Atlantic Climate Adaptation Solutions Association

Solutions d'adaptation aux changements climatiques pour l'Atlantique

Forecasting Economic Damages from Storm Surge Flooding :

A Case Study in the Tantramar Region of New Brunswick

By

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A CASE STUDY IN THE TANTRAMAR REGION OF NEW BRUNSWICK

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Table of Contents

Acknowledgements

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Glossary of Key Terms

Adaptation:
A response or action that seeks to reduce the regions vulnerability to flooding

Avoided damage (or avoided damage cost):
Refers to costs from flood related damage that are or can be avoided by undertaking some action to reduce flood vulnerability.

Damage costs (or flood damages):
The direct and indirect cost associated with damage or disruption to property, infrastructure, production, or people resulting from flood events.

Depth-damage curve (also known as stage-damage curves):
Refers to the relationship between the depth of floodwaters and amount or percentage of damage caused. As floodwater depths increase so do flood damages.

Dyke top-up:
A hypothetical scenario where existing dykes are systematically top-up to increase the total height of existing dykes.

Expected annual damages:
Refers to the expected (or anticipated) value of damages in any given year by accounting for the probability of all possible flood severities occurring.

Flood risk:
Flood risk is a probability and magnitude of a flood occurrence.

Flood vulnerability:
Refers to the extent of harm, which can be expected under certain conditions of exposure, susceptibility, and resilience to flood events.

Implementation costs:
Refers to the cost of implementing adaptation scenarios or policy actions

Relocation:

A hypothetical scenario where a policy is enacted to relocate highly vulnerable properties to areas of limited vulnerability. The scenario captures the potential avoided damages that would result if relocation occurred. The exact mechanism of relocation was not explored and does not necessarily imply a forced relocation. Relocation could be supported through a range of wide policy options including tax incentives and strategic land-use planning.

Executive Summary

Climate change-related hazards (e.g., intensified storms, coastal flooding associated with sea level rise, etc.) are globally pervasive yet geographically-specific problems that demand a societal commitment to adapt in order to minimize the impact of the associated risks. The Tantramar region of South-East New Brunswick is a coastal zone subject to strong tidal forces from the upper Bay of Fundy, and relies on an approximately 33-km dyke system to protect the Town of Sackville, an interprovincial railway and highway, and surrounding agricultural lands.

Previous work, supported by the Atlantic Climate Adaptation Solutions Association (ACASA) and Mount Allison University, documented the significant flood risks facing the Tantramar region. Recently published sea-level estimates for an 8.9m, 1-in-10 yr. storm surge, for instance, could overtop approximately 90% of the existing dyke system and temporarily inundate 20% of the town of Sackville, New Brunswick.

In an effort to better understand the economic costs associated with climate-change related flood risk, this study was conducted as part of a partnership between Green Analytics and Mount Allison University, and was funded by ACASA, Mount Allison University and the Social Sciences and Humanities Research Council of Canada (SSHRC). Sea level estimates were obtained from Daigle (2012) and combined with assets-at-risk (e.g., residences, warehouses, etc.) within a geographic information system (GIS) housed at Mount Allison University.

Using a regime of climate-change scenarios and known assets-at-risk, three objectives were defined: (1) to characterize the existing (or baseline) potential damages associated with storm surge flooding; (2) to characterize how these potential damages are likely to change with predicted increases in climate change-related sea-level rise; and (3) demonstrate how adaptation scenarios can be analyzed for their effectiveness in reducing exposure to flood damages.

The total impact of flooding (i.e., damage) in a community depends on the depth of the floodwater and the type and number of assets exposed to flooding. Defining assets at risk and assessing the cost of impact is a non-trivial exercise as there are many types of assets, each of which can differ as to their vulnerability. The most readily quantifiable assets included: residential, commercial and public properties, contents of properties, agricultural crops, and vehicles. Less tangible aspects include human illness, clean-up costs, business disruption, temporary displacement, etc.

A common approach to assess the direct impacts involves the use of something referred to as a “stage damage curve”, which relates the depth of floodwater to the expected severity of the damage.

Fortunately, the relationship between flood depth and damage to a given asset is relatively consistent, justifying the use of already established stage damage curves produced by the U.S. Army Corps of Engineers. Time and resource constraints did not allow the measurement of intangible assets.

The value of single structure properties were equated with the assessed value of the parcels on which they were located, weighted by the percent of the structure's areas that may be inundated. In the case of multiple structures, assessed values were divided among the different structures weighted by the building's footprint. Vehicles were distinguished as cars, vans, SUVs and pickup trucks to yield an expected average ownership based on an NRCAN assessment of New Brunswick households, and market values assessed from a scan of local used vehicle prices.

Agricultural damage was linked to the area of the agricultural parcel anticipated to be flooded (weighted by the percentage of the parcel actually devoted to production), and assessed as either of two classes: (1) tame hay, or (2) composite row crop. Market value of tame hay was based on 10-year average yield per hectare, while row crops were assessed using a weighted average of the market values of wheat, oat, barley, corn, soybeans, and corn for grain and corn for fodder. Damages due to flooding (impact factors) were based on published monthly vulnerabilities to damage weighted by the likelihood of storm events in each month. On an annual basis, composite row crops are expected to be more vulnerable to flooding than tame hay (47.2% vs. 21.3%).

Expected annual costs of flood damage were estimated by summing the expected annual damage costs for all relevant flood depths. We used five different climate scenarios (baseline 2000, future 2025, future 2055, future 2085 and future 2100) to encompass the anticipated effects of a changing climate, and calculated the expected annual costs of flood damage to storms with return periods between 5 and 100 years.

To evaluate the potential for community adaptation to offset the expected costs, we drew on the input from local stakeholders in combination with general flood mitigation literature to define the following adaptive strategies:

1. Status quo (baseline), assuming that no mitigation or adaptation measures are undertaken and all system changes can be attributed to climate change.

2. Dyke top-up, involving a 1 m increase in dyke height from 8.5 m to 9.5 m above sea level, a 2-3 year delay to coordinate policy and secure funding, and a 5 year work plan resulting in completion by 2020.

3. Relocation, where highly vulnerable properties are relocated to areas of limited vulnerability. This scenario does not imply a forced relocation or expropriation. Rather, it captures the potential avoided damages that would result if relocation occurred. Such relocation could be supported through a range of policy options including tax incentives and strategic land-use planning. For the purpose of this analysis it was assumed that: 1) it would take 13 years to coordinate policy and funding to support this strategy; and 2) relocation would commence in 2025, and would not be complete until 2045.

4. Mixed strategy, involving both dyke top-up and relocation.

There are many possible adaptation strategies that could be explored. The strategies chosen for this project are meant to showcase the two likely to provide significant benefits in terms of damage costs avoided. Also, due to data limitation implantation costs could not be calculated in much detail.

For a "do nothing" strategy at the present (year 2000) baseline, expected annual costs are $1,490,012. As climate change intensifies, these costs are expected to increase to $1,693,784 by 2025, $2,164,178 by 2055, and $3,114,966 by 2085. Over the next 100 years, if the climate futures occur as forecasted, the total present value of the expected annual damages is $59.3 million. By comparison, in absence of future climate change (beyond the present baseline) present value of costs would total $48.6 million, emphasizing that the damages resulting from future climate change induced sea-level rise represent an expected 22% increase.

Our estimates for avoided damage costs over the next 100 years reveal that relocation out of the 1-in-10 year, 8.9 m flood zone alone could protect the community from $24,381,964 in damage, while dyke top-up alone could avert $40,295,039. Mixing both of these strategies could prevent $44,085,091 in losses.

We caution that these estimates do not encompass the full range of impacts that might be expected during a flood incident, nor does this study address the full range of possible adaptation strategies. Non-market (intangible) costs are very difficult to quantify, but could include such things as the loss of recreational activity, loss of sentimental items, and increased stress and deterioration of health. Costs associated with emergency measures, response and cleanup could not be estimated in this study, nor could lost productivity to businesses. Nevertheless, for the Tantramar region the price of non-action in the face of anticipated climate change is high and lends urgency to the need to explore and adopt adaptation plans.

1. Introduction

Green Analytics in partnership with Mount Allison University received funding as part of the New Brunswick Regional Adaptation Collaborative Project to research and evaluate potential economic damages from storm surge flooding in the Tantramar region of New Brunswick. This research is a component of a larger research project on flood vulnerability being coordinated by Dr. David Lieske at Mount Allison University.

Preparing for and adapting to climate change requires an understanding of the risk and vulnerability being faced on a community-by-community basis. In the Tantramar region, one of the larger climate change related threats is changing flood risk associated with increased sea-level rise. The extent to which communities, such as the Town of Sackville and the Tantramar region, should develop adaptation plans designed to address this risk depends on the anticipated costs of future flooding events (Lantz et al. 2011). Building off the research conducted by Daigle (2012), which estimated changes in storm surge flood heights from projected changes in sea-level rise, the current research was able to examine the potential costs of flood damages to the Town of Sackville and surrounding region.

1.1 Research Objective

This research project sought to conduct a comparative analysis of economic damages associated with storm surge related coastal flooding under future climate change scenarios in the community of Sackville, New Brunswick and identifies potential implications for community adaptation strategies. To accomplish this, three primary objectives were defined:

1. Characterize the existing (or baseline) potential damages associated with storm surge flooding
2. Characterize how those potential damages are likely to change with predicated increases in climate change related sea-level rise
3. Demonstrate how adaptation scenarios can be analyzed for their effectiveness in reducing exposure to flood damages

1.2 Overview of this Report

This report is organized as follows:

- Chapter 2 sets the context by providing background information on the study area and theory of assessing flood related damages.
- Chapter 3 outlines and details the methods used to approximate potential damages attributable to climate change.
- Chapter 4 presents the results of the comparative analysis and explores implications of adaptation on flood damages.
- Chapter 5 discusses the results placing them in context with existing research and highlights research limitations.
- Chapter 6 provides general conclusions and recommendations.

2. Background and Context

The issue of sea-level rise and its implications for coastal communities in New Brunswick has become a growing concern as climate change science continues to advance our understanding of the issue. Indeed, it has become a priority to improve climate change adaptation decision making through a number of research initiatives supported by the Atlantic Climate Change Adaptation Solutions Association. Research recently completed explored the anticipated impact on storm surge flooding levels along the New Brunswick coast from changes in sea-level rise caused by climate change (Lieske and Bornemann 2011 and Daigle 2012). The results projected an increase in flood risk over the next century for coastal communities across New Brunswick including those in the Tantramar region (Daigle 2012). However, to date the potential economic damage associated with this increased flood risk has not been documented for the Tantramar region nor has how the region could use such information to inform decisions on adaptation solutions.

2.1 Study Area and Local Context

To understand flood risk and potential economic damages, it is first important to understand the study area and local context. The study area was defined as the area exposed to storm surge floodwaters in the Tantramar region. Figure 1 depicts this area in the case of floodwaters reaching a height of 8.9 m above sea-level. As can be seen in Figure 1, the area encompasses portions of the Town of Sackville and a variety of agricultural and rural areas up the Tantramar River valley.

This region is particularly unique as it is situated in the upper portion of the Bay of Fundy and subject to the largest tides in the world. In addition, there is a network of dykes spanning some 33 km that have historically been managed for the purpose of agriculture. As was reported in Lieske and Bornemann (2011)[1], early Acadian settlers created agricultural lands from existing salt marshes by building a system of dykes called aboiteaus. Aboiteaus have a valve that allows water to drain at low tide and prevents salt water from entering during high tide. Since dykes would be periodically overtopped, the aboiteaus allowed salt water to drain. More recently dykes have been maintained by the Province of New Brunswick to protect agricultural activity. Interestingly, while part of the Town of Sackville is located on dykelands and the town is protected to some degree by the system of dykes, the defence of Sackville against floods is not the primary objective of the dyke system.

[1] *Original background history from Lieske and Bornemann (2011) was based on NSDAM (1987).*

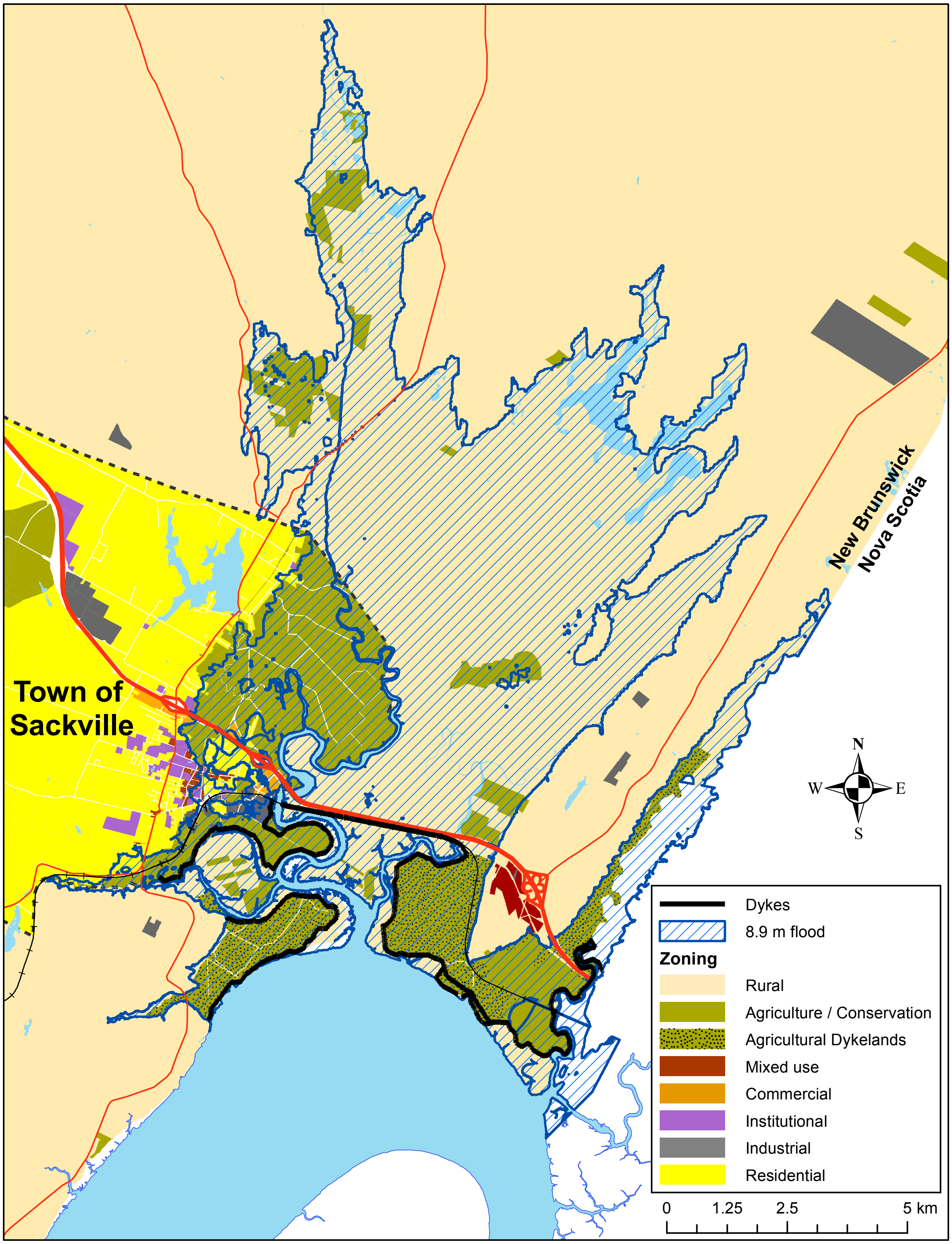

Figure 1. *Study Area Map of an 8.9 Metre Flood in the Tantramar Region*

2.2 Historical Flooding in the Tantramar Region

Historically, flooding in the Tantramar region has primarily resulted from rainfall, though other factors such as snowmelt, high tides, and ice or debris blocking channels have also contributed to flooding (Environment Canada 1991). However, the largest floods on record in the Tantramar region, the Saxby Gale in 1869 and another storm in 1759, resulted from storm surge (NSDAM 1987). Over the past fifty years the Town of Sackville and the surrounding region has been impacted by two significant flooding events, one in the spring of 1962, which had a depth of 8.0 m, and the other in the fall of 1999.

The Flood of 1962

The most severe flooding event in recent history, which also impacted other areas of New Brunswick, Nova Scotia, and Prince Edward Island, occurred in the first week of April, 1962 (Moncton Daily Times 1962; Sackville Tribune-Post 1962). This flood resulted from three consecutive days of heavy rain that coincided with the spring freshet. As outlined in Table 1 the public, residential, and commercial / industrial sectors all suffered flood damages.

Figure 2. *View of the 1962 flood at Charles Street, Sackville, NB (photo courtesy of R. Dixon)*

In the days following the flood, damage estimates ranged from several thousand to one million dollars (1962 CAD)[2]. Several weeks later the estimated cost of damage was refined to a total of $197,000 and it was suggested that this amount could increase by $30,000 (Sackville Tribune-Post 1962). The majority of this total was attributed to losses suffered by business and industry ($175,000), followed by the municipality ($12,000), and then private residents ($10,000). These estimates do not account for lost revenue or structural damage suffered by business / industry, nor did they include residential damages other than furnishings.

***Table 1**. Documented Impacts of the 1962 flood*

Sector	Impact
Public	Municipal infrastructure • Streets, sidewalks, sewage system, and general property • Raw sewage leaked into flood waters posing risk to drinking water and health Transportation infrastructure • Rail service to Nova Scotia and Prince Edward Island disrupted due to washouts and submerged tracks and a train was trapped by floodwater near Sackville. Individuals on passenger trains had to be bussed from Amherst to Moncton. Electrical infrastructure • Power outage due to a flooded transformer on Lorne Street. Power crews brought in another transformer from Moncton. • Entire town was without power for 3 hours, 80% of residents without power for 22 hours
Residential	Tangible damages • Damage to homes • Damage to cars Intangible damages • Evacuation of residents (50 residents left homes, 20 were evacuated by boat). The Salvation Army took care of evacuated residents.
Commercial / Industrial	Damages to various business and industrial machinery • Chignecto Bakeries, Enterprise Foundary, Blacks Hardware, Johnstone's Supermarket, Armco Drainage Company, and Atlantic Wholesalers Limited

[2] *After accounting for inflation, $1 in 1962 is equivalent to $7.73 in 2012 (Bank of Canada 2012).*

The Flood of 1999

The most recent significant flooding event in Sackville, which occurred on September 23, 1999, also resulted from heavy rainfall (Sackville Volunteer Fire Department n.d.). This flood resulted in damages to the public, residential, and commercial / industrial sectors. Several residential basements were flooded, as were some business, and public infrastructure such as the fire station and train station.

The Sackville Volunteer Fire Department was particularly busy responding to calls over a 24 to 36 hour period. They were called out to rescue people living on Route 106 at Carters Turn and Frosty Hollow whose houses were surrounded by floodwaters. In one case a boat was used since Route 106 was submerged by water. The fire department also provided other assistance, including transporting a parent to their sick child. In order to maintain service and adequate emergency response, fire trucks and rescue units were stationed in certain key areas in case floodwaters cut off parts of the Town of Sackville or surrounding regions. The costs incurred by the fire department related to this flooding event are detailed in Table 2.

Table 2*. Costs Incurred by Fire Department Related to the 1999 Flood*

Expense	Value
Labour (225 hours)	$1,968.75
Fuel	$200.00
Truck repair	$1,500.00
Portable pump repair	$500.00
Radio communication repair	$1,000.00
Purchase of material to assist in water blockage	$500.00
Rainwear	$500.00
Food preparation for workers	$500.00
Total	$6,168.75

2.3 Assessing Economic Impacts of Flood Risk and Vulnerability

As articulated by Forster et al. (2008), flood risk is a combination of potential damage and probability of flooding. Vulnerability results from the exposure of assets, which would be damaged, under a flood event with a given probability (Merz et al. 2007). Since we don't know when a flood will occur and therefore when the economic damages are expected to occur, we can use the predicted probability of associated flood events to estimate what is called the expected annual damages. This calculation can be described by the following mathematical equation:

$$\sum D_i \times P_i$$

where D_i = damage costs for flood event *i*

P_i = probability for flood event *i*

Therefore, to approximate the expected annual damages from flooding requires accounting for the damages associated with a range for flood events. Flood damages are typically classified into direct and indirect damages, where direct damages are those resulting from physical contact with flood water (e.g. damage to buildings) and indirect damages are those result from the direct damages impacting people and property outside the flood location (e.g. traffic disruption) (Jonkman et al. 2008; Merz et al., 2010b). Damages can also be tangible, such as damage to buildings, or intangible, such as psychological distress (Jonkman et al. 2008).

The total impact of flooding (i.e. damage) in a community depends on the depth of the floodwater and the type and number of assets exposed to flooding (Broekx et al. 2011). As such, information is required on the area that is expected to be flooded, the impacted assets, and the damage to these assets. Jonkman et al. (2008) identify three steps for assessing direct impacts: 1) determine the characteristics of the flood; 2) obtain information on land use and assets; and 3) assess the impacts (i.e. damage) to these assets.

When assessing the exposure of assets or elements at risk of damages, it is typical to categorize or classify these into different sectors. In most cases classification is based on economic sectors, such as residential, commercial, agriculture, and public as a result of the different characteristics of assets within each category (Merz et al., 2010b). For instance, flood damage to residential buildings largely depends on flood depth whereas damage to agricultural crops depends on the duration of the flood and the season during which the flood occurs (Forster et al., 2008). Table 3 provides a summary of the potential damages of flooding by sector.

***Table 3.** Summary of Potential Damages by Economic Sector*

Sector	Asset or Action	
Residential	*Response:* Flood alleviation & prevention Evacuation and accommodation *Property:* Housing - structure Housing – contents Personal item loss Vehicles *Disruption:* Forgone recreation/ leisure time Hardship Lost work Societal disruption	*Health:* Fatalities Illness Injuries Psychological traumas (e.g. anxiety) *Other:* Clean-up and landscaping Historical and cultural losses Lost energy supply
Commercial / Industrial	*Response:* Flood alleviation & prevention *Disruption:* Business interruption (lost days) Temporary displacement *Production:* Reduced production inside flooded area Reduced production outside flooded area	*Property & Equipment:* Buildings Depreciable assets Inventory Vehicles *Other:* Clean-up costs and landscaping Golf course damage Lost energy supply
Agriculture	*Response:* Flood alleviation & prevention Moving from high to low value crops in seasonally flooded area Permanent relocation Temporary displacement *Production:* Arable land Livestock Cropland Grassland Horticulture Pasture	*Property & Equipment:* Buildings Machinery Inventory *Other:* Clean-up costs and landscaping Erosion of agricultural land Fertility losses Lost energy supply
Public	*Response:* Emergency planning Emergency services Police Fire Other (e.g. military) Evacuation Healthcare facilities Nursing homes Schools Flood alleviation & prevention Healthcare activities Rescue operations *Disruption:* Lost energy supply Road traffic Temporary displacement	*Infrastructure:* Airport Communication Flood infrastructure Public buildings & institutions Parks and playing fields Railways Roads and highways Sewer Transit Utilities Water *Other:* Clean-up and landscaping Undermined trust in public authorities

Once assets are identified it is possible to assess how they would be impacted. It is common to use stage damage curves to estimate the direct impacts of flood events (e.g., Johnston et al. 2006, Jonkman et al. 2008, and Broekx et al. 2011), especially in situations where there is limited information on historical flooding. Stage damage curves relate the depth of floodwaters to the damage an asset would sustain. Figure 3 depicts a hypothetical stage damage curve that relates the depth of flood water to the proportion of damage sustained by a given asset. Stage damage curves can be developed through the use of survey instruments (e.g. Joy 1993 and Lantz et al. 2011). While it is preferable to develop a unique set stage damage curves for each community, the data requirements to do so limit the feasibility of developing such geographically specific stage damage curves (Davis et al. 2003). However, the relationship between flood depth and damage to a given asset is relatively consistent justifying the use of generic curves. While the research team is not aware of any curves specifically developed for use in Canada, the U.S. Army Corps of Engineers have developed curves that can be used throughout the United States to assess the impacts to residential structures and content (USACE 2010). Generalized depth-damage curves have been used extensively in the United States (e.g. Johnston et al. 2006) and in Canada. For instance, an Environment Canada study examining sea-level rise along New Brunswick's Northumberland Strait coast relied on the Army Corps' standardized curves (Environment Canada 2006).

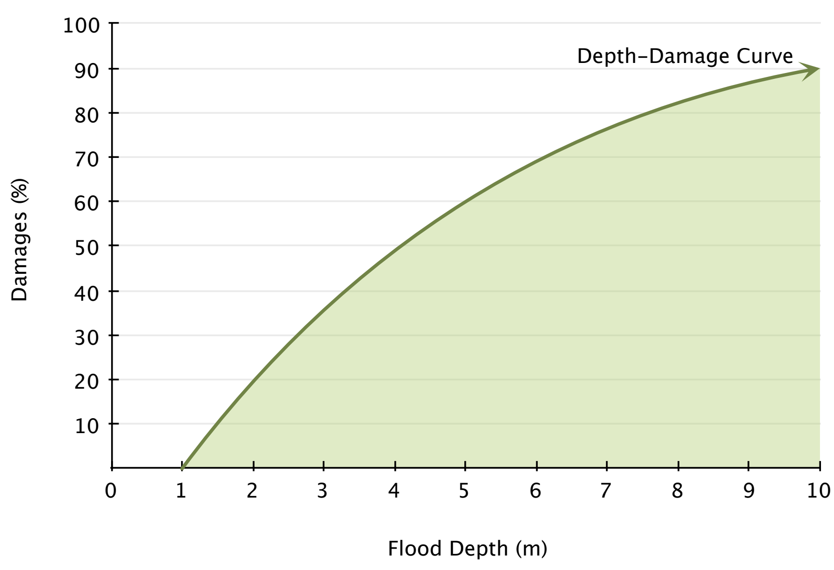

Figure 3. *Hypothetical Flood Stage Damage Curve*

Estimating indirect impacts is much more challenging. Jonkman et al. (2008) suggest using input-output models to assess the economic impacts outside of the flooded area.[3] Other indirect impacts such as societal disruption, psychological trauma, and undermined trust in public authorities are even harder to assess.

Due to its seasonal nature, it can also be difficult to assess the impacts to agriculture. Losses on rural and agricultural land are typically expected or assumed to be lower (or less significant) than those in urban areas. As a result, agricultural losses are often neglected or only roughly accounted for (Forster et al., 2008) With agricultural land, damages from flooding depend largely on the timing of the flood in relation to the growing stage of a given crop, the flow velocity of flood water, duration of crop flooding, and the deposition of pollutants (Forester et al., 2008). Several studies have included the impacts to the agricultural sector in their analysis (e.g., Hall et al. 2006, Forster et al. 2008, Jonkman et al. 2008, Broekx et al. 2011, and Kousky et al. 2011). For a comprehensive treatment of agricultural related flood damages see Forster et al. (2008), who outlines two approaches, using monthly or yearly timeframes, for estimating the flood damages (and risk) sustained by agriculture. Pivot et al. (2002), suggest agricultural damages can be categorized into two broad categories: immediate losses from damage to crops at the time of flooding and longer-term impacts resulting from damage to soil characteristics (e.g. from pollution, compaction, or erosion).

Several different approaches for estimating the economic costs (or benefits) of flooding have been used. The most common approach seems to be using the actual market value of flood damage (e.g. Joy 1993, Brody et al. 2007, Evrard et al. 2007, and Forster et al. 2008). Techniques for estimating this value include: replacement cost; reconstruction cost; value of the damage; property values; assessed damages; costs reported by households; and the value of lost production. Non-market valuation techniques have also been used to estimate willingness to pay for flood risk reduction or flood prevention measures (e.g. Brouwer and Bateman 2005, Zhai et al. 2006, Zhai et al. 2007, and Bin et al. 2008) or willingness to accept compensation for flood impacts (e.g. Lantz et al. 2011). These include stated preference techniques, such as contingent valuation and choice experiments, as well as revealed preference techniques, such as hedonic pricing. Value transfer has also been used (e.g. Kousky et al. 2011). This technique transfers existing estimates of economic benefits (or costs) from a site for which an economic value has been estimated to the site under investigation.

[3] *Input-output models are a form of economic analysis that relies on the structural nature of the economy to track impacts or shocks from one sector of the economy to all the related sectors. In other words, a direct impact or shock from flooding, for example, will have impacts up and down the supply chain of the impacted sector. In this way input-output analysis can assess some indirect impacts. For more information on input-output models see ten Raa (2006).*

2.4 Comparative Analysis of Flood Damages

Changes to a system can influence the relationship between flood probability and flood damages. These changes can be the result of a changing climate leading to more regular extreme flooding events or the result of a human modification to the system (i.e. an engineered flood wall). Figure 4 depicts a hypothetical change in the damage-probability relationship. The dark green shaded area between the current and future curves therefore represents the increased flood damages associated with the change to the system.

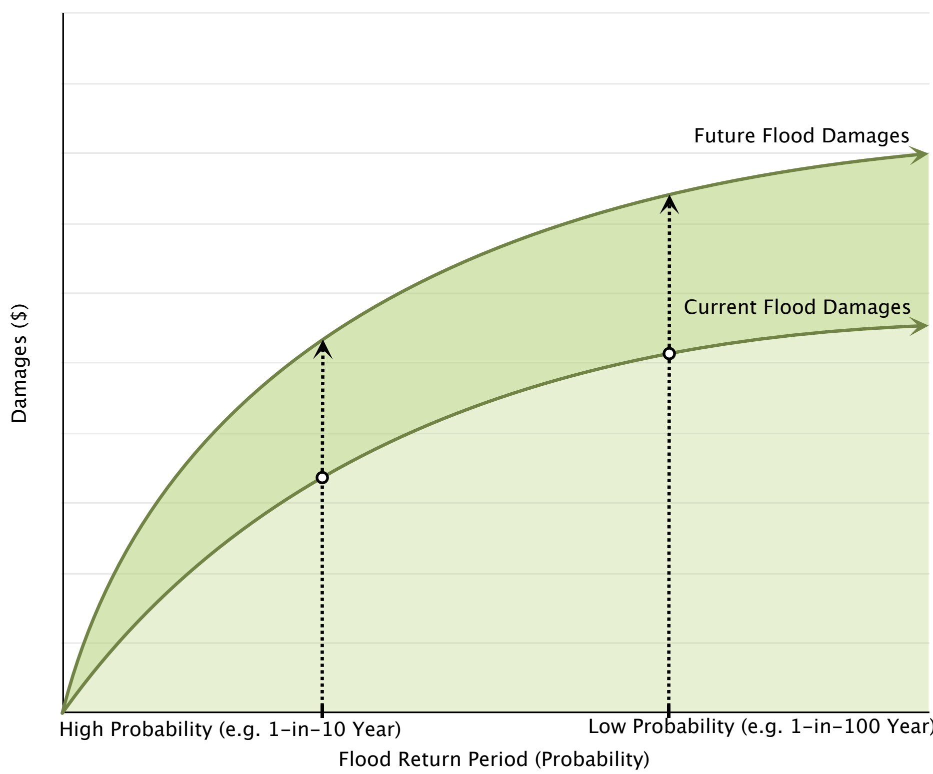

Figure 4. *Flood Damage – Probability Relationship*

This comparative analysis allows one to determine the additional damage costs that may result from a changing climate or the avoided damage costs resulting from taking steps to adapt to forecasted future changes. This general approach has been employed for estimating climate change induced damage costs (Lantz et al. 2011) as well as for assessing adaptive strategies (e.g. Smith 1999, Lekuthai and Vongvisessonjai 2001, Hall et al. 2006, Michael 2007, Pruszak and Zawadzka 2008, Broekx et al. 2011, and Kousky et al. 2011). The basic steps involved in such an approach are:

1. Establish a baseline assessment by identifying impacts of flooding and estimate costs into the future (e.g. expected annual damage cost), given current management practices and socio-economic conditions;

2. For the adaptive scenario which includes modifications to flood management (e.g. setting the dikes back), identify the impacts of flooding and estimate the costs of these impacts into the future (e.g. expected annual damage cost); and

3. To determine the benefit of the adaptive strategy (i.e. the avoided flood damages), subtract the total adaptive scenario cost from the total cost of flood damage estimated for the baseline scenario.

3. Methods

This section details the methods employed to assess the potential economic impacts resulting from flood risk in the Tantramar region of New Brunswick. As outlined in the previous chapter, assessing the cost of flooding generally involves three steps. The first step is to identify the characteristics of flooding (e.g. return period, extent, depth, duration, impact of sea-level rise, etc.). The second step determines which assets are impacted and to what extent. The third step determines the value of impacts (i.e. damage cost). This general process was adopted for this research and repeated for a series of flood events with varying flood depths and flood event probabilities. Damage estimates were then organized to depict flood damages for a range of climate change futures and adaptation scenarios, ultimately forming the comparative analysis.

3.1 Assessing Damages by Flood Risk

Each of the three steps required to assess the damages for each flood depth and probability combination are described in detail in the following sections.

3.1.1 STEP 1: Identifying flood characteristics in the Tantramar region

To characterize the exposure of the Tantramar region to flooding, the research team relied on estimates provided by Daigle (2012). Daigle (2012) estimated key flood characteristics (i.e. flood depth and flood probability) under current conditions and projected how those characteristics would change given forecasted increases in sea levels. Flood depths and the associated probabilities under the baseline climate condition and four climate futures are described in Table 4.

Table 4. *Flood Depth (in metres above sea-level) by Return Period and Climate Scenario*

Return Period	Baseline 2000	Future 2025	Future 2055	Future 2085	Future 2100
1-in-5 year	8.8	8.8	9.2	9.5	9.8
1-in-10 year	8.9	9.0	9.3	9.7	9.9
1-in-25 year	9.0	9.1	9.4	9.8	10.0
1-in-50 year	9.0	9.2	9.5	9.9	10.1
1-in-100 year	9.1	9.3	9.6	10.0	10.2

3.1.2 STEP 2: Identifying assets impacted by flooding

The assets impacted by the different flood depths were identified using a GIS analysis. Key features of this analysis are outlined below, while a more detailed account can be found in Appendix A. The analysis largely focused on determining the extent of the floodwaters for a given return period and climate scenario and identifying the assets, such as structures and land parcels, which would be impacted by such flooding.

To achieve this a relational database was developed to house key characteristics of each property and asset expected to be flooded as determined by the GIS analysis. In accordance with Army Corps of Engineers recommendations (USACE 2012), the identified characteristics included data on a structure or parcel's location, elevation above sea-level, type (i.e. sector), and size. This also involved the development of a model used to predict structural features that are required when using depth-damage curves (e.g. number of storeys, split-level or not, and presence of a basement). Additional information collected during this step included determining the extent of a buildings footprint that would be inundated with floodwater as well as the assessed value of each property. All property characteristics and related information were gathered for each flood depth (as summarized in Table 4 above).

3.1.3 STEP 3: Assessing the Costs of Flooding by Sector

Potential flood damages or losses were estimated for each of the residential, commercial / industrial, agricultural, and public sectors. The assessment of costs focussed on tangible losses in the key sectors. Thus this assessment accounts for damages to property, equipment, or infrastructure, in the case of the residential, commercial / industrial, and public sectors, as well as damages to crops (i.e. lost production), in the case of the agricultural sector. Unfortunately, it was not possible to measure the cost of damage to intangible assets due to time and resource constraints. The following sections outline the various methods used to assess the cost of damage to structures and their contents, vehicles, and agricultural crops.

3.2 Assessing the Cost of Damage to Structures and their Contents

While the assessment of flood damage costs to structures varied slightly by sector, the approach for residential, commercial / industrial, and public sectors generally followed procedures developed by the U.S. Army Corps of Engineers (USACE 2011). The details of procedures used are described below.

Using the database developed in Step 2 (described above), each structure expected to be flooded was identified, as were its key characteristics, including the ground elevation of each structure above sea level and an estimate of each structure's value. The value of the structure was assumed to be the assessed value of the parcel on which it is located. In cases where there were multiple structures on the same parcel, assessed value was divided among the different structures according to the area of each building's footprint. In addition, since the structure's area may not be completely inundated during a flood, the assessed value was weighted by the percent of the structure's footprint that was flooded. The elevation above sea-level of a structure's first floor was assumed to correspond to the elevation of the structure itself. Other considerations specific to each sector include:

- To be included in the assessment of residential flood damages, structures had to be located on parcels classified as residential or agricultural and have a positive number of residential units.
- To be included in the assessment of commercial / industrial flood damage costs, structures had to be located on commercial or industrial parcels. While certain commercial structures may have residential units (e.g. second floor apartments), our analysis classified all structures located on commercial parcels into the commercial / industrial sector.
- To be included in the assessment of public flood damage costs, structures had to be located on parcels classified as government (i.e. municipal, provincial, or federal) or non-profit (e.g. church or university).

The depths, in relation to the sea-level, of the floodwater for each return period and climate scenario are used to determine the height of the floodwater relative to a structure's first floor. For a building to be included in the analysis the floodwater had to have a height above, or equal to, the structure's first floor. For each flood depth the percent damage to each individual structure was estimated by applying an existing structural depth-damage curve developed by the U.S. Army Corps of Engineers (USACE 2003; CDWR 2012). Structure damage curves differed by sector and type of structure:

- Six depth-damage curves were used to estimate structural damage in the residential sector (USACE 2003). The curves correspond to three different types of structures, with and without basements: one storey buildings; two or more storey buildings; and split-level buildings. All residential structures for which a type could not be determined were assumed to be one storey buildings.[4]
- Two depth-damage curves were used to estimate damage to commercial / industrial and public sector structures (CDWR 2012). The curves correspond to one and two storey buildings without basements. All commercial / industrial or public sector structures for which a type could not be determined and those determined to be split-level buildings were assumed to be one storey structures. Those structures determined to have more than two storeys were assigned the depth-damage curves developed for a two storey building.

[4] We tested this assumption by running the analysis assuming all unknown residential structures to be two story buildings. As this only impacted a small subset of the property parcels overall impact on the avoided damage cost estimates was minimal (approximately 2% lower than those reported in the following sections).

In certain cases damage to contents of each structure can be assessed. In the case of the residential sector the value of contents was not required as content depth-damage curves are designed to measure content damage as a proportion of structure value. However, such curves were not available for the commercial / industrial and public sectors.[5] Therefore, content value for these sectors were estimated using content-to-structure value ratios developed by the U.S. Army Corps of Engineers for different types of structures (CDWR 2012). Content value for the commercial / industrial and public sectors was estimated by multiplying these ratios by the weighted assessed value. For each flood depth, damage to each individual structure's contents was estimated by applying an existing content depth-damage curve developed by the U.S. Army Corps of Engineers (USACE 2003; CDWR 2012). Content damage curves differed by sector and type of structure:

- Six depth-damage curves were used to estimate damage to the contents of residential structures (USACE 2003). These curves correspond to three types of residential structures, with and without basements: one storey buildings; two or more storey buildings; and split-level buildings. Content depth-damage curves developed for one storey buildings were used to estimate the damage to contents of residential structures for which a type could not be determined.
- Many different depth-damage curves were used to estimate the damage to the contents of commercial / industrial and public structures (CDWR 2012). These curves correspond to 21 different classes of building occupancy (e.g. retail, government, warehouse, church, etc.) for one and two storey structures. The contents of all commercial / industrial or public sector structures for which a type could not be determined, and those determined to be split-level buildings, were assumed to have the same content-depth damage curves as one storey structures. Similarly, the contents of structures determined to have more than two storeys were assigned the content depth-damage curves developed for two storey buildings.

For each flood depth, the cost of damage to each structure and its contents was estimated by multiplying the percent of damage, as determined by depth-damage curves, associated with the given flood depth by each asset's estimated value. The total cost of damage to an asset in a particular sector is calculated by summing the cost of damage to individual assets yielding a total expected cost of flood damage to structures in the residential, commercial / industrial, and public sectors.

[5] *Certain content depth-damage curves estimate damage as a percent of content value, while other curves estimate damage as a percent of structure value (USACE 2003). The curves used in the residential sector are designed to assess content damage cost as a percent of structural value, while those used in the commercial / industrial and public sectors assess cost as a percent of content value.*

3.3 Assessing the Cost of Damage to Residential Vehicles

The approach used to estimate cost of damages to vehicles parked at residences also relied on depth-damage curves. The procedures, informed by USACE (2009), are outlined below.

Vehicles expected to be flooded were assumed to be located on parcels with flooded structures having residential units. The elevation of each vehicle was assumed to correspond to the elevation of each residential structure. The number of vehicles located at a residential structure was estimated by multiplying the number of residential units per structure by the average number of vehicles owned by New Brunswick Households, which was 1.55 (NRCAN 2011).

Since vehicle damage depends on the body type of each vehicle, the average number of vehicles per household was decomposed by car, van, SUV, and pickup truck body types yielding an expected average ownership for each type. This was done by multiplying each body type's share of the Canadian light vehicle market by the average number of vehicles owned by New Brunswick households. Thus, on average we expect that a household, or residential unit, in Sackville owns 0.916 cars, 0.198 vans, 0.198 SUVs, and 0.236 pickup trucks.

The value of vehicles was estimated using the price of used vehicles in local markets. A non-random survey of used car inventories listed on the websites of dealerships in Sackville (Rod Allen Co.), Amherst (D.R. Polley Used Cars Ltd), and Moncton (Murray's Used Cars) was used to estimate the average price of vehicles. The results of this survey are summarized in Table 5.

***Table 5**. Summary of Vehicle Information Used to Estimate Vehicle Related Damages*

Vehicle Type	Share of Canadian Light Vehicles	Expected Average Household Ownership	Average Price	USACE Depth-Damage Curve
Cars (including station wagons)	59.1 %	0.916	$10,468	Sedan
Vans	12.8 %	0.198	$10,797	Minivan
Sport Utility Vehicles	12.8 %	0.198	$11,854	SUV
Pickup Trucks	15.2 %	0.236	$15,317	Pickup
Total	**100.0 %**	**1.55**		

The depth of floodwater, in relation to sea-level, for each return period and climate scenario (outlined in Table 4) were used to determine the height of floodwater relative to each vehicle. For a vehicle to be included in the analysis floodwater had to have a height above, or equal to, the elevation of the structure at which it would be parked. The percent damage to each individual vehicle was determined using vehicle depth-damage curves developed by the U.S. Army Corps of Engineers (USACE 2009). As shown in Table 5 four curves were used to estimate damage to the different types of vehicles.

Using the average value of used vehicles for each vehicle type in the Sackville and surrounding area and the percent damage to each type of vehicle (determined using depth-damage curves), potential damage to vehicles was estimated. The resulting amount was then multiplied by the average number of vehicles per household, by body type. These amounts were then summed yielding the expected damage cost per residential structure.[6] The estimated cost of damage to vehicles owned by an average residential unit was then summed over the total number of residential units impacted by flooding yielding an aggregate cost of flood damage to residential vehicles.

Finally, household members may move their vehicles to higher ground if they are given warning of potential flooding. Thus, not all of the vehicles located at residences in the flood zone are likely to be damaged. To account for this, the aggregate cost of flood damage to residential vehicles was weighted by the percentage of households not moving at least one vehicle to higher ground given between 6 and 12 hours of warning, which was 19.4%, according to U.S. Army Corps of Engineers surveys (USACE 2009).

3.4 Assessing the Cost of Damage to Agricultural Crops

The cost of flood damages to the agricultural sector was estimated using an approach that differs somewhat from that used to assess damage costs to structures and their contents. The procedures, which are outlined below, followed Forster et al. (2008). Assessment of damage costs in the agricultural sector was limited to crops. Consequently, the analysis does not account for impacts to other types of agriculture, such as livestock operations. In such cases it was assumed operators are able to move their animals to higher ground.[7] The impacts to non-residential agricultural structures, such as barns, were also not included in the analysis.

[6] *In a few cases there were multiple structures per parcel which complicated the calculation of vehicle damage. In these cases we first assumed that each structure had the same number of units as the parcel. The cost of damage to vehicles associated with each structure was then calculated separately. Finally, an average of these separate cost estimates was calculated resulting in the cost of damage to vehicles at the level of the parcel. This approach yielded cost estimates that are comparable with those from parcels with a single structure and avoided double counting of vehicle damage for parcels with multiple structures.*

[7] *The costs of relocating animals to higher ground and associated costs of replacement feed were not included due to data limitations.*

For parcels to be included in the damage assessment of agricultural crops they had to be classified as agricultural and the percentage of the parcel used for agriculture had to be positive. Two types of agricultural crops were considered: (1) tame hay, grown on parcels identified as having an agricultural use of hay, formed land, or formed marsh; and (2) a "composite crop" comprised of several crops, grown on parcels with an agricultural use defined as "other". The agricultural classification "other" included buildings, row crop, orchard, and un-used land. To account for these a composite crop was developed to represent the average across the landscape and this composite crop was assumed for all agricultural land classified as "other". An agricultural parcel was either classified as growing tame hay or composite crop — it is assumed that one parcel cannot be used to grow both crops.

The area of an agricultural parcel expected to be inundated given a particular flood return period and climate scenario was determined in the geo-spatial analysis (Step 2). The entire area of an agricultural parcel may not be used for agricultural purposes. Therefore, the area of each agricultural parcel anticipated to be flooded was weighted by the percentage of the parcel devoted to agriculture.

The market value for the tame hay and composite row crops was estimated by multiplying total annual yield per hectare by price per unit of yield. Agricultural yields for crops in New Brunswick were obtained from Statistics Canada (Table 001-0010). Average crop prices, at the national level, were obtained from Agriculture and Agri-Food Canada (AAFC 2012). In a few select cases crop prices from Ontario were used since New Brunswick level data was not available (OMAFRA 2011).

Estimating the annual market value per hectare for tame hay was straightforward. The annual market value of tame hay, calculated by multiplying the 10 year average yield per hectare by the price per unit yield, was estimated at $654.55 per hectare.

Determining a market value for the composite row crop was more complicated. Since a hectare of the composite row crop could be composed of several different crops, a weighted average of wheat, oat, barley, corn for grain, soybeans, and fodder corn market prices was estimated. The annual market value of each of these six crops was estimated following the same procedure used for tame hay. Weights were determined by calculating each crop's share of the total area harvested at the provincial scale. Data from Statistics Canada (Table 001-0010) was used to determine the 10 year average of the area harvested in New Brunswick for each of the six crops[8]. The annual market value per hectare for the composite row crop, estimated at $778.19, was then calculated by taking the weighted average of annual market values of the six crops. Table 6 summarizes the agricultural data used to establish market value.

[8] *To be included, crops must have been grown in 2011. If the crops had been grown for a period less than 10 years the average of the available data was used.*

Table 6. Agricultural Data Used to Establish Production Value of Tame Hay and Composite Crop

Crop	Yield (kg/ha)	Price ($/t)	Value ($/ha)	Harvested Area (ha)	Share
Wheat	2980	$318.00	$947.64	2905	8.1%
Oats	2480	$244.00	$605.12	8930	24.9%
Barley	3020	$188.00	$567.76	14260	39.8%
Corn (grain)	6733	$236.00	$1,588.99	3900	10.9%
Soybeans	2250	$447.00	$1,005.75	3800	10.6%
Corn (fodder)	25863	$30.60	$791.41	2050	5.7%
Tame Hay	5158	$126.90	$654.55	72515	N / A

Impact to agricultural crop production depends on the stage of the crop at the time of flooding. To account for this, the probability of a flood occurring in each month was approximated using frequency and intensity of hurricanes and tropical storms passing within 200 nautical miles of Sackville since the 1860's. Information on the monthly frequency of hurricanes and tropical storms was obtained from the National Oceanic and Atmospheric Administration's online database.[9]

Table 7. Estimated Probability of Flood Occurrence by Month

Month	Frequency	Aggregate Intensity	Probability
January	0	0	0
February	1	1	0.002
March	0	0	0
April	0	0	0
May	1	3	0.006
June	4	12	0.025
July	7	29	0.06
August	19	90	0.187
September	41	212	0.44
October	27	112	0.232
November	5	18	0.037
December	1	5	0.01
Total	**106**	**482**	**1.00**

[9] *http://www.csc.noaa.gov/hurricanes/#*

The maximum intensity of these storms was approximated using a linear eight-point scale from 1, representing an extra tropical storm, to 8, representing a category five hurricane. An aggregate intensity of storms occurring in a particular month was calculated by summing the individual storm intensities for that month. Probability weights for each month were calculated by dividing the corresponding monthly aggregate storm intensities by the sum of all monthly aggregate storm intensities (Table 7).

Each crop was then attributed a damage impact factor, which is the expected damage a crop suffers when flooded. The factor varies by crop type and month of flooding (Forster et al. 2008).[10] For example, a damage impact factor of 100% indicates total loss of the crop. Since damage impact factors have not been developed specifically for New Brunswick crops, factors reported in the literature for other regions (Henson, 1987) were used as a starting point and modified in consultation with the New Brunswick Department of Agriculture, Aquaculture and Fisheries. Through this consultation damage impact factors were developed for hay, silage, grain, and corn (Table 8).[11] The impact factor for hay was used to assess damage to tame hay, while an average of the annual impact factors for silage, grain, and corn factors was used for the composite crop. The resulting annual damage impact factors used in the analysis were 21.3% for tame hay and 47.2% for the composite row crop.

The cost of flooding per hectare, either tame hay or the composite, was estimated by multiplying the crop specific annual market values and the corresponding crop specific annual damage impact factors together. The resulting annual cost of damage per hectare of crop was multiplied by the agricultural area of a parcel anticipated to be flooded yielding the cost of damages per parcel. The total annual cost of flood damage to agricultural crops was estimated by summing the annual damage costs incurred on each individual parcel.

[10] *Duration of flooding can also influence crop damages, which were not accounted for due to data and forecasting limitations. However, anecdotal information local from stakeholders suggests that it can take 3 days to several weeks (depending on tidal cycles, size of storm surge, and precipitation) for storm surge floodwater to drop below 1 metre as a result of the system of dykes and aboiteaus.*

[11] *To simplify the analysis monthly impact factors were converted to annual impact factors by taking a weighted average. Each monthly impact factor was multiplied by corresponding probability of flooding and then summed together.*

Table 8. Agricultural Monthly Damage Impact Factors by Crop Type

Month	Hay	Silage	Grain	Corn
January	0%	0%	0%	0%
February	0%	0%	0%	0%
March	0%	0%	0%	0%
April	10%	25%	30%	0%
May	20%	45%	50%	10%
June	80%	45%	80%	50%
July	90%	35%	90%	80%
August	50%	45%	90%	85%
September	10%	45%	20%	90%
October	0%	25%	0%	40%
November	0%	0%	0%	0%
December	0%	0%	0%	0%
Weighted Average	**21.3%**	**37.5%**	**33.3%**	**70.9%**

3.5 Determining the Expected Annual Cost of Flood Damage

Flood risk is characterized as the product of the probability of a given flood event and its corresponding damage, aggregated over all possible flood events (Hall et al., 2006). This is typically referred to as expected annual cost of flood damage and is a representation of annual flood risk. Therefore, expected annual damage is estimated by multiplying each damage cost associated with a given flood depth by the probability of such a flood occurring in a given year, and then aggregating over the probability range of interest. This provides an expected annual damage cost of all floods or of floods between certain return periods given a specific climate scenario. The procedures adopted for this approach, which are similar to those in Kousky et al. (2011), are outlined below.

1. Estimate total cost of flood damage

   The total cost of a flood of a certain depth is estimated by summing the cost of damage to each impacted asset. Thus, the total cost of the damage resulting from a flood with a particular depth was calculated by summing the cost of damage to each sector's structures and their contents and adding it to the cost of damage to residential vehicles and agricultural crops. This calculation was completed for all flood depths.

2. Develop stage-damage curves

For each climate scenario, calculated total damage costs for each return period (1-in-5, -10, -25, -50, and -100 years) were plotted against the probability of these floods occurring. Using regression techniques the relationship between cost of flood damage and flood probability was estimated based on these data points. A number of functional forms were explored and the relationship with the largest R^2 statistic was selected to represent the stage-damage curve.

3. Calculate expected annual cost

For the purposes of this research, the expected annual cost of flood damage was calculated between the return periods of 1-in-5 and 1-in-100 years. This was done by taking the integral of the depth-damage function (area under the curve) between the probabilities corresponding to the 5 and 100 year return periods (i.e. 0.2 and 0.01 respectively).

This process was repeated for all climate scenarios. A total of five relationships were developed, one for each scenario (i.e. baseline 2000, future 2025, future 2055, future 2085, and future 2100). Once the expected annual cost of flood damage was calculated, it is possible to estimate the present value of the cost of flood damage over a certain period of time. We calculated the present value of the expected annual cost of flood damage over a horizon of 100 years (i.e. 2012 to 2112).[12] A social time preference rate of 3% was used to discount future costs (TBCS 2007).

3.6 Assessing the Influence of Adaptive Strategies

To demonstrate how communities, such as the Town of Sackville and Tantramar region, assess the influence of adaptation strategies a series of adaptive strategies or options were identified. Previous research explored some adaptations through a stakeholder engagement process. Feedback from the stakeholder focus group held on April 19, 2011 identified the following adaptation options (Lieske et al., 2011):

- Sacrifice some dykes to protect critical infrastructure that is difficult to move
- Move sewage treatment plant
- Zoning changes to minimize exposure to flood risks
- Increase the height of dykes
- Relocate residents and businesses

[12] *This time horizon encompasses all five different climate scenarios, with each scenario having different expected annual flood damage costs: baseline 2000; future 2025; future 2055; future 2085; and future 2100. We accounted for the differing annual expected cost of flood damages resulting from each climate scenario using a stepwise procedure. The expected annual cost of flood damage was assumed to be constant over the time periods that corresponded to particular climate scenarios.*

- Build storm surge barriers
- Remove dykes for conservation
- Create a spillway so floodwater is diverted to non-municipal areas
- Create a citizen storm watch
- Develop a "green corridor" where more marshy areas are allowed to develop to sponge up water in Sackville (in low lying areas)
- Climate data: Have regular reports in town with Environment Canada
- Warning systems should be in place

These suggestions formed the starting point for scoping the adaptation strategies. Drawing on input from local stakeholders in combination with general flood mitigation literature, the research team outlined three adaptation scenarios for analysis in addition to the 'status quo' or baseline scenario as a starting point for the Tantramar region to consider:

1. **Status Quo** – this baseline scenario assumed that no mitigation or adaptation measures are undertaken and therefore presents the baseline scenario of flood risk exposure in the Tantramar region.

2. **Dyke Top-up** – this scenario examined the costs (and associated reductions in flood risk) with improving the structural integrity and height of existing dykes.

3. **Relocation** – this scenario examined the costs (and associated reductions in flood risk) from a hypothetical scenario where a policy is enacted to relocate highly vulnerable properties to areas of limited vulnerability. This scenario does NOT imply a forced relocation or expropriation. Rather, it captures the potential avoided damages that would result if relocation occurred. Such relocation could be supported through a range of policy options including tax incentives and strategic land-use planning.

4. **Natural Infrastructure** – this scenario considered the use of natural infrastructure to minimize exposure to flood risks through restoration of estuaries and wetlands throughout the floodplain.

3.6.1 Stakeholder Focus Group

To capture local knowledge, expertise, and policy implications, a half-day workshop was held on May 31, 2012 to present preliminary findings and discuss the feasibility, both physically and politically of each adaptation scenario. The workshop brought together a select group of local experts and stakeholders representing a range of knowledge areas including: local policy, hydrology, agriculture, dyke management, and wetland management. Each scenario was explored in detail, discussing their effectiveness to reduce flood risk, policy implications, and expected costs. The general consensus was centred on the timing of scenarios. For instance, dyke top-up was considered the most effective short-term solution, allowing time to develop longer-term strategies and policies necessary to provide more permanent protection from flood vulnerability (e.g. relocation strategies). Given the location of Sackville in relation to the dykes, there was also general consensus that large-scale naturalization would be relatively ineffective at reducing flooding from storm surge events. However, it was seen to be a valuable and more effective strategy that should be employed on a localized scale throughout Sackville to address stromwater issues and precipitation-based flooding. As a result of these discussions, in addition to the status quo, adaptation scenarios were redefined to the following:

1. **Dyke top-up** – Increase dyke heights by 1 m from 8.5 m to 9.5 m above sea-level.[13] For the purpose of analysis it was assumed that it would take 2 to 3 years to coordinate policy and funding to support this adaptation, implying that construction would begin in 2015. It was estimated that these modifications could be feasibly completed over a 5 year timeframe (Robichaud, 2012). Therefore completion of a dyke top-up could be done by 2020. It was therefore, assumed that flood risk exposure would remain at current levels until completion in 2020 at which point flood risk is reduced by the increased protection from higher dykes.

2. **Relocation** – relocation efforts would target those areas flooded in the current 1-in-10 year flood (a flood 8.9 m above sea-level). However, agricultural uses of the land were assumed to continue, as this land use is more adaptable to flooding. Discussion with the focus group around this strategy highlighted that it would take a number of years to coordinate policy and funding to support this adaptation, and that it would need to be slowly phased in over time. For the purpose of this analysis, relocation was assumed to begin in 2025 and would take 20 years to complete. We assumed that flood risk exposure would decline linearly over the 20 year period of implementation, implying that a few properties are relocated each year.

3. **Mixed strategy** – involving both dyke top-up and relocation.

Each of the adaptation scenarios were analyzed using the approach described in Section 3.1 and compared against the flood costs under the baseline (non-adaptive) scenario to determine an approximation of the avoided damages associated with each adaptation scenario. It should be noted that costs of each strategy (e.g. maintenance costs over time) as well as strategy success (e.g. degradation of flood mitigation infrastructure and the probability of failure, which may increase over time) was not

[13] *Increasing the height of the dykes above 9.5 m is not considered feasible.*

formally accounted for in the analysis. As such the estimates of damage costs under the dyke top up scenario are is likely overestimated.

3.6.2 Determining Avoided Damages of Adaptive Strategies

The benefit of each adaptive strategy was estimated by calculating the value of ***avoided*** flood damage costs (Kousky et al. 2011). Each adaptive strategy leads to lower present value damage costs than doing nothing. The benefit of an adaptive strategy is the difference between the present value damage costs associated with the strategy and the present value damage costs expected to result from doing nothing.

Using the procedures outlined in Sections 3.1 through 3.5, the cost of flood damage to structures and their contents, residential vehicles, and agricultural crops resulting from the flooding associated with each adaptive strategy were estimated. The cost of damage associated with flood depths below the height of a dyke was assumed to be zero. If the depth of the flood is higher than the dyke, positive flood damages were calculated. Relocating highly vulnerable properties was assumed to eliminate the costs of flooding that would have occurred in the vulnerable ‘relocation’ zone.

4. Results

This chapter summarizes the flood damage assessment for the status quo climate and each of the four anticipated climate futures, as well as the results from the comparative analysis.

4.1 Flood Damages for the Baseline Climate

Examining the damages costs associated with the Baseline scenario, illustrated in Figure 5, demonstrates the relatively small marginal impact of flood damage between more frequent flooding of 1-in-5 and 1-in-10 year floods and less frequent flooding of 1-in-100 year floods. This is largely the result of the geographic and elevation characteristics of the area. Floods of larger depths tend have little impact on the area of land flooded, and therefore number of properties damaged. Rather, increased flood depths mean increased damage resulting from deeper submersion of properties from floodwater.

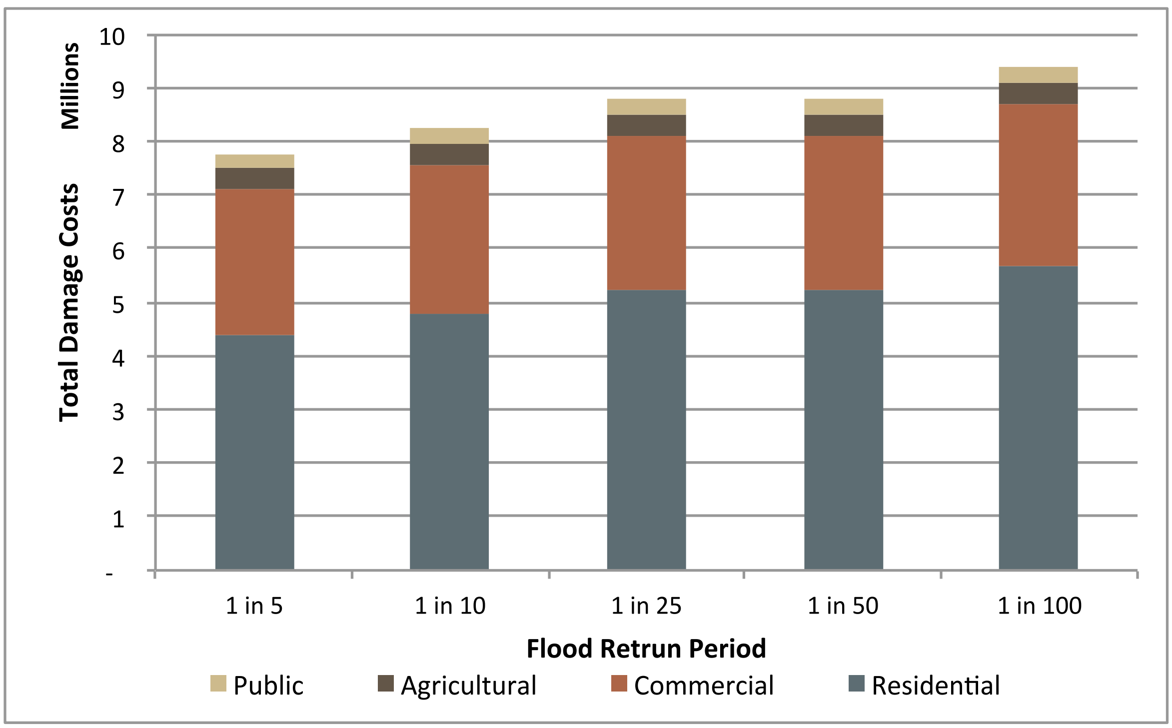

Figure 5. *Sector Damage Costs by Flood Return Period for the Baseline Climate*

In addition, Figure 5 also highlights that residential and commercial damages account for the majority of damages with agriculture and public property being significantly less affected. Depending on the flood return period residential damages account for 58 to 63% of total damages. Commercial, agricultural and public damages account for 33 to 37%, 4 to 5%, and 3% of total damages, respectively. This result is not surprising given the nature of agriculture being a fairly adaptive land use and public property anticipated to be flooded consisted largely of recreational areas. However, it should be noted damages for each categories have only been partially estimated. Table 3 (above) outlines a larger range of potential damage, which includes indirect and non-market impacts that have not been estimated here. This is particularly notable for the public sector. For instance, the wastewater treatment lagoon would be flooded in a 1-in-10 year flood. While actual structural damage to the lagoon would be minimal from a cost perspective, the health impacts of floodwaters containing large amounts of sewage could be much more significant.[14]

The estimation of expected annual damages for the baseline climate scenario is summarized in Figure 6. The figure displays the estimated relationship between total damage costs and flood probability with the area under the curve representing expected annual damage of $1.49 million dollars.

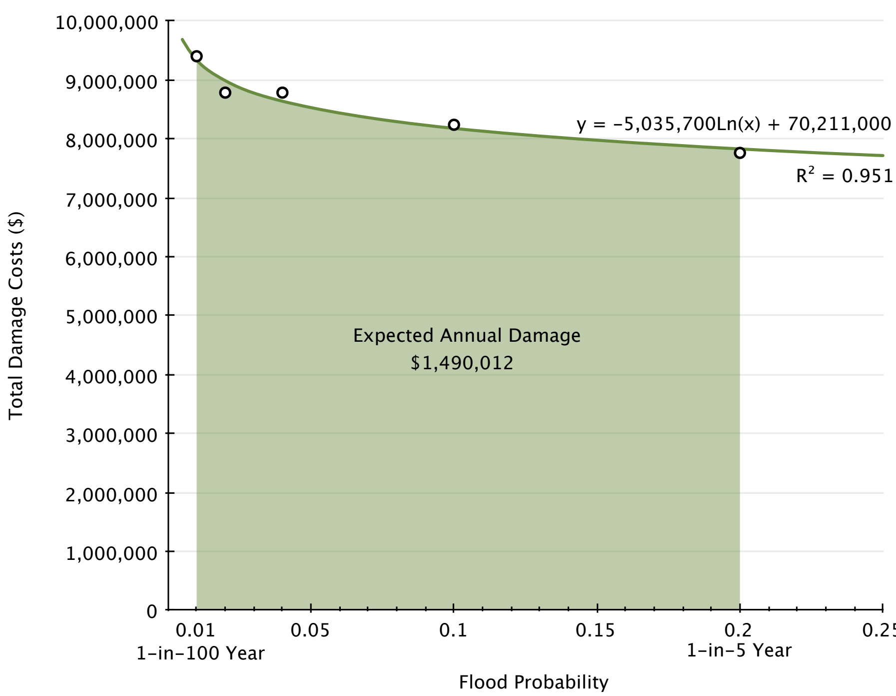

Figure 6. *Total Damage Costs and Expected Annual Damage for the Baseline Climate*

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[14] Infrastructure (such as roads and storm/service networks) could also greatly increase the public costs. Again, these could not be accounted for due to data limitations at the time of this report. However, the Town of Sackville is in the process of improving infrastructure data that could be available future analysis.

4.2 Flood Damages under Anticipated Climate Futures

Expected annual damage costs associated with each of the four climate futures forecasted by Daigle (2012) are summarized in Figure 7. The analysis for each anticipated climate future yielded expected annual damages increasing over time from $1.69 million in 2025 to $3.65 million by 2100.

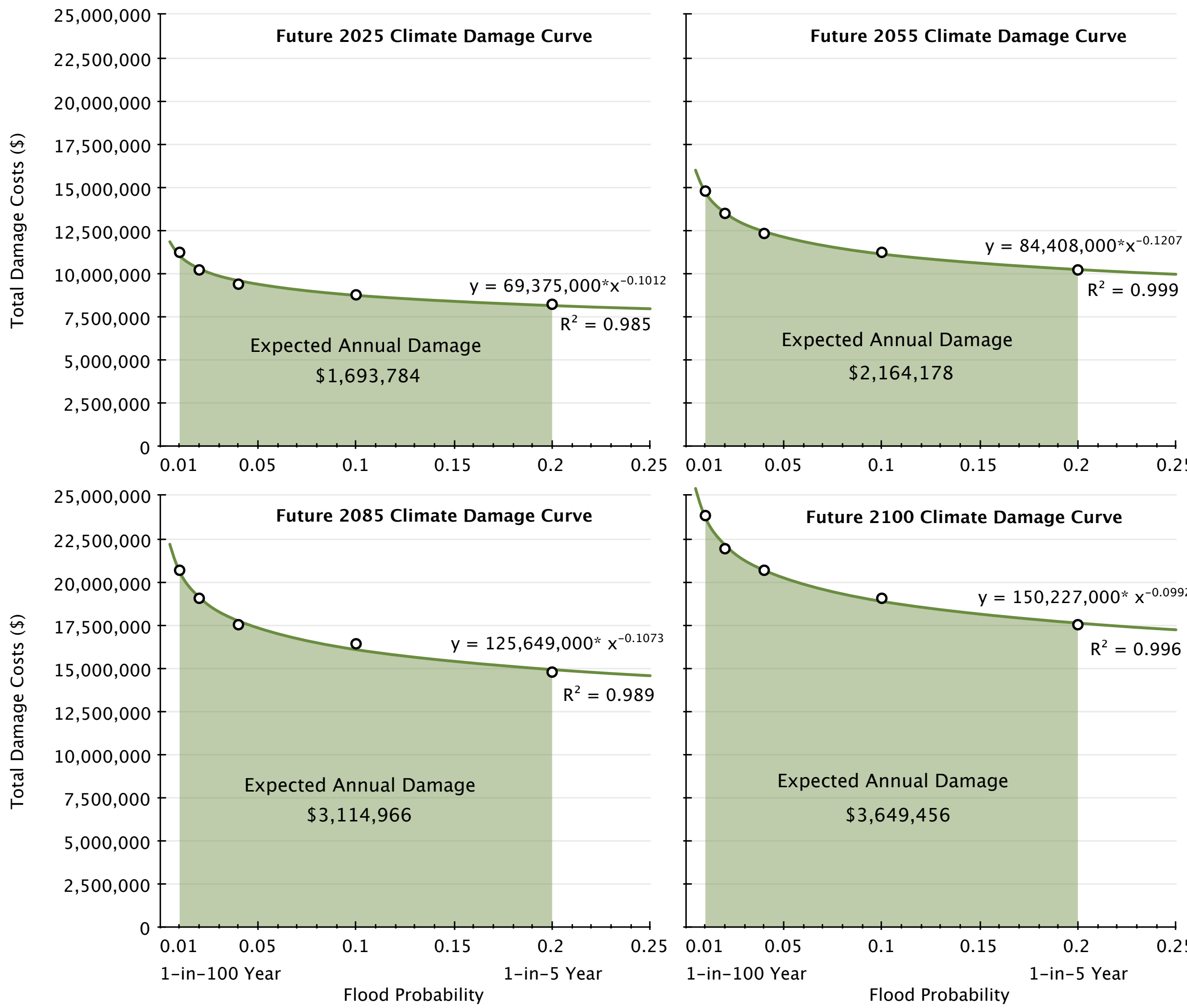

Figure 7. *Total Damage Costs and Expected Annual Damage for the Future Climate Scenarios*

Table 9 compares expected annual damages for each anticipated climate future with the status quo climate. A small increase in expected annual damages is anticipated by 2025 increasing by just over $200,000 to $1.69 million. By 2055 expected annual damages increase by almost $675,000. By 2085, expected annual damage is estimated to more then double the baseline increasing to $3.11 million, an increase of $1.62 million.

Over the 100 year time horizon (2012 to 2112), if the climate futures occur as forecasted, the total present value of the expected annual damage costs is $59.3 million. By comparison if we did not anticipate a changing climate and projected the baseline expected annual damage out over the next 100 years the present value is $48.6 million. Therefore, climate change induced sea-level rise would increase damages by 22%.

***Table 9**. Comparison Expected Annual Damage Costs by Climate Future and Adaptation Scenarios*

Climate Future	Expected Annual Damages	Change from Baseline Conditions
Baseline: 2000	$1,490,012	
Future: 2025	$1,693,784	$203,772
Future: 2055	$2,164,178	$674,166
Future: 2085	$3,114,966	$1,624,954
Future: 2100	$3,649,456	$2,159,444

4.3 Influence of Adaptation Strategies

With such potential increases in flood damages, a range of actions might be undertaken to minimize exposure to these risks. As described in Section 3.6, four adaptation strategies were defined: status quo, dyke top-up, relocation, and mixed strategies. Table 10 summarizes the expected annual damage costs for each adaptation strategy under each possible climate future, while Figure 8 (below) graphically depicts annual damage costs over the next 100 years.

The status quo depicts the scenario described in Section 4.2 and is shown in Figure 8 (below). Dyke top-up was assumed to provide protection from floods with depths up to 9.5 metres above sea-level. As a result, the dyke system would provide protection against floods with depths associated with a 1-in-100 year flood for both the baseline climate and 2025 future climate. It was suggested that it would take about 5 to 7 years to coordinate efforts and actually build up the dyke system (Robichaud 2012). As a result, the baseline expected annual damage was assumed to hold until the completion of the dyke top-up around 2020. The higher dyke heights would also protect against all floods save the 1-in-100 year flood for the 2055 future climate.[15] Beyond 2055, flood depths reach a point that would over top an extra metre of dyke height for all examined return periods. This relationship is depicted in Figure 8 (below), which shows a large jump in expected annual damages in 2085. The relationship highlights that dyke top-up provides immediate protection. However, in the long run, if climate trends continue as forecasted, dyke top-up will be ineffective.

***Table 10**. Comparison Expected Annual Damage Costs by Climate Future and Adaptation Scenarios*

Climate Future	Status Quo	Dyke Top-up	Relocation	Mixed: Dyke Top-up & Relocation
Baseline: 2000	$1,490,012	$0[a]	$73,160	$0[a]
Future: 2025	$1,693,784	$0[a]	$84,346	$0[a]
Future: 2055	$2,164,178	$140,494	$202,003	$23,159
Future: 2085	$3,114,966	$3,114,966	$698,406	$698,406
Future: 2100	$3,649,456	$3,649,456	$1,030,428	$1,030,428

[a] Expected annual damage of $0 results form two factors: (1) assumption that dyke top-up fully protects the town of Sackville (i.e. no dyke failure) up to depths of 9.5m above sea-level; and (2) expected annual damages were estimated over the probability range 1-in-5 year to 1-in-100 year floods. In reality expected annual damage is positive. However, the probability of a flood that would breach the dyke at this height would be low. Such floods could not be incorporated into the analysis due to data limitations.

The relocation strategy involves relocating infrastructure outside high risk areas. Such a strategy would be a complex undertaking requiring carefully thought out policies and planning. Consequently, it was assumed that it would take until about 2025 to coordinate, educate, and develop suitable policy for such a strategy. In addition, this would be a costly undertaking requiring a number of years to implement. For the sake of argument, it was assumed this process would take about 20 years; hence the continuous reduction in expected annual damage between 2025 and 2045. Once the infrastructure is moved out of high risk areas, flood damages occur only from areas of lower risk resulting in significant long-term reductions in expect annual damage.

The mixed strategy recognizes the short term nature of the dyke top-up and the long term nature of relocation. Combining the two strategies provides protection in the short term resulting from the dyke top-up, in particular avoiding damages in high risk areas, allowing the region the time necessary to implement a more permanent solution such as relocating high risk infrastructure.

[15] *It should be noted that probability of dyke failure was not accounted for in this analysis. As a result these damages are likely underestimated.*

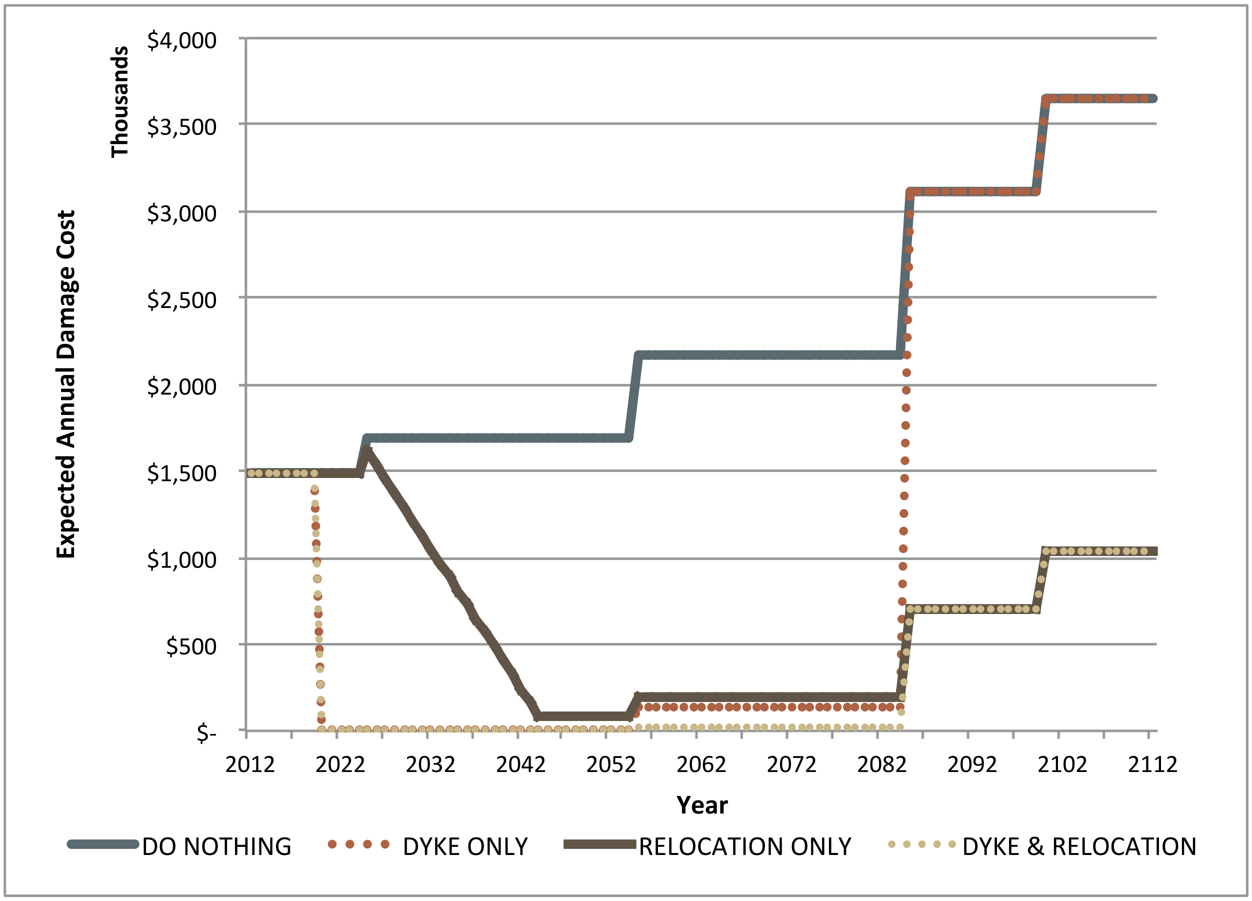

Figure 8. *Forecasted Expected Annual Damage Costs for the Next 100 Years by Adaptation Scenario*

Discounting expected annual damage costs over the next 100 years for each scenario, assuming the climate changes as forecasted by Daigle (2012), yields estimates of the damage costs in present value terms. Table 11 summarizes the present value of expected annual damages for each scenario over the next 100 years and compares it to the non-adaptive status quo. Over the next 100 years, dyke top-up alone was forecasted to avoid just over $40 million in damages, while relocation would avoid just over $30 million in damages. Jointly, both scenarios combined would avoid approximately $46 million.

It should be noted that, in present value terms, dyke top-up avoided flood damages are dominant relative to relocation avoided flood damages within the mixed strategy. This results from the timing of avoided flood damages. Because the dyke top-up provides immediate protection to relocation areas, benefits from relocation actions within the mix strategy do not start to accrue until 2085, the point at which the dyke top-up becomes ineffective. Since avoided damage costs occur so far in the future, when we calculate the present value these benefits are significantly discounted. As a result the mixed strategy only provides an additional $6 million in present value avoided damages relative to the dyke top-up strategy, despite the fact that relocation alone provides $30 million in present value avoided damages. However, if we compare the status quo ($3.1 million) and mixed ($0.7 million) scenarios in climate future 2085 from Table 10 (above), we see a reduction of $2.4 million in expected annual damage. These avoided damages are due entirely to relocation.

***Table 11**. Present Value of Avoided Damage Costs Over the Next 100 Years by Adaptation Scenario*

Adaptation Scenario	Status Quo	Adaptation	Avoided Damage
Dyke Top-up	$59,256,582	$18,961,542	$40,295,040
Relocation	$59,256,582	$29,252,854	$30,003,728
Dyke Top-up and Relocation	$59,256,582	$12,734,299	$46,522,283

4.3.1 Costs of Implementing Adaptation Strategies

Quantifying the cost of implementing adaptation scenarios is a somewhat more difficult task that requires detailed planning and design to achieve the desired changes in flood risk. Available data limited our ability to rigorously assess the costs of implementing adaptation scenarios, though some rough estimates can be made. Given the approximate nature of the costs, it is not recommended that definitive conclusions be made by comparing the costs of adaption to the benefits described above (i.e. avoided damages).

Discussion with local dyke experts suggested that a dyke top-up strategy could be reasonably implemented over a five year period, subject to available funding. Proposed costs for dyke top-up were described as follows:[16]

- Construction costs for building dykes up (excluding the CN rail line) = $850,000
- Construction costs for a new dyke required behind the existing CN rail line = $750,000
- Construction management and engineering = $200,000

The total anticipated costs related to constructing dyke top-up was approximated to be $1,250,000. However, this does not include the long term maintenance costs that be necessary to maintain dyke functioning. A relocation strategy would require some policy research and development to determine the most effective and efficient way to relocate high risk assets. A number of policy mechanisms could be

[16] *Personal communication, C. Robichaud (2012).*

explored ranging direct purchase of land by government to using tax or other incentive mechanisms to encourage individuals to relocate from high risk areas to low risk areas. Depending on the type of mechanism used, the costs could vary significantly. If we assume that land purchase is used (at fair market value) such a strategy would cost about $19.7 million.[17] However, this would be implemented over the assumed 20 year implementation period between 2025 and 2045. Therefore, the present value of those costs, assuming land purchase is implemented evenly over the 20 year period, would be $10.3 million. Costs associated with the mixed scenario would be the sum of both relocation and dyke top-up scenarios.

[17] *Estimates based on assessed value of high risk properties flagged under the relocation scenario.*

5. Limitations

There are a number of methods for determining flood depths and their impacts for when assessing flood related damages. Relying on previous research that established storm surge flood depths and probabilities (Daigle, 2012), we linearly interpolated flood depths and intersected these levels with a digital elevation model to determine the area flooded. This approach has been shown to have limitations in accurately outlining areas that would be flooded (Apel et al. 2009). In addition, the influence that dykes play in the hydrodynamics of storm surge flooding is not fully captured. This approach can result in estimates of flooded area that are larger than they would actually be (Apel et al. 2009). Our approach also does not account for the influence of erosion, wave damage, or flow velocity (USACE 2011). Therefore, results should be interpreted as an upper bound on flood damage. Much more costly and time intensive methods are required to fully capture the effects of erosion, wave or flow damages and influence of dykes on the hydrodynamics of the storm surge flooding. However, given the objective of this research to demonstrate what could be achieved with existing data the results provide a reasonable cost effective assessment of potential damages. But more importantly, the results also illustrate how those damages might change under different climate futures and adaptation scenarios.

Storm surges are most often accompanied by large storms or tropical depressions, particularly in the Tantramar region. Such storms are known to bring large amounts of rainfall, which can exacerbate the flood impacts of a storm surge. Given the large tidal movements of the Bay of Fundy and the local context of the system of dykes and aboiteaus, such rainfall can contribute significantly to the level and duration of flooding. However, existing data only allowed for assessment of storm surge related flooding. Consequently, results and conclusion do not fully reflect the full flood vulnerability of the Town of Sackville.

In addition, results should be considered a partial analysis since it was only possible to assess potential damages to property (e.g. buildings, contents, inventory, vehicles, etc.). Other important components of potential damages that could not be incorporated can be summarized in three key areas:

- Cost of emergency measures, response and cleanup. These are difficult to anticipate or forecast into the future as costs can vary significantly depending on how much warning local residents have and the state of a region's emergency preparedness plans. The most straightforward way to measure these costs is to rely on historical data. Unfortunately, for this case the only historical flood with notable impacts occurred in 1962 and the associated data is limited.

- Lost productivity to businesses from disruptions to the supply chain or reduced productivity from employees not able to get to work. These are difficult items to forecast into the future without target surveys or interviews with local business.

- Non-market costs of flooding. These costs are largely intangible in nature and include items such as a reduction in recreational activities, loss of sentimental items, or increased stress or anxiety. Unfortunately data on these impacts are rarely collected since obtaining reliable data requires surveying affected individuals immediately following a flood event (Lantz et al. 2011).

Without detailed historical data on these flood related damages it is difficult to incorporate them into the comparative assessment conducted in this report. While some historical data was available (summarized in Section 2.2) it was not detailed enough to generate relationships between flood damages and flood return periods nor did it fully capture the missing components described above.

Finally, the analysis assumes no changes to population, increases in urban development, or other changes to social, economic, and spatial configuration of flood vulnerable areas. In other words the analysis holds 2012 conditions constant. While this is an unrealistic assumption, it allows for unbiased inter-temporal comparison.

6. Discussion and Conclusion

As risk management continues to become a more dominant approach to flood control policy, the importance to estimating economic flood damages will continue to grow (Merz et al. 2010b). Indeed, as public resources become increasingly scarce alongside increasing vulnerability due to climate change, optimizing mitigation and adaptation measures will be essential. While data availability and access present a number of pragmatic challenges, this research demonstrates a straightforward approach that can help communities like Sackville and the Tantramar region assess, weigh, and plan for mitigation and adaptation measures to deal with changing flood vulnerability in a cost effective manner.

Given the forecasted changes in flood characteristics (Daigle 2012) over the next 100 years, climate change induced sea-level rise was estimated to increase economic vulnerability of flooding by 22%, holding all other factors constant. However, flood vulnerability is a complex function of social, economic, and institutional dimensions (Merz et al. 2010). Consequently, if social, economic, and institutional structures change, the region's vulnerability could be reduced or intensified.

The results highlight the implications of flood adaptation strategies. Dyke top-up was found to provide immediate protection, such that the present value of expected annual damages could be reduced by $40 million. However, in the long run, if climate trends continue as forecasted, dyke top-up will eventually become ineffective requiring a long-term strategy that places more emphasis on reducing flood effects or outcomes as opposed to focusing on flood defense mechanisms. One such strategy would be the relocation of infrastructure out of high risk areas. The results highlight that relocation provides significant long-term reductions in expected annual damage. By 2085, relocation would provide an expected annual damage ($1.6 million) that is almost half of that from the dyke top-up scenario ($3.1 million). However, given the long-term nature of these avoided damage costs, the present value of expected annual damage from the relocation strategy over the next 100 years was $29.3 million, a reduction of $30.0 million over the status quo ($59.3 million).

The mixed strategy recognizes the short term nature of the dyke top-up and the long term implementation required for relocation. Combining the two strategies provides significant protection in the short term through the dyke top-up allowing the region the time necessary to implement more permanent flood risk management solutions, such as relocating high risk infrastructure. Combined, the two strategies were found to avoid $46.5 million in flood damages over 100 years (in present value terms).

The results suggested that the majority of the calculated damages were attributable to residential and commercial sectors. Interestingly, historical data across the province of New Brunswick indicates that 70% of damages are attributable to the public sector, 20% to private property, and 10% to agriculture (Environment Canada 1989). While this seems to contradict our findings, public sector impacts referred to include damage to transportation networks and utility systems. These were outside the scope of this research and not included in the results. However, proportions reported by Environment Canada (1989) highlight that considering a broader range of flood impacts could mean that flood damage costs are significantly larger than we report for the Town of Sackville and surrounding region. For instance, Yevdokimov (2012) conducted a preliminary assessment of climate change impacts on the transportation system in the Tantramar region, specifically focused on the Atlantic Canada Gateway and Trade Corridor (e.g. TransCanada Highway and the CN Rail Line). Yevdokimov (2012) examined a range of climate change related impacts to the trade corridor from increased precipitation and extreme weather events to increased sea levels and associated increased flooding. While these impacts are associated with the flooding events being addressed here, our research is primary focused on the community related impacts and therefore, did not account for impacts to interprovincial / interregional travel, trade flows, or infrastructure damages.

Considering the components of flood damages that could not be fully incorporated into the analysis, other research has demonstrated their relative proportions in other jurisdictions and contexts. In the UK total emergency costs from flooding have been shown to account for approximately 15% of total economic flood losses (Penning-Rowsell and Wilson 2006). Similarly, Lantz et al. (2011) conducted a survey in Fredericton, New Brunswick and found that non-market or intangible components of flood damages amounted to 23 to 42% of total costs depending on the severity of the flood. Other research has reported such damages range from as low as 16% (Lekuthai and Vongvisessomjai 2001) to a high of over 70% of total costs (Green and Penning-Rowsell 1989). Environment Canada (1989) also reports indirect damages are normally estimated at 50% of direct damages. If this holds, expected annual damages under the baseline scenario would increase from $1.49 million to $2.24 million.

In addition to economic losses, increasing flood damages can have other indirect impacts not mentioned above. Chronic flooding can impact the perception and attitudes of those living in high risk areas, which has impacts for quality of life and the perceived prosperity of a community. On the other hand, flood defence structures have been shown to produce a “levee-effect” where once a dyke is constructed it may create a false perception of security for residents and community officials that can lead to greater development within dyke lands and reduce flood awareness (Tobin 1995; Merz et al. 2010). This is particularly relevant in context of this research as results show how effective a dyke top-up strategy can be over the next 50 years. If expectations and development patterns are not carefully managed during this time period there is potential for significant long term increases in flood damages. As such, a shift in thinking is required to evolve from solely relying on flood defense to an integrated flood risk management strategy focused on flood outcomes (or risks). This can help create a notion of “living with floods” that acknowledges the illusion of complete safety against flood damages (Institution of Civil Engineers 2001; Merz et al. 2010).

Adaptation is complex, will involve creative policy solutions, and will be strongly influenced by public knowledge, attitudes and preferences. Future research should explore the public attitudes and preferences for adaptation and minimization of flood risk and vulnerability. Future research should also explore multi-attribute evaluations of flood management (e.g. Shai et al. 2007) as the Tantramar region continues to improve its understanding of the pressures it faces imposed by a changing climate. As well, it will be important to gain an understanding of the human health and well-being benefits of flood alleviation. Much progress has been made in this area of research, particularly in the UK (e.g. Defra and Environment Agency 2004). Ultimately, however, the Tantramar region needs to develop an integrated strategy that brings together key stakeholders to properly manage flood risks being faced by all stakeholders to ensure both short and long term reductions in flood vulnerability.

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8. Appendix A: Data Processing and Management

8.1 Summary of Datasets

Data sources have been compiled that can be used to assess the economic impact of flooding in the Tantramar Dykelands. These data sets consist of: real property parcels, zoning (municipal and rural), agriculture and buildings. Real property parcels provide information on the spatial boundary, ownership, property type code (PTC), assessment value ($), and number of residential units for all parcels. In some cases, multiple parcels have the same assessment information; these were merged to avoid overestimating damages. Zoning consists of general classes of allowable land use. Since zoning is defined locally, zoning should take precedence over provincially defined PTC. However, when zoning and PTC correspond, the PTC can provide a more detailed description of actual land use. For example, if the zoning is commercial, the PTC provides 38 different sub-classes of commercial (restaurants, gas bars, banks, etc).

Table 12. *Summary of Datasets*

Dataset	Attributes	Attribute description
Real property parcels	Ownership	Owner name can indicate land use
	Property type code	Specific description of land use
	Assessment value	Assessed value of property
	Units	Number of residential units
Zoning	Zoning code	Allowable land use. This layer spans municipal and rural areas that have different regulations.
Agriculture	Agricultural use	Local mapping of agricultural use. Identifies multiple agricultural uses on parcels. Focus on formed land, hay and pasture. Does not include row crops.
Buildings	Building type	Building type, presence of basement, and total number of buildings on the corresponding parcel

Agriculture maps were provided by the NB Department of Agriculture. While there are 24 agricultural PTCs, these agricultural maps provide the location of multiple agricultural uses on each parcel. The focus of these maps is to identify improved/formed land, as well as pasture and hay; and does not identify all agricultural uses including row crops. Therefore, a combination of the agricultural mapping and agricultural PTCs will be required to identify agricultural use. Building footprints were digitized by the Mt Allison Geospatial Modelling Lab and attributes indicate if the building is primary or secondary, and where available the presence of a basement and type (one-storey, multi-storey and split level). Primary buildings were identified as being the largest building (or buildings of equal size) on a parcel; smaller buildings such as a garage are considered secondary. Table 12 provides a summary of the datasets.

8.2 Overlapping Boundaries

The boundaries of the 4 datasets do not always coincide. Some parcels have multiple zones or multiple agricultural uses. When these boundaries overlap, there are often discrepancies between the attribute data. When discrepancies exist, locally defined attributes have precedence. Agricultural mapping and Zoning both have precedence over parcel Property Type Codes (PTC).

In order for the attributes of all datasets to be maintained, boundaries are overlaid using a spatial union. A spatial union (Figure 9) creates new polygons based on the boundaries of all input layers: parcels, agricultural mapping and zoning. Each new polygon keeps the attributes for all overlapping layers.

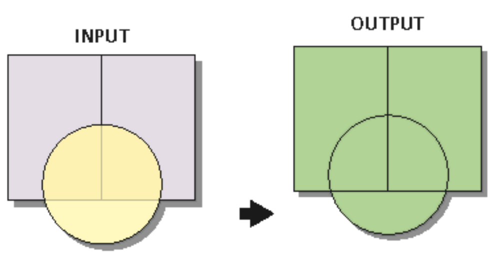
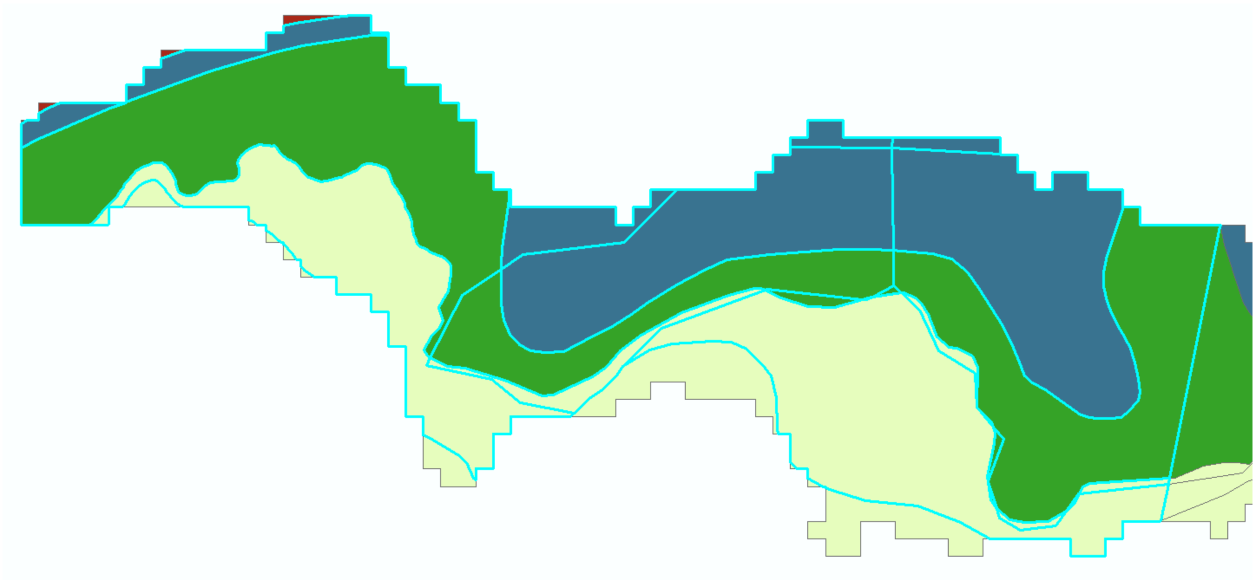


Figure 9. *Spatial Union*

Figure 9 shows the output for union where a single parcel was split into 12 polygons, each with different zoning and agricultural uses. This is not a common scenario as most parcels are not split, and when they are it is usually into 2 or 3 polygons, however, this provides a good example to explain the data. The field "unique" identifies all polygons of the same parcel. As you can see in Figure 10, each of the 12 polygons have the same property type code (dairy farm), assessment value and number of residential units (none). This single parcel was divided into 3 agricultural uses (hay, formed land and other), and 3 zones (Agricultural/conservation, rural residential and rural).



Unique	P_TYPE_COD	CURR_ASSMT	NUM_UNITS	AgUse	Zone_	area_whole	Shape_Area	pct_flood
4665	609	183700	0	3	RURAL	145055.8825	639.833418	0.004411
4665	609	183700	0	3	A/C	145055.8825	13621.445356	0.093905
4665	609	183700	0	3	RR	145055.8825	12640.971423	0.087146
4665	609	183700	0	0	RURAL	145055.8825	10822.713326	0.074611
4665	609	183700	0	0	A/C	145055.8825	18293.038245	0.12611
4665	609	183700	0	0	RR	145055.8825	4745.717284	0.032716
4665	609	183700	0	2	RURAL	145055.8825	1216.018281	0.008383
4665	609	183700	0	2	A/C	145055.8825	6487.558722	0.044725
4665	609	183700	0	2	RR	145055.8825	11545.602504	0.079594
4665	609	183700	0	0	RURAL	145055.8825	15956.859292	0.110005
4665	609	183700	0	0	A/C	145055.8825	413.208617	0.002849
4665	609	183700	0	0	RR	145055.8825	485.64784	0.003348

Figure 10. *Example of a Union where One Parcel has Multiple Zones*

8.3 Polygon Flood Depth

Once the parcels, agricultural mapping and zoning were combined, elevation statistics were calculated for each polygon. Each polygon was given a unique identifier "PolygonID2". Flood depth statistics were generated for each polygon from the highest resolution elevation data available. Figure 11 shows the extent of the high-precision LiDAR elevation data and the lower-precision provincial Digital Elevation Model (DEM). The LiDAR elevation surface has vertical precision of ~ 0.15 m and a horizontal spacing of ~1 m. The provincial DEM has a vertical precision of ~1.5 m and a horizontal spacing of ~30 m. When polygons fall across the boundary of the two elevation sources, these polygons are split for separate calculations. The fields "poly_elev_mean" and "poly_elev_min" provide the mean and minimum elevations for each polygon. The flood depth is calculated by subtracting the elevation statistics from each reference water level.

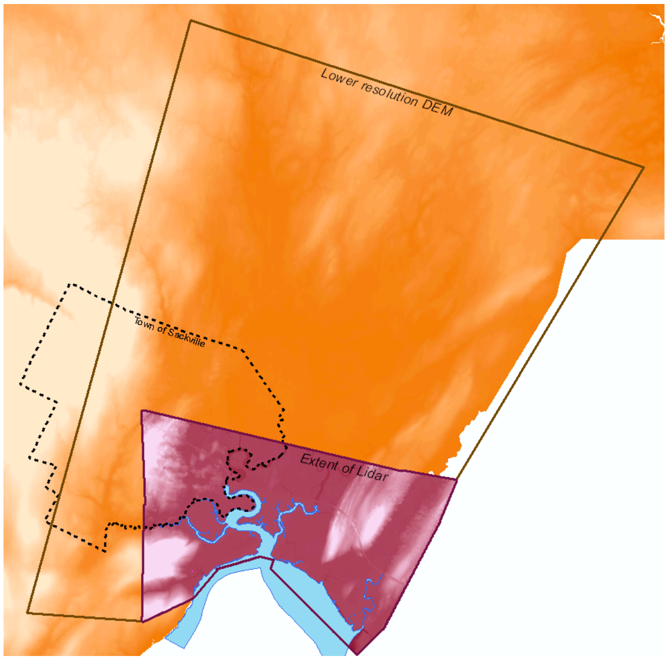


Figure 11. *Location of Elevation High-Resolution LIDAR and Lower-Resolution DEM Data*

8.4 Building Footprint, Height and Flood Depth

Buildings in flood prone areas were digitized by the Mt. Allison Geospatial Modelling Lab. The footprints were digitized using the highest resolution orthometric imagery available: 10 cm in the LiDAR coverage, and 50 cm elsewhere. The precision of building corners is approximately 2 times the pixel size. Each building has been assigned to a single “PolygonID2”. When a building spans 2 or more parcels the building is assigned to a single polygon to avoid counting a building twice. Figure 12 shows an example of a building that falls on two different parcels. The building was assigned to the northern polygon because a step was visible on that property.

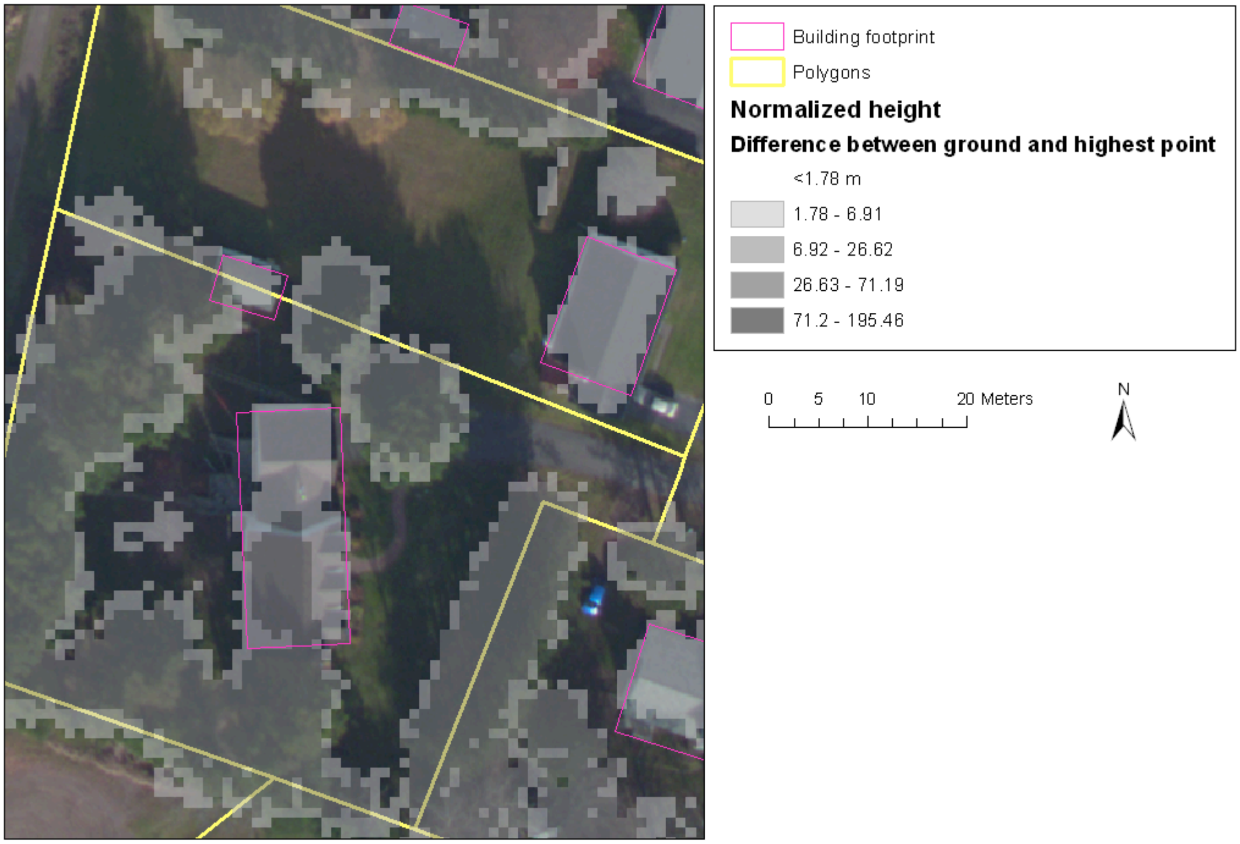


Figure 12. *Example of Mismatch between Building Footprints and Parcels*

Building heights were estimated using a Normalized Height (NH) raster. NH is the difference between the ground and first return elevation rasters. Building height statistics (min, max, mean, range, std and sum) were generated from all non-ground NH values within the entire building footprint. Some elevations within the building footprint are higher than the roof such as: overhanging trees, chimney and wires (Figure 13). Since there are non-building elevations within the building footprint, the maximum NH value is often higher than the building height. By comparing the NH statistics to 100 measured buildings, it was found that a quadratic equation of NH mean and NH standard deviation best estimates building height. Buildings that were not measured (by a digital range finder), and not surveyed by LiDAR, were assumed to have no-basement and are multi-storey as to avoid overestimating building damages.

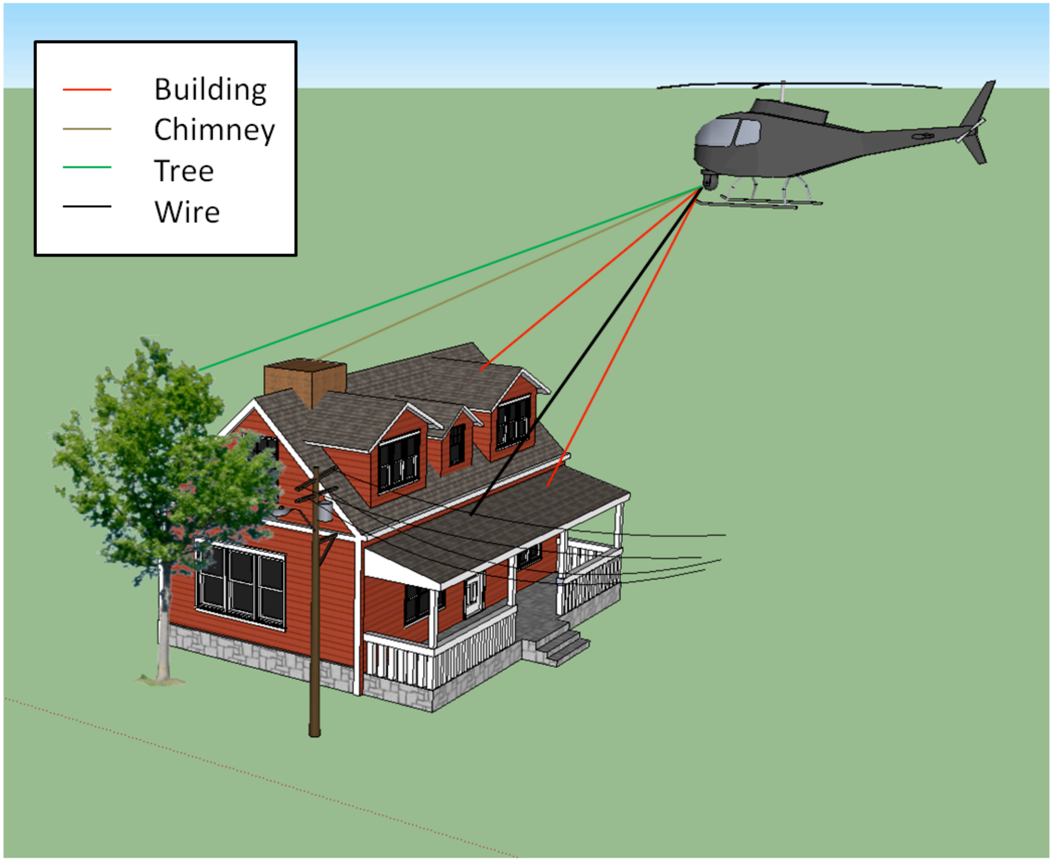


Figure 13. Possible LIDAR returns over a building footprint

Since flood damages differ by building type, each building was classified as one- or multi-storey. Using Classification And Regression Tree (CART) techniques, a cut-off value of 5.6 m was found that best classifies one- and multi-storey buildings (approximately 80% accuracy, as compared to measured buildings). Split-level buildings could not be identified and were removed from the analysis.

8.5 Relationship between Attribute Files

Two sets of building and polygon attribute files were created to improve the efficiency of processing the LiDAR data. The first set contains two master files of all the (1) buildings and (2) polygons that could be affected by flooding. The master files contain all attributes about the type and elevation of the buildings and polygons. For each flood scenario, additional files are created that list the buildings and polygons affected, as well as the area flooded. The flood scenario tables are related to the master attributes by unique identifiers ‘polygonID2’ for the polygons, and ‘unique’ for the buildings.