in rainfall intensity that may result in a 0.30 m increase in groundwater elevation, and, 2) a 0.15 m rise in mean sea level.

In this sense a vulnerability is considered to exist, the score is >1.

The Town of Placentia operates with its own staff and political representatives, and on a case by case basis, with the support of professionals and others.

With respect to the current resources and mandate, Adaptive Capacity is perceived to exist, and the score is > 1.

Adaptation management measures are recommended.

7.5.2 Lifecycle Planning

Prudent ownership and responsibility provides a requirement to better prepare for the long term understanding of the current and changing groundwater elevations and storm water run off flooding potential.

A potential example is with respect to the new storm water line that is planned for the street in front of the Town Hall. Currently some catch basins collect and convey rain water running off from the hard asphalt surfaces of paved areas. A rising sea level and groundwater elevation could influence the design and construction of the pipeline and trench. This could

happen when there is a concern of buoyant forces potentially acting on the piping infrastructure.

In our opinion, the resources (human, equipment, time, opportunity and financial) or capacity currently being applied seem insufficient to meet the anticipated future goals of the Town of Placentia.

In this sense a vulnerability is considered to exist, the score is >1.

The Town of Placentia operates with its own staff and political representatives, and on a case by case basis, with the support of professionals and others.

With respect to the current resources and mandate, Adaptive Capacity is perceived to exist, and the score is > 1.

Adaptation management measures are recommended.

7.6 Recommendations

7.6.1 Lifecycle Planning

Adaptation management measures are recommended.

- Have a long term lifecycle planning system for municipal infrastructure
- Prioritize the infrastructure order involved with in lifecycle planning
- Where most appropriate, include climate change considerations
- Anticipate long term financial requirements for infrastructure repair, renewal, and replacement, and source or raise funds appropriately
- Consider a life cycle management system that is run and updated by the Town of Placentia, audited by an appropriate professional, and copied to NL Municipal Affairs on a regular basis for future reference.
- The design and construction of the new storm sewer line in front of the building could also account for the rise in groundwater elevations considered in this case study evaluation, where there is a concern of buoyant forces potentially acting on the piping infrastructure.

7.6.2 Policies and Procedures

Adaptation management measures are recommended.

- The Town of Placentia intends to make a coordinated technical and political case in support of its flood plain policy application goals. These goals need to take into account that the indicated climate change for this area includes: 1) a 12% increase in rainfall intensity that may result in a 0.30 m increase in groundwater elevation, and, 2) a 0.15 m rise in mean sea level.

8.0 Roads and Culverts (Dunville)

8.1 Description

Route 100 highway from Whitbourne to Placentia runs through the Dunville portion of the Town of Placentia municipal unit. Uphill on the north side is a steep slope with some residences, small evergreen trees on minimal soil cover, and outcrops of bedrock. There are some barren patches within the tree cover. The forest is not logged at present, but was in the past, and when the exposed soil eroded, barren patches without tree cover were the result. The south (lower) side of the road slopes steeply towards the water, where there are more residential homes. Route 100 is at right angles to the water runoff route from north to south.

Flooding problems have involved rainfall events, partially and temporarily blocked culverts, water building up at places along the upslope of the road, water punching through culvert and road locations, and water overtopping the road and causing rapid erosion. The results have included washouts of portions of the road, replacements of road and culvert sections, the flooding of residential homes, and the temporary isolation of portions of the community.

In August 2007, post-tropical storm rainfall resulted in extensive road and culvert damage in the area, and to many homes and private properties. The initial disaster response in Dunville by NL Transportation and Works was part of a multimillion dollar regional effort. Previous storm events have also caused road damage throughout the Cape Shore area.

Some relevant measurements, dimensions, information, and elevations are:

- 0.35 is the typically used storm water run off coefficient for a forested area
- Intensity-Duration-Frequency information used is associated with the St Lawrence station (Burin Peninsula) Route 100 Dunville culvert design is based on 1:100 year return period design flows

8.2 Climate and Climate-related Projections

Climate Event for Roads and Culverts (Dunville)	Current levels	Predicted for 2050	Predicted Change
Rainfall		+0.30m	+ 12%
Land Use Storm Water Runoff			
Steep slope, shallow bedrock	0.5	0.5	0
Steep slope, shallow bedrock PLUS decrease in tree cover	0.5	0.7	+40%
Forested area, deeper soil	0.35	0.35	0
Rainfall and Land Use Runoff (0.7)			+ 52%

Land Use Storm Water Runoff Coefficient
The storm water runoff coefficient for steep sloped land, with very shallow bedrock close to surface, rises from 0.5 to 0.7 (+40%). These values relate to a change from a thinly forested area on steep land overlying shallow bedrock (0.5), to where tree cutting results in open fields (0.7). This is for the steep slopes immediately adjacent to Route 100. Elsewhere in the water shed draining into the culvert, other values may be appropriate. A 0.35 value seems reasonable for forested areas, on flatter land, and more significant soil depths than those immediately adjacent to Route 100.

Combined Rainfall and Land Use Runoff Coefficient
In the rational method, the peak discharge flow rate (Q) passing through a culvert is estimated by multiplying an applicable land use runoff coefficient (C), by the rainfall intensity (I), and the watershed area (A) draining to the culvert.

Storm water rainfall intensity increases by 12% as applied to the storm water runoff calculations and the local Intensity-Duration-Frequency (IDF) curve.

A rise in rainfall intensity of 12% becomes a 12% rise in the culvert flow rate (Q).

A 40% rise in the land use storm water runoff coefficient (C) from 0.5 to 0.7, for a steep sloped land with very shallow bedrock, close to surface, becomes a 40% rise in the flow rate (Q) for that particular area or portion of an area draining into a culvert.

A combination of changes for the indicated Rainfall (+12%) and land use Runoff (+40%) becomes a 52% rise in the culvert flow rate (Q), if the coefficients are used for the entire Area of interest.

8.3 Roads and Culverts Performance Measures

Performance Measure	Current Status
Maintenance, Operations and Monitoring	Specific maintenance, operations, and monitoring activities are conducted to support the intended capacity and function of the Route 100 road and culvert system in Dunville.
Stability	The potential for storm water run off to result in erosion around the culverts and of the road bed materials provides an opportunity for instability to occur.
Capacity	Post-tropical storm rainfalls in August 2007resulted in rain water run off flow rate beyond the culverts current capacity.
Strength	The structural integrity of the culverts is the ability to maintain itself and withstand the forces being placed on it by natural and human activities (i.e. traffic over it, water through it).

Performance Measure	Current Status
Lifecycle Planning	Infrastructure asset lifecycle planning do not incorporate adaptations for climate and other changes into its decision-making.
Property Protection (Insurance)	In spite of previous property protection efforts associated with the road and culvert system extensive damage to both Crown and Town assets, and private property occurred.
Policies and Procedures	
Emergency Planning	The locally applicable emergency planning procedures were applied and updated in response to the August 2007 storm

8.4 Results: Step 3 Vulnerability Assessment

Table below presents the climate-infrastructure interactions vulnerability scores for the Roads and Culverts (Dunville). The PIEVC protocol suggests further analyses under Step 4 for vulnerability scores between 12 and 36.

Roads and Culverts Performance Measures	Climate Parameter	Vulnerability
Capacity	Rainfall-runoff	30
Stability	Rainfall-runoff	25
Insurance / Protection	Rainfall-runoff	24
Insurance / Protection	Runoff (Land Use)	24
Maintenance	Rainfall-runoff	24
Stability	Runoff (Land Use)	20
Capacity	Runoff (Land Use)	18
Lifecycle Planning	Rainfall-runoff	16
Policy and Procedures	Rainfall-runoff	16
Strength	Rainfall-runoff	16
Maintenance	Runoff (Land Use)	15
Capacity	Rainfall	12
Emergency Planning	Rainfall-runoff	12
Lifecycle Planning	Runoff (Land Use)	12
Maintenance	Rainfall	12
Policy and Procedures	Runoff (Land Use)	12
Stability	Rainfall	12
Strength	Runoff (Land Use)	12

Emergency Planning	Runoff (Land Use)	9
Lifecycle Planning	Rainfall	9
Insurance / Protection	Rainfall	8
Emergency Planning	Rainfall	6
Policy and Procedures	Rainfall	4
Strength	Rainfall	4

8.5 Results: Indicator Analysis

Further analyses were conducted on Capacity, Stability, Insurance/ Protection, Maintenance, Lifecycle Planning, Strength, Emergency Planning and policy and Procedures. Listed in order of priority based on the Vulnerability scores above.

8.5.1 Capacity

One way of estimating the peak flow on smaller streams (with < 25 km2 in drainage area) is the Rational Method. The design peak flow (Q) for a storm event of given frequency passing through a culvert is based on the multiplication of an applicable land use runoff coefficient (C), rainfall intensity (I), and upstream drainage area (A).

$Q = C \times I \times A$

In the Dunville area, the 1:100 year return period peak flow is used for culvert sizing along Route 100, and a 1:50 year return period peak flow is often used for culvert sizing under other roads in the area with a different designation. The typically, but not exclusively applied value of the runoff coefficient is 0.35, which corresponds to a forested area, not too steep, with underlying soil. Applied intensity values come from data for the St Lawrence weather station, on the Burin Peninsula. The travel time value is influenced by the grades and topography information. Typically 1:50,000 mapping is used, but where available some digital 1:2500 mapping is used. The drainage area value is based on interpreting available topographic information. Culverts are typically designed with a capacity that assumes the end is open. A 50 mm x 50 mm metal screen is often placed at the end of a culvert which reduces the effective capacity of the culvert. Any accumulation of debris such as pieces of cut bush or plastic bags will also reduce the effective capacity of the culvert.

The Dunville area also has a former railway bed running through it*. The drainage characteristics from when the line was operating, typical a generation or two ago, may be changing. The condition of the rail bed trail has worsened in more recent years, and water ponds in some places that were not flooded in the past. If the former railway bed either is introducing more water into the area, allowing more water to stay in the area, or is no longer

* The rail line through Jerseyside was abandoned in the 1920s; other branch lines were decommissioned in 1984.

allowing water to drain as quickly from the area. Culvert design decision makers might reconsider the values already being used for the effective drainage area, and the associated runoff coefficient used in the peak flow estimation.

Prudent ownership, responsibility, and the current design intentions provides a requirement to improve the understanding of reasonably anticipated run off loads or flow through rates, and the effective capacity of the constructed and maintained culvert in accomplishing this.

Since the August 2007 storm resulted in extensive property damage and cost to both the public and private sectors, an internal review by NL Transportation and Works seems merited on the current culvert sizing decision making, practices, and typical working assumptions. Those used in the past seem insufficient to handle increased flows that are associated with climate and other changes, as indicated in this case study evaluation.

Therefore a vulnerability would exist, and the score is >1.

With respect to the context of continuing to use the currently applied practices, Adaptive Capacity is not perceived to exist, and the score is < 1.

New initiatives are recommended.

8.5.2 Stability

During 2007 post-tropical storm, instability occurred when road bed materials were eroded from high water in ditches, from around culverts, and from water washing over the asphalt to the “downstream side” and then eroding road bed materials between the asphalt and culvert.

If upstream culvert owners took actions that reduce the potential for capacity problems to occur at their culverts, this would reduce the potential for storm water to run down roads connecting to Route 100, over Route 100, and eroding road bed materials on the other side of Route 100.

There is a relationship between the size of a ditch alongside the road, and the flow rate of the storm water passing through it. The ditching along Route 100 in this area partially has a hard bedrock face, and softer materials below the road and adjacent shoulder. Very high water elevations result in the erosion of some shoulder supporting road bed materials, causing some partial instability to the road.

This also applies to the lower soft ditch materials, especially around the culverts.

In other jurisdictions, some “steel” culvert pipe in high flow and erosion conditions has distorted, with ends folded inwards. This reduces the effective capacity, increases the hydraulic pressure or push on the folded area, reduces the friction bond between the pipe and the soil, and causes shifting in the pipe. On occasion, pipes have been pushed completely through the road bed, with a subsequent collapse in the then unstable and unsupported road. The Route 100 infrastructure owner installs concrete head walls or

equivalent rigid supports on a per-case or as needed basis. This could be considered, or reconsidered, for the Dunville locations, given the anticipated increase in storm water flow rates.

Compared to older “steel” culvert piping, the newer aluminium coated culverts used by the Route 100 infrastructure owner (if the coating remains intact) and concrete pipe have a longer life span. This results in reduced opportunity for long-term corrosion to go through the pipe wall, and a reduced instability potential from the subsequent washout of road bed materials and creation of voids adjacent to portions of the pipe.

In our opinion, the resources (human, equipment, time, opportunity and financial) currently being applied to these considerations, appear to be insufficient.

Therefore a vulnerability is considered to exist, and the score is >1.

With respect to the context of continuing to use the currently applied practices, Adaptive Capacity is not perceived to exist, and the score is < 1.

The Route 100 road and culvert infrastructure owner does have potential access to sufficient resources to meet the stability performance objectives. These stability questions would have been addressed at other locations within its jurisdiction. For Dunville, the recent experiences, and anticipated future storm water run off rates loadings make a case for considering if such resources merit their application at this particular location.

New initiatives are recommended.

8.5.3 Property Protection (Insurance)

To a certain extent, climate change and land use changes affecting run-off coefficients “upstream” of the road and culvert system, are not ones that can be influenced by the infrastructure owner. That infrastructure owner can improve maintenance and change the practices used for the design and construction of new culverts, thereby allowing for greater flow capacity than was available in August 2007. These adjustments may also result in a greater water discharge capacity than previously existed for the Dunville road and culvert system.

Improvements in highway drainage efficiency that result in higher peak flows could result in “downstream” culverts having insufficient capacity, thereby resulting in local flood and erosion events.

While the Route 100 Dunville road and culvert infrastructure owner is not responsible for the protection of downstream public and private property, there are some responsibilities if the action or inaction of the infrastructure owner results in the creation or transfer of flood risk to other property owners. Communicating to downstream culvert owners and decision makers that more water than previously expected may be coming their way, provides an opportunity for them to similarly respond and prepare for changing conditions.

Current levels of downstream property protection associated with the Route 100 Dunville road and culvert infrastructure are anticipated to decrease if there is no accounting for the indicated climate and other changes. Also, when these climate and other changes are accounted for in the Route 100 Dunville road and culvert system, other downstream culvert owners may not have been accounted for this, and the perceived or desired level of protection to property may not be what is intended (i.e. protection against a specific 10, 20, or 50 year storm event).

Senior management could mandate technical staff to enter into more effective communications with other jurisdictions, such as the Town of Placentia, about these changing circumstances.

This could also be helpful with upstream culvert owners and operators as well. When those culverts have insufficient effective capacity during a storm water run off event, the potential exists for the water to take other unanticipated routes. During the August 2007 Chantal event, water rolled over Route 100, from uphill streets, causing damage to downstream property and erosion of materials from the road bed.

In our opinion, some current policies and procedures may be unresponsive to the projected climate and land use changes.

In this sense a vulnerability is considered to exist, and the score is >1.

Changed mandates and policies by senior management can be accommodated.
With respect to the potentially available resources of the infrastructure owner, Adaptive Capacity is perceived to exist, and the score is > 1.

Adaptation management measures are recommended.

8.5.4 Lifecycle Planning

Culvert designs have largely been based on historical data and conditions which would continue to be a sound approach if hydro-climatic conditions were not projected to change during this century. The traditional approach to peak flow estimation often is reflected in textbooks, accepted practices, best management plans, and where applicable, specific codes or regulatory guidelines.

Although many engineers and technical specialists increasing are aware of changing climatic conditions, information on the local effects of climate change is often lacking or in some cases even contradictory. Furthermore, engineers often lack the guidance or support of senior management with respect to climate change, as adaptation is often associated with increased costs.

However, if senior management clearly mandated consideration of climate and other anticipated future changes, and made supporting resources available, then consideration of climatic change would become routine in design efforts.

Prudent ownership and responsibility encourages one to understand current and changing potential flood risks.

In our opinion, the resources (human, equipment, time, opportunity and financial) or capacity currently being applied is insufficient to meet the anticipated future goals of the infrastructure owner for better total lifecycle planning of infrastructure assets.

Therefore, with respect to the current resources and mandate, a vulnerability is considered to exist, and the score is >1.

It is perceived that those currently responsible for the design, construction, maintenance and operation of culverts in the area, could apply sufficient resources in the future, such that the desired performance goals are achieved.

Therefore, Adaptive Capacity is perceived to exist, and the score is > 1.

Adaptation management measures are recommended.

8.5.5 Policies and Procedures

For the applicable current policies and procedures associated with the infrastructure, the greater case for change is anticipated, in response to indicated climate and other changes.

Currently the NL Transportation and Works Design Specifications includes a drawing for a 50 mm x 50 mm mesh screen for the end of culverts. It is understood that the original intent of these end screens was to discourage people from entering culverts. This size of screen can have a significant and typically unaccounted influence on the culvert capacity which is often calculated as an open pipe. The end screens can plug up fairly quickly with plastic shopping bags, cut brush, and more debris. This occurs during a rain storm event, thereby reducing the effective flow capacity of the culvert, and increasing the possibility of erosion of the road embankment and required greater maintenance efforts.

Currently, the infrastructure owner relies on Intensity – Duration – Frequency IDF curves from Environment Canada. These are not always for the site of particular interest to the infrastructure owner, are sometimes based on aged information, and do not take into account anticipated changes in the future.

This case study provides an example where site-specific IDF curves are produced for the present and for 2050. This was done for Placentia. The possibility exists to prepare IDF curves for specific times and locations, for use on specific infrastructure projects.

Current policies regarding end screens and the use of Environment Canada IDF curve information, can result in culvert design decision making having insufficient capacity to adequately account for end screen based capacity reductions, and IDF information that has incorporated the indicated climate change information.

Some policies and procedures may be currently unresponsive if the intent is to account for the indicated climate and land use changes.

In this sense a vulnerability is considered to exist, and the score is >1.

Changed mandates and policies by senior management could result in designs with a greater capacity to adapt to climate and other changes. With respect to the potentially available resources of the infrastructure owner, Adaptive Capacity is perceived to exist, and the score is > 1.

Adaptation management measures are recommended.

8.5.6 Strength

The practice in this jurisdiction is to use “steel” culverts. In response to a shorter than desired lifecycle for steel and zinc coated culverts, the recently enacted policy is to use pipes with an aluminium coating. If the coating is scratched, cut, or similarly compromised, a shorter than desired lifecycle may be the result.

While the culvert handling, construction, and material abrasion may influence the culverts with an aluminium coating and by extension, the integrity of the structure over time, climate and other changes do not affect the structural integrity of the structure over time.

The current structural integrity performance by the typical road and culvert components would not significantly change in response to indicated climate and other changes.

Vulnerability is not considered to exist, and the score is < 1.

No additional analysis is made.

8.5.7 Maintenance, Operations and Monitoring

The current activities include regular inspections for the accumulation of cut bush, plastic bags, and other debris at the ends of the culverts where they can decrease the effective conveyance capacity of the culvert, thereby possibly increasing flow velocities through the culvert, resulting in downstream erosion or scour, or in upstream flooding. The debris most often accumulates as a result of storm run off.

In our opinion, some current policies and procedures with respect to culvert management may be inadequate in providing means to respond to anticipated climate and land use changes.

In this sense a vulnerability is considered to exist, and the score is >1.

Changed mandates and maintenance policies can be made by the infrastructure owner.

With respect to the potentially available resources of the infrastructure owner, Adaptive Capacity is perceived to exist, and the score is > 1.

Adaptation management measures are recommended.

8.5.8 Emergency Planning

The local authorities are satisfied with the current state of their preparations. The capacity of their emergency planning is perceived to exceed the storm risks.

Vulnerability is not considered to exist, and the score is < 1.

No additional analysis is made.

8.6 Recommendations

The general trends and conclusions in this section apply when the change involved is the combination of Rainfall and Runoff Combined, Runoff Only, and Rainfall Only.

8.6.1 Capacity

New initiatives are recommended.

- Review of current practices and consider the merits of taking additional factors into account when calculating desired culvert capacities
- In determining the locally applicable rainfall intensity, consider using the “Placentia” Intensity Duration Frequency (IDF) curves and associated information that have been prepared as part of this case study, and which are included in this document.
- In determining the watershed area (A) draining into the culvert, consider whether the former railway line bed, and its deteriorating condition since abandonment, influences the effective area being drained.
- In determining the appropriate land use storm water run off coefficient, consider the merits of using a 0.5 value for areas, or portions of areas that are thinly forested, on steep slopes, and on top of very thin soil and shallow bedrock.
- In determining the appropriate land use storm water run off coefficient, consider the merits of accounting for a progressive change in land use cover from a thin forest to an open field where trees are relatively slow to grow, on thin soil and shallow bedrock, by possibly using a value of 0.7.

- Account for the reduction in capacity when calculating culvert sizing, caused by the presence of end screens and the potential accumulation of debris.

8.6.2 Stability

New initiatives are recommended.

- Consider what measures could be done by upstream culvert owners and others to reduce potential capacity problems at upstream culverts that would result in storm water flowing down connecting roads, and over Route 100.
- Evaluate the potential for the anticipated storm water flow rate and ditch size to result in the erosion of road bed materials, especially at a higher elevations. Where an unacceptable potential exists, take actions to reduce this potential (i.e. ditch size, number and location of culverts, and use of more erosion resistant road bed surface materials)
- Similarly evaluate the potential for the anticipated flow to result in the erosion along ditches, and especially around culverts. Where an unacceptable potential exists, take action to reduce this potential (i.e. increasing ditch sizes, changing the number and location of culverts, additional features to reduce flow velocity and lining or placing more erosion resistant materials or vegetation)
- Consider or reconsider in view of climate and other changes, if the increased storm water run off flow rate merits the construction of a culvert head wall or equivalent to help keep the opening rigid

8.6.3 Maintenance, Operations and Monitoring

Adaptation management measures are recommended.

- Have the technical staff determine the appropriate culvert size and capacity based on anticipated current and future storm water run off rates, and considering reductions in flow capacity due to end screens and potential debris accumulation
- Designers to provide field supervisors with clear opinions or performance goals, on the acceptable quantity of accumulated debris at culvert ends
- Provide sufficient resources (time, opportunity, equipment, human, and financial) such that field supervisors can investigate uphill or upstream areas, and be aware of trends regarding potential debris accumulation
- Provide sufficient resources such that field supervisors, coordinating with others, can have accumulated debris removed before the desired effective culvert capacity is compromised
- Provide sufficient resources such that field supervisors can coordinate a response to the early detection of erosion trends in ditch and road materials.

8.6.4 Property Protection (Insurance)

Adaptation management measures are recommended.

- Communicate changes in culvert sizes and effective flow rates to other appropriate representatives of “downstream” culverts and infrastructure. It is possible that culvert changes in the Route 100 area would influence culvert and other infrastructure performance in another “downstream” area.

- Communicate changes associated with a potential flow rate, with appropriate representatives of “upstream” culvert and infrastructure as well. Improved effective capacity “upstream” increases the potential for storm water to stay in desired channels, and reduce the erosion potential in unexpected areas.

8.6.5 Policies and Procedures

Adaptation management measures are recommended.

- Have senior management review the use of 50 mm x 50 mm screens at the end of culverts, and consider procedures such that maintenance forces making decisions on potentially installing new screens would consult with the designer regarding acceptable effective capacity. Screens are specified for use in the Dunville area at a couple of locations, although additional ones may have been installed by maintenance forces. When used, screens are based on a drawing in the Design Specifications. If the intent is to keep people out of the culvert, an increased mesh size would still accomplish this. Any mesh screen may reduce the effective flow rate capacity to something less than what a designer anticipated when an open culvert was assumed. A larger screen mesh would also result in a smaller reduction in the effective flow capacity of the culvert.
- Have senior management consider having site-specific Intensity-Duration-Frequency (IDF) curves prepared for areas where infrastructure design and construction are anticipated in the near future. Have senior management consider having site-specific Intensity-Duration-Frequency (IDF) curves prepared for areas where infrastructure design and construction are anticipated in the near future.

8.6.6 Lifecycle Planning

Adaptation management measures are recommended.

- Have senior management mandate and support the consideration by designers of “climate change adaptation” or other reasonably anticipated future changes, during the design and preparation of technical specifications. Therefore, technical designers would no longer solely rely on historical data. Ensure that resources exist for the technical people to have these additional considerations taken into account.
- For each major culvert design, evaluate the runoff coefficient based on current and future values for existing and upstream land uses. Coefficients, and corresponding travel times, may vary over portions or areas of same watershed areas.
- On a seven year rotating basis, consider if the land use run off coefficient used in the culvert design merits a change and the corresponding consequences for the infrastructure involved.
- On a seven year rotating basis consider if available climate change information regarding rainfall amounts or intensities, sufficiently merits or justifies the preparation of new IDF curves.

8.6.7 Strength

No further action.

8.6.8 Emergency Planning

No further action.

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APPENDIX 6 – FLOODWALL MONITORING EQUIPMENT CONCEPT A125
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APPENDIX 8 – PEAK FLOW ESTIMATION A140
APPENDIX 9 – PLACENTIA NL IDF RAINFALL INFORMATION A157

Appendix 1.1 – PIEVC Worksheet 1.1 (Breakwater)

Worksheet 1 Project Definition

In this step the practitioner will define the global project parameters. This step will define:

- Which particular infrastructure is being assessed;
- Its location;
- Unique climatic, geographic considerations; and
- Uses of the infrastructure.

This is the first step of narrowing the focus to allow efficient data acquisition and assessment.

4.1.1 Identify Infrastructure which is to be evaluated for climate change vulnerability	
Choose Infrastructure: Breakwater	
General Description: Owned and operated by the Town of Placentia, but originally built with Government of Canada resources in the early 1990s. Constructed of stone, used railway ties, pressure treated wood in one portion, and with a boardwalk on top, as a response to flooding between1960 and 1989. There has been no flooding of Downtown Placentia since it was built. Current regular maintenance and monitoring efforts are minimal. The structure receives continuous wave action. Occasional waves currently overtop the Breakwater. The potential exists for erosion to compromise the breakwater in both a functional and physical way. A catastrophic failure of this Breakwater would result in the flooding of substantially all of the downtown of the Community of Placentia.	
Additional background & detailed information sources	
	Links and references
The Coastline of Eastern Newfoundland (2003)	Catto et al. (2003); and references cited therein
Design Construction Drawings and survey information	Town of Placentia
Supplemental Information	Catto et al. (2006) Catto (2006a, 2006b) Catto and Hickman (2004) Vasseur and Catto (in press)

4.1.2 Identify Climate Factors of Interest
State general Climate factors to be considered
Mean sea level rises by 0.150 metres
Storm surge for high tide remains at 2 metres above mean sea level
Wave height potentials increase by 0.25 metres (from 5.00 m to 5.25 m)
Wave height potentials continue to occur at the current frequency
The combined change in sea level, storm surge and wave height potential is 0.400 metres, from 7.00 m (2 + 5), to 7.40 m (0.15 + 2 + 5.25).
Additional background & detailed information sources
The Coastline of Eastern Newfoundland (2003, Catto et al.)
Ouranos Report to PIEVC for Placentia Case Study

4.1.3 Identify the Time Frame
To 2050
Notes: From 2007.12.19 project Kick-off Telephone meeting with GNL-EC and PIEVC.
4.1.4 Identify the Geography
On a flat, coastal peninsula of very free flowing beach wash material, with little or no organic material. Groundwater elevation is tidal elevation on the downtown portion of this peninsula.
Notes:

4.1.5 Identify the Jurisdictional Considerations	
	Notes:
Breakwater is owned, operated and maintained by the Town of Placentia	

4.1.6 Site Visit
Summary of findings from interviews[1]
The Breakwater performance is consistently acceptable to owner – operator.
The total volume of water that sprays over the top is acceptable to Town.
There is no real maintenance or monitoring program for the Breakwater structure.
There is no pattern of life cycle asset management considerations being made.
There has been no new stone placed work addition since early 1990's construction.
There is no perception that erosion is or is not occurring at the Breakwater.
Municipal activities could include some monitoring activities in the future.
The current municipal emergency contingency plan accounts for Breakwater failure.
There has been no property damage on the town side of the Breakwater.
There are no real municipal plans or policies that directly relate to the Breakwater, but that may change as a result of this case study.
The Town of Placentia and the NL government have discussions about the application of the provincial flood plain risk and development policy.
Key Observations
Construction drawing information, coupled with survey information commissioned by this case study, and observations, provide dimensions.
Very strong wave action, and the movement of stone on the beach, may or may not be part of an erosion pattern that could ultimately undermine the foundation of the structure.
Areas for follow-up in subsequent steps
These are incorporated into the Worksheet 5 Recommendations.

[1] Notes from interviews shall be kept by Consultant for future reference. There will be no need to append these documents to the Worksheets.

4.1.7 Assess Data Sufficiency	
State Assumptions proposed for the assessment, if any	
	Rationale
Self evident trends as "Experience to date" in infrastructure performance capacity and loads, are used in Worksheet 4 Indicator Analysis. For example, the specifics regarding the structural performance may be uncertain during this evaluation, but the structural capacity C exceeds the structural loads L being placed on it. So one may reasonably assume that C>L, without knowing the specific values for C or L.	
Where insufficient information currently available	
Identify process to develop data	**Process**
There was no available infrastructure data in the initial phases of this case study. Eventually the Consultant had meetings with the infrastructure owner and a useful information exchange resulted.	
Sufficient data was available for this evaluation. The Town of Placentia, and Newfoundland and Labrador – Transportation and Works, responded to our information requests in timely and effective ways.	
Where data cannot be developed, identify the data gap as a finding in Step 5 of the Protocol – Recommendations. **List Data Gap as findings to be sent to STEP 5 (Worksheet 5: Section 4.5.2)**	
1. Sufficient data was available for this evaluation. The Town of Placentia, and Newfoundland and Labrador – Transportation and Works, responded to our information requests in timely and effective ways.	
2.	
3.	
4.	
5.	

Date:	2008.02.22
Prepared under the Responsibility of:	Cameron Consulting Inc. (Cameron Ells, P.Eng.)

Appendix 1.2 – PIEVC Worksheet 1.2 (Floodwall)

Worksheet 1 Project Definition

In this step the practitioner will define the global project parameters. This step will define:

- Which particular infrastructure is being assessed;
- Its location;
- Unique climatic, geographic considerations; and
- Uses of the infrastructure.

This is the first step of narrowing the focus to allow efficient data acquisition and assessment.

4.1.1 Identify Infrastructure which is to be evaluated for climate change vulnerability	
Choose Infrastructure: Floodwall	
General Description: Owned and operated by the Town of Placentia, but originally built with Government of Canada resources in the early 1990's. Constructed of interlocking steel sheet piles. It is located along the backside of the peninsula flanking downtown Placentia to the east. When the Main Breakwater is effective, storm surge sea water is essentially deflected along the perimeter of the peninsula. Construction was a response to flooding 1960-1989. There has been no flooding of Downtown Placentia since it was built. It has been effective at conveying the deflected storm surge water away from the community. Current regular maintenance and monitoring efforts are minimal. The structure receives continuous tidal action, and wave action during periods of high seas. Occasional waves currently come over the top of the Flood Wall. The potential exists for tidal splash zone corrosion to compromise the Flood Wall in both a functional and physical way. A catastrophic failure of this Flood Wall would result in the flooding of substantially all of downtown Placentia.	
Additional background & detailed information sources	
	Links and references
The Coastline of Eastern Newfoundland (2003)	Catto et al. (2003); and references cited therein
Design Construction Drawings and survey information	Town of Placentia (hopefully)
Supplemental Information	Catto et al. (2006) Catto (2006a, 2006b) Catto and Hickman (2004) Vasseur and Catto (in press)

4.1.2 Identify Climate Factors of Interest
State general Climate factors to be considered
Mean sea level rises by 0.150 metres
Storm surge for high tide remains at 2 metres above mean sea level
Wave height potentials increase by 0.25 metres (from 5.00 m to 5.25 m)
Wave height potentials continue to occur at the current frequency
The combined change in sea level, storm surge and wave height potential is 0.400 metres, from 5.00 m (2 + 3), to 5.30 m (0.15 + 2 + 3.15).
Additional background & detailed information sources
The Coastline of Eastern Newfoundland (2003, Catto et al.; and references cited therein)
Ouranous Report to PIEVC for Placentia Case Study
Supplemental Information: Catto et al. (2006); Catto (2006a, 2006b); Catto and Hickman (2004); Vasseur and Catto (in press)

4.1.3 Identify the Time Frame
To 2050
Notes: From 2007.12.19 project Kick-off Telephone meeting with GNL-EC and PIEVC.
4.1.4 Identify the Geography
On a flat, coastal peninsula of very free flowing beach wash material, with little or no organic material. Groundwater elevation is tidal elevation on the downtown portion of this peninsula.
Notes:

4.1.5 Identify the Jurisdictional Considerations	
	Notes:
The Flood Wall is owned, operated and maintained by the Town of Placentia.	

4.1.6 Site Visit
Summary of findings from interviews[2]
The Flood Wall performance is consistently acceptable to owner – operator.
The total volume of water that sprays over the top is acceptable to Town.
There is no real maintenance or monitoring program for the Flood Wall structure.
There is no pattern of life cycle asset management considerations being made.
There has been no corrosion protection work since the early 1990's construction.
Municipal activities could include some monitoring activities in the future.
The current municipal emergency contingency plan accounts for Flood Wall failure.
There has been no property damage on the town side of the Flood Wall.
There are no real municipal plans or policies that directly relate to the Flood Wall, but that may change as a result of this case study.
The Town of Placentia and the NL government have discussions about the application of the provincial flood plain risk and development policy.
Key Observations
Construction drawing information, coupled with survey information commissioned by this case study, and observations, provide dimensions.
Water moving into this back bay side of the Placentia peninsula, goes "upstream" around the narrow channel where the lift bridge is located. There is no real wave action against the flood wall. There are tidal actions or tidal based water elevation changes.
Areas for follow-up in subsequent steps
These are incorporated into the Worksheet 5 Recommendations.

[2] Notes from interviews shall be kept by Consultant for future reference. There will be no need to append these documents to the Worksheets.

4.1.7 Assess Data Sufficiency	
State Assumptions proposed for the assessment, if any	
	Rationale
Self evident trends as "Experience to date" in infrastructure performance capacity and loads, are used in Worksheet 4 Indicator Analysis. For example, the specifics regarding the structural performance may be uncertain during this evaluation, but the structural capacity C exceeds the structural loads L being placed on it. So one may reasonably assume that C>L, without knowing the specific values for C or L.	
Where insufficient information currently available	
Identify process to develop data	**Process**
There was no available infrastructure data in the initial phases of this case study. Eventually the Consultant had meetings with the infrastructure owner and a useful information exchange resulted.	
Sufficient data was available for this evaluation. The Town of Placentia, and Newfoundland and Labrador – Transportation and Works, responded to our information requests in timely and effective ways.	
Where data cannot be developed, identify the data gap as a finding in Step 5 of the Protocol – Recommendations. **List Data Gap as findings to be sent to STEP 5 (Worksheet 5: Section 4.5.2)**	
1. Sufficient data was available for this evaluation. The Town of Placentia, and Newfoundland and Labrador – Transportation and Works, responded to our information requests in timely and effective ways.	
2.	

Date:	2008.02.22
Prepared under the Responsibility of:	Cameron Consulting Inc. (Cameron Ells, P.Eng.)

Appendix 1.3 – PIEVC Worksheet 1.3 (Town Hall / Flood Plain)

Worksheet 1 Project Definition

In this step the practitioner will define the global project parameters. This step will define:

- Which particular infrastructure is being assessed;
- Its location;
- Unique climatic, geographic considerations; and
- Uses of the infrastructure.

This is the first step of narrowing the focus to allow efficient data acquisition and assessment.

4.1.1 Identify Infrastructure which is to be evaluated for climate change vulnerability

Choose Infrastructure:
Flood Plain (Flat) TOWN HALL Location (Community of Placentia)

General Description:
If circumstances are acceptable for the recently constructed Town Hall, they may be representative of other downtown flood plain locations as well. A storm water sewer line is planned in front of the building. A sanitary sewer line runs from the downtown to treatment plant by the Breakwater. Storm water drainage activity historically was minimal, and made use of the absorptive capacity of the porous, coarse, marine washed, surface soil material. The flooding in downtown Placentia that occurred in the 1960's, 1970's and 1980's did not happen again after the construction of the Breakwater and Flood Wall. Downtown Placentia did not experience any flooding during the August 2007 (Tropical Storm Chantel) flooding in Dunville.

If the Breakwater, Flood Wall, and Lift Bridge operate in the future as intended, the current flood plain risk to the Town Square Hall could be impacted by a combination of an increased quantity of precipitation as rain, and a decreased capacity of the ground to absorb storm water due to either higher groundwater (or tidal) elevations. The photo presented was taken prior to construction of Breakwater and Flood Wall

Additional background & detailed information sources

	Links and references
The Coastline of Eastern Newfoundland (2003)	Catto et al. (2003); and references cited therein
Supplemental Information	Catto et al. (2006) Catto (2006a, 2006b) Catto and Hickman (2004) Vasseur and Catto (in press)
Ouranous Report to PIEVC for Placentia Case Study	

4.1.2 Identify Climate Factors of Interest
State general Climate factors to be considered
Mean sea level rises by 0.150 metres. Groundwater elevation is mean sea level.
Groundwater is approximately 1 meter below grade at Town Square Hall building.
Storm water rainfall intensity increases 12% from current level in IDF curve format. If all the rain goes into beach ridge soil material, having an effective porosity of 0.33, assume it is a 0.30 m change in groundwater elev.
The combined change in sea level and rain is 0.45 metres
Additional background & detailed information sources
The Coastline of Eastern Newfoundland (2003, Catto et al.; and references cited therein)
Appendix of this case study report.
Supplemental Information: Catto et al. (2006); Catto (2006a, 2006b); Catto and Hickman (2004); Vasseur and Catto (in press)

4.1.3 Identify the Time Frame
To 2050
Notes: From 2007.12.19 project Kick-off Telephone meeting with GNL-EC and PIEVC.
4.1.4 Identify the Geography
On a flat, coastal peninsula of very free flowing beach wash material, with little or no organic material. Groundwater elevation is tidal elevation on the downtown portion of this peninsula.
Notes:

4.1.5 Identify the Jurisdictional Considerations	
	Notes:
Town Square Hall is owned, operated and maintained by the Town of Placentia.	

4.1.6 Site Visit
Summary of findings from interviews[3]
The Town Hall performance with respect to flood plain type risks is consistently acceptable to owner – operator.
There has been no flooding in downtown Placentis since the breakwater and Flood Wall were constructed. Late winter "snow melt" conditions, include some short term ponding of water on some streets. This is acceptable to Town.
There is no real maintenance or monitoring program for the downtown peninsular Placentia regarding flood risks.
There is no pattern of life cycle asset management considerations being made.
There is some municipal storm water drainage piping under some streets. A new one will be built in front of the Town Hall in the near future.
Municipal activities could include some monitoring activities in the future.
The current municipal emergency contingency plan accounts for area flooding.
Groundwater elevation and mean les level are historically the same thing in this area. Expect some influence with Flood Wall.
There are municipal policies that directly relate to the Flood Plain risk and development policy that relate to types of approved development within designated areas, and with some detailed conditions such as elevation.
The Town of Placentia and the NL government have discussions about the application of the provincial flood plain risk and development policy.
Key Observations
Construction drawing information and observations, provide dimensions and elevation information.
Areas for follow-up in subsequent steps
These are incorporated into the Worksheet 5 Recommendations.

[3] Notes from interviews shall be kept by Consultant for future reference. There will be no need to append these documents to the Worksheets.

4.1.7 Assess Data Sufficiency	
State Assumptions proposed for the assessment, if any	
	Rationale
Self evident trends as "Experience to date" in infrastructure performance capacity and loads, are used in Worksheet 4 Indicator Analysis. For example, the specifics regarding the structural performance may be uncertain during this evaluation, but the structural capacity C exceeds the structural loads L being placed on it. So one may reasonably assume that C>L, without knowing the specific values for C or L.	
Where insufficient information currently available	
Identify process to develop data	**Process**
There was no available infrastructure data in the initial phases of this case study. Eventually the Consultant had meetings with the infrastructure owner and a useful information exchange resulted.	
Sufficient data was available for this evaluation. The Town of Placentia, and Newfoundland and Labrador – Transportation and Works, responded to our information requests in timely and effective ways.	
Where data cannot be developed, identify the data gap as a finding in Step 5 of the Protocol – Recommendations. **List Data Gap as findings to be sent to STEP 5 (Worksheet 5: Section 4.5.2)**	
1. Sufficient data was available for this evaluation. The Town of Placentia, and Newfoundland and Labrador – Transportation and Works, responded to our information requests in timely and effective ways.	
2.	
3.	

Date:	2008.02.22
Prepared under the Responsibility of:	Cameron Consulting Inc. (Cameron Ells, P.Eng.)

Appendix 1.4 – PIEVC Worksheet 1.4 (Roads and Culverts)

Worksheet 1 Project Definition

In this step the practitioner will define the global project parameters. This step will define:

- Which particular infrastructure is being assessed;
- Its location;
- Unique climatic, geographic considerations; and
- Uses of the infrastructure.

This is the first step of narrowing the focus to allow efficient data acquisition and assessment.

4.1.1 Identify Infrastructure which is to be evaluated for climate change vulnerability	
Choose Infrastructure: Flood Plain (Sloped) Road and Culvert System (Dunville area of Town of Placentia)	
General Description: Route 100 highway from St. John's to Placentia runs through Dunville. Uphill on one side is a steep slope with some residences, small evergreen trees on minimal soil cover, and outcrops of bedrock. There are some barren patches to the tree cover. The forest is not logged now, but was in the past, and when the exposed soil blew away, barren patches without tree cover were the result. The downside of the road slopes steeply towards the water, where there are more residential homes. Route 100 is perpendicular to the water runoff route. Flooding problems have involved rainfall events, partially and temporarily blocked culverts, water building up at places along the upside of the road, water punching through culvert and road locations, water overtopping the road and causing rapid erosion. The results have included washouts of portions of the road, replacements of road and culvert sections, the flooding of residential homes, and the temporary isolation of portions of the community.	
Additional background & detailed information sources	
	Links and references
Flood assessment	Catto and Hickman (2004); Vasseur and Catto (in press), and references therein; Catto et at. (in press)
Geological mapping	Catto (1992); Catto and Taylor (1999); King (1988)
Climate Parameters	Banfield (1981, 1993); Catto et al. (2003); Vasseur and Catto (in press), and references therein
Ouranos	

4.1.2 Identify Climate Factors of Interest
State general Climate factors to be considered
Rain fall increases 12% from current level IDF curve information.
Runoff coefficient (Rational Method) changes 40% from 0.5 (thin forest) to 0.7.
The combined change in rainfall and cover runoff is 52%
Additional background & detailed information sources
Appendix information provided in case study report.

4.1.3 Identify the Time Frame
To 2050
Notes: From 2007.12.19 project Kick-off Telephone meeting with GNL-EC and PIEVC.
4.1.4 Identify the Geography
Route 100 in the Dunville area is a relatively flat road along the side of a steep slope. Often the land has a very shallow soil layer on top of shallow bedrock. The road appears to be on a significant quantity of road bed soil material.
Notes:

4.1.5 Identify the Jurisdictional Considerations	
	Notes:
Route 100 is owned, operated and maintained by Newfoundland and Labrador Department of Transportation and Works	
4.1.6 Site Visit	

Summary of findings from interviews[4]
After the August 2007 post storm Chantal event and response, the community and provincial emergency contingency plans are in excellent shape.
Some post-disaster replacement culverts are being designed in winter of 2008 for summer construction. Results from this case study can be considered in design.
Provincial NL practice is for new culverts to be metal - aluminium double coated.
Provincial NL practice is to also have rigid end pieces used on a case by case basis.
Provincial NL practice is for new culverts to have metal end screens (50 x 50 mm). Local and NL maintenance efforts respond to debris build ups at screens.
Provincial NL practice for area is to use the St. Lawrence IDF curve information, use a run off coefficient value of 0.35 which can be adjusted for local conditions, and to use 1:50,000 scale mapping in determining areas and slopes for water shed areas feeding into culverts. Some 1:2500 scale mapping is available as well. Traditional culvert design method (Q=CIA) is used.
Multi-million dollar provincial NL response in region to storm Chantal damage. Driving through area now, after cleanup, does not show evidence of damage.
Increasing Route 100 culvert capacities may lead to more than originally anticipated water flow on downstream or downhill culverts and infrastructure.
Up hill or upstream from Route 100, trees in watershed area being cut and harvested by local residents. Currently available resources to NL and Placentia are not able to effectively influence the unmanaged local tree harvesting activities.
Economic activity has potential for local land use to have more residential and other development. This land use change can also influence storm water runoff.
Key Observations
The website www.Placentia.ca has a link to a series of August 2007 photos.
Immediately adjacent to Route 100, the steep sloped land has trees growing on a very shallow layer of soil, that is on top of very shallow bedrock. It is expected that once cut, trees are slow to grow back, and there is a high soil erosion potential.
Areas for follow-up in subsequent steps
These are incorporated into the Worksheet 5 Recommendations.

[4] Notes from interviews shall be kept by Consultant for future reference. There will be no need to append these documents to the Worksheets.

4.1.7 Assess Data Sufficiency	
State Assumptions proposed for the assessment, if any	
	Rationale
Self evident trends as "Experience to date" in infrastructure performance capacity and loads, are used in Worksheet 4 Indicator Analysis. For example, the specifics regarding the structural performance may be uncertain during this evaluation, but the structural capacity C exceeds the structural loads L being placed on it. So one may reasonably assume that C>L, without knowing the specific values for C or L.	
Where insufficient information currently available	
Identify process to develop data	**Process**
There was no available infrastructure data in the initial phases of this case study. Eventually the Consultant had meetings with the infrastructure owner and a useful information exchange resulted.	
Sufficient data was available for this evaluation. The Town of Placentia, and Newfoundland and Labrador – Transportation and Works, responded to our information requests in timely and effective ways.	
Where data cannot be developed, identify the data gap as a finding in Step 5 of the Protocol – Recommendations. **List Data Gap as findings to be sent to STEP 5 (Worksheet 5: Section 4.5.2)**	
1. Sufficient data was available for this evaluation. The Town of Placentia, and Newfoundland and Labrador – Transportation and Works, responded to our information requests in timely and effective ways.	
2.	
3.	

Date:	2008.02.22
Prepared under the Responsibility of:	Cameron Consulting Inc. (Cameron Ells, P.Eng.)

Appendix 2 – PIEVC Worksheet 2

Worksheet 2 Data Gathering and Sufficiency

In this step the practitioner will provide further definition regarding the infrastructure and the particular climate effects that are being considered in the evaluation. The practitioner will undertake a data acquisition exercise and identify where, in their professional judgment, whether the data is insufficient due to:

- Poor quality;
- High levels of uncertainty; or
- Lack of data altogether.

This step further focuses the evaluation and starts to establish activities to in-fill poor quality or missing data.

4.2.1 State Infrastructure Components which are to be evaluated for climate change vulnerability[5] **(reference Appendix A – Global Infrastructure Listing)**		
General Description	**Data** **Infill Missing Data using reasonable assumptions**	**Reference and Assumptions** **on data and infill data**
Breakwater	Design - Construction Drawings from Town of Placentia resources	Worksheet 1.1
Flood Wall	Design - Construction Drawings from Town of Placentia resources	Worksheet 1.2
Flat Flood Plain Downtown (Town Hall example location)	Design - Construction Drawings from Town of Placentia resources	Worksheet 1.3
Sloped Flood Plain, Road & Culvert System (Dunnville)	Design values for Rain and Land Use Coef. from NL-TW	Worksheet 1.4

[5] Where available, review operations incident reports, daily logs. Interview infrastructure owners and operators to identify historical events that may not be documented or retrievable from databases.

4.2.2 State Climate Baseline		
State general Climate Parameters for use in STEP 3 of Assessment **(Reference Appendix B – Climate Change Parameters List)** **(Additional Reference – PIEVC Data Integrity and Availability Review)**		**Climate information source**
Sea Level (Mean) = Geodetic elevation of 0 m locally		Definition
Storm Surge with Wind Assisted Wave (7 m for I1 and 5 m for I2)		The Coastline of Eastern Newfoundland (2003, Catto et al.); supplemental references as indicated; unpublished data, Geological Survey of Canada; unpublished data, NL Geological Survey; unpublished data, Dept of Geography, Memorial University; plus experienced local knowledge
Rainfall Precipitation as IDF curve information		IDF information for Placentia (current and for 2050) in Case Study Report. Currently used baseline information from NL-TW (St. Lawrence NL station).
Runoff storm water / land use or cover coefficient		Universal Runoff Calculation Method (Q=CIA) coefficient. Currently used baseline information from NL-TW (Regional office responsible for culvert design in Dunville area).

List Extreme Climate event		
Frequency	**Duration**	**State Justification** for infill of missing data
Extreme event frequency n/a except as incorporated in Intensity – Duration – Frequency curve information for precipitation as rain	Extreme event duration n/a except as incorporated in Intensity – Duration – Frequency curve information for precipitation as rain	
Storm Chantel (2007)		
Storm Florence (2006)		
Winter Storms, 2005		
Winter storms, 2004		
Storm Frances (2004)		
Storm Michael (2000)		
January 2000 storm		
Storms Irene, Gert-Harvey, Floyd (1999)		
Storm Felix (1995)		
Storms Bob and Hallowe'en (1991)		
Storm Hugo (1989)		

4.2.3 State Climate Change Assumptions			
Relevance & applicability of **Observed global or regional climate change trends**	**Incremental changes** to infrastructure	**% increase or decrease to Climate Change Baseline based on TRENDS**	**Infill data** (where appropriate) **& reference sources** - Provide written justification
Increased incidence of coastal erosion – Catto et al. 2003, 2006; Catto 2006a, 2006b; Vasseur and Catto in press		Sea level (mean) + 150 mm	Regional trends
Relevance & applicability of **Observed global or regional climate change trends**	**Incremental changes** to infrastructure	**% increase or decrease to Climate Change Baseline based on SENSITITY ANALYSIS**	**Infill data** (where appropriate) **& reference sources** - Provide written justification

State and Describe Climate Change Models used, if any	
	Reference
Noted in Ouranos Report for this PIEVC Case Study Evaluation	
Practitioner Defined Climate Change Assumptions	**Rationale**
Sea level rise (0 m + 0.15 m above mean sea level to 2050)	Trends (Project Report)
Storm surge with Wind Assisted Wave (+5% above 2 m tidal range) For Breakwater it is +0.25m (5% x (5=7-2)m) above mean sea level (MSL); For Flood Wall it is +0.15m (5% x (3=5–2) m) above MSL	DFO Report - The Coastline of Eastern Newfoundland (2003, Catto et al.); Catto et al., 2006; Catto 2006a, 2006b; Vasseur and Catto in press
Combined change in sea level, tide, + wind assisted storm surge for Breakwater - 7 m (+0.4 = 0.15 + 0.25) above mean sea level (MSL); Flood Wall - 5 m (+0.3 = 0.15 + 0.15) above MSL	Catto et al., 2003, 2006; Catto 2006a, 2006b; Vasseur and Catto in press
Rainfall as locally derived IDF & precipitation + 12%	IDF values for 2050 (Project report)

Runoff storm water / land use cover coefficient – from a forest setting that is changing due to tree cutting and residential land use (For Dunville with this soil on shallow bedrock and steep slopes - from 0.5 to 0.7m +40%). NL-TW uses 0.35 value in general for the Avalon area, plus local adjustments. (Potential economic development would influence the clearance of trees and change of land use cover. It almost happened recently with potential smelter)	Universal run off calculation coefficients NL-TW on current / historical value. Consultant Opinion for forest area immediately adjacent to Route 100 and potential for change in land use by 2050
Combined influence on culvert design from change in Rain plus Runoff from land use cover coefficient (12% + 40%) 52%	Opinion of Consultant

4.2.4 State Time Frame	
Infrastructure Safe Operation Time Period	**Time (Years)**
Now to 2050 for all infrastructure being evaluated in this case study.	
Design Life of Infrastructure components	
Infrastructure Component	**Time (Years)**
Now to 2050 for all infrastructure being evaluated in this case study.	To 2050 (42-50 years)
Useful Life Remaining	**Time(Years)**
Other Relevant Comments	
Now to 2050 for all infrastructure being evaluated in this case study.	

4.2.5 Geography	
Major Components of local geography	**Reference**
Downtown Placentia located on beach ridge material	Catto 1992; Catto and Taylor, 1999; Forbes 1984, 1985; Forbes and Shaw, 1991; Shaw et al, 1999
In 1988 Flood Risk Map, Pink was already wet; Orange a 20 yr flood event; and yellow a 100 year flood event	Canada – Newfoundland Flood Damage Reduction Program map (1988)
Not applicable	

4.2.6 Specific Jurisdictional Considerations	
Jurisdiction that have direct control or influence on infrastructure	
Newfoundland and Labrador for Route 100 Road and Culvert in Dunville	
Town of Placentia is the owner and has operational influence on the Breakwater and Flood Wall	
Flood Plain in downtown is under Town of Placentia jurisdiction but the Province of Newfoundland and Labrador has influence through the interpretation of Flood Plain development policy applications.	
Sections of laws and bylaws that establish legal structure for the infrastructure	**Reference**
Not applicable	Not applicable
Sections of regulations that establish legal structure for the infrastructure	**Reference**
Not applicable	Not applicable
Relevant Standards to the design, operation and maintenance of the infrastructure	**Reference**
Breakwater and Flood Wall heights intended for 1:100 year event	Construction Drawings

4.2.6 Specific Jurisdictional Considerations	
For Route 100 Road and Culvert system in Dunville, the highway design and maintenance practices used by NL Transportation and Works (ie. Supervisor observation of culverts 1-3 times a month)	Conversation with NL-TW
Relevant Guidelines for design, operation and maintenance of the infrastructure	**Reference**
For the downtown Placnetia flood plain area – possibly the Flood Plain Policy	NL and Town of Placentia
Town of Placentia and NL Environment and Conservation have a difference of opinion regarding the application of flood risk policies. This does not directly bear on the application of PIEVC protocol on this case study. There will be more Town of Placentia efforts in the future support of their opinion and interpretation (ie. Policies and Procedures).	
Infrastructure owner/operator administrative processes and policies as they apply to the infrastructure	**Reference**
Breakwater owner-operator is Town of Placentia – no policies	Town of Placentia
Flood Wall owner-operator is Town of Placentia – no policies	Town of Placentia
Downtown Flood Plain (Town Hall as example building location) owner-operator is Town of Placentia – NL Flood Policy applications are influential	Town of Placentia
Route 100 Road and Culvert system in Dunville owner-operator is NL Transportation and Works – Design practices (not a written code), Construction “Design Specification” book, and practices regarding operations and maintenance (that vary with available resources)	NL Transportation and Works

4.2.7 Other Change Effects	
Changes in use pattern that increase/decrease the capacity of the infrastructure	**Reference**
For Route 100 Road and Culvert system in Dunville, change in land use cover that increase storm water runoff, if unaccounted for, may reduce the available capacity of the culvert to convey the anticipated rain fall. NL Transportation value for land use coefficient cover is 0.35 in general for the Avalon area, including the Dunville portion of the Town of Placentia. Consultant opinion for the area immediately adjacent to Route 100, although not necessarily the full watershed, is 0.5 now and increasing to possibly 0.7 depending on continuing trends of area tree cutting and property development.	
Operation and maintenance practices that increase/decrease capacity of infrastructure	**Reference**
For Route 100 Road and Culvert system in Dunville, if there is low maintenance is high debris accumulation, culvert capacity reduced	Opinion of Consultant
Flood Wall corrosion rate may increase in “splash” zone if low maintenance	Opinion of Consultant
For the Breakwater, minimal to no monitoring and maintenance could make it easier for erosion to compromise the foundation of the infrastructure.	Opinion of Consultant
Changes in management policy that affect the load pattern on the infrastructure	**Reference**
For Route 100 (Dunville) road and culverts, land use changes in uphill / upstream watershed area from policy changes, lack or policy or enforcement.	Opinion of Consultant
For Route 100 (Dunville) road and culverts, the NL Transportation maintenance policy can influence the amount of temporary partial blockages on water passing through culverts	Opinion of Consultant
NL Flood Risk Policy – intent, derivation, and application.	Opinion of Consultant
Changes in Laws, Regulations and Standards that affect the load pattern on the infrastructure	**Reference**
For Route 100 (Dunville) road and culverts, land use changes in uphill / upstream watershed area from policy changes, lack or policy or enforcement.	Opinion of Consultant

4.2.8 Assess Data Sufficiency		
Comment on using relatively short term measurements to make long term predictions		**Limitations**
This time frame is reflected in the considered reliability of the change assumptions.		
Data Evaluation	**Comment**	**Effect on Assessment**
Data Gaps	Sufficient data was available for this evaluation. The Town of Placentia, and NL – Transportation and Works, responded to our information requests in timely and effective ways.	
Data Quality	Sufficient data quality was available for this evaluation.	
Data Accuracy	Sufficient data accuracy was available for this evaluation.	
Applicability of Trends	The use of trends for the sea level elevation change value is prudent, practical, and useful.	
Reliability of selected climate models	Model selection made by Ouranos.	
Reliability of climate change assumptions/scenarios	If applying a scale of 0 – 7, the combined sea level and storm surge values are a 7 (certain); the rate rain fall change would be a 6 (probable) and, and the run off coefficient change due to changes in land use and cover would be a 4 (possible).	
Other Factors	**No comment.**	

4.2.8 part c **Establish Priority in referenced documents**	
Reference Document	**Reference Priority (highest reliance first)**
The Coastline of Eastern Newfoundland (2003, Catto et al.); and supplemental references indicated	(1)
Project Report (Placentia IDF and other changes for current and 2050)	(2)
Ouranos Report for this PIEVC Case Study Evaluation	(3)
Construction drawing information from Town of Placentia	(4)
January 2008 Survey data (NewLab Engineering)	(5)
NL-TW current values for Rainfall and Runoff coefficients from land use	(6)

4.2.8 part d **Data Sufficiency**	
Identify process to develop data, where insufficient	
Data Needed	**Process**
Sufficient data was available for this evaluation.	The Town of Placentia, and Newfoundland and Labrador – Transportation and Works, responded to our information requests in timely and effective ways.
Where data cannot be developed, identify the data gap as a finding in Step 5 of the Protocol – Recommendations. **List Data Gap as findings to be sent to STEP 5 (Worksheet 5: Section 4.5.2)**	
1. Reductions in some of the uncertainties encountered during this evaluation, are anticipated to be the results of implementing some of the case study recommendations on management actions.	
2.	

Date:	2008.02.22
Prepared under the Responsibility of:	Cameron Consulting Inc. (Cameron Ells, P.Eng.)

Appendix 3 – PIEVC Worksheet 3

Worksheet 3 Vulnerability Assessment

In this section the practitioner will identify the infrastructure's response to the most relevant climate effects. This will be done by developing prioritized lists of relevant parameters which are then grouped to expose detrimental system responses. The grouped parameters, or relationships, are combinations of: Infrastructure component performance response; and Climate effects.

4.3.1 Prioritization Methodology

The practitioner is required to prioritize a number of climate-infrastructure interactions, or relationships. The default prioritization system is based on a scale of **1 to 10. The** practitioner is directed to select a scale value based on either probability or severity of outcomes. The procedure directs the practitioner to select the scale values from either Figure 7 or Figure 8 based on whether the scale factor is based on probability or severity.

Figure 7: Probability Scale Factors

Scale	Probability[a,b,c]		
	Method A	**Method B**	**Method C**
0	negligible or not applicable	<0.1 % <0.1 / 20	negligible or not applicable
1	improbable / highly unlikely	5 % 1 / 20	improbable 1:1 000 000
2	remote	20 % 4 / 20	remote 1:100 000
3	occasional	35 % 7 / 20	occasional 1:10 000
4	moderate / possible	50 % 10 / 20	moderate 1:1 000
5	often	65 % 13 / 20	probable 1:100
6	probable	80 % 16 / 20	frequent 1:10
7	certain / highly probable	>95 % >19 / 20	continuous 1:1

a) Choose Method A, Method B or Method C to select the priority.
b) Record in project documentation the Method that was used.
c) Use the same Method for all probability prioritization in the evaluation.

Figure 8: Severity Scale Factors

Scale	Magnitude	Severity of Consequences and Effects
	Method D	**Method E**
0	no effect	negligible or not applicable
1	measurable 0.0125	very low / unlikely / rare / measurable change
2	minor 0.025	low / seldom / marginal / change in serviceability
3	moderate 0.050	occasional loss of some capability
4	major 0.100	moderate loss of some capacity
5	serious 0.200	likely regular / loss of capacity and loss of some function
6	hazardous 0.400	major / likely / critical / loss of function
7	catastrophic 0.800	extreme/ frequent/ continuous / loss of asset
d) Choose Method D or Method E to select the priority. **e) Record in project documentation the Method that was used.** **f) Use the same Method for all magnitude prioritization in the evaluation.**		

As appropriate, the practitioner may select an alternative prioritization methodology.

If the practitioner selects an alternative prioritization methodology they are directed to substantiate and document this choice in the project report.

Use a Matrix to record and compare initial assessment

Create a matrix using spreadsheet software.

1. As described in section 4.3.5, the header row will comprise of relevant climate events
2. As described in section 4.3.4, the header columns will comprise of the relevant infrastructure components, and the subcomponent performance response to relevant climate change factors. Appendix C provides some Performance Responses to consider.
3. Practitioners are asked to refer to the general template matrix provide in the Step 3 Worksheet. An example from an actual assessment is provided in Appendix E.

4.3.4 Populate the header columns of the Assessment Matrix with the relationships between Infrastructure Component and their Performance Response to Climate Change.

a. For each sub-component of the infrastructure, examine and record possible response to climate events.
b. Record the relevant Infrastructure Components and Sub-Components and the Effects in the corresponding header columns in the Assessment Matrix.

4.3.4 Performance Response Relationship
EFFECTS on Infrastructure Components by Climate Events
(Reference Appendix C Example Performance Responses)

Generally anticipated EFFECTS on the infrastructure arising from the climate and other change parameters	Structural Integrity	Serviceability	Functionality	Operations and Maintenance	Emergency response risk	Insurance Considerations	Policies and Procedures	Economics	Public Health and Safety	Environmental Effects	Other (Stability)	Other (Life Cycle)
Infrastructure Component												**Y/N**
I1 – Breakwater, Stone construction	Y W	Y	Y W	Y W	Y W	Y W	Y W	Y	Y	Y	Y W	Y W
I2 – Steel Sheet Pile Flood Wall	Y W	Y	Y W	Y W	Y W	Y W	Y W	Y	Y	Y	Y W	Y W
I3 – Flat Flood Plain, Town Square Hall, Downtown Placentia	Y W	Y	Y W	Y W	Y W	Y W	Y W	Y	Y	Y	Y W	Y W
I4 – Sloped Flood Plain, Road & Culvert - Dunville	Y W M	Y	Y W M	Y W M	Y W M	Y W M	Y W M	Y	Y	Y	Y W M	Y W M

Y – Considered by Consultant for Case Study Project Report
W – Workshop Consultation Topic (Town of Placentia representatives)
M – Meeting topic as general discussion, not explicit scoring (NL Transportation reps)

Populate the first title column of the Assessment Matrix with affected infrastructure components and sub-components onto the Assessment Matrix in section 4.3.6.
Populate the second title column with the corresponding EFFECTS onto the Assessment Matrix in section 4.3.6.

4.3.5 Populate the header row of the Assessment Matrix with relevant Climate Events

a. Using the list of climate effects developed in Section 4.2.2, insert relevant factors in the header row of the Assessment Matrix.

4.3.5 Prioritize Climate Effects & Performance Response Relationship
Relevant Climate Events (from Worksheet 2 – section 4.2.2)
For I1 – Combine C1 + C2
For I2 – Combine C1 + C2
For I3 – Combine C1 + C3
For I4 – Evaluate C3 alone, C4 alone, and Combination of C3 +C4
Populate the header row of the Assessment Matrix in section 4.3.6

4.3.6 Assessment Matrix Formation: Climate Data Effect vs Infrastructure Component Performance Scaling

Use the Assessment Matrix to Scale the Performance Response of the Infrastructure Components

a. For each sub-component and Performance Response, using the Severity Scale factors outlined in Figure 8 (S_R), populate the matrix cells under the corresponding the S_R column.

b. For each sub-component and Performance Response, using the Probability Scale factors outlined in Figure 7 (S_C), populate the matrix cells under the corresponding S_C columns.

c. For each sub-component and Performance Response, Calculate the Priority of the Relationship using the following equation:

$$P_C = S_C \times S_R$$

Where:

P_C = Priority of Climate Effect
S_C = Scale factor for Climate Effect
S_R = Scale factor for Performance Response

Insert the value of P_C in the corresponding cell under the P_C column for the relevant sub-component Performance Response to the each Climate Event. The practitioner may choose to use the spreadsheet to automatically calculate these values as the assessment progresses.

Double Click on the item below to access a general matrix template.

Infrastructure Components	Performance Responses	Climate Event 1		
Administration/Operation		Y/N	S_C	S_R
Personnel	*Relationships from 4.3.4*			
Facilities/equipment	*Relationships from 4.3.4*			
Records	*Relationships from 4.3.4*			
Process/Infrastructure Elements				
Process 1	*Relationships from 4.3.4*			
Process 2	*Relationships from 4.3.4*			
Process 3	*Relationships from 4.3.4*			

For ease of viewing, highlight the Priority Values P_C that is greater than 36 with red colour. Transfer the information to worksheet 4 for numeric Indicator Analysis.

(Refer to Example Matrix, Appendix E of the PIEVC Engineering Protocol - 10Oct2007)

PIEVC Case Study - Placentia NL Assessment Matrix
2008.02.21

Infrastructure of Interest	Performance Response Type	Sea Level Change			Storm Surge Change			Sea Level and Storm Surge Change			Rainfall Change			Sea Level and Rainfall Change			Runoff (Land Use) Change			Rainfall and Runoff Change		
		Sc	Sr	Pc	Sc	Sr	Pc	Sc	Sr	Pc	Sc	Sr	Pc	Sc	Sr	Pc	Sc	Sr	Pc	Sc	Sr	Pc
Breakwater	Strength	2	1	2	5	2	10	5	3	15												
Breakwater	Capacity	3	2	6	4	4	16	6	4	24												
Breakwater	Stability	4	4	16	5	3	15	5	5	25												
Breakwater	Maintenance	4	5	20	3	2	6	5	5	25												
Breakwater	Emergency Planning	2	1	2	3	1	3	3	1	3												
Breakwater	Insurance / Protection	1	1	1	3	2	6	3	3	9												
Breakwater	Policy and Procedures	2	3	6	2	2	4	2	3	6												
Breakwater	Lifecycle Planning	2	5	10	2	5	10	3	5	15												
Flood Wall	Strength	1	1	1	2	2	4	3	3	9												
Flood Wall	Capacity	3	3	9	4	3	12	6	3	18												
Flood Wall	Stability	3	2	6	2	2	4	3	2	6												
Flood Wall	Maintenance	3	4	12	5	4	20	6	4	24												
Flood Wall	Emergency Planning	1	1	1	2	1	2	2	1	2												
Flood Wall	Insurance / Protection	2	1	2	2	1	2	3	1	3												
Flood Wall	Policy and Procedures	2	1	2	2	1	2	3	1	3												
Flood Wall	Lifecycle Planning	2	5	10	2	5	10	3	5	15												
Flood Plain	Strength	1	1	1							1	1	1	1	1	1						
Flood Plain	Capacity	1	2	2							3	2	6	4	2	8						
Flood Plain	Stability	1	1	1							2	1	2	2	1	2						
Flood Plain	Maintenance	2	1	2							2	3	6	3	3	9						
Flood Plain	Emergency Planning	1	1	1							2	1	2	2	1	2						
Flood Plain	Insurance / Protection	1	1	1							4	2	8	3	3	9						
Flood Plain	Policy and Procedures	2	4	8							2	4	8	3	5	15						
Flood Plain	Lifecycle Planning	1	5	5							2	5	10	2	5	10						
Road & Culvert	Strength										4	1	4				4	3	12	4	4	16
Road & Culvert	Capacity										4	3	12				6	3	18	6	5	30
Road & Culvert	Stability										4	3	12				5	4	20	5	5	25
Road & Culvert	Maintenance										4	3	12				5	3	15	6	4	24
Road & Culvert	Emergency Planning										3	2	6				3	3	9	4	3	12
Road & Culvert	Insurance / Protection										4	2	8				6	4	24	6	4	24
Road & Culvert	Policy and Procedures										2	2	4				3	4	12	4	4	16
Road & Culvert	Lifecycle Planning										3	3	9				4	3	12	4	4	16

4.3.7 Evaluate Potential Cumulative Effects

Review the Assessment Matrix and evaluate the cumulative impact of combining or sequencing climate events to assess the possibility of these combined events yielding a higher impact compound event.[6]

For those combined climate events identified, enter the compound event into the header row of the Assessment Matrix and create a new assessment column

For the compound events, complete the scaling and prioritization exercise outlined in Section 4.3.6

The practitioner must exercise professional judgment in establishing ***probable*** combined events to avoid assessing multiple, improbable, combinations.

4.3.8 Prioritize Climate Effects & Performance Response Relationship
Transfer Climate Parameter with Priority of 36 or more, Go immediately to STEP 5 (Section 4.5.2 in Work Sheet 5) and assess appropriate recommendations to address the identified vulnerability. **List the Infrastructure Components from the Assessment Matrix transferred to STEP 5 below:**
1. No combination scored 36 or higher.
2.
For relationships with calculated Priority between 12 and 36 from the Assessment Matrix, categorize the Relationship for further Indicator Analysis in Step 4 (Section 4.4.4 and 4.4.8 in Worksheet 4)
1. Breakwater - Maintenance, Operations and Monitoring (Sea Level and Storm Surge)
2. Breakwater – Stability (Sea Level and Storm Surge)
3. Breakwater – Capacity (Sea Level and Storm Surge)
4. Breakwater – Strength (Sea Level and Storm Surge)
5. Breakwater - Lifecycle Planning (Sea Level and Storm Surge)
6. Breakwater - Property Protection (Insurance) (Sea Level and Storm Surge) - <12 No Requirement for Indicator Analysis

[6] For example, the individual impact of hail and rain events may be given priorities less than 12 while the cumulative impact of a hail event followed by rain may be given a priority greater than 12. Or, a single 100-year storm event is considered to be minor while two such events over a 48-hour period are viewed to be very significant.

7. Breakwater - Policies and Procedures (Sea Level and Storm Surge) - <12 No Requirement for Indicator Analysis
8. Breakwater - Emergency Planning (Sea Level and Storm Surge) - <12 No Requirement for Indicator Analysis
9. Flood Wall - Maintenance, Operations and Monitoring (Sea Level and Storm Surge)
10. Flood Wall – Capacity (Sea Level and Storm Surge)
11. Flood Wall - Lifecycle Planning (Sea Level and Storm Surge)
12. Flood Wall – Strength (Sea Level and Storm Surge) - <12 No Requirement for Indicator Analysis
13. Flood Wall - Policies and Procedures (Sea Level and Storm Surge) - <12 No Requirement for Indicator Analysis
14. Flood Wall – Stability (Sea Level and Storm Surge) - <12 No Requirement for Indicator Analysis
15. Flood Wall - Property Protection (Insurance) (Sea Level and Storm Surge) - <12 No Requirement for Indicator Analysis
16. Flood Wall - Emergency Planning (Sea Level and Storm Surge) - <12 No Requirement for Indicator Analysis
17. Flood Plain (Town Hall) - Policies and Procedures (Sea Level and Rainfall)
18. Flood Plain (Town Hall) - Lifecycle Planning (Sea Level and Rainfall)
19. Flood Plain (Town Hall) - Property Protection (Insurance) (Sea Level and Rainfall) - <12 No Requirement for Indicator Analysis
20. Flood Plain (Town Hall) - Maintenance, Operations and Monitoring (Sea Level and Rainfall) - <12 No Requirement for Indicator Analysis
21. Flood Plain (Town Hall) – Capacity (Sea Level and Rainfall) - <12 No Requirement for Indicator Analysis
22. Flood Plain (Town Hall) - Emergency Planning (Sea Level and Rainfall) - <12 No Requirement for Indicator Analysis
23. Flood Plain (Town Hall) – Stability (Sea Level and Rainfall) - <12 No Requirement for Indicator Analysis
24. Flood Plain (Town Hall) – Strength (Sea Level and Rainfall) - <12 No Requirement for Indicator Analysis
25. Road and Culvert (Dunville)- Capacity (Rainfall and Runoff)
26. Road and Culvert (Dunville) – Stability (Rainfall and Runoff)
27. Road and Culvert (Dunville) - Maintenance, Operations and Monitoring

(Rainfall and Runoff)
28. Road and Culvert (Dunville) - Property Protection (Insurance) (Rainfall and Runoff)
29. Road and Culvert (Dunville) - Policies and Procedures (Rainfall and Runoff)
30. Road and Culvert (Dunville) - Lifecycle Planning (Rainfall and Runoff)
31. Road and Culvert (Dunville) – Strength (Rainfall and Runoff)
32. Road and Culvert (Dunville) - Emergency Planning (Rainfall and Runoff)
33. Road and Culvert (Dunville)- Capacity (Runoff Only)
34. Road and Culvert (Dunville) – Stability (Runoff Only)
35. Road and Culvert (Dunville) - Maintenance, Operations and Monitoring (Runoff Only)
36. Road and Culvert (Dunville) - Property Protection (Insurance) (Runoff Only)
37. Road and Culvert (Dunville) - Policies and Procedures (Runoff Only)
38. Road and Culvert (Dunville) - Lifecycle Planning (Runoff Only)
39. Road and Culvert (Dunville) – Strength (Runoff Only)
40. Road and Culvert (Dunville)- Capacity (Rainfall Only)
41. Road and Culvert (Dunville) – Stability (Rainfall Only)
42. Road and Culvert (Dunville) - Maintenance, Operations and Monitoring (Rainfall Only)
If Practitioner choose to use a different cut-off value other then 36, state the chosen value and document the rationale for the decision in this section.
Disagree with concept that >36 must directly go to Step 5 and between 12 – 16 must go to Step 4 Indicator Analysis, or that any replacement number is appropriate for general use. Different people will score things differently – sometimes relatively higher than other people and sometimes lower. The score itself is not a driver, but the high scores in general do merit a more immediate determination of conclusions and recommendations. It is recommended to PIEVC instead that the decision of when something is to be evaluated with Indicator Analysis, be at the discretion of the Evaluator. Some scores associated with, for example, maintenance may score in this range, but do not merit an

analysis based on calculating Vulnerability or Adaptive Capacity.

4.3.9 Data Sufficiency	
Identify process to develop data, Where insufficient	
Data Needed	**Process**
In general	Insufficient data influenced Recommendations made – typically as Management Actions.
Where data cannot be developed, identify the data gap as a finding in Step 5 of the Protocol – Recommendations. **List Data Gap as findings to be sent to STEP 5 (Worksheet 5: Section 4.5.2)**	
1.	
2.	
3.	
4.	
5.	
6.	

Date:	2008.02.22
Prepared under the Responsibility of:	Cameron Consulting Inc. (Cameron Ells, P.Eng.)

Appendix 4 –

Worksheet 4 Indicator Analysis

The purpose of this Worksheet is to determine the relationship between the Performance Responses loads placed on the infrastructure and its capacity. Vulnerability exists when infrastructure has insufficient capacity to withstand the effects placed on it. Adaptive Capacity exits when the infrastructure has sufficient capacity to withstand increasing climate change effects.

In this study, the Indicator Analysis was not performed. The project team decided that this was not relevant or necessary for the infrastructures in question. The Vulnerability and Adaptive Capacity calculations focus on the strength of the infrastructure to withstand the increased loads from the sea level rise and storm surge. For this project, the strength of the Breakwater and Flood Wall were considered to have sufficient Adaptive Capacity. There was concern that the strength of these infrastructures could change later without foreknowledge due to insufficient monitoring, maintenance and lifecycle planning. These concerns are addressed in the recommendations.

Appendix 5 – PIEVC Worksheet 5

Worksheet 5 Recommendations

4.5.1 State Limitations	
MAJOR ASSUMPTIONS[7]	• Mean sea level has a Geodetic elevation of 0 m.
Available infrastructure information and sources	For Breakwater and Floodwall, engineering drawings are owned by Town of Placentia. For Flood Plain (Town Hall location), the Town of Placentia has Flood Plain mapping and from their engineer (Newlab Engineering Limited) building expansion drawings with elevations. No specific drawings encountered during case study for Road and Culvert system. Some information may exist with NL Transportation.
Available climate and information	Sea level elevation and wind assisted storm surge changes in case study technical appendix (Norm Catto and Ouranos). Rainfall changes are from case study technical appendix (AMEC). Conversion of rainfall values to Intensity Duration Frequency (IDF) curve format in a case study technical appendix (AMEC and Anderson).
Available Other Change Information and sources	Storm water run off coefficient values for varying land uses in a case study technical appendix (Anderson).
Use of Generic/specific examples to represent population	Not used in this case study
Uncertainty and related concepts	Sea level, storm surge and rainfall are considered to be certain. Change in land use likely to be based on economic conditions.
Other	

[7] Notionally, these are the same major assumptions that underlie the entire assessment as determined in Step 1 and Step 2 of this Protocol. They may include boundary conditions used to define the study area, time frame, refurbishment schedules, etc.

4.5.2 Recommendations

Infrastructure Component • **Showing Vulnerability from Combination Relationship Assessments (from Work Sheet 3: 4.3.6 & 4.3.7, Priority values > 36)** • **Showing Vulnerability from Quantitative Assessment (from Work Sheet 4: 4.4.9, V_R >1)** • **Lack of Adaptive Capacity (from Work Sheet 4: 4.4.10, A_R<1)** • **Report on Data Gaps (from Worksheets 1-4: 4.1.7, 4.2.8, 4.3.8, 4.4.12)**	**Remedial Engineering Action**	**Management Actions**	**No further Action**	**Recommendation Priority (User defined)**	**Comments**
Report on Data Gaps					**Incl. in Management Actions**
From Worksheet 3, no Infrastructure – Change – Performance relationship being evaluated had a "Priority" value > 36.					**None Applicable**
Lack of Adaptive Capacity					**A_R <1 Noted when Applicable**
From Worksheet 4, Vulnerability (Vr >1) exists for the following:					
Breakwater - Maintenance, Operations and Monitoring (Sea Level and Storm Surge)		X		1 / 8	**V_R >1 Provided in line below A_R <1**
Breakwater - Maintenance, Operations and Monitoring (Sea Level and Storm Surge) New initiatives are recommended. • Those associated with Stability, Capacity and Strength performance objectives					
Breakwater – Stability		X		2 / 8	**V_R >1 Provided in line below A_R <1**

4.5.2 Recommendations					
Infrastructure Component • **Showing Vulnerability from Combination Relationship Assessments (from Work Sheet 3: 4.3.6 & 4.3.7, Priority values > 36)** • **Showing Vulnerability from Quantitative Assessment (from Work Sheet 4: 4.4.9, V_R >1)** • **Lack of Adaptive Capacity (from Work Sheet 4: 4.4.10, A_R<1)** • **Report on Data Gaps (from Worksheets 1-4: 4.1.7, 4.2.8, 4.3.8, 4.4.12)**	**Remedial Engineering Action**	**Management Actions**	**No further Action**	**Recommendation Priority (User defined)**	**Comments**
(Sea Level and Storm Surge)					

4.5.2 Recommendations

Infrastructure Component • Showing Vulnerability from Combination Relationship Assessments (from Work Sheet 3: 4.3.6 & 4.3.7, Priority values > 36) • Showing Vulnerability from Quantitative Assessment (from Work Sheet 4: 4.4.9, V_R >1) • Lack of Adaptive Capacity (from Work Sheet 4: 4.4.10, A_R<1) • Report on Data Gaps (from Worksheets 1-4: 4.1.7, 4.2.8, 4.3.8, 4.4.12)	Remedial Engineering Action	Management Actions	No further Action	Recommendation Priority (User defined)	Comments
Breakwater - Stability (Sea Level and Storm Surge) New initiatives are recommended. • Seek sufficient information to conclude in a timely manner that either an erosion trend exists that could undermine the structure, or that eroded material is being deposited on the beach side of the structure, or that the total volume of sand and gravel on the beach side of the structure is fairly consistent but is moving around due to wave action*. • Collect anecdotal information from Town residents and staff regarding exposed sand, stone cover, and potential of erosion to Breakwater. Maintain this on file with the Town of Placentia for future reference. • Review stone cover beach profiles made at time of construction • Have the Town of Placentia maintain a regularly updated photographic record of sand and stone conditions on the sea side of the Breakwater. Consider starting with monthly intervals and changing to seasonal, annual, and multi-year intervals as trends become established. • Conduct an intensive “beach profile” using surveyor total station equipment or functionally similar equipment. Document the exposed sand and stone conditions on the sea side of the Breakwater. Use the data to calculate a stone and sand volume with respect to the geodetic elevation of 0 m. Successive beach profiles have been made since about 1980. The data is held by Don Forbes of GSC Atlantic. Most recent profiles have used total station survey equipment. Compare results with interpretation of original beach profiles. Have an appropriate professional review the accumulated information and provide an opinion on an appropriate time interval range for further “beach profile” efforts. • Engineering review of potential stability issues in 2018 and at approximately 10 year intervals.					

4.5.2 Recommendations					
Infrastructure Component • **Showing Vulnerability from Combination Relationship Assessments (from Work Sheet 3: 4.3.6 & 4.3.7, Priority values > 36)** • **Showing Vulnerability from Quantitative Assessment (from Work Sheet 4: 4.4.9, V_R >1)** • **Lack of Adaptive Capacity (from Work Sheet 4: 4.4.10, A_R<1)** • **Report on Data Gaps (from Worksheets 1-4: 4.1.7, 4.2.8, 4.3.8, 4.4.12)**	**Remedial Engineering Action**	**Management Actions**	**No further Action**	**Recommendation Priority (User defined)**	**Comments**
Breakwater – Capacity (Sea Level and Storm Surge)	x	x		3 / 8	**V_R >1 Provided in line below A_R <1**
Breakwater - Capacity (Sea Level and Storm Surge) New initiatives are recommended. • Add a new buoy to the Smartbay.ca network to monitor wave action and tides at Point Verte • Have a regular report made of the relevant SmartBay.ca results and copied to the Town of Placentia for future reference • At regular intervals, such as five years, collect anecdotal information from Town residents and staff regarding wave action over the Breakwater. Maintain this on file with the Town of Placentia for future reference. • If concerns grow regarding wave action over the Breakwater, consider adding passive splash monitor(s) and documenting the results.					
Breakwater – Strength (Sea Level and Storm Surge)		x		4/8	**V_R >1 Provided in line below**

4.5.2 Recommendations					
Infrastructure Component • **Showing Vulnerability from Combination Relationship Assessments (from Work Sheet 3: 4.3.6 & 4.3.7, Priority values > 36)** • **Showing Vulnerability from Quantitative Assessment (from Work Sheet 4: 4.4.9, V_R >1)** • **Lack of Adaptive Capacity (from Work Sheet 4: 4.4.10, A_R<1)** • **Report on Data Gaps (from Worksheets 1-4: 4.1.7, 4.2.8, 4.3.8, 4.4.12)**	**Remedial Engineering Action**	**Management Actions**	**No further Action**	**Recommendation Priority (User defined)**	**Comments**
Breakwater - Strength (Sea Level and Storm Surge) Adaptation management measures are recommended. • Perform regular reported inspections by the Town Works Chief / designate • Conduct an engineering inspection in 2018, and at approximately 10 year intervals.					
Breakwater - Lifecycle Planning (Sea Level and Storm Surge)		x		5/8	**V_R >1 Provided in line below**
Breakwater - Lifecycle Planning (Sea Level and Storm Surge) Adaptation management measures are recommended. • Have the Breakwater included in Town of Placentia asset management • Anticipate and financially prepare for a major renewal, renovation, or replacement of the infrastructure by 2050					
Breakwater - Property Protection (Insurance) (Sea Level and Storm Surge)			X	6/8	**V_R <1 No Further Action**

4.5.2 Recommendations					
Infrastructure Component • **Showing Vulnerability from Combination Relationship Assessments (from Work Sheet 3: 4.3.6 & 4.3.7, Priority values > 36)** • **Showing Vulnerability from Quantitative Assessment (from Work Sheet 4: 4.4.9, V_R >1)** • **Lack of Adaptive Capacity (from Work Sheet 4: 4.4.10, A_R<1)** • **Report on Data Gaps (from Worksheets 1-4: 4.1.7, 4.2.8, 4.3.8, 4.4.12)**	**Remedial Engineering Action**	**Management Actions**	**No further Action**	**Recommendation Priority (User defined)**	**Comments**
Breakwater - Policies and Procedures (Sea Level and Storm Surge)			x	7/8	**V_R <1 No Further Action**
Breakwater - Emergency Planning (Sea Level and Storm Surge)			X	8/8	**V_R <1 No Further Action**
Flood Wall - Maintenance, Operations and Monitoring (Sea Level and Storm Surge)		x		1/8	**V_R >1 Provided in line below A_R <1**

4.5.2 Recommendations					
Infrastructure Component • **Showing Vulnerability from Combination Relationship Assessments (from Work Sheet 3: 4.3.6 & 4.3.7, Priority values > 36)** • **Showing Vulnerability from Quantitative Assessment (from Work Sheet 4: 4.4.9, V_R >1)** • **Lack of Adaptive Capacity (from Work Sheet 4: 4.4.10, A_R<1)** • **Report on Data Gaps (from Worksheets 1-4: 4.1.7, 4.2.8, 4.3.8, 4.4.12)**	**Remedial Engineering Action**	**Management Actions**	**No further Action**	**Recommendation Priority (User defined)**	**Comments**
Flood Wall - Maintenance, Operations and Monitoring (Sea Level and Storm Surge) New initiatives are recommended. • Those associated with Capacity and Strength performance objectives					
Flood Wall – Capacity (Sea Level and Storm Surge)		x		2/8	**V_R >1 Provided in line below A_R <1**

4.5.2 Recommendations

Infrastructure Component • Showing Vulnerability from Combination Relationship Assessments (from Work Sheet 3: 4.3.6 & 4.3.7, Priority values > 36) • Showing Vulnerability from Quantitative Assessment (from Work Sheet 4: 4.4.9, V_R >1) • Lack of Adaptive Capacity (from Work Sheet 4: 4.4.10, A_R<1) • Report on Data Gaps (from Worksheets 1-4: 4.1.7, 4.2.8, 4.3.8, 4.4.12)	Remedial Engineering Action	Management Actions	No further Action	Recommendation Priority (User defined)	Comments

Flood Wall - Capacity
(Sea Level and Storm Surge)

New initiatives are recommended.

- Seek to have water level observation information recorded by the NL Transportation and Works Placentia Lift Bridge staff (manned 24 / 7)
- Seek to have water level information maintained by Town of Placentia for future reference.
- Seek to have high / low or yes / no water level information collected and maintained for the top meter of the Flood Wall at a high wall elevation, relatively close to the Lift Bridge
- Have a Professional Review of the accumulating water level information and have an opinion provided on the frequency and duration that the water level rises to within 1 m of the top of the Flood Wall at the measuring point.
- Add a new buoy to the Smartbay.ca network to monitor wave action and tides at Point Verde
- Have a regular report made of the relevant SmartBay.ca results and copied to the Town of Placentia for future reference
- At regular intervals, such as five years, collect anecdotal information from Town residents and staff regarding wave action over the Flood Wall. Maintain this on file with the Town of Placentia for future reference.
- If concerns grow regarding wave action over the Flood Wall, consider adding passive splash monitor(s) and documenting the results.

4.5.2 Recommendations					
Infrastructure Component • **Showing Vulnerability from Combination Relationship Assessments (from Work Sheet 3: 4.3.6 & 4.3.7, Priority values > 36)** • **Showing Vulnerability from Quantitative Assessment (from Work Sheet 4: 4.4.9, V_R >1)** • **Lack of Adaptive Capacity (from Work Sheet 4: 4.4.10, A_R<1)** • **Report on Data Gaps (from Worksheets 1-4: 4.1.7, 4.2.8, 4.3.8, 4.4.12)**	**Remedial Engineering Action**	**Management Actions**	**No further Action**	**Recommendation Priority (User defined)**	**Comments**
Flood Wall - Lifecycle Planning (Sea Level and Storm Surge)				3/8	**V_R >1 Provided in line below**
Flood Wall - Lifecycle Planning (Sea Level and Storm Surge) Adaptation management measures are recommended. • Have the Flood Wall included in Town of Placentia asset management • Anticipate and financially prepare for a major renewal, renovation, or replacement of the infrastructure by 2050 • Perform regular reported inspections by the Town Works Chief / designate					
Flood Wall – Strength (Sea Level and Storm Surge)		x		4/8	**V_R >1 Provided in line below** **A_R <1**

4.5.2 Recommendations					
Infrastructure Component • **Showing Vulnerability from Combination Relationship Assessments (from Work Sheet 3: 4.3.6 & 4.3.7, Priority values > 36)** • **Showing Vulnerability from Quantitative Assessment (from Work Sheet 4: 4.4.9, V_R >1)** • **Lack of Adaptive Capacity (from Work Sheet 4: 4.4.10, A_R<1)** • **Report on Data Gaps (from Worksheets 1-4: 4.1.7, 4.2.8, 4.3.8, 4.4.12)**	**Remedial Engineering Action**	**Management Actions**	**No further Action**	**Recommendation Priority (User defined)**	**Comments**
Flood Wall - Strength (Sea Level and Storm Surge) Adaptation management measures are recommended. • Have a professional opinion on the degree and rate of corrosion, especially in the wet / dry splash zone. • Have a professional opinion on a cost effective set of measures such that corrosion does not compromise the strength of the steel sheet pile wall or the capacity to keep water on the salt water side of the wall.					
Flood Wall – Stability (Sea Level and Storm Surge)			X	5/8	**V_R <1 No Further Action**
Flood Wall - Policies and Procedures (Sea Level and Storm Surge)			x	6/8	**V_R <1 No Further Action**
Flood Wall - Property Protection (Insurance) (Sea Level and Storm Surge)			x	7/8	**V_R <1 No Further Action**
Flood Wall - Emergency			x	8/8	**V_R <1 No Further Action**

4.5.2 Recommendations					
Infrastructure Component • **Showing Vulnerability from Combination Relationship Assessments (from Work Sheet 3: 4.3.6 & 4.3.7, Priority values > 36)** • **Showing Vulnerability from Quantitative Assessment (from Work Sheet 4: 4.4.9, V_R >1)** • **Lack of Adaptive Capacity (from Work Sheet 4: 4.4.10, A_R<1)** • **Report on Data Gaps (from Worksheets 1-4: 4.1.7, 4.2.8, 4.3.8, 4.4.12)**	**Remedial Engineering Action**	**Management Actions**	**No further Action**	**Recommendation Priority (User defined)**	**Comments**
Planning (Sea Level and Storm Surge)					
Flood Plain (Town Hall) - Policies and Procedures (Sea Level and Rainfall)		x		1/8	**V_R >1 Provided in line below**
Flood Plain (Town Hall) - Policies and Procedures (Sea Level and Rainfall) Adaptation management measures are recommended. • The Town of Placentia intends to make a coordinated technical and political case in support of its flood plain policy application goals.					
Flood Plain (Town Hall) - Lifecycle Planning (Sea Level and Rainfall)		x		2/8	**V_R >1 Provided in line below**

4.5.2 Recommendations

Infrastructure Component • Showing Vulnerability from Combination Relationship Assessments (from Work Sheet 3: 4.3.6 & 4.3.7, Priority values > 36) • Showing Vulnerability from Quantitative Assessment (from Work Sheet 4: 4.4.9, V_R >1) • Lack of Adaptive Capacity (from Work Sheet 4: 4.4.10, A_R<1) • Report on Data Gaps (from Worksheets 1-4: 4.1.7, 4.2.8, 4.3.8, 4.4.12)	Remedial Engineering Action	Management Actions	No further Action	Recommendation Priority (User defined)	Comments
Flood Plain (Town Hall) - Lifecycle Planning (Sea Level and Rainfall) Adaptation management measures are recommended. • Have a long term lifecycle planning system for municipal infrastructure • Prioritize the infrastructure order involved with in lifecycle planning • Where most appropriate, include climate change considerations • Anticipate long term financial requirements for infrastructure repair, renewal, and replacement, and source or raise funds appropriately • Consider a life cycle management system that is run and updated by the Town of Placentia, audited by an appropriate professional, and copied to NL Municipal Affairs on a regular basis for future reference. • The design and construction of the new storm sewer line in front of the building could also account for the rise in groundwater elevations considered in this case study evaluation, where there is a concern of buoyant forces potentially acting on the piping infrastructure.					
Flood Plain (Town Hall) -			x	3/8	**V_R <1 No Further Action**

4.5.2 Recommendations					
Infrastructure Component • **Showing Vulnerability from Combination Relationship Assessments (from Work Sheet 3: 4.3.6 & 4.3.7, Priority values > 36)** • **Showing Vulnerability from Quantitative Assessment (from Work Sheet 4: 4.4.9, V_R >1)** • **Lack of Adaptive Capacity (from Work Sheet 4: 4.4.10, A_R<1)** • **Report on Data Gaps (from Worksheets 1-4: 4.1.7, 4.2.8, 4.3.8, 4.4.12)**	**Remedial Engineering Action**	**Management Actions**	**No further Action**	**Recommendation Priority (User defined)**	**Comments**
Property Protection (Insurance) (Sea Level and Rainfall)					
Flood Plain (Town Hall) - Maintenance, Operations and Monitoring (Sea Level and Rainfall)			x	4/8	**V_R <1 No Further Action**
Flood Plain (Town Hall) – Capacity (Sea Level and Rainfall)			x	5/8	**V_R <1 No Further Action**
Flood Plain (Town Hall) - Emergency Planning (Sea Level and Rainfall)			x	6/8	**V_R <1 No Further Action**
Flood Plain (Town Hall) – Stability			x	7/8	**V_R <1 No Further Action**

4.5.2 Recommendations					
Infrastructure Component • **Showing Vulnerability from Combination Relationship Assessments (from Work Sheet 3: 4.3.6 & 4.3.7, Priority values > 36)** • **Showing Vulnerability from Quantitative Assessment (from Work Sheet 4: 4.4.9, V_R >1)** • **Lack of Adaptive Capacity (from Work Sheet 4: 4.4.10, A_R<1)** • **Report on Data Gaps (from Worksheets 1-4: 4.1.7, 4.2.8, 4.3.8, 4.4.12)**	**Remedial Engineering Action**	**Management Actions**	**No further Action**	**Recommendation Priority (User defined)**	**Comments**
(Sea Level and Rainfall)					
Flood Plain (Town Hall) – Strength (Sea Level and Rainfall)			x	8/8	**V_R <1 No Further Action**
Road and Culvert (Dunville) – Capacity (Rainfall and Runoff)	x			1/8	**V_R >1 Provided in line below A_R <1**

4.5.2 Recommendations

Infrastructure Component • Showing Vulnerability from Combination Relationship Assessments (from Work Sheet 3: 4.3.6 & 4.3.7, Priority values > 36) • Showing Vulnerability from Quantitative Assessment (from Work Sheet 4: 4.4.9, V_R >1) • Lack of Adaptive Capacity (from Work Sheet 4: 4.4.10, A_R<1) • Report on Data Gaps (from Worksheets 1-4: 4.1.7, 4.2.8, 4.3.8, 4.4.12)	Remedial Engineering Action	Management Actions	No further Action	Recommendation Priority (User defined)	Comments
Road and Culvert (Dunville) - Capacity (Rainfall and Runoff) New initiatives are recommended. • Review of current practices and consider the merits of taking additional factors into account when calculating desired culvert capacities • In determining the locally applicable rainfall intensity, consider using the "Placentia" Intensity Duration Frequency (IDF) curves and associated information that have been prepared as part of this case study, and which are included in this document. • In determining the watershed area (A) draining into the culvert, consider whether the former railway line bed, and its deteriorating condition since abandonment, influences the effective area being drained. • In determining the appropriate land use storm water run off coefficient, consider the merits of using a 0.5 value for areas, or portions of areas that are thinly forested, on steep slopes, and on top of very thin soil and shallow bedrock. • In determining the appropriate land use storm water run off coefficient, consider the merits of accounting for a progressive change in land use cover from a thin forest to an open field where trees are relatively slow to grow, on thin soil and shallow bedrock, by possibly using a value of 0.7. • Account for the reduction in capacity when calculating culvert sizing, caused by the presence of end screens and the potential accumulation of debris.					

4.5.2 Recommendations					
Infrastructure Component • **Showing Vulnerability from Combination Relationship Assessments (from Work Sheet 3: 4.3.6 & 4.3.7, Priority values > 36)** • **Showing Vulnerability from Quantitative Assessment (from Work Sheet 4: 4.4.9, V_R >1)** • **Lack of Adaptive Capacity (from Work Sheet 4: 4.4.10, A_R<1)** • **Report on Data Gaps (from Worksheets 1-4: 4.1.7, 4.2.8, 4.3.8, 4.4.12)**	**Remedial Engineering Action**	**Management Actions**	**No further Action**	**Recommendation Priority (User defined)**	**Comments**
Road and Culvert (Dunville)- Stability (Rainfall and Runoff)	x			2/8	**V_R >1 Provided in line below A_R <1**

4.5.2 Recommendations

Infrastructure Component • Showing Vulnerability from Combination Relationship Assessments (from Work Sheet 3: 4.3.6 & 4.3.7, Priority values > 36) • Showing Vulnerability from Quantitative Assessment (from Work Sheet 4: 4.4.9, V_R >1) • Lack of Adaptive Capacity (from Work Sheet 4: 4.4.10, A_R<1) • Report on Data Gaps (from Worksheets 1-4: 4.1.7, 4.2.8, 4.3.8, 4.4.12)	Remedial Engineering Action	Management Actions	No further Action	Recommendation Priority (User defined)	Comments
Road and Culvert (Dunville) - Stability (Rainfall and Runoff) New initiatives are recommended. • Consider what measures could be done by upstream culvert owners and others to reduce potential capacity problems at upstream culverts that would result in storm water flowing down connecting roads, and over Route 100. • Evaluate the potential for the anticipated storm water flow rate and ditch size to result in the erosion of road bed materials, especially at a higher elevations. Where an unacceptable potential exists, take actions to reduce this potential (i.e. ditch size, number and location of culverts, and use of more erosion resistant road bed surface materials) • Similarly evaluate the potential for the anticipated flow to result in the erosion along ditches, and especially around culverts. Where an unacceptable potential exists, take action to reduce this potential (i.e. increasing ditch sizes, changing the number and location of culverts, additional features to reduce flow velocity and lining or placing more erosion resistant materials or vegetation) • Consider or reconsider in view of climate and other changes, if the increased storm water run off flow rate merits the construction of a culvert head wall or equivalent to help keep the opening rigid					
Road and Culvert (Dunville) -		x		3/8	**V_R >1 Provided in line below**

4.5.2 Recommendations					
Infrastructure Component • **Showing Vulnerability from Combination Relationship Assessments (from Work Sheet 3: 4.3.6 & 4.3.7, Priority values > 36)** • **Showing Vulnerability from Quantitative Assessment (from Work Sheet 4: 4.4.9, V_R >1)** • **Lack of Adaptive Capacity (from Work Sheet 4: 4.4.10, A_R<1)** • **Report on Data Gaps (from Worksheets 1-4: 4.1.7, 4.2.8, 4.3.8, 4.4.12)**	**Remedial Engineering Action**	**Management Actions**	**No further Action**	**Recommendation Priority (User defined)**	**Comments**
Maintenance, Operations and Monitoring (Rainfall and Runoff)					
Road and Culvert (Dunville) - Maintenance, Operations and Monitoring (Rainfall and Runoff) Adaptation management measures are recommended. • Have the technical staff determine the appropriate culvert size and capacity based on anticipated current and future storm water run off rates, and considering reductions in flow capacity due to end screens and potential debris accumulation • Designers to provide field supervisors with clear opinions or performance goals, on the acceptable quantity of accumulated debris at culvert ends • Provide sufficient resources (time, opportunity, equipment, human, and financial) such that field supervisors can investigate uphill or upstream areas, and be aware of trends regarding potential debris accumulation • Provide sufficient resources such that field supervisors, coordinating with others, can have accumulated debris removed before the desired effective culvert capacity is compromised • Provide sufficient resources such that field supervisors can coordinate a response to the early detection of erosion trends in ditch and road materials.					
Road and Culvert (Dunville) -		x		4/8	**V_R >1 Provided in line below**

4.5.2 Recommendations					
Infrastructure Component • **Showing Vulnerability from Combination Relationship Assessments (from Work Sheet 3: 4.3.6 & 4.3.7, Priority values > 36)** • **Showing Vulnerability from Quantitative Assessment (from Work Sheet 4: 4.4.9, V_R >1)** • **Lack of Adaptive Capacity (from Work Sheet 4: 4.4.10, A_R<1)** • **Report on Data Gaps (from Worksheets 1-4: 4.1.7, 4.2.8, 4.3.8, 4.4.12)**	**Remedial Engineering Action**	**Management Actions**	**No further Action**	**Recommendation Priority (User defined)**	**Comments**
Property Protection (Insurance) (Rainfall and Runoff)					
Road and Culvert (Dunville) - Property Protection (Insurance) (Rainfall and Runoff) Adaptation management measures are recommended. • Communicate changes in culvert sizes and effective flow rates to other appropriate representatives of "downstream" culverts and infrastructure. It is possible that culvert changes in the Route 100 area would influence culvert and other infrastructure performance in another "downstream" area. • Communicate changes associated with a potential flow rate, with appropriate representatives of "upstream" culvert and infrastructure as well. Improved effective capacity "upstream" increases the potential for storm water to stay in desired channels, and reduce the erosion potential in unexpected areas.					
Road and Culvert (Dunville) - Policies and Procedures (Rainfall and Runoff)		x		5/8	**V_R >1 Provided in line below**

4.5.2 Recommendations					
Infrastructure Component • **Showing Vulnerability from Combination Relationship Assessments (from Work Sheet 3: 4.3.6 & 4.3.7, Priority values > 36)** • **Showing Vulnerability from Quantitative Assessment (from Work Sheet 4: 4.4.9, V_R >1)** • **Lack of Adaptive Capacity (from Work Sheet 4: 4.4.10, A_R<1)** • **Report on Data Gaps (from Worksheets 1-4: 4.1.7, 4.2.8, 4.3.8, 4.4.12)**	**Remedial Engineering Action**	**Management Actions**	**No further Action**	**Recommendation Priority (User defined)**	**Comments**
Road and Culvert (Dunville) - Policies and Procedures (Rainfall and Runoff) Adaptation management measures are recommended. • Have senior management reconsider the use of 50 mm x 50 mm screens at the end of culverts. Screens are commonly used and is a drawing in the Design Specifications. If the intent is to keep people out of the culvert, an increased mesh size would still accomplish this. Any mesh screen will reduce the effective flow rate capacity to something less than what a designer anticipated when an open culvert was assumed. A larger screen mesh would also result in a smaller reduction in the effective flow capacity of the culvert. • Have senior management consider having site-specific Intensity-Duration-Frequency (IDF) curves prepared for areas where infrastructure design and construction are anticipated in the near future.					
Road and Culvert (Dunville) - Lifecycle Planning (Rainfall and Runoff)		x		6/8	**V_R >1 Provided in line below**

4.5.2 Recommendations

Infrastructure Component • Showing Vulnerability from Combination Relationship Assessments (from Work Sheet 3: 4.3.6 & 4.3.7, Priority values > 36) • Showing Vulnerability from Quantitative Assessment (from Work Sheet 4: 4.4.9, V_R >1) • Lack of Adaptive Capacity (from Work Sheet 4: 4.4.10, A_R<1) • Report on Data Gaps (from Worksheets 1-4: 4.1.7, 4.2.8, 4.3.8, 4.4.12)	Remedial Engineering Action	Management Actions	No further Action	Recommendation Priority (User defined)	Comments
Road and Culvert (Dunville) - Lifecycle Planning (Rainfall and Runoff) Adaptation management measures are recommended. • Have senior management mandate and support the consideration by designers of "climate change adaptation" or other reasonably anticipated future changes, during the design and preparation of technical specifications. Therefore, technical designers would no longer solely rely on historical data. Ensure that resources exist for the technical people to have these additional considerations taken into account. • For each major culvert design, evaluate the runoff coefficient based on current and future values for existing and upstream land uses. Coefficients, and corresponding travel times, may vary over portions or areas of same watershed areas. • On a seven year rotating basis, consider if the land use run off coefficient used in the culvert design merits a change, and the corresponding consequences for the infrastructure involved. • On a seven year rotating basis consider if available climate change information regarding rainfall amounts or intensities, sufficiently merits or justifies the preparation of new IDF curves.					
Road and Culvert (Dunville) –			x	7/8	**V_R <1 No Further Action**

4.5.2 Recommendations					
Infrastructure Component • **Showing Vulnerability from Combination Relationship Assessments (from Work Sheet 3: 4.3.6 & 4.3.7, Priority values > 36)** • **Showing Vulnerability from Quantitative Assessment (from Work Sheet 4: 4.4.9, V_R >1)** • **Lack of Adaptive Capacity (from Work Sheet 4: 4.4.10, A_R<1)** • **Report on Data Gaps (from Worksheets 1-4: 4.1.7, 4.2.8, 4.3.8, 4.4.12)**	**Remedial Engineering Action**	**Management Actions**	**No further Action**	**Recommendation Priority (User defined)**	**Comments**
Strength (Rainfall and Runoff)					
Road and Culvert (Dunville) - Emergency Planning (Rainfall and Runoff)			x	8/8	**V_R <1 No Further Action**
Road and Culvert (Dunville) – Capacity (Runoff Only)	x			1/7	**V_R >1 Provided in line below A_R <1**

4.5.2 Recommendations

Infrastructure Component • Showing Vulnerability from Combination Relationship Assessments (from Work Sheet 3: 4.3.6 & 4.3.7, Priority values > 36) • Showing Vulnerability from Quantitative Assessment (from Work Sheet 4: 4.4.9, V_R >1) • Lack of Adaptive Capacity (from Work Sheet 4: 4.4.10, A_R<1) • Report on Data Gaps (from Worksheets 1-4: 4.1.7, 4.2.8, 4.3.8, 4.4.12)	Remedial Engineering Action	Management Actions	No further Action	Recommendation Priority (User defined)	Comments
Road and Culvert (Dunville) - Capacity (Runoff Only) New initiatives are recommended. • Review of current practices and consider the merits of taking additional factors into account when calculating desired culvert capacities • In determining the locally applicable rainfall intensity, consider using the "Placentia" Intensity Duration Frequency (IDF) curves and associated information that have been prepared as part of this case study, and which are included in this document. • In determining the watershed area (A) draining into the culvert, consider whether the former railway line bed, and its deteriorating condition since abandonment, influences the effective area being drained. • In determining the appropriate land use storm water run off coefficient, consider the merits of using a 0.5 value for areas, or portions of areas that are thinly forested, on steep slopes, and on top of very thin soil and shallow bedrock. • In determining the appropriate land use storm water run off coefficient, consider the merits of accounting for a progressive change in land use cover from a thin forest to an open field where trees are relatively slow to grow, on thin soil and shallow bedrock, by possibly using a value of 0.7. • Account for the reduction in capacity when calculating culvert sizing, caused by the presence of end screens and the potential accumulation of debris.					

4.5.2 Recommendations					
Infrastructure Component • **Showing Vulnerability from Combination Relationship Assessments (from Work Sheet 3: 4.3.6 & 4.3.7, Priority values > 36)** • **Showing Vulnerability from Quantitative Assessment (from Work Sheet 4: 4.4.9, V_R >1)** • **Lack of Adaptive Capacity (from Work Sheet 4: 4.4.10, A_R<1)** • **Report on Data Gaps (from Worksheets 1-4: 4.1.7, 4.2.8, 4.3.8, 4.4.12)**	**Remedial Engineering Action**	**Management Actions**	**No further Action**	**Recommendation Priority (User defined)**	**Comments**
Road and Culvert (Dunville)- Stability (Runoff Only)	x			2/7	**V_R >1 Provided in line below A_R <1**

4.5.2 Recommendations					
Infrastructure Component • **Showing Vulnerability from Combination Relationship Assessments (from Work Sheet 3: 4.3.6 & 4.3.7, Priority values > 36)** • **Showing Vulnerability from Quantitative Assessment (from Work Sheet 4: 4.4.9, V_R >1)** • **Lack of Adaptive Capacity (from Work Sheet 4: 4.4.10, A_R<1)** • **Report on Data Gaps (from Worksheets 1-4: 4.1.7, 4.2.8, 4.3.8, 4.4.12)**	**Remedial Engineering Action**	**Management Actions**	**No further Action**	**Recommendation Priority (User defined)**	**Comments**
Road and Culvert (Dunville) - Stability (Runoff Only) New initiatives are recommended. • Consider what measures could be done by upstream culvert owners and others to reduce potential capacity problems at upstream culverts that would result in storm water flowing down connecting roads, and over Route 100. • Evaluate the potential for the anticipated storm water flow rate and ditch size to result in the erosion of road bed materials, especially at a higher elevations. Where an unacceptable potential exists, take actions to reduce this potential (i.e. ditch size, number and location of culverts, and use of more erosion resistant road bed surface materials) • Similarly evaluate the potential for the anticipated flow to result in the erosion along ditches, and especially around culverts. Where an unacceptable potential exists, take action to reduce this potential (i.e. increasing ditch sizes, changing the number and location of culverts, additional features to reduce flow velocity and lining or placing more erosion resistant materials or vegetation) • Consider or reconsider in view of climate and other changes, if the increased storm water run off flow rate merits the construction of a culvert head wall or equivalent to help keep the opening rigid					
Road and Culvert (Dunville) -		x		3/7	**V_R >1 Provided in line below**

4.5.2 Recommendations					
Infrastructure Component • **Showing Vulnerability from Combination Relationship Assessments (from Work Sheet 3: 4.3.6 & 4.3.7, Priority values > 36)** • **Showing Vulnerability from Quantitative Assessment (from Work Sheet 4: 4.4.9, V_R >1)** • **Lack of Adaptive Capacity (from Work Sheet 4: 4.4.10, A_R<1)** • **Report on Data Gaps (from Worksheets 1-4: 4.1.7, 4.2.8, 4.3.8, 4.4.12)**	**Remedial Engineering Action**	**Management Actions**	**No further Action**	**Recommendation Priority (User defined)**	**Comments**
Maintenance, Operations and Monitoring (Runoff Only)					

Road and Culvert (Dunville) - Maintenance, Operations and Monitoring (Runoff Only)

Adaptation management measures are recommended.

- Have the technical staff determine the appropriate culvert size and capacity based on anticipated current and future storm water run off rates, and considering reductions in flow capacity due to end screens and potential debris accumulation
- Designers to provide field supervisors with clear opinions or performance goals, on the acceptable quantity of accumulated debris at culvert ends
- Provide sufficient resources (time, opportunity, equipment, human, and financial) such that field supervisors can investigate uphill or upstream areas, and be aware of trends regarding potential debris accumulation
- Provide sufficient resources such that field supervisors, coordinating with others, can have accumulated debris removed before the desired effective culvert capacity is compromised
- Provide sufficient resources such that field supervisors can coordinate a response to the early detection of erosion trends in ditch and road materials.

4.5.2 Recommendations					
Infrastructure Component • **Showing Vulnerability from Combination Relationship Assessments (from Work Sheet 3: 4.3.6 & 4.3.7, Priority values > 36)** • **Showing Vulnerability from Quantitative Assessment (from Work Sheet 4: 4.4.9, V_R >1)** • **Lack of Adaptive Capacity (from Work Sheet 4: 4.4.10, A_R<1)** • **Report on Data Gaps (from Worksheets 1-4: 4.1.7, 4.2.8, 4.3.8, 4.4.12)**	**Remedial Engineering Action**	**Management Actions**	**No further Action**	**Recommendation Priority (User defined)**	**Comments**
Road and Culvert (Dunville) - Property Protection (Insurance) (Runoff Only)		x		4/7	**V_R >1 Provided in line below**
Road and Culvert (Dunville) - Property Protection (Insurance) (Runoff Only) Adaptation management measures are recommended. • Communicate changes in culvert sizes and effective flow rates to other appropriate representatives of "downstream" culverts and infrastructure. It is possible that culvert changes in the Route 100 area would influence culvert and other infrastructure performance in another "downstream" area. • Communicate changes associated with a potential flow rate, with appropriate representatives of "upstream" culvert and infrastructure as well. Improved effective capacity "upstream" increases the potential for storm water to stay in desired channels, and reduce the erosion potential in unexpected areas.					
Road and Culvert (Dunville) - Policies and Procedures (Runoff Only)		x		5/7	**V_R >1 Provided in line below**

4.5.2 Recommendations					
Infrastructure Component • **Showing Vulnerability from Combination Relationship Assessments (from Work Sheet 3: 4.3.6 & 4.3.7, Priority values > 36)** • **Showing Vulnerability from Quantitative Assessment (from Work Sheet 4: 4.4.9, V_R >1)** • **Lack of Adaptive Capacity (from Work Sheet 4: 4.4.10, A_R<1)** • **Report on Data Gaps (from Worksheets 1-4: 4.1.7, 4.2.8, 4.3.8, 4.4.12)**	**Remedial Engineering Action**	**Management Actions**	**No further Action**	**Recommendation Priority (User defined)**	**Comments**
Road and Culvert (Dunville) - Policies and Procedures (Runoff Only) Adaptation management measures are recommended. • Have senior management reconsider the use of 50 mm x 50 mm screens at the end of culverts. It is commonly used and is a drawing in the Design Specification book. If the intent is to keep people out of the culvert, an increased mesh size would still accomplish this. Any mesh screen will reduce the effective flow rate capacity to something less than what a designer anticipated when an open culvert was assumed. A larger screen mesh would also result in a smaller reduction in the effective flow capacity of the culvert. • Have senior management consider having site specific Intensity-Duration-Frequency (IDF) curves prepared for areas where infrastructure design and construction are anticipated in the near future.					
Road and Culvert (Dunville) - Lifecycle Planning (Runoff Only)		x		6/7	**V_R >1 Provided in line below**

4.5.2 Recommendations					
Infrastructure Component • **Showing Vulnerability from Combination Relationship Assessments (from Work Sheet 3: 4.3.6 & 4.3.7, Priority values > 36)** • **Showing Vulnerability from Quantitative Assessment (from Work Sheet 4: 4.4.9, V_R >1)** • **Lack of Adaptive Capacity (from Work Sheet 4: 4.4.10, A_R<1)** • **Report on Data Gaps (from Worksheets 1-4: 4.1.7, 4.2.8, 4.3.8, 4.4.12)**	**Remedial Engineering Action**	**Management Actions**	**No further Action**	**Recommendation Priority (User defined)**	**Comments**
Road and Culvert (Dunville) - Lifecycle Planning (Runoff Only) Adaptation management measures are recommended. • Have senior management mandate and support the consideration by designers of "climate change adaptation" or other reasonably anticipated future changes, during the design and preparation of technical specifications. Therefore, technical designers would no longer solely rely on historical data. Ensure that resources exist for the technical people to have these additional considerations taken into account. • For each major culvert design, evaluate the runoff coefficient based on current and future values for existing and upstream land uses. Coefficients, and corresponding travel times, may vary over portions or areas of same watershed areas. • On a seven year rotating basis, consider if the land use run off coefficient used in the culvert design merits a change, and the corresponding consequences for the infrastructure involved. • On a seven year rotating basis consider if available climate change information regarding rainfall amounts or intensities, sufficiently merits or justifies the preparation of new IDF curves.					
Road and Culvert (Dunville) – Strength (Runoff Only)			x	7/7	**V_R <1 No Further Action**

4.5.2 Recommendations					
Infrastructure Component • **Showing Vulnerability from Combination Relationship Assessments (from Work Sheet 3: 4.3.6 & 4.3.7, Priority values > 36)** • **Showing Vulnerability from Quantitative Assessment (from Work Sheet 4: 4.4.9, V_R >1)** • **Lack of Adaptive Capacity (from Work Sheet 4: 4.4.10, A_R<1)** • **Report on Data Gaps (from Worksheets 1-4: 4.1.7, 4.2.8, 4.3.8, 4.4.12)**	**Remedial Engineering Action**	**Management Actions**	**No further Action**	**Recommendation Priority (User defined)**	**Comments**
Road and Culvert (Dunville) – Capacity (Rainfall Only)	x			1/3	**V_R >1 Provided in line below A_R <1**

4.5.2 Recommendations

Infrastructure Component • Showing Vulnerability from Combination Relationship Assessments (from Work Sheet 3: 4.3.6 & 4.3.7, Priority values > 36) • Showing Vulnerability from Quantitative Assessment (from Work Sheet 4: 4.4.9, V_R >1) • Lack of Adaptive Capacity (from Work Sheet 4: 4.4.10, A_R<1) • Report on Data Gaps (from Worksheets 1-4: 4.1.7, 4.2.8, 4.3.8, 4.4.12)	Remedial Engineering Action	Management Actions	No further Action	Recommendation Priority (User defined)	Comments
Road and Culvert (Dunville) - Capacity (Rainfall Only) New initiatives are recommended. • Review of current practices and consider the merits of taking additional factors into account when calculating desired culvert capacities • In determining the locally applicable rainfall intensity, consider using the "Placentia" Intensity Duration Frequency (IDF) curves and associated information that have been prepared as part of this case study, and which are included in this document. • In determining the watershed area (A) draining into the culvert, consider whether the former railway line bed, and its deteriorating condition since abandonment, influences the effective area being drained. • In determining the appropriate land use storm water run off coefficient, consider the merits of using a 0.5 value for areas, or portions of areas that are thinly forested, on steep slopes, and on top of very thin soil and shallow bedrock. • In determining the appropriate land use storm water run off coefficient, consider the merits of accounting for a progressive change in land use cover from a thin forest to an open field where trees are relatively slow to grow, on thin soil and shallow bedrock, by possibly using a value of 0.7. • Account for the reduction in capacity when calculating culvert sizing, caused by the presence of end screens and the potential accumulation of debris.					

4.5.2 Recommendations					
Infrastructure Component • **Showing Vulnerability from Combination Relationship Assessments (from Work Sheet 3: 4.3.6 & 4.3.7, Priority values > 36)** • **Showing Vulnerability from Quantitative Assessment (from Work Sheet 4: 4.4.9, V_R >1)** • **Lack of Adaptive Capacity (from Work Sheet 4: 4.4.10, A_R<1)** • **Report on Data Gaps (from Worksheets 1-4: 4.1.7, 4.2.8, 4.3.8, 4.4.12)**	**Remedial Engineering Action**	**Management Actions**	**No further Action**	**Recommendation Priority (User defined)**	**Comments**
Road and Culvert (Dunville)- Stability (Rainfall Only)	x			2/3	**V_R >1 Provided in line below A_R <1**

4.5.2 Recommendations

Infrastructure Component • Showing Vulnerability from Combination Relationship Assessments (from Work Sheet 3: 4.3.6 & 4.3.7, Priority values > 36) • Showing Vulnerability from Quantitative Assessment (from Work Sheet 4: 4.4.9, V_R >1) • Lack of Adaptive Capacity (from Work Sheet 4: 4.4.10, A_R<1) • Report on Data Gaps (from Worksheets 1-4: 4.1.7, 4.2.8, 4.3.8, 4.4.12)	Remedial Engineering Action	Management Actions	No further Action	Recommendation Priority (User defined)	Comments
Road and Culvert (Dunville) - Stability (Rainfall Only) New initiatives are recommended. • Consider what measures could be done by upstream culvert owners and others to reduce potential capacity problems at upstream culverts that would result in storm water flowing down connecting roads, and over Route 100. • Evaluate the potential for the anticipated storm water flow rate and ditch size to result in the erosion of road bed materials, especially at a higher elevations. Where an unacceptable potential exists, take actions to reduce this potential (i.e. ditch size, number and location of culverts, and use of more erosion resistant road bed surface materials) • Similarly evaluate the potential for the anticipated flow to result in the erosion along ditches, and especially around culverts. Where an unacceptable potential exists, take action to reduce this potential (i.e. increasing ditch sizes, changing the number and location of culverts, additional features to reduce flow velocity and lining or placing more erosion resistant materials or vegetation) • Consider or reconsider in view of climate and other changes, if the increased storm water run off flow rate merits the construction of a culvert head wall or equivalent to help keep the opening rigid					
Road and Culvert (Dunville) -		x		3/3	**V_R >1 Provided in line below**

4.5.2 Recommendations					
Infrastructure Component • **Showing Vulnerability from Combination Relationship Assessments (from Work Sheet 3: 4.3.6 & 4.3.7, Priority values > 36)** • **Showing Vulnerability from Quantitative Assessment (from Work Sheet 4: 4.4.9, V_R >1)** • **Lack of Adaptive Capacity (from Work Sheet 4: 4.4.10, A_R<1)** • **Report on Data Gaps (from Worksheets 1-4: 4.1.7, 4.2.8, 4.3.8, 4.4.12)**	**Remedial Engineering Action**	**Management Actions**	**No further Action**	**Recommendation Priority (User defined)**	**Comments**
Maintenance, Operations and Monitoring (Rainfall Only)					

Road and Culvert (Dunville) - Maintenance, Operations and Monitoring (Rainfall Only)

Adaptation management measures are recommended.

- Have the technical staff determine the appropriate culvert size and capacity based on anticipated current and future storm water run off rates, and considering reductions in flow capacity due to end screens and potential debris accumulation
- Designers to provide field supervisors with clear opinions or performance goals, on the acceptable quantity of accumulated debris at culvert ends
- Provide sufficient resources (time, opportunity, equipment, human, and financial) such that field supervisors can investigate uphill or upstream areas, and be aware of trends regarding potential debris accumulation
- Provide sufficient resources such that field supervisors, coordinating with others, can have accumulated debris removed before the desired effective culvert capacity is compromised
- Provide sufficient resources such that field supervisors can coordinate a response to the early detection of erosion trends in ditch and road materials.

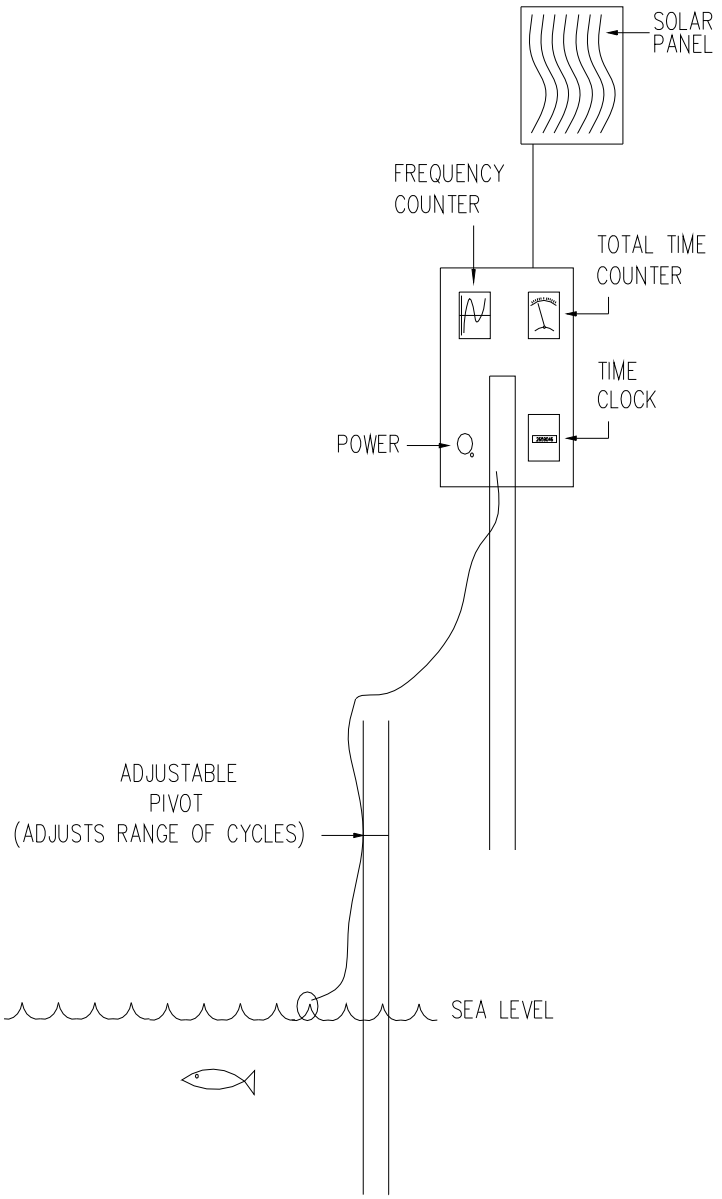
4.5.2.f **Report on the other conclusions, trends, insights and limitations**
No comment.

Date:	2008.02.22
Prepared under the Responsibility of:	Cameron Consulting Inc. (Cameron Ells, P.Eng.)

Appendix 6 – Floodwall Monitoring Equipment Concept

(SCG Industries – Saint John, NB)

BASIC EQUIPMENT ASSEMBLY OF EXPERIMENT REGARDING POSSIBLE RISE IN SEA LEVEL



Appendix 7 – Ouranos Data

Climate change in Canada: Climate scenarios for the public infrastructure vulnerability assessment

Placentia Water resources infrastructure (coastal breakwater) case study

Produced for the *Public Infrastructure Engineering Vulnerability Committee* (PIEVC)

By Ouranos

January 2008

Ouranos, a research consortium on regional climatology and adaptation to climate change, is a joint initiative of the Government of Québec, Hydro-Québec, and the Meteorological Service of Canada with the participation of UQAM, Université Laval, McGill University, and the INRS. Valorisation Recherche Québec collaborated on the establishment and financing of Ouranos. The opinions and results presented in this publication are the sole responsibility of Ouranos and do not reflect in any way those of the aforementioned organizations.

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1. Introduction

The Canadian Council of Professional Engineers set up the Public Infrastructure Engineering Vulnerability Committee (PIEVC) to examine the vulnerability of public infrastructure to climate change across the nation. A series of case studies serve to assess infrastructure vulnerability with the protocol proposed in Phase 1 of the PIEVC initiative and provide feedback on the state of different categories of infrastructure throughout the country. The current study is located in the Placentia region (Newfoundland) and focuses on water resources infrastructure, namely a coastal breakwater that serves to protect an urban flood plain.

The draft engineering protocol requires information on a variety of climatic elements to use as input towards estimating the vulnerability of infrastructure to climate change. Estimates of climatic elements enable numerical estimations of the exposure of the infrastructure and help identify which changes in climatic conditions will have the most impact on its vulnerability.

In order to provide coherent results for all of the pilot projects, the vulnerability analyses must be based on plausible and comparable scenarios of climate change for the various regions of the country. Ouranos has been mandated to provide this data.

This report provides historical climate data and climate change scenarios for the Placentia region on the vulnerability of the City's coastal breakwater infrastructure.

The data provided in this report is intended for the use of this case study only and should not be used for any other purpose because the results are specific to the characteristics of this project (location, timeframe, etc.).

2. Methodology

2.1. Selection of weather stations

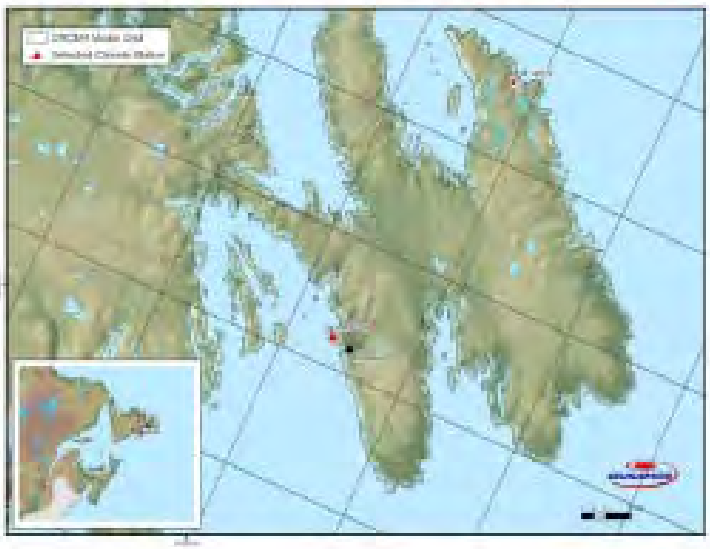
Observed weather station data was obtained from Environment Canada's national archives for the area of interest. Archived data were screened in order to select stations deemed to have a sufficiently long/complete record. Selection criteria included: a data series minimum length of 20 years, with less than 10% missing data and a final year being no earlier than 1995. A summary of the selected stations is presented in Table 2.1. The distribution of the stations within the study region is shown in Figure 2.1.

***NB – after selection criteria were applied only a single climate station (Argentia : id 8400104) remained with adequate daily wind data*

Table 2.1 Selected Environment Canada station data for variables of Temperature, Precipitation, Snow and Wind (Selection was based on the criteria of a minimum record length of 20 years and a maximum of 10% missing data, and final year no earlier than 1995).

	Climatic Variables
ID	WIND
8400104	yes

Figure 2.1 Canadian Regional Climate Model (CRCM4) grid and location of selected climate stations within the study area.



2.2. *Choice of climate model*

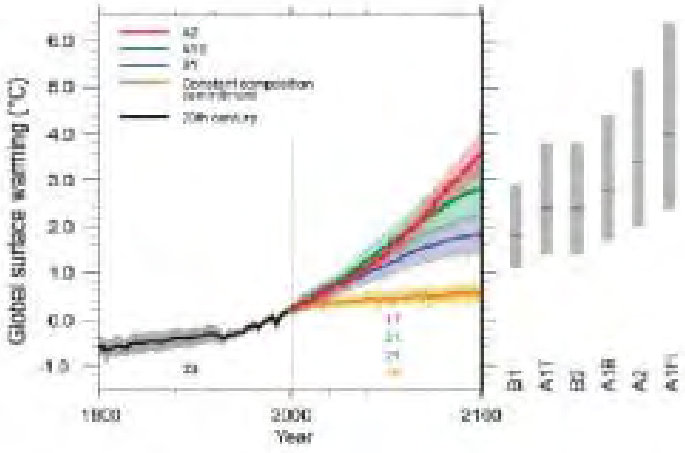
Impacts and adaptation projects should, in a best-case scenario, be based on projections of multiple climatic simulations in order to ensure that uncertainty of future climate projections is fully explored and incorporated in decision-making processes. Furthermore, in a regional context, such as the current PIEVC pilot project, downscaling of coarse resolution Global Circulation Model (GCM) output is desirable. Regional climate modeling employing the commonly termed approach of dynamical downscaling is one area of expertise covered by the Ouranos consortium and its research partners. Ouranos has contributed to the development of the Canadian Regional Climate Model (CRCM; Caya and Laprise, 1999) which, like other regional climate models (RCMs), uses principles of conservation on energy, mass and movement to generate temporal series of *physically coherent climatic variables*. Developed using the same physical principles as GCMs, RCMs concentrate on a portion of the globe and allow production of simulations at higher spatial resolution (approximately 45km for the CRCM compared to the several hundred seen with typical GCMs). Dynamical downscaling can have a particular advantage in simulating meso-scale weather events when compared with global models. As such, extreme events (particularly precipitation events) are typically better reproduced by regional modeling efforts. Plummer *et al.* (2006) showed that general observed patterns of precipitation and temperature are relatively well reproduced over North America by the CRCM (version 3.7.1). Regional comparison of CRCM precipitation output (again version 3.7.1) and corresponding intensity duration frequency curves showed favourable results versus observed values for southern Quebec (Mailhot *et al.* 2007). Mailhot *et al.* also state that there is good indication that CRCM results are statistically consistent with observations in terms of extreme rainfall estimates.

In general the majority of CRCM simulations produced by Ouranos for impacts and adaptation purposes focus on the future period of 2041-2070 (termed horizon 2050). However, due to increasing demand for climatic scenarios for different future periods a small number of continuous simulations have been produced for the period 1961-2100. Two of these simulations have been selected for use in this case study. The simulations were produced using the Canadian Regional Climate Model, version 4.1.1 (CRCM 4.1.1) (Music and Caya, 2007; Brochu and Laprise, 2007). This selection was based on the advantages of having increased spatial resolution (compared to GCMs), the availability of continuous future daily series for the period 1961-2100. The choice was also due to the time constraints imposed for completion of the project. This particular report presents results for a single future period (2050), however, previous PIEVC pilot studies had future horizons of interest of 2020, 2050 and 2080. Thus the choice of simulations was also made in order to maintain continuity with other pilot studies.

NB - it is important to note that, due to the restricted number of simulations, caution is required in the interpretation of any modeling effort or analysis based on the scenarios provided. Use of only 2 simulations is sufficient for sensitivity analyses but lacks the robustness provided by the use of a large ensemble of simulations (recommended for decision-making or policy planning; see Conclusions - section 4 of this report).

The two simulations (CRCM 4.1.1 ACU; CRCM4.1.1 ADC) were carried out for a domain centred over Québec and covering an area of approximately 5050km by 4000km with a horizontal grid-size mesh of 45 km (true at 60 degrees north latitude) for the period 1961-2100. The simulations were driven at their boundaries by atmospheric fields taken from simulation output of the 4th and 5th members of the third generation coupled Canadian Global Climate Model (CGCM3)., Both global and regional simulations were performed using the IPCC SRES A2 greenhouse gas (GHG) and aerosol projected evolution[1]. Figure 2.2 shows the simulated mean global temperature evolution according to the multiple GCM output grouped under various SRES different scenarios. It is interesting to note that the emissions scenarios diverge very little before approximately 2050.

Figure 2.2 Mean global temperature evolution according to the multiple GCM output grouped under various SRES different scenarios.



2.2.1. *Future sea level change scenarios*

Variables of sea level change and other ocean processes are ***not simulated in the regional model***. Instead, the CRCM relies directly on the pilot model's ocean components. As such, future scenarios for sea-level change were determined from the CGCM3.

[1] "The A2 storyline and scenario family describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing population. Economic development is primarily regionally oriented and per capita economic growth and technological change more fragmented and slower than other storylines." (Nakicenovic et al., 2000)

It is important to note that sea level data is unavailable at this time for runs 4 & 5 of the CGCM3 (pilot models for the RCM simulations); consequently, future scenarios had to be based on CGCM3 run 1 data.

2.3. Climate model simulations and time periods

A total of 3 CRCM grid cells surrounding the city of Placentia were selected to construct future climate scenarios. Corresponding grid cell data from the two CRCM 4.1.1 simulations described in section 2.2 (ACU and ADC) were extracted and used to calculate the climate indices listed in section 2.4. Future changes in indices were determined for one future period or horizon; **horizon 2050** (2041-2070); with respect to the present period (**1961-1990**).

CGCM3 Run1 sea level change data was a time series of average global sea-level change for the period 1850 – 2100. Again, future changes were determined for horizon 2050.

Changes (or deltas) in indices are calculated as either the difference or ratio between simulated future conditions and simulated present day conditions. Deltas can then be applied to calculated observed values either through addition (difference) or multiplication (ratio).

2.4. Description of climate indices

The choice and priority of climate indices was made in consultation with the client in terms of project needs as well as in terms of the limitations of the climate model simulations. Calculated indices were chosen from those having been known and used in the climate literature in the past.

Sea Level Change indices

a. Global average sea level change (Sea_level):
   - *Global mean sea level change in metres with respect to present conditions (average 1961-1990)*

Wind indices
**Wind index values in m/s indicate values of average wind speed over a 6h period.*
***NB – A 6hour timestep was used as this is the minimum timestep available for analysis for the CRCM4 data.*

a. Monthly average 6h Windspeed (Monthly AVG WIND6h):
   - Average 6h windspeed for a given month over the time period

b. Yearly Max. 6hour Wind (*Avg annual MAX6h*):

- average maximum yearly 6h Wind

$$Avg_annual_MAX6h = \left(\sum_{i=1}^{I} (wind365i) \right) / I$$

Calculated as the sum of $wind365i$ for years i through I divided by the number of years. Where $wind365i$ is the highest 6h mean windspeed for a given year i.

2.5. Regionalization of climate indices

Climate indices listed in section 3.1 were calculated for each climate station and each RCM grid cell individually. A regional value for each index is then determined by taking the average of all stations (grid points) within the study area. These regional values are presented in the results section of this report.

3. Results

3.1 Climate scenarios for Sea level rise and Wind indices

SEA LEVEL RISE indices

SEA LEVEL RISE : Sea level
Future Change - horizon 2050 (metres)
0.14

WIND indices

WIND : Monthly AVG WIND6h			
Month	*Observed (km/h)*	*Future Change ACU*	*Future Change ADC*
		2050 (ratio)	*2050 (ratio)*
January	29.48	0.98	1.02
February	27.77	0.96	0.98
March	26.45	1.03	1.04
April	22.84	1.06	1.02
May	19.74	0.98	1.04
June	20.16	1.01	0.97
July	19.01	0.98	1.05
August	19.68	0.98	0.99
September	21.42	0.99	0.96
October	24.60	0.99	0.99
November	26.64	1.04	0.99
December	29.17	0.96	0.96

WIND : Avg annual MAX6h		
Observed (km/h)	*Future Change ACU*	*Future Change ADC*
	2050 (ratio)	*2050 (ratio)*
76.38	1.01	0.96

3.2 *Literature review for other climate indices*

Although climate scenarios for temperature changes and changes in precipitation patterns are quite reliable, there is far greater uncertainty linked to projections for relatively small-scale or very localized atmospheric phenomena. Most authors agree that GHG concentrations do have an effect on these events; however, it remains difficult to find reliable projections that indicate future trends of intensity, direction or frequency for events such as storms, intense winds or other extreme events (Maarten, 2006). Climate scenarios are therefore difficult to produce for certain very localized events (wind gusts, tornadoes, thunderstorms) or events where processes are complex and depend on a number of factors (hurricanes, ice storms). The observed data is insufficient to validate the model outputs for these events.

Moreover, any seemingly apparent trend stemming from the observed data must be interpreted carefully as an increase could result from a combination of factors such as:

- increased weather station coverage
- improved quality of the data collected
- changes in land use (and corresponding increases in damage claims).

Consequently, among the list of climate elements that were requested for the Placentia case study, it is not possible to provide sound numerical climate scenarios that could be used for the infrastructure vulnerability assessment. The following is the list of climate variables that fall under this category with a review of the literature explaining possible changes.

WIND (hurricanes, tornadoes, thunderstorms, winds gusts)

According to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC, 2007), it is "more likely than not" that the observed trend of hurricane intensification since the 1970s is linked to human-induced greenhouse gas emissions. The report also claims that "it is likely that future tropical cyclones (typhoons and hurricanes) will become more intense, with larger peak wind speeds and more heavy precipitation associated with ongoing increases of tropical sea surface temperatures." However, there is no clear trend in terms of the frequency of tropical cyclones. Although some authors claim that there has been an increase in the frequency of hurricanes, namely in the North Atlantic (Holland *et al.* 2007, Webster *et al.* 2005), there remains much debate as to the possible mechanisms explaining this.

Results from some model simulations suggest that the atmosphere over mid-latitude land areas could become more unstable in the future, suggesting that an increase in convective activity is quite probable (Balling *et al.* 2003). However, researchers have been unable to identify significant increases in overall severe storm activity as measured in the magnitude and/or frequency of thunderstorms, hail events, tornadoes, hurricanes, and winter storm activity in North America. Increasing trends in damages caused by these events seem to be more closely linked to changes in demography and land use (Balling *et al.* 2003)

4. Conclusion

The case studies carried out within the PIEVC initiative to assess infrastructure vulnerability to climate change using the protocol developed in Phase 1 of the initiative require plausible and reliable climate scenarios based on similar methodologies in order to compare the relative vulnerability of various infrastructures throughout the country.

This report provides historical climate data and climate change scenarios for the Placentia region on the vulnerability of the City's coastal breakwater infrastructure.

Prudence is required in the interpretation of analyses based on the future scenarios provided. Climate scenario production was limited to the use of only 2 simulations. Furthermore, these simulations were produced by the same regional climate model (CRCM 4.1.1), driven by two runs of the same GCM (CGCM3) and the same GHG emissions scenario (SRES A2). In short, the predicted changes cover only a small portion of the spectrum or envelope of changes that would be produced via the use of multiple SRES scenarios and multiple driving models (or even multiple RCMs). **As such, it is recommended that any decision or policy making activities be based on an expanded version of the present case study.**

At present, large ensemble analyses using strictly RCM output are not possible over North America. However, Ouranos continues to produce RCM simulations, and is also actively involved in the North American Regional Climate Change Assessment Program (NARCCAP http://www.narccap.ucar.edu/), an international program that will serve the high resolution climate scenario needs of the United States, Canada, and northern Mexico, using regional climate model, coupled global climate model, and time-slice experiments. The needs of the PIEVC (i.e. simulations with a fine spatial resolution, and inclusion of a number of extreme indices) would be best addressed using an ensemble of multiple RCM driven by multiple pilot GCMs such as will be produced with NARCCAP project This approach would allow a large inclusion of possible futures and thus better cover the envelope of uncertainty. Further research continues to be needed in climate modeling and climate scenarios in order to provide reliable data for climate change vulnerability and impacts assessments.

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Appendix 8 – Peak Flow Estimation

(RV Anderson – Fredericton NB)

PEAK FLOW ESTIMATION USING THE RATIONAL METHOD

INTRODUCTION

Highway culverts and bridges should be designed to handle peak flows, with due consideration given to fish passage during moderate and low-flow conditions. A basin's climate and physiographic properties affect the peak flow from a drainage basin to the point of interest, i.e. the bridge or culvert structure.

The designer must select the return period of the peak flow to be used during the design of highway infrastructure. The return period is the amount of time between consecutive events of the same magnitude, usually expressed in years that would occur on average over a long period given that the basin's climate and physiographic characteristics do not change appreciably. Two considerations should be taken into account when selecting the return period of peak flows used in the design of highway infrastructure: the design life of the structure, and the required reliability. For most highway infrastructure, the return period of peak design flows should exceed the design life of the infrastructure, usually 50 years or more years. The importance of the infrastructure in terms of required reliability depends upon the amount of traffic and the availability of good-quality alternate routes. On most major roads, the design life generally should be the 1:100 year flood event or greater.

Another factor is the amount of change in basin characteristics that would likely occur over the design life of the structure in question. There are two types of change worth considering: land use changes resulting from human activities such as clear cutting of forests and urban development, and natural or human-induced climatic changes. In either case, large changes in basin characteristics may make the application of a particular method invalid, or the determination of accurate flows unreliable if based solely on past land use and hydro-climatic conditions.

Various methods exist for determining peak flows including the Rational Method, the Natural Resources Conservation Service (NRCS) method, the prorating of single station frequency results for nearby hydrometric stations with a basin with similar characteristics to the one under consideration, and the use of regional regression equations, such as those provided by Rollings (1999). Different methods give different estimates of peak flows, and it is often difficult to determine which method may provide the best results for a particular site. This section contains a discussion of one of these methods, the Rational Method, which as been widely applied in the Province of Newfoundland and Labrador.

THE RATIONAL METHOD

The Rational Formula is an empirical formula relating runoff to rainfall intensity. It is expressed in the following form:

$$Q = 0.00275\, C_f\, CiA = 1/360\, C_f\, CiA,$$

where
- Q = peak flow in cubic metres per second m^3/s,
- C_f = coefficient for less frequent storm events,
- C = runoff coefficient (weighted),
- i = rainfall intensity in millimetres (mm) per hour, and
- A = drainage area in hectares.

The Rational Method has become ingrained into hydrotechnical engineering practice, especially with respect to land development. It provides a reasonable basis for estimating peak flows with limited information requirements. More complex approaches to peak flow estimation may give better results, but only if more detailed climate and hydrologic information applicable to the drainage basins is available.

1.1. Basic Assumptions

The basic assumptions of the Rational Method are as follows:

1. The peak rate of runoff (Q) at any point is a direct function of the average rainfall intensity (I) for the time of concentration (T_c) to that point, and occurs when the entire basin is contributing.

2. The rainfall intensity is uniform over the basin and steady with time.

3. The frequency of the flood is the same as that of the rainfall. Therefore, the recurrence interval of the peak discharge is the same as the recurrence interval of the average rainfall intensity.

4. The peak discharge at any point is a function of the average rainfall intensity of a storm whose duration is equal to the time of concentration at that point. The time of concentration is the time required for the runoff to become established and flow from the most distant point of the drainage area to the point of discharge (New Jersey Department of Transportation, 2003).

1.2. General Limitations

Since the Rational Method is based on a large number of assumptions, the design engineer should consider how these assumptions might affect the peak-flow estimates for different basins, some of which may have unusual circumstances. In the Placentia area, drainage basin area, basin slope and land cover should be taken into account before applying the rational method.

Intense point rainfall and mean basin area rainfall (average rainfall) can differ greatly over a large area. A reason to limit use of the Rational Method to small watersheds pertains to the assumption that rainfall is constant throughout the entire watershed. Severe storms generally cover a very small area. This is particularly true for thunderstorms. Applying a high rainfall intensity corresponding to less frequent event storm to a large watershed could greatly increase flow estimates, as a high rainfall intensity will unlikely occur over a large basin at any given time. For that reason the Rational Method should be applied to small drainage areas. Guidance in the literature varies but generally it is recommended that the Rational Method be used on basins less than 200 hectares (2.0 km^2), unless the overall watershed is subdivided into sub-basins and the effect of routing through any drainage channels is considered. For rural basins with a common land use, the Rational Method has been used for preliminary design of infrastructure with upstream basins as large as 25 km^2.

Since a hydrograph produced by the Rational Method does not reflect the total runoff or the intensity variations of a real storm, it cannot take into account surface storage. Therefore, the Rational Method has limitations when applied to basins with large depression storage. The Rational Method should not be used for the design and analysis of detention ponds or whenever pond routing calculations will be performed.

The storm duration gives the length of time over which average rainfall intensity persists. Neither the storm duration nor intensity indicate how the intensity varies during the storm, nor do they consider how much rain fell before the period in question.

1.3. Drainage Area, A

The drainage basin area is determined by delineating a drainage basin area on topographic mapping of suitable scale and contour interval and then doing planimetry of the outlined basin. Generally, the effective drainage basin area is assumed equal to the total drainage area, as information to the contrary is often lacking and incorporating ineffective flow areas would result in over-estimation (more conservative) estimates thereby resulting in a factor of safety.

1.4. Coefficient for Less Frequent Events, C_f

Less frequent, higher intensity storms will produce greater runoff because infiltration and other losses have a smaller effect on runoff. An adjustment of the Rational Method for use with major storms can be made by multiplying the right side of the rational formula by a frequency factor C_f. For return periods of 1:15 years or less, $C_f = 1.0$. The values coefficient C_f for the 1:20 year, 1:50 year, and 1:100 year return periods are 1.1, 1.2 and 1.25 respectively. Alternatively, the decreasing effect of hydrologic losses on peak flows during higher runoff events can be taken into account by selecting higher runoff coefficients for less frequent events.

1.5. Runoff Coefficient, C

The runoff coefficient (C), also called the “coefficient of imperviousness,” is a dimensionless value representing the ratio of runoff to rainfall. Factors that contribute to C are related to the condition of the land, what is on the land, and the character of the rainfall (Iowa Department of Transportation, 2007). These factors may include previous moisture conditions, rainfall characteristics (duration, intensity, and frequency), and drainage basin characteristics (land cover, amount and type of surface storage, soil characteristics, slope, imperviousness). Several authors have published tables of C values, and the values provided in these tables are based mainly on the integrated effects of select basin characteristics, usually slope and land cover. Few publications qualify them with storm type or soil conditions, which may result in a potential error that increases with the amount of pervious surfaces in the basin. Several hydrologic textbooks and hydrologic design manuals contain tables of runoff coefficients for different land uses, with some tables containing runoff coefficients for different basin slopes, soil types, and design flood frequencies. A few runoff coefficients for different land uses and basin slopes are given as examples in the Table 1 below.

Table 1. Runoff Coefficients for Use in the Rational Method

Land Use	Ground Slope		
	Flat	Rolling (2% - 10% slope)	Hilly (> 10% slope)
Impervious areas, pavement and roofs	0.90	0.90	0.90
Residential (7 -12 units per hectare)	0.50	0.55	0.60
Pervious areas, lawns	0.17	0.22	0.35
Light industrial areas	0.50	0.70	0.80
Woodland and Forests	0.10	0.15	0.25
Unimproved areas	0.10	0.20	0.30

Source: Oregon Department of Transportation (2005).

For the drainage basins in the Placentia area, the above runoff coefficients may be appropriate, as the basins generally are steep. It is, however, important to consider land use changes if deforestation or development takes place in the upstream basin.

If the runoff coefficient was selected considering storm frequency, the use of the coefficient for less frequent events, $C_{f,}$, in the Rational Method may not be necessary. Furthermore, the use of the coefficient for less frequent events may be unnecessary for highly impervious areas, as the product of C_f and the runoff coefficient, C, could exceed unity.

When a single drainage area is composed of distinct parts with different runoff coefficients, a composite C based on a weighted average can be determined for use in the Rational formula. Caution should be exercised that a portion of a drainage basin's area with a value of C much higher or lower than the rest of the drainage basin's area does not skew the estimate of peak flows unreasonably.

The major source of uncertainty in the application of the Rational Method arises from the estimation of the runoff coefficient (Maidment, 1993). Considerable judgement and experience are required in selecting values of C for design. Therefore, selection of runoff coefficients will account for much of the variation in the results. In the design of critical infrastructure, values of runoff coefficients can be checked by using observed flood data in a given region. In the absence of such information, minimum runoff coefficients can be specified for use in the Rational formula, such as given in the table below, in order to guarantee that all infrastructure has at least been designed to a common minimum standard.

Urbanization changes the character of the land surface, especially by increasing the amount of impervious surfaces (such as paved surfaces and building roofs). When potential upstream development could affect peak flows during the life of the infrastructure, runoff coefficients should be chosen taking into account the characteristics of potential development. These post-development runoff coefficients will likely be greater than pre-development runoff coefficients.

1.6. Rainfall Intensity, i

Precipitation intensity-duration-frequency (IDF) information is necessary for the specific locality in which the Rational Method will be used. The rainfall intensity required in the Rational Method corresponding to the time of concentration (T_c) for the upstream basin is obtained from the IDF information.

Environment Canada has produced intensity-duration-frequency (I-D-F) tables for the St. John's Airport and St. Lawrence climate stations (Table 2). The I-D-F information is presented in Table 3.

Table 2. Climate Stations with Intensity-Duration-Frequency (I-D-F) Analyses

Station Name	Latitude	Longitude	Elevation, m	Approx. Distance from Placentia, km	Period of Record Used
St. Lawrence	46° 55'	55° 23'	45	115 SW	1969 to 1990 inclusive
St. John's Airport	47° 37'	52° 44'	131	103 NE	1949, 1961 to 1989 inclusive

Table 3. Existing I-D-F Information for Nearby Climate Stations

ST. LAWRENCE	RAINFALL INTENSITY, mm/hr from IDF Data 1990								
Return period	$i_{24\ hour}$	$i_{12\ hour}$	I 6 hour	$i_{2\ hour}$	$i_{1\ hour}$	$i_{30\ minutes}$	$i_{15\ minutes}$	$i_{10\ minutes}$	$i_{5\ minutes}$
2	2.9	5.1	8.6	15.4	21.4	29.0	39.9	49.4	63.7
5	3.5	6.2	10.6	19.8	27.6	36.8	49.5	60.0	75.6
10	3.9	6.8	11.9	22.7	31.7	41.7	55.9	67.1	83.5
25	4.5	7.7	13.6	26.4	36.9	48.4	64.0	75.9	93.5
50	4.9	8.3	14.8	29.1	40.8	53.3	69.9	82.5	100.9
100	5.2	9.0	16.0	31.8	44.6	58.0	75.9	89.1	108.3
ST. JOHN'S	**RAINFALL INTENSITY, mm/hr from IDF Data 1989**								
Return period	$i_{24\ hour}$	$i_{12\ hour}$	I 6 hour	$i_{2\ hour}$	$i_{1\ hour}$	$i_{30\ minutes}$	$i_{15\ minutes}$	$i_{10\ minutes}$	$i_{5\ minutes}$
2	2.6	4.3	6.7	11.5	17.0	24.4	34.0	40.5	55.2
5	3.2	5.3	8.4	15.2	21.6	32.2	45.7	55.0	77.1
10	3.6	6.0	9.6	17.7	24.7	376.4	53.4	64.7	91.6
25	4.0	6.8	11.0	20.8	28.6	43.9	70.4	85.8	94.8
50	4.4	7.4	12.1	23.2	31.5	48.8	70.4	85.8	123.5
100	4.7	8.0	13.2	25.5	34.4	53.6	77.6	94.8	137.0

Intensity-duration-frequency data was derived for Placentia using information on the mean annual and standard deviation of extreme rainfall (X and S respectively) obtained from information in Hogg and Carr (1985). The rainfall amounts were then determined for different durations and returns periods using the following equation:

$$X_T = X + K S$$

where K is a coefficient for different return periods provided in Hogg and Carr (1985).

Rainfall intensity was then determined by dividing rainfall amounts by storm duration. The resulting intensity-duration-frequency results, and similar results for St. John's and St. Lawrence, are presented in tabular form in Table 4. The derived I-D-F curves for Placentia are presented in Figure 1.

A comparison of the I-D-F curves for three locations derived using information from the rainfall atlas revealed that they match reasonably the I-D-F curves available for the two climate stations (St. John's Airport and St. Lawrence). As more recent I-D-F curve information was not available, they were assumed to be representative of present-day conditions. Analyses of monthly rainfall data for the two climate stations revealed no clear trend that could be indicative of changing climate conditions during the past two decades, thereby providing some support (albeit indirect and inconclusive) for this assumption. For present-day peak flow estimation using the rational method, the 1989 St. John's and 1990 St. Lawrence I-D-F information probably would be used in determining rainfall intensities for that region of Newfoundland.

1.7. Time of Concentration, T_c

The time of concentration (T_c) is defined as the time it takes for runoff to travel from the hydraulically most distant point in a drainage area to the downstream point of interest, such as the culvert location. Areas with long concentration times are far less susceptible to high-intensity rainfall. The Rational Method assumes that the peak runoff rate occurs when the rainfall intensity lasts as long or longer than the time of concentration, T_c.

One of the major difficulties of the Rational Method lies in determination of the time of concentration, which is required to estimate the rainfall intensity to be used in the Rational formula. The time of concentration is defined as the time taken for storm runoff to travel from the most remote point of the basin to the location of the culvert or bridge or sewer under consideration. Several different methods exist to estimate the time of concentration with differing assumptions and validity under different circumstances. Therefore, different methods give different results, thereby creating some uncertainty with respect to rainfall intensities to use in the rational formula. The selection of a suitable method to calculate time of concentration is based on judgement (Maidment, 1993).

Some methods, such as the Kirpich Method, are easy to apply but do not take into account the characteristics of the drainage area. The Kirpich method produces relatively short times of concentration compared to other methods (Roads and Transportation Association of Canada, 1982), and therefore corresponding rainfall intensities would be greater. The Kirpich method may be used to derive conservative (larger) design flows for critical infrastructure on small basins (< 1.0 km^2) in the Placentia area, but other methods generally will be more applicable.

For rural (non-urban) basins, the NRCS (formerly SCS) upland and curve number methods and the Bransby-Williams method are among the methods that may be used to determine the time of concentration. The NRCS methods can be applied to drainage basins of 10 km^2 or less, whereas the Bransby-Williams method may be used for basins up to 25 km^2 (Roads and Transportation Association of Canada, 1982). For the Placentia area, the Bransby-Williams equation can be used. It takes into account shape, length and slope, which are important factors in the hydrology of the smaller basins in the Placentia area. It does not take into account soils and land use, and therefore may underestimate times of concentration on permeable and forested basins (Roads and Transportation Association of Canada, 1982). Generally, the Newfoundland and Labrador Department of Transportation and Works currently determines the time of concentrations using the Bransby-Williams equation and/or the Ontario Method (Derrick Petten, personal communication to Cameron Ells of Cameron Consulting Incorporated, February 7, 2008).

Since the rainfall is assumed to be uniform across the entire site, the same duration and intensity must be applied to all subcatchments. As T_c is a physical characteristic of each subcatchment, the time-to-peak will also vary, depending on the T_c for each subcatchment. When combining flows from several areas, all subcatchments must be subject to the same rainfall conditions. Therefore, summing the peak flows produced by different durations would be incorrect as the assumption of uniform rainfall across the site would be invalidated. This further illustrates the inherent difficulty of using the Rational Method for complex watersheds.

Table 4. Rainfall Intensities for Placentia, St. John's and St. Lawrence, Newfoundland, Derived using the Rainfall Atlas

PLACENTIA	**RAINFALL INTENSITY, mm/hr based on Hogg and Carr (1985)**								
Return period	**$i_{24\ hour}$**	**$i_{12\ hour}$**	**I 6 hour**	**$i_{2\ hour}$**	**$i_{1\ hour}$**	**$i_{30\ minutes}$**	**$i_{15\ minutes}$**	**$i_{10\ minutes}$**	**$i_{5\ minutes}$**
2	3.1	4.5	7.3	12.6	17.8	26.5	39.8	44.1	64.3
5	3.6	5.5	8.9	16.6	23.0	34.5	51.5	56.9	86.5
10	4.0	6.1	9.9	19.3	26.5	39.8	59.3	65.3	101.3
15	4.2	6.4	10.5	20.8	28.4	42.8	63.6	70.0	109.6
20	4.4	6.6	10.9	21.9	29.8	44.9	66.7	73.4	115.4
25	4.5	6.8	11.2	22.7	30.9	46.6	69.0	75.9	119.9
50	4.9	7.4	12.1	25.2	34.1	51.5	76.3	83.8	133.7
100	5.3	8.0	13.1	27.7	37.3	56.5	83.5	91.7	147.5
ST. LAWRENCE	**RAINFALL INTENSITY, mm/hr based on Hogg and Carr (1985)**								
Return period	**$i_{24\ hour}$**	**$i_{12\ hour}$**	**I 6 hour**	**$i_{2\ hour}$**	**$i_{1\ hour}$**	**$i_{30\ minutes}$**	**$i_{15\ minutes}$**	**$i_{10\ minutes}$**	**$i_{5\ minutes}$**
2	3.0	5.2	8.9	14.7	21.1	30.7	38.4	57.6	65.3
5	3.7	6.2	10.6	18.7	26.3	37.8	49.4	74.1	85.4
10	4.1	6.8	11.8	21.3	29.7	42.4	56.6	85.0	98.8
15	4.4	7.2	12.5	22.8	31.7	45.1	60.7	91.1	106.3
20	4.6	7.4	12.9	23.8	33.0	46.9	63.6	95.4	111.5
25	4.7	7.6	13.3	24.6	34.1	48.4	65.8	98.7	115.6
50	5.1	8.2	14.4	27.1	37.3	52.7	72.6	108.9	128.1
100	5.5	8.8	15.5	29.6	42.6	57.1	79.4	119.0	140.5
ST. JOHN'S	**RAINFALL INTENSITY, mm/hr based on Hogg and Carr (1985)**								
Return period	**$i_{24\ hour}$**	**$i_{12\ hour}$**	**I 6 hour**	**$i_{2\ hour}$**	**$i_{1\ hour}$**	**$i_{30\ minutes}$**	**$i_{15\ minutes}$**	**$i_{10\ minutes}$**	**$i_{5\ minutes}$**
2	2.5	4.1	6.6	11.1	15.9	24.1	40.0	41.5	65.0
5	3.1	5.0	8.1	14.8	20.8	31.7	50.6	54.5	87.3
10	3.5	5.6	9.1	17.3	24.1	36.8	57.7	63.1	102.0
15	3.7	5.9	9.7	18.6	26.0	39.7	61.6	67.9	110.4
20	3.9	6.2	10.1	19.6	27.2	41.7	64.4	71.3	116.2
25	4.0	6.4	10.4	20.4	28.2	43.2	66.5	73.9	120.7
50	4.4	6.9	11.3	22.7	31.3	48.0	73.1	82.0	134.5
100	4.7	7.5	12.2	24.9	34.4	52.7	79.6	90.0	148.2

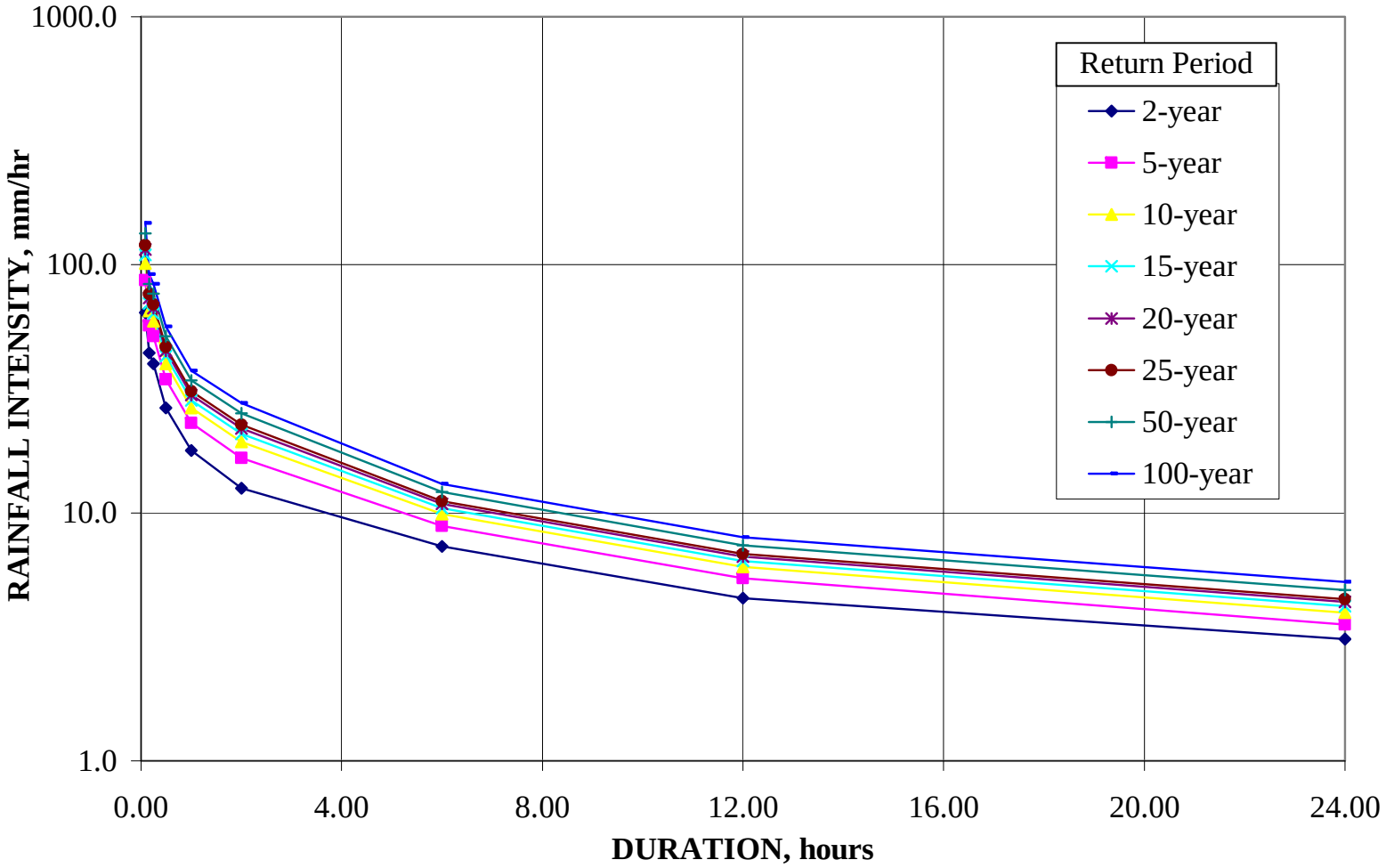

Figure 1. Derived Intensity-Duration-Frequency Curves for Placentia, Newfoundland, based on Hogg and Carr (1985) Rainfall Frequency Atlas for Canada.

CLIMATE CHANGE

1.8. Expected Changes

Highway infrastructure should be designed to withstand peak flows resulting from storms that occur during its design life. In the past, climatic change was not a major factor in highway design, as past hydro-climatic conditions could be reasonably assumed to be representative of future conditions. The consensus of many climate specialists is that the climate will change rapidly during the 21st century due largely to the effects of human activity on atmospheric composition (IPCC, 2007a). As hydrology would be influenced greatly by climatic change and possibly by the land use changes resulting from a changing climate, changes have to be made in the way peak flows are estimated. Generally, this involves modification of some of the input parameters used in empirical methods of flow estimation, and this is true of the determination of peak flood flows using the Rational method.

In the Rational formula, peak flow is a function of drainage area, runoff coefficient and rainfall intensity. Unless some physiographic barrier defining the drainage divide is altered or the effective area contributing to peak flow changes, climate change will not alter drainage basin area. In Newfoundland, major changes in vegetation due to climatic change will probably be less likely than in some other parts of the country, but this should be re-evaluated as additional information becomes available. Therefore, it is generally reasonable to assume that climate change will not alter basin area and runoff coefficients appreciably. This is not the case, however, for rainfall intensity.

Generally, the intensity of precipitation events is predicted to increase during this century, particularly in tropical and high latitude areas that experience increases in mean precipitation (IPCC, 2007a). Even in areas where mean precipitation decreases (most subtropical and mid-latitude regions), precipitation intensity is projected to increase but there would be longer periods between rainfall events (IPCC 2007a). For Placentia, projections are an increase in rainfall amounts of 12% by 2050 over present-day conditions (Gary Lines 2007, personal communication; Stephen Green, 2008, personal communication). It was assumed that this increase in rainfall amounts could be applied to the rainfall intensities previously derived for Placentia based on the rainfall atlas, which compared reasonably well to the I-D-F curves for the St. John's airport and St. Lawrence climate stations.

Future trends in hurricane frequency and intensity remain very uncertain. Some experimental climatic modelling projects some increases in both peak wind speeds and precipitation intensities (IPCC, 2007b). The pattern is clearer for extra-tropical storms, which are likely to become more intense, but perhaps less frequent in the mid-latitudes (IPCC, 2007b). Based on recent storm tracks over Avalon peninsula, it can be assumed that the Placentia area may be vulnerable to more intense extra-tropical storms in the future. This may be a consideration when selecting freeboard, including the level that water levels can reach relative to the top of the culvert or bridge waterway opening.

1.9. Rainfall Intensity

It was assumed that projected increases in rainfall amounts at Placentia of 12% by 2050 over present-day conditions (Gary Lines 2007, personal communication; Stephen Green, 2008, personal communication) could be applied to the rainfall intensities previously derived for Placentia based on the rainfall atlas, which compared reasonably well to the I-D-F curves for

the St. John's airport and St. Lawrence climate stations. Table 5 provides values of rainfall amounts and intensity for different return periods and storm durations considering 12% increase in rainfall amounts. Rainfall-intensity-duration (I-D-F) curves for 2050 based on the aforementioned assumptions (an upward shift of 12% in terms of rainfall intensity) are provided in the Figure 2. Equations approximating these I-D-F curves were developed in the form:

$Q = C (t)^{-a}$

where Q is the discharge in m^3/s for s specific return period and duration, t is the duration in hours, and C is a coefficient and a is an exponent. Values of "C" and "a" are given in Table 6.

Table 6. Coefficient and Exponent for Use in Approximate I-D-F Curve Equations for Placentia, Newfoundland

Coefficient and Exponent for Use in Exponential Equation Defining Present-day I-D-F (Based on the Rainfall Atlas)			Coefficient and Exponent for Use in Exponential Equation Defining 2050 I-D-F Curves		
Return Period, Years	COEFFICIENT	EXPONENT	Return Period, Years	COEFFICIENT	EXPONENT
2	17.81	0.536	2	19.94	0.536
5	22.64	0.558	5	25.36	0.558
10	25.90	0.567	10	29.01	0.567
15	27.73	0.570	15	31.06	0.570
20	29.01	0.573	20	32.50	0.572
25	30.00	0.575	25	33.60	0.575
50	33.04	0.579	50	37.00	0.579
100	36.05	0.583	100	40.38	0.583

Table 5. Rainfall Amounts and Intensities Derived for Placentia, Newfoundland for Different Storm Durations and Return Periods

Climate Change Rainfall Amounts (mm) Assuming a 12% Increase In Rainfall Amounts									
Return period	**$X_{24\ hour}$**	**$X_{12\ hour}$**	**$X_{6\ hour}$**	**$X_{2\ hour}$**	**$X_{1\ hour}$**	**$X_{30\ minutes}$**	**$X_{15\ minutes}$**	**$X_{10\ minutes}$**	**$X_{5\ minutes}$**
2	83.1	61.0	49.2	28.1	20.0	14.8	11.2	8.2	6.0
5	95.4	73.3	59.6	37.2	25.8	19.3	14.4	10.6	8.1
10	106.6	81.5	66.4	43.3	29.7	22.3	16.6	12.2	9.5
15	112.9	86.1	70.3	46.7	31.9	24.0	17.8	13.1	10.2
20	117.3	89.4	73.0	49.1	33.4	25.2	18.7	13.7	10.8
25	120.7	91.9	75.1	50.9	34.6	26.1	19.3	14.2	11.2
50	131.1	99.5	81.5	56.5	38.2	28.9	21.4	15.6	12.5
100	141.5	107.1	87.8	62.2	41.8	31.6	23.4	17.1	13.8
Climate Change Rainfall Intensities (mm/hr) Based on a 12% Increase In Rainfall Amounts									
Return period	**$i_{24\ hour}$**	**$i_{12\ hour}$**	**$i_{6\ hour}$**	**$i_{2\ hour}$**	**$i_{1\ hour}$**	**$i_{30\ minutes}$**	**$i_{15\ minutes}$**	**$i_{10\ minutes}$**	**$i_{5\ minutes}$**
2	3.5	5.1	8.2	14.1	20.0	29.7	44.6	49.4	72.0
5	4.0	6.1	9.9	18.6	25.8	38.7	57.7	63.7	96.9
10	4.4	6.8	11.1	21.6	29.7	44.6	66.4	73.1	113.4
15	4.7	7.2	11.7	23.3	31.9	48.0	71.3	78.4	122.8
20	4.9	7.4	12.2	24.5	33.4	50.3	74.7	82.2	129.3
25	5.0	7.7	12.5	25.4	34.6	52.1	77.3	85.0	134.3
50	5.5	8.3	13.6	28.3	38.2	57.7	85.4	93.9	149.8
100	5.9	8.9	14.6	31.1	41.8	63.3	93.5	102.7	165.1

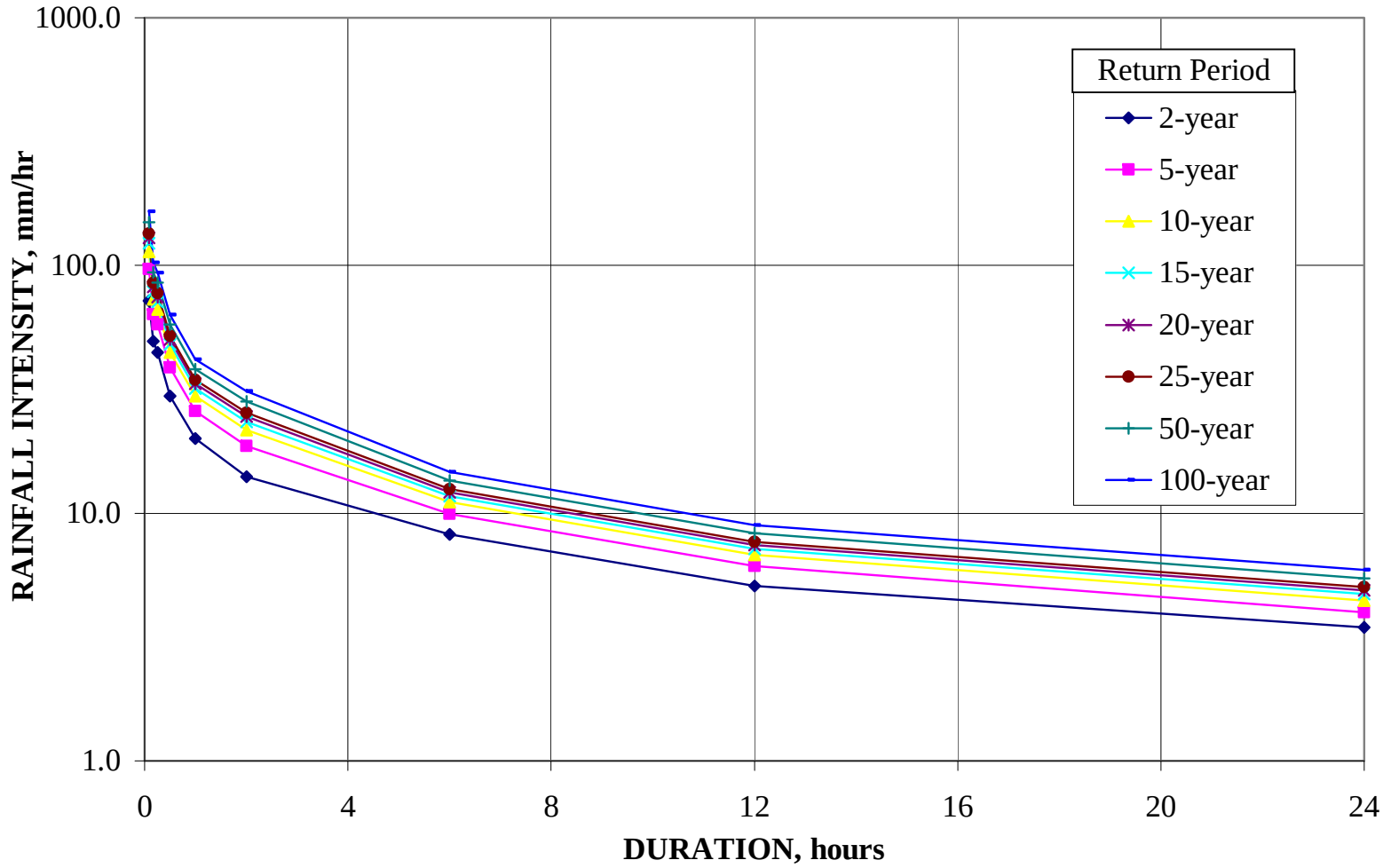

Figure 2. Intensity-Duration-Frequency Curves for Placentia, Newfoundland, considering Climate Change to 2050

SUMMARY AND CONCLUDING REMARKS

Knowledge of the magnitude and effects of climate change at the regional and local levels is still evolving. Nevertheless, there is consensus among atmospheric scientists that climate change is occurring and among much of the civil engineering profession that climate change has to be considered in engineering design of drainage infrastructure. Climate change is expected to impact hydrology in the Placentia area over the next 50 years. This is a factor that needs to be considered during replacement and rehabilitation of existing structures and the design of new drainage systems.

The Rational Method is an empirical approach to estimation of peak runoff values. Basin characteristics and rainfall intensity are used. As it is assumed that the rainfall intensity is uniform over the basin and steady with time over the storm duration, the Rational Method should be applied only to small drainage basins.

Drainage basin characteristics are represented by the drainage basin area upstream of the project site and a runoff coefficient. The runoff coefficient is an integration of such factors as topography, vegetation, land use, soil type, and degree of imperviousness. Generally, for Newfoundland, climate change is not expected to result in major changes to runoff coefficients. An adjustment to the runoff coefficient could be made to account for expected changes in vegetation, but currently there is little evidence to indicate that changes in vegetation due to climate change would have a major effect on runoff in the Placentia area by the year 2050. It is more likely during design that a runoff coefficient would need to be increased to account for future human activity, such as clear-cutting and development.

Climate change is expected to result in increased rainfall amounts and intensity in the Placentia area. Current estimates are for a 12% increase from 2000 to 2050. It was assumed that the I-D-F information for Placentia based on the rainfall atlas could be used as a representation of present-day conditions and design practices. This was considered in the preparation of I-D-F curves to be used when applying the Rational Method to the estimation of peak flows in the Placentia area for the year 2050.

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Appendix 9 – Placentia NL IDF Rainfall Information

(AMEC – St. John's, Newfoundland and Labrador)

It is estimated that there will be approximately a 12% increase in precipitation for eastern Newfoundland out to the year 2050. When considering the amount of precipitation increase for eastern Newfoundland up to 2050 one has to consider both the natural variability of precipitation amounts and the climate change induced amounts. With respect to eastern Newfoundland the major natural occurring influence for precipitation is the North Atlantic Oscillation (NAO) (Figure 1).

When the NAO is positive there are corresponding low pressure variations extending from Iceland though the Arctic. This is combined with high pressure variations along the subtropical Atlantic which results is statistically stronger westerly winds across the mid-latitudes. This results in more severe winters over eastern Canada and the northwest Atlantic and thus a corresponding increase in precipitation.

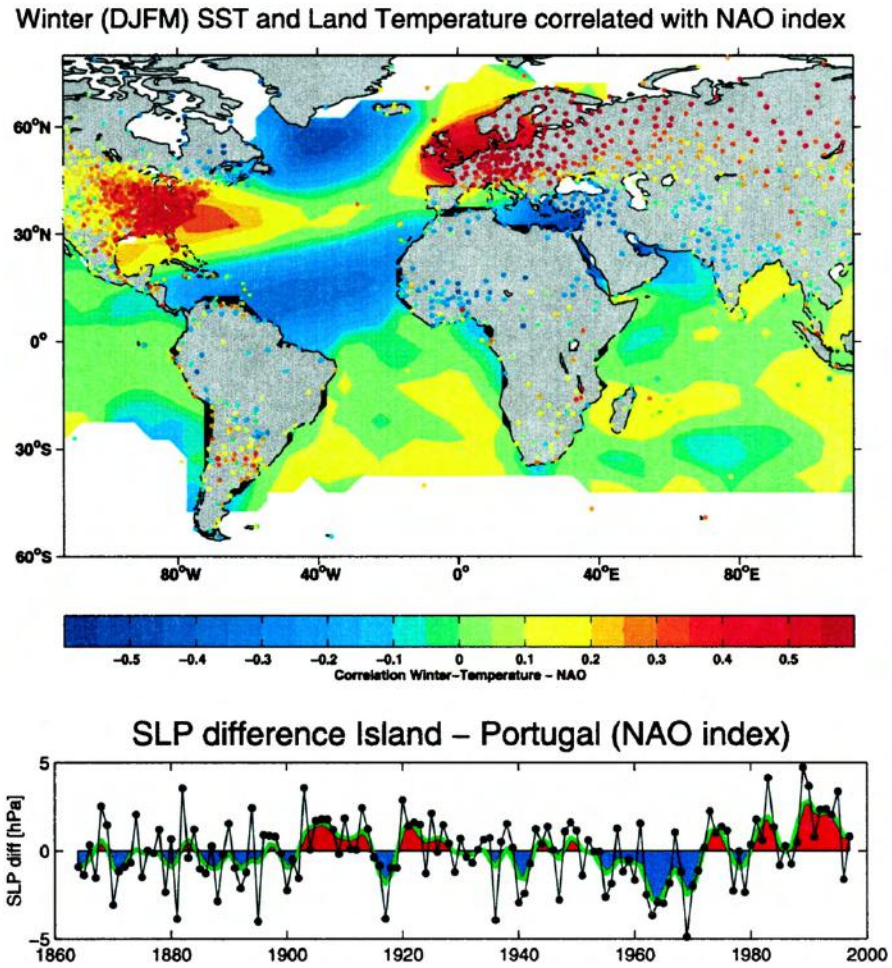

Figure 1, Spatial correlation map of mean winter (DJFM) station temperature and sea surface temperature (SST) correlated against the NAO index (Lower) (1).

If you combine the increase in westerly winds with the corresponding increase in precipitation, and the during the winter months the eastern region of Newfoundland is typically located on the jet-stream, the net result is an increase in liquid precipitation. Eastern Newfoundland residents are well aware that during the winter that approximately a 100 mile

east, or west, migration of a low pressure system can mean the difference between 25 cm of snow or 25 mm of rain. This is entirely due to the orientation of jet-stream which acts as the primary steering mechanism for low pressure systems.

It is of note that the NAO has had a more positive phase over the past 30 years with a magnitude that is unprecedented in the observational record over the negative phase. This indicates that the amount of precipitation on average has been increasing over the past 30 years.

Some of the most pronounced anomalies have occurred since the winter of 1989, when record positive values of the NAO index have been documented (Fig. 1 *Lower*). Moreover, the trend in the NAO accounts for a myriad of remarkable changes in the climate over the middle and high latitudes of the Northern Hemisphere, as well as in marine and terrestrial ecosystems. Among these changes are:

- Milder winters in Europe downstream and across Asia, juxtaposed against more severe winters over eastern Canada and the northwest Atlantic (2);
- Pronounced regional changes in precipitation patterns, resulting in the advance of some northern European glaciers and the retreat of Alpine glaciers (3, 4);
- Changes in sea-ice cover in both the Labrador and Greenland Seas as well as over the Arctic (5);
- Pronounced decreases in mean sea level pressure (SLP) over the Arctic and changes in the physical properties of Arctic sea water (6, 7);
- Changes in the intensity of convection in the Labrador and the Greenland-Iceland Seas, which in turn influence the strength and character of the Atlantic meridional overturning circulation (8);
- Stratospheric cooling over the polar cap and total column ozone losses poleward of 40°N (9);
- Changes in the production of zooplankton and the distribution of fish (e.g., ref. 10), and changes in the length of the growing season over Europe (11).

Based on the above information presented it is estimated that given the increase in positive phase of the NAO over the past 30 years there has been approximately a 9 - 10% increase in annual precipitation for eastern Newfoundland. Assuming that this trend continues for the next 30 to 40 years (out to 2050) it can be conservatively be argued that we can expect a further 9 to 10% increase in precipitation amounts. These estimates are based on historic trends and the assumption that what has happened in the past will continue into the future. Given the geographic area of interest (eastern Newfoundland) with respect to the overall global area there is currently no global climate model that can't effectively resolve the direct impacts on eastern Newfoundland so any prediction of changes to eastern Newfoundland has to be based on historical data in conjunction with an educated estimate.

If we consider that the NAO positive phase has been increasing over the past 30 years it is reasonable to assume that the next positive phase of the NAO will be greater then that of what is currently being experienced. Many climate change scientists suggest that the increase in the positive phase of the NAO is primarily due to anthropogenic emissions as

opposed to natural variability. Based on the climatic observations of the past 30 plus years, (Figure 1), this maybe a reasonable explanation for the consecutive phase increase with time. Considering possible anthropogenic influences it would be prudent to increase the amount of precipitation experienced by eastern Newfoundland. A conservative estimate would be 3 to 4% by 2050. This would bring the increase in precipitation amounts to approximately 12% by 2050.

Information used for the Placentia area originates from the weather stations in St. John's on the north east side of the Avalon peninsula, and St Lawrence, on the south east side of the Burin peninsula. Relative to Placentia, both the St. John's and St. Lawrence locations are more exposed to and receive a greater influence from ocean borne precipitation and wind. Relative to St. John's and St. Lawrence, the local conditions for Placentia are more influenced by the land mass due to its position on the western side of the Avalon peninsula, and less so by the Labrador and Gulf Stream ocean currents.

One would expect the rainfall in Placentia to be less than St. Lawrence or St. John's. Some limited information from Argentia, very close to Placentia, supports this trend.

Statistical downscaling information (12) for St. John's reflects both the exposed location and the influence of local synoptic scale events such as tropical storms. Stephenville, on the west coast of the island of Newfoundland, is more similar to Placentia than St. John's, but is still more exposed to ocean influences. Stephenville does not have the equivalent land masses to the west of it, as Placentia does. Gander is not influenced by ocean borne precipitation and winds in the same way that St. John's, Stephenville or to a lesser extent Placentia are. In reviewing the Statistical Downscaling information, a fit for Placentia would be between Gander (+4%) and Stephenville (+16%), but closer to the latter

As stated above without the input of a sufficiently resolved global climate model, estimates of increased precipitation for eastern Newfoundland have to be based on history and educated estimates. Following this formula it is conservatively estimated that Placentia Newfoundland can expect a 12% increase in annual precipitation by 2050.

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