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Thesis

Spatial–temporal modelling for estimating impacts of storm surge and sea level rise on coastal communities: The Case of Isle Madame in Cape Breton, Nova Scotia, Canada

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Abstract

More frequent and harsh storms coupled with sea level rise are affecting Canada's sensitive coastlines. This research studies Isle Madame in Cape Breton, Nova Scotia which has been designated by Natural Resource Canada as a sea level rise vulnerable coastal community in Canada. The research models the spatial and temporal impacts of sea level rise from storm surge by focusing on identifying vulnerable areas in the community via geographical information systems (GIS) using ArcGIS, as well as modeling dynamic coastal damage via system dynamics using STELLA. The research evaluates the impacts in terms of the environmental, social, cultural, economic pillars that profile the coastal community for a series of modelled Storm Scenarios. This research synthesizes information from a variety of sources including the coastal ecology and natural resources, as well as human society and socioeconomic indicators included in the four mentioned pillars. The objective of the research is to determine vulnerable areas on Isle Madame susceptible to storm damage, and consequently, to improve local community knowledge and preparedness to more frequent harsh storms. This research therefore presents a dynamic model for the evaluation of storm impacts in Isle Madame designed with the goal to help the community ultimately to plan and implement a strategy to adapt to pending environmental change.

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First and foremost, I am heartily thankful to my supervisor, Dr. Dan Lane. His supervision, encouragement and support from the initial to the final level helped me in the completion of this research work.

It is a pleasure to thank Mr. Joan Clannon and Joel Bowen of Development Isle Madame Association (DIMA) for allowing me to access to the Isle Madame spatial data set through Access Nova Scotia which made this thesis possible.

Last but not the least, my family; especially I would like to thank Hooman who patiently encouraged me all the time.

Sahar Pakdel

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Glossary

CD	Chart Datum
DA	Dissemination Area
DD	Direct Damage
DFO	Fisheries and Oceans Canada
DEM	Digital Elevation Model
CMHC	Canada Mortgage and Housing Corporation
DMTI	Desktop Mapping Technologies Inc.
DST	Decision Support Toolbox
EC	Environmental Canada
EPOI	Enhanced Points of Interest
FDT	Florida Department of Transportation
GIS	Geographic Information System
GUI	Graphical User interface
HURDAT	North Atlantic Hurricane Database
ICSP	Integrated Community Sustainability Plan
Km/h	Km per Hour
LiDAR	Light Detection and Ranging
mb	Millibars
MOWL	Maximum Observed Water Level
NHC	National Hurricane Center
NOAA	Natural Oceanic & Atmospheric Administration
NRCan	Natural Resources Canada
SD	System Dynamics
SIC	Standard Industrial Code
SLRT	Sea level Rise Tool
SSD	Spatial System Dynamics
TDD	Total Direct Damage
TID	Total Indirect Damage
TSD	Total Storm Damage
UTC	Universal Coordinated Time
VBA	Visual Basic for Application

Introduction

1.1 Motivation and Problem Definition

Undeniable trends and impacts of climate change are globally more and more visible especially in coastal communities around the world (World View of Global Warming 2011). As noted in the IPCC 4th Assessment Report, Working Group II: Impacts, Adaption and Vulnerability: “coastal storms are threatening vital infrastructure, settlements and facilities” (Mimura et al 2007, p. 689) on which the existence of coastal communities like Isle Madame in Cape Breton, Nova Scotia, Canada depend.

Isle Madame – and all of Richmond County are designated as high-risk areas to sea level rise and storm surges. According to the Natural Resources Canada (NRCan) sensitivity estimates, the “High Sensitivity to Sea Level Rise” for Isle Madame (and a large part of eastern Cape Breton) “reflects the degree to which the coastline is expected to experience physical changes such as flooding, erosion, beach migration, land subsidence, and coastal dune destabilization” (NRCan, 2010).

Dolan and Walker (2004) point out that Canada has the longest coastline in the world. However, they also note that about one third of Canada’s coastline is “highly sensitive” to the threat of sea-level rise and its negative impacts on coastal communities.

According to the Standing Senate Committee on Emergency Preparedness report, “Canadians have no assurance that essential government operations will function during emergencies” (Canada 2008). For instance, in Canada severe weather events “have shown that aid from regional and national governments can be slow to reach impacted areas, and cannot be counted on to provide immediate emergency help” (Young 2008).

As Mehdi et al (2006) notes, coastal communities can be better prepared. This can be done by including local community knowledge, as well as local provincial and federal government services, to anticipate storm impacts, and to make important decisions about using their limited resources (Mehdi et al. 2006). This is what is being considered by the International Community-University Research Alliance (ICURA) project, C-

Change. This project, entitled "Managing Adaptation to Environmental Change in Coastal Communities: Canada and the Caribbean" began in June 2009 as a collaboration among university researchers and community members, in both Canada and the Caribbean region. The objective of the project is to work together "on research pertaining to coastal adaptation to the impacts of storm surge and sea level rise".

This thesis research has been carried out as part of the C-Change project with focus on one of the four Canadian communities, namely, Isle Madame, Cape Breton, Nova Scotia. For more information about the C-Change ICURA project see also: www.coastalchange.ca and http://www.facebook.com/coastalchange. The goal of this research as part of the overall C-Change project is to determine the most vulnerable areas on Isle Madame susceptible to storm damage, to develop a model of storm damage estimation, and consequently, to improve local community knowledge and preparedness for storm surge and sea level rise.

1.2 Research Questions and Research Objectives

The focus of this research is on modelling the impacts of storm surge and sea level rise on the coastal community of Isle Madame. With respect to this focus, there are a number of questions that this research addresses by presenting a model that integrates the spatial representation of the vulnerable coastal community with a temporal system dynamics model to examine the impacts of storms. The research questions are as follows:

1. How to describe the spatial characteristics of the community area of interest as a means of profiling the community status?
2. Given this description, what are the community's most vulnerable areas to storm surge and sea level rise in the coastal zone?
3. What will be the expected impacts of storm surge and sea level rise severe Storm Scenarios on the community and how can these impacts be measured within the community system for the case of Isle Madame?

In response to these research questions, the objectives of this thesis are to complete the following:

1. Describe spatially, using maps and the ArcGIS software, the area of interest that is Isle Madame with respect to its environmental, economic, social, and cultural dimensions.
2. Use the ArcGIS software and available data, to model Isle Madame coastal storm surge based on historical information, and to identify the vulnerable areas of the Isle Madame coastal zone most affected by rising sea level and storm surges.
3. Use the ArcGIS spatial representation of the community to value assets, assets at risk, and estimate spatial expected damages for modelled Storm Scenarios facing the community.
4. Model and evaluate the temporal impacts and estimate damage valuation on the community profile from storm surge and sea level rise by the use of system dynamics modeling and STELLA.

In this study, the research uses data obtained for Isle Madame in Cape Breton, Nova Scotia, Canada. The results of this study are presented in the form of descriptive maps, tables, graphs, and expected site damage evaluations from modelled Storm Scenarios.

1.3 Outline of the Research

This research describes community vulnerabilities for the specific case of Isle Madame and models how vulnerabilities can lead to estimating storm damages. The intent of the research is to present a tool made with the ArcGIS mapping software and the STELLA systems dynamics modelling software to model and estimate the impacts of storm surge and sea level rise for modelled storms in the coastal area for Isle Madame. This information will be used to model the impacts to the environmental, economic, social, and cultural pillars used to describe the community. All these activities will apply to one of Canada’s sensitive coastlines, and specifically to the communities and villages of Isle Madame, Cape Breton.

This thesis contains six chapters:

- Chapter 1 - topic introduction, motivation, research objectives and thesis outline (the current chapter).
- Chapter 2 - literature reviews on the topics of coastal vulnerabilities and threats, geographic information systems, system dynamics, integration of GIS and SD, and the application of storms to the case of Isle Madame.
- Chapter 3 - the research methodology describing the available data for Isle Madame, the data analysis, Storm Scenario modelling, Isle Madame assets valuations and assets at-risk determination, and spatial and temporal damage estimation procedures.
- Chapter 4 - presents the analysis and expected total damage estimates for modelled Storm Scenarios based on the spatial GIS model.
- Chapter 5 – presents the analysis and expected direct and indirect damage estimate for modelled Storm Scenarios based on the temporal System dynamics model.
- Chapter 6 - presents the thesis conclusions and recommendations for future research.

The bibliography, including web-links are provided at the end of the thesis followed by the set of appendices designed to provide complete disclosure of the model data and analysis. The Appendices include:

A) The Community Data Profile template for describing the community system.
B) The list of ArcGIS layers (their descriptions and their sources) for the Isle Madame community profile and the full description of the Isle Madame geographical data set.
C) The Standard Industrial Classification (SIC) of major groups used in the description of Isle Madame's economic sector.
D) Detailed Economic Status Quo for the Case of Isle Madame by Points in the SIC Major Groups and Division.
E) The Graphical User Interface (GUI) code for the Isle Madame ArcMap model of coastal flooding.
F) The System Dynamics Model STELLA equation code for the temporal estimation of the storm damage model.

G) Isle Madame Historical Storm Information (HURDAT files data) and storm tracks.

H) Detailed Storm Scenario Damage Estimates from the System Dynamics Model.

2 Literature Review

The review of the literature related to the proposed research is divided into four fundamental parts. These are: 2.1 Coastal environmental vulnerabilities associated with increased storm severity; 2.2 Geographical Information Systems (GIS) tools; 2.3 System dynamics modelling; 2.4 Combining GIS and SD models for spatial-temporal analysis; and finally, 2.5 Description of the community of Isle Madame and historical Storms events. The literature review below is presented in these sub-sections.

2.1 Coastal environmental and vulnerabilities

As stated in Chapter 1, Isle Madame and surroundings have been identified as a vulnerable coastal area that is threatened by sea level rise (NRCan 2010, Dolan and Walker 2004). Sea level rise is a gradual but generally recognized phenomenon that engenders gradual change to the coastal environment. Dolan and Walker also note that coastal communities' vulnerabilities are also understood in terms of communities' own abilities to be resilient to, and to resist the affects of sea level rise and storm surge. In their words:

> "Coastal environmental exposure includes sensitivity, resilience and resistance to climate changes. The potential of a coastal system to be affected by storm surge and sea level rise defines its sensitivity. Resistance explains system stability to possible sea-level rise and storm surge impacts, while the capacity of the system respond to and recover from impacts is a reflection of its resilience. Together, these terms define natural coastal vulnerability". (Dolan and Walker 2004)

Sea level rise may cause a number of adverse affects. These include: higher tides and water tables, more flooding, coastal zone erosion, salinization of freshwater (lakes and wells), and changes to wet land ecological communities.

As the 2007 IPCC 4th assessment report states, "Many small islands are highly vulnerable to the impacts of climate change and sea-level rise", while at the same time having "limited natural, human and economic resources" (Mimura et al 2007, p.690 and 691). Mimura et al (2007) also remind us that globally:

> "Most of these small island economies are reliant on a limited resource base and are subject to external forces, such as changing terms of trade, economic liberalization, and migration flows. Adaptive capacity to climate change is generally low, though traditionally there has been some resilience in the face of environmental change." (Mimura et al 2007, p.691)

It is acknowledged that Isle Madame, located along Canada's Atlantic coast is likewise an area of relatively limited population and economic potential, as discussed further in section 2.5 below.

The following sub-sections discuss community vulnerability in further detail according to: 2.1.1 global climate changes; 2.1.2 impacts of coastal climate change on islands communities; 2.1.3 characterizing vulnerability; and 2.1.4 vulnerability assessment.

2.1.1 Global climate changes

In the past decade, large changes in climate have happened very quickly. For example, the following items are reported in the Intergovernmental Plan on Climate Change (IPCC) reports IPCC (2001), Mimura et al (2007) and NASA (2010):

- "In the last century, the global sea level rose about 17 centimetres, in the last decade this rate is nearly double of the last century" ;
- "Today, Carbon Dioxide Levels are higher than any time in the past one thousand years" ;
- "In the last century, global ocean and air temperatures rose three-quarters of a degree Celsius, which is twice the rate in the past 50 years";

- "Movement of many species of plants and animals to higher elevations or closer to the poles as evidence and response to global warming and climate changes".

Further dramatic evidence of the changing climate is provided from the U.S. National Aeronautics and Space Agency (NASA) that notes the recent changes in averages in global temperature and sea level rise, polar ice sheets melting, and increases in carbon dioxide in the air (NASA 2010).

From all evidence, it is concluded that climate change is a real phenomenon and one that needs to considered for its potential impacts, especially on coastal communities witnessing sea level rise and more frequent severe storms.

2.1.2 Impacts of coastal climate change on islands communities

The impacts of sea level rise on most coastal communities go beyond the physical consequences. Coastal communities vulnerable to sea level rise also have negative impacts to communities' economic and social well-being (Mimura et al 2007). Mimura et al (2007) also attribute to Cocklin (1999) the idea that:

> "Climate change and sea-level rise are not unique contributors to the extreme vulnerability of small islands. Other factors include socio-economic conditions, natural resource and space limitations, and the impacts of natural hazards such as tsunami and storms. In the Pacific, as in the Caribbean, vulnerability is also a function of internal and external political and economic processes which affect forms of social and economic organizations that are different from those practiced traditionally (Cocklin 1999)." (Mimura et al 2007, p.692 and 693)

The literature notes the wide-ranging impacts of sea level rise and coastal storms. It is important to keep in mind these multidimensional elements when analysing coastal community impacts from the changing climate.

2.1.3 Characterizing vulnerability

In this research, Cutter's definition is considered as the applied definition of vulnerability. According to Cutter (1996), vulnerability is a "rhetorical warning of danger representing a potential for loss". This is representative of the situation for coastal communities. Further, Dolan and Walker (2004) characterize vulnerability in three classes, namely: (a) physical, (b) social, and (c) integrated physical and socioeconomic vulnerabilities. These classes of vulnerability are consistent with the multidimensional impacts and are defined specifically as follows:

a) Physical vulnerability – indicates the "exposure to hazardous events such as droughts and floods (physical one), and points out how this affects people and structures so its focus is to identify vulnerable places" (Dolan and Walker 2004).

b) Social vulnerability - is a "function of social conditions which is risky for people in the various sort of stresses like climate-related, political, or economic" (Dolan and Walker 2004). Social conditions that "restrain access to resources such as social security and income make it hard for people to cope with impacts. Consequently, protection from the social forces is more vital than protection from natural exposure" (Dolan and Walker 2004).

c) Integration of physical and socio-economic vulnerabilities - is a "physical risk and a social response within a defined geographic context" (Dolan and Walker 2004). Of particular interest to this thesis, Wu et al. (2002) integrate the physical and social vulnerabilities using GIS to assess the spatial vulnerability of flooding from storms and seal level rise projections in a coastal area .

2.1.4 Vulnerability Assessments

According to the earlier IPCC-CZMS (1992) report, vulnerability in the coastal zone is defined by "the degree of incapability to cope with the impacts of climate change and accelerated sea level rise" (Dolan and Walker 2004).

Application of the IPCC "common methodology" for assessing coastal vulnerability predicted storm and sea level rise impacts toward planning response strategies for reducing storm damages. The response or "adaptation" strategies were characterized by strategies to "protect", "adapt", "retreat", or "do nothing" (Dolan and Walker 2004).

Harvey specifies the multidimensional aspect of coastal vulnerability alluded to in the 1992 IPCC-CZMS (1992) report when he states:

> "Vulnerability assessment includes the susceptibility of the coastal zone to physical changes resulting from climate change, the anticipated impacts on socioeconomic and ecological systems, and available adaptation options". (Harvey et al 1999, p.50).

In this same way, Dolan and Walker (2004) criticized the IPCC report by noting that

> "...most vulnerability assessments based on the common methodology do not consider scales appropriate enough to provide adequate community level guidance regarding climate change adaptation... Others have provided altered approaches to respond to the limitation of that methodology, such as technical and data availability constraints, and the ineffectiveness in assessing the wide range of technical, institutional, economic and cultural elements in different regions" (Dolan and Walker 2004, p.2).

In this thesis, we adopt the more general multidimensional view of coastal vulnerabilities and assessment toward identifying appropriate local response strategies.

2.2 Geographical Information Systems Tools

Geographic information systems are tools that enable the multidimensional description and analysis of the coastal zone. According to the Environmental Systems Research Institute (ESRI); "GIS gives an ability to combine a variety of datasets in an infinite number of ways, it is a tool for nearly every field of knowledge from archaeology to zoology" (ESRI 2007). These datasets include economic, social, and cultural information as well as the physical and geographic nature of coastal areas (Mark et al 1997). Thus, GIS tools provide a useful means of incorporating these aspects in the work of this thesis.

There are a number of different GIS software packages, such as ArcGIS, MapInfo, InterGraph GeoMedia, Manifold, SmallWorld, MS MapPoint, and Google Earth. From all these, ESRI's ArcInfo which is used in this research, has dominated the market for years because of its availability, power, and ease of use.

2.3 System Dynamics

System Dynamics (SD) was founded by Forrester in 1961. Forrester saw SD as a way to analyze and represent complex systems and their behaviour through a set of tools and a theory of system structure (Forrester 1971).

Taylor and Radzicji (2008) give a clear and simple definition of system dynamics:

> "System dynamics is an approach to understanding the behaviour of complex systems over time. It deals with internal feedback loops and time delays that affect the behaviour of the entire system and it are a simulation modeling technique for framing, understanding, and discussing complex issues and problems." (Taylor and Radzicji 2008, p.2)

In the SD approach, "the entire system must be studied in order to find the affects of any changes in the system. The most important aspect is interaction between elements of a system that determine the system behaviour" (Simonovic and Ahmad 2005).The other aspect is feedback. According to Simonovic and Ahmad (2005), a

> "feedback system is influenced by its own past behaviour.Negative feedback or balancing feedback loop (which oppose the initial action) and positive feedback or reinforcing feedback (which reinforce the initial action) is two different types of feedback. On the other hand there is a dynamics of a system which indicate the changes over time". (Simonovic and Ahmad 2005)

According to the System Dynamics Society (2009), the steps of the System Dynamics methodology are as follows:

- "Defining problems dynamically, in terms of graphs over time.
- Striving for an endogenous, behavioural view of the significant dynamics of a system, a focus inward on the characteristics of a system that themselves generate or exacerbate the perceived problem.
- Thinking of all concepts in the real system as continuous quantities interconnected in loops of information feedback and circular causality.
- Identifying independent stocks or accumulations (levels) in the system and their inflows and outflows (rates).
- Formulating a behavioural model capable of reproducing, by itself, the dynamic problem of concern. The model is usually a computer simulation model expressed in nonlinear equations, but is occasionally left unquantified as a diagram capturing the stock-and-flow/causal feedback structure of the system.
- Deriving understandings and applicable policy insights from the resulting model.
- Implementing changes resulting from model-based understandings and insights." (System Dynamics Society 2009)

There are several software packages that deliver systems dynamics modelling techniques. In this research, the system dynamics software used is called STELLA from isee Systems software and it is very user friendly. According to isee Systems; "Systems Thinking software like STELLA is an increasingly valuable tool for constructing understanding about all kinds of dynamic systems from natural environments to team dynamics to economic markets." (isee Systems 2011, p.1)

2.4 Combining GIS and System Dynamics

The topic of combining spatial considerations with temporally changing elements of a system has been of interest to researchers since the development of GIS and SD. It has been noted that:

> "GIS deals with the data, its position in a spatial coordinate system, its attributes, and its spatial interrelation with each other. System Dynamics is used to understand problems which are dynamic (involve quantities which change over time), and also involves the notion of feedback" (Singhasaneh et al 1991).

The GIS and SD software packages have their own strengths and weaknesses, as summarized by Singhasaneh et al 1991 and provided in Table 2.1 below.

	GIS	System Dynamics
GIS Capability		
• Position with respect to a known coordinate system	Yes	Yes, can be done using "array" in Dynamo III, with severe limitation.
• Attributes of each point in the coordinate system	Yes	Yes
• Spatial interrelations with each other	Yes	Yes. In a certain way
• Producing "thematic" map	Yes	No
Modeling Capability		
• Repetitive calculation	No. (Can be done manually)	Yes.
• Dynamic	No. (Can be done manually)	Yes.
• Feedback	No	Yes.
• Producing graphs of any variable over time	No	Yes.

Table 2.1: Comparison between GIS and SD packages

Source: modified from Singhasaneh et al (1991)

Bajracharya et al (2009) attribute to Ahmad and Simonovic (2004) the following idea:

> "While system dynamics is robust in representing temporal processes with restricted spatial modeling capabilities, on the other hand, the strength of GIS lies in spatial analysis and modeling with limited representation of temporal processes. The integration of GIS and system dynamics provides a logical alternative to model spatial dynamic systems. System Dynamics's modeling framework allows the integration of the physical, social, economic and ecological processes in order to understand behaviour of a complex system." (Bajracharya et al 2009, p.223)

According to Van Deursen (2000), "several researchers recognize different levels of integration of GIS and models". Van Deursen (2000) also ranked these levels as shown in Figure 2.1below:

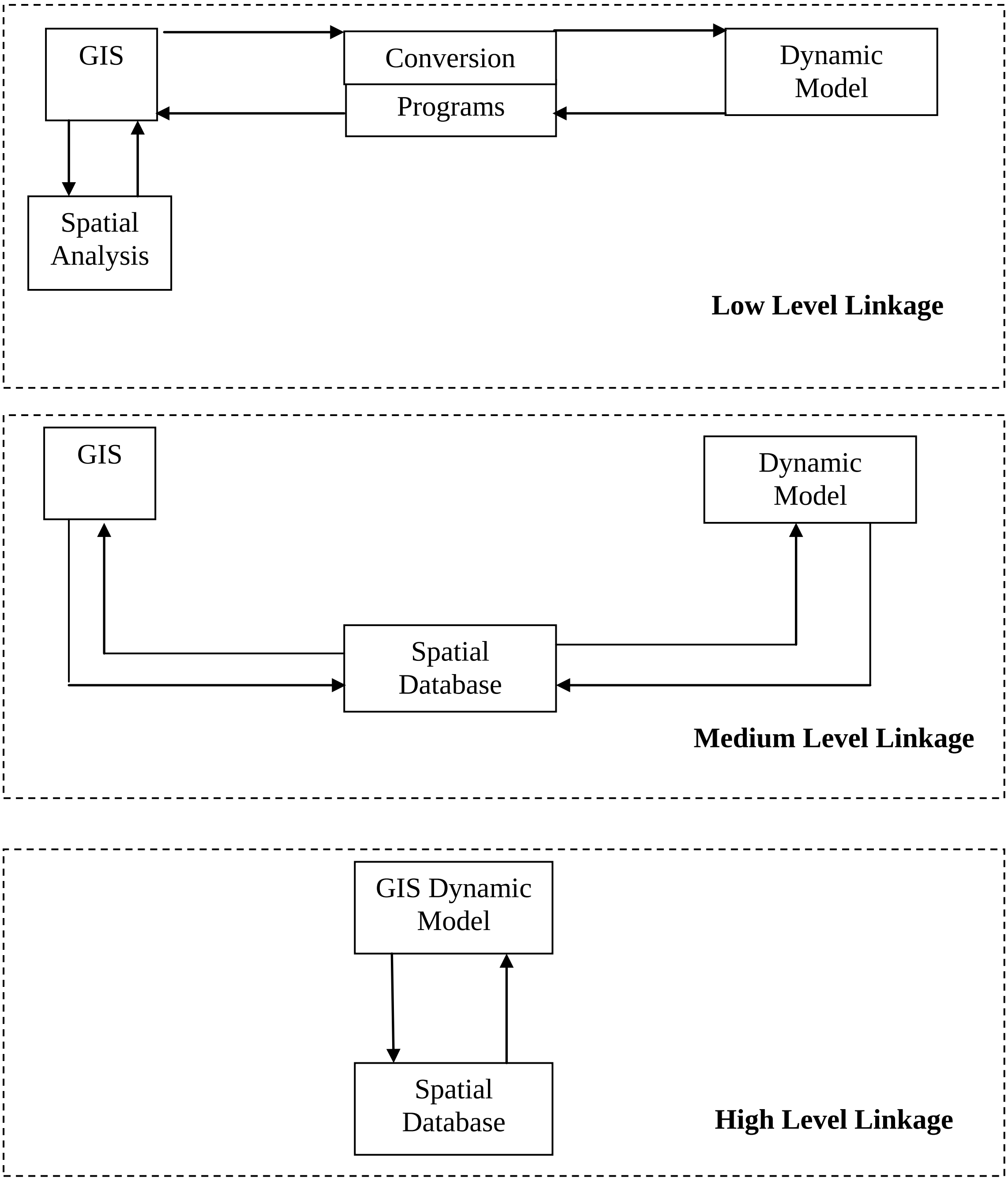

Figure 2.1: Levels of integration between GIS and (dynamic) models.
Source: modified from Van Deursen (2000)

From Figure 2.1, the simplest level of integration of GIS and SD is “Low level linkage”. This approach separates the GIS model and the SD model and exchanges information via translated files. This approach “is characterized by the use of conversion programs and procedures, and data exchange between models and GIS using files" (Van Deursen, 2000).

Many researchers have been developed applications that link GIS to SD using low level of integration between model and GIS. These include the applied works of Cabecinha et al. (2009), Aragon et al. (2006), Deursen and Wesseling (1996), Singhasaneh et al (1991), and Clark (1990).

As Van Deursen (2004) reports,

> "The use of low level linkage yields a number of difficulties. The primary use of the GIS databases might be completely different from the required use in the model. The databases are poorly geared to be used in the models, and the results of the model are difficult to be incorporated in the structure of the GIS database. It is therefore that the linkage between GIS and the model is an ad hoc solution. Frequently the linkage between the model and GIS is a once-only exercise, and the database used for the model is not updated along with the GIS database" (Van Deursen 2000, p.17).

From Figure 2.1 above, the "medium level linkage" between GIS and SD is characterized by more sophisticated data exchange. This typically takes the form of a common database that can be accessed directly by both the GIS and SD models.

The "high level linkage" (Figure 2.1), the distinction between SD model and GIS is fuzzy, , and the SD model becomes an option of the GIS application (Van Deursen 2000). Bajracharya et al. (2009), Pullar (2004), Mazzoleni et al (2006), Pullar (2003), Mazzoleni et al (2003) and Bernard L. and Kruger T. (2000) develop examples of high level integration applications.

Some of the advantages and disadvantages of these three levels are summarized by Van Deursen (2000) in Table 2.2.

Low Level Integration	Advantages	The development of low level integration is less time consuming than the higher level integration
		Use of existing programs for GIS and dynamic models yields well known and reliable components for spatial modeling
	Disadvantage	Laborious and time consuming
		Not flexible
		Error prone because several steps of user interaction are required
		New versions of GIS or model require modification of conversion software
		Redundancy and consistency problems due to the use of several instances of the same database
Medium Level Integration	Advantages	Entire GIS functionality available for manipulation and analysis of input and results of the model
		Increased speed (no overhead of conversion of data)
		Easier maintenance of databases, reduced consistency and redundancy problems
	Disadvantage	Requires a relatively open GIS structure
		Low level approach for model integration
High Level Integration	Advantages	Integration of GIS functionality for manipulation of input, results and formulation of the model
		No overhead for conversion between GIS and models and between individual models
		Rapid development of new models
		Easy maintenance of models
	Disadvantages	Current generation of commercial GIS does not fully support dynamic modelling
		Investment in development of tools and functionality is high
		Lack of specialists insight may yield invalid model concepts and formulations, the user is fully responsible for the model formulation

Table 2.2: The advantages and disadvantages of the levels of integrating GIS and SD
Source: modified from Van Deursen (2000)

In the Bajracharya et al (2009) high level linkage application, they create a new software called Decision Support Toolbox (DST) which has four main modules:

“(1) Knowledge-database module which is metadata management system,

(2) Spatial analysis module which provides basic GIS function and geo-processing tools,

(3) Modeling and Storm Scenario analysis which has two sub modules first one is for viewing qualitative models and second one is System Dynamics Model (SDM), and

(4) Decision analysis module which consists of multi-criteria analysis" (Bajracharya et al. 2009).

Figure 2.2 illustrates this integration of the Bajracharya et al. (2009) developed software description.

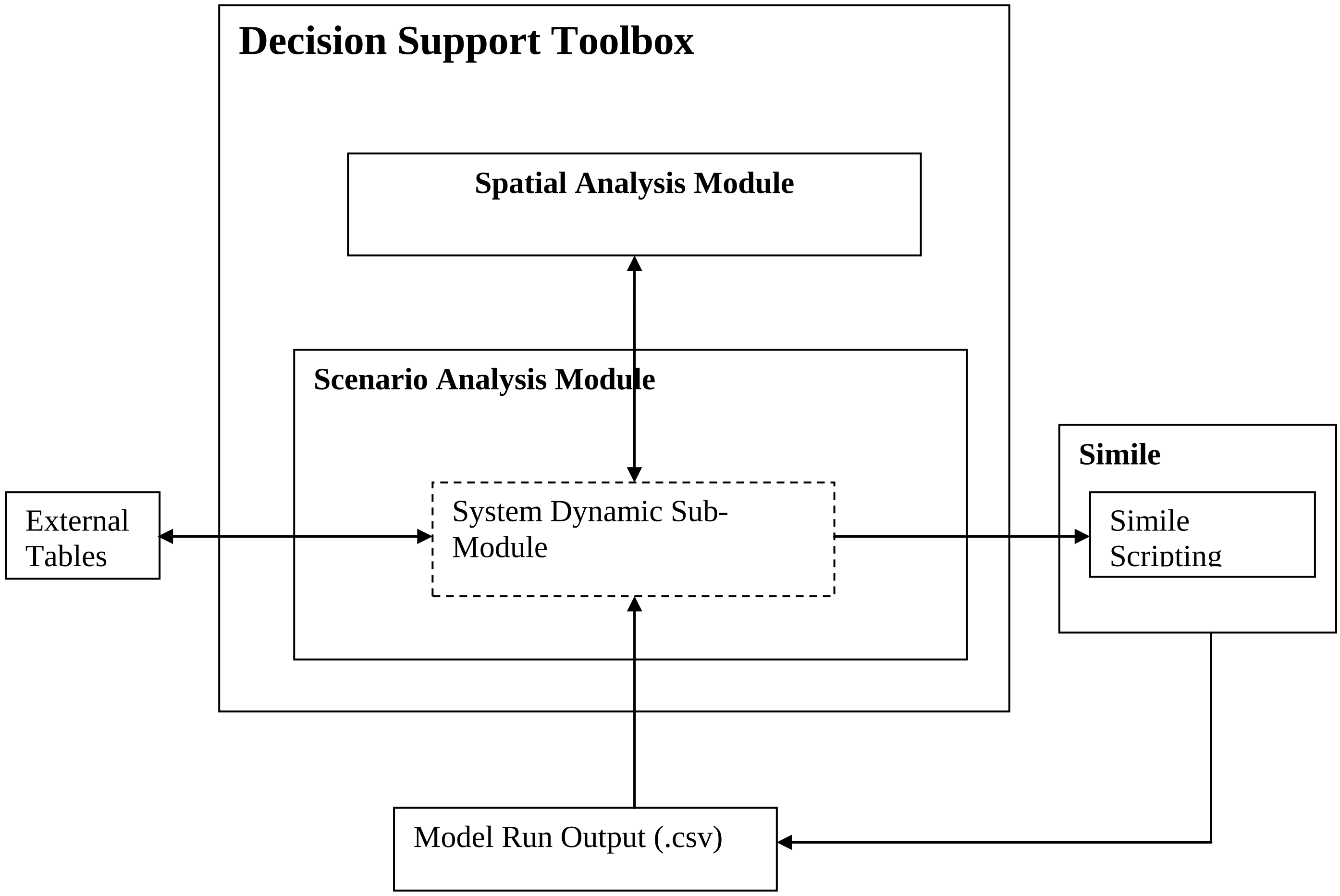

Figure 2.2: Integration of GIS and SD model
Source: modified from Bajracharya et al (2009)

It is noted that Bajracharya et al (2009) presented a descriptive methodology only. In other words, they did not discuss how their description could be applied in common and complex systems characterized by a large state space and subject to the curse of dimensionality, and with multiple time steps. Their work provides evidence that "high level linkage" of GIS and SD modelling has not yet attained operational status.

Alternatively, Ahmad and Simonovic (2004) develop a system referred to as "Spatial Systems Dynamics". In this approach,

> "Systems Dynamics techniques are used to describe and link the physical, economic and social baselines through visual spatial and temporal maps as part of spatial system dynamics... Spatial mapping and visualization will be used to simulate and animate hypothetical situations for community discussions including exploring the impacts and responses of adaptation and mitigation strategies to perceived and real threats" (Ahmad and Simonovic 2004).

The Ahmad and Simonovic model is an example of a "medium level linkage" whereby the GIS and SD models are run simultaneously through a shared database.

> "Initially, GIS provides spatial information to the SD model. The SD model, through dynamic modelling, identifies changes in the spatial features with time and communicates them back to GIS. These changes in space in turn affect decisions/policies in time. Thus, processes can be modeled in time and space in an integrated way while capturing the feedback." (Ahmad and Simonovic, 2004)

Figure 2.3 illustrates the process of SSD modeling from Ahmad and Simonovic (2004).

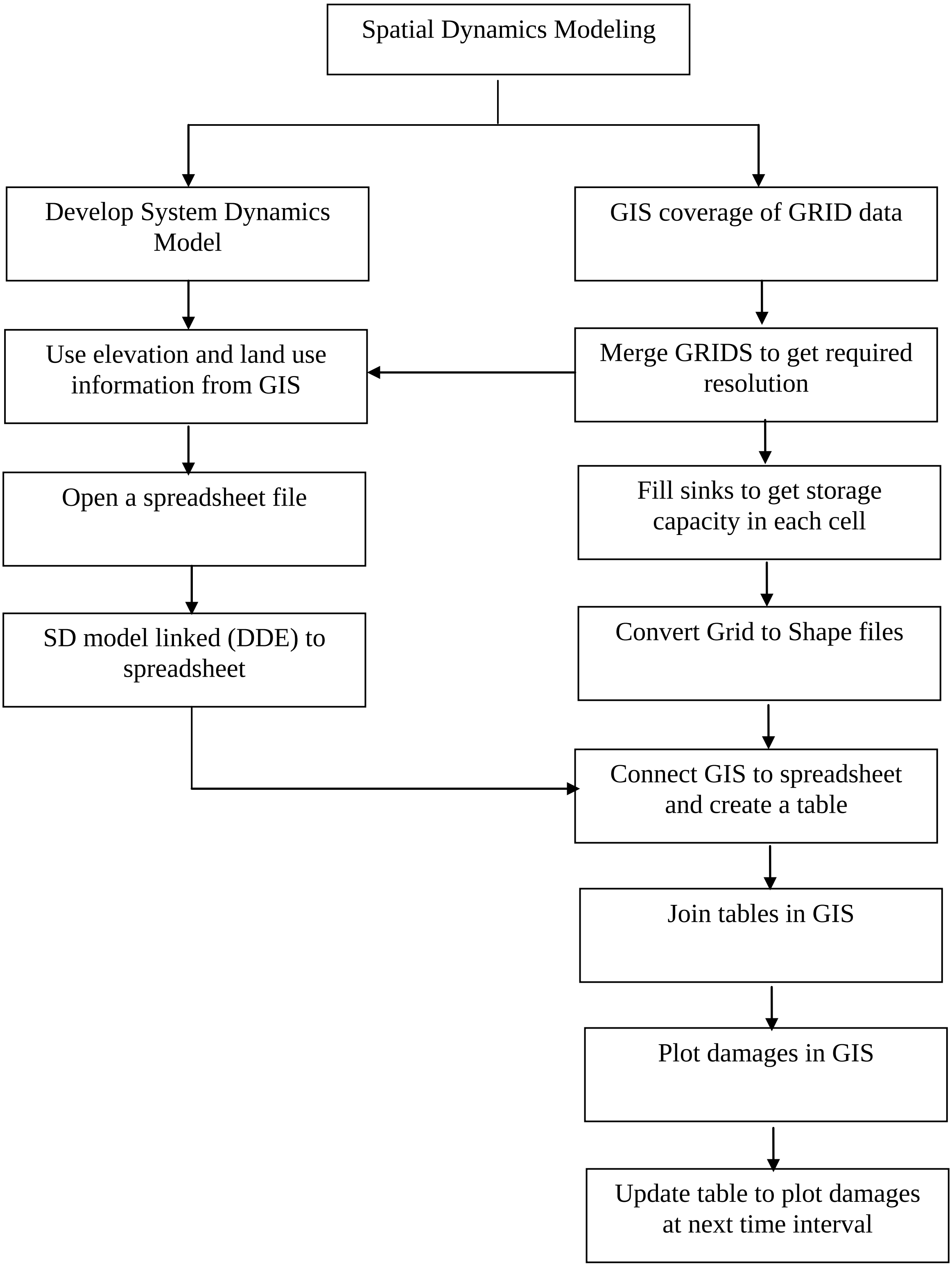

Figure 2.3: Flow Diagram of SSD process

Source: modified from Ahmad and Simonovic (2004)

Although the SSD methodology of Ahmad and Simonovic (2004) work captures both the power of GIS and the SD environments, it still has its limitations. The most important issue of the Simonovic and Ahmad (2005) research that remains unresolved is the "curse of dimensionality" characterized by the need to define the dynamics of many spatial states over time. This issue was observed in the Simonovic and Ahmad (2004) work and more recently in the results that they have investigated using the proposed methodology (Ahmad 2010).

In this study, in order to link the 4 community descriptive pillars (environmental, social, economic, and cultural) together, a spatial system dynamics (SSD) model was initially designed using the Ahmad and Simonovic (2004) methodology. Subsequently, in the case of Isle Madame (discussed further below) there is multiple spatial Dissemination Areas (DA). ("A dissemination area (DA) is a small, relatively stable geographic unit composed of one or more adjacent dissemination blocks with a population of 400 to 700 persons" (Statistics Canada, 2007)). Using the SSD methodology with defined linkage between each DA and the multiple time steps for each DA, then the model would face the curse of dimensionality issue described by Ahmad and Simonovic (2004) and Ahmad (2010).

HAZUS is a GIS based software developed by U.S. Federal Emergency Management Agency (FEMA). It can be used to estimate the damages resulting from natural hazards namely earthquake, hurricane and flood. This software uses GIS to estimate physical, social and economic impacts of these natural hazards (FEMA 2011). The software is distributed at no charge by the agency and can be used alongside ESRI ArcGIS. Among HAZUS models, flood model is in particular interest to this research. This model can provide analysis for annualized damages from flooding. To provide such evaluations the software uses a number of extensive United States national databases or inventories. These databases encompass information such as the demographic of the study region, square footage of different buildings, location of vulnerable facilities, transportation, agriculture products and vehicles (FEMA 2011).

HAZUS Flood Model methodology consists of two processes: (1) flood hazard analysis and (2) flood loss estimation analysis. In flood hazard analysis, factors such as ground elevation, discharge and frequency are used for modeling the spatial variation in flood velocity and depth (FEMA 2011). Based on the results of this process, the next process calculates physical and economic damage by using vulnerability curves. Physical losses can be direct and induced. Direct physical losses include damages of building stock, essential services (e.g., police station), and high potential loss facilities (e.g., dam), transportation systems, utility systems and agriculture products and vehicles. Induced physical damage consists of fires, debris and hazardous materials. Direct socioeconomic losses include shelter, casualties and economics. The model also considers indirect economic losses. These results can be converted to a series of reports and maps by the software. One can conclude that HAZUS Flood Model is a highly sophisticated and powerful model which, by utilizing extensive databases, is capable of providing damage estimations on various pillars (physical, social and physical) of a U.S. community.

As already mentioned, HAZUS relies on many sources of data and in the case of United States the required data are already available for various states and can be ordered free of charge from FEMA (2011) along with the software. However, FEMA (2011) states important factors that have to be considered when applying HAZUS outside of United States. International users should develop databases that are compatible with HAZUS. These include demographics, building stock, high hazard facilities, essential facilities, utility and transportation systems, shelters, casualties and metadata. In the absence of such inventories, extensive time is required to develop these databases for an international applicability. Furthermore, the international user may require modifying the parameters of the model to reflect the new situation. For example, damage functions should be modified to reflect the behaviour of the buildings in other countries. These modifications can be very time consuming and may be very hard to do for small communities such as Isle Madame. In this thesis, a simpler model has been developed to estimate the number of assets at risk for each pillar of the study and then estimate damages to these assets (Chapter3). Future study may focus on applying and modifying the HAZUS Flood Model to various coastal communities in Canada.

In this research, a low level of integration of the GIS spatial information with the SD temporal impacts of storms is applied whereby data from the GIS will send its results to an Excel spreadsheet file manually, and after some data transformation, the results are imported from the Excel file to the SD model for further analysis of the temporal aspects. This simple integration is one means of connecting the data results from the GIS to the SD model expressing storm dynamics.

2.5 The Community of Isle Madame and Historical Storms

This section includes five subsections which focus on the community of Isle Madame. These subsections include (2.5.1) the general description of Isle Madame and its communities; (2.5.2) storm surge and sea level rise – data sources for extraction of Storm Scenarios and impacts; (2.5.3) description of Historical Storm Profiles affecting Isle Madame in recent years; (2.5.4) estimations of impacts and damages caused by historical storms on Isle Madame; and (2.5.5) the description of Isle Madame spatial data used in this research.

2.5.1 Description of Isle Madame

Statistics Canada (2007) reports that:

> "Isle Madame is the largest island in an archipelago situated off the southwest coast of Cape Breton Island, Nova Scotia near the Atlantic Ocean entrance to the Strait of Canso, which separates Cape Breton Island from the mainland of Nova Scotia. Isle Madame consists of three main island communities: Isle Madame, Petit-de-Grat Island to the east, and Janvrin's Island to the west. The island is comprised of a number of small communities including: Little Anse, Arichat, Petit de Grat, Lennox Passage, West Arichat, Janvrin's Island, Alderney Point, Boudreauville, Cape Auguet, Cap La Ronde, D'Escousse, Lochside, Martinique, Poirierville, Pondville, Pondville South, Port Royal, Poulamon, Rocky Bay, Samson's Cove; and St. Marys. The island archipeligo is approximately 16 km long and 11 km wide or 176 sq km in area. Isle Madame is home to approximately 3,500 residents" (Statistics Canada, 2007).

In terms of economic activity, Isle Madame has historically been a port for cod fishing and sea trade. There are some fishery operations still active in Isle Madame, such as Premium SeaFoods, Ltd., in Arichat. Moreover, there is a community development association called DIMA (Development Isle Madame Association) which introduces and develops business and recreational opportunities in Isle Madame for the benefit of Isle Madame residents (C-Change, 2011).

Figure 2.4 shows the Arichat inner harbour. This area has sunk over time. Approximately 75 years ago, the area now under water in the inner harbour was the site of a baseball field and a place for grazing cattle. As can be seen from the figure (dated 2004) there are many houses close to the shoreline as well as one of the main roads on the island which are all vulnerable to flooding from storm surges.

Figure 2.4: The town of Arichat in Isle Madame and inner Arichat Harbour
Source: Isle Madame (2004)

For example, and most recently, following the New Year's Day storm of 2010, January 2, 2010, a storm surge washed over the newly completed Veteran's Memorial Highway in Arichat on the Chemin d'en Bas (Lower Road) coastal highway as seen in the Figure 2.10, causing localized flooding. Also noted in Figures 2.4-2.6 are many houses located in vulnerable areas very close to the shoreline.

Figure 2.5: View of Low and High Roads, Arichat, Isle Madame

Source: Isle Madame (2004)

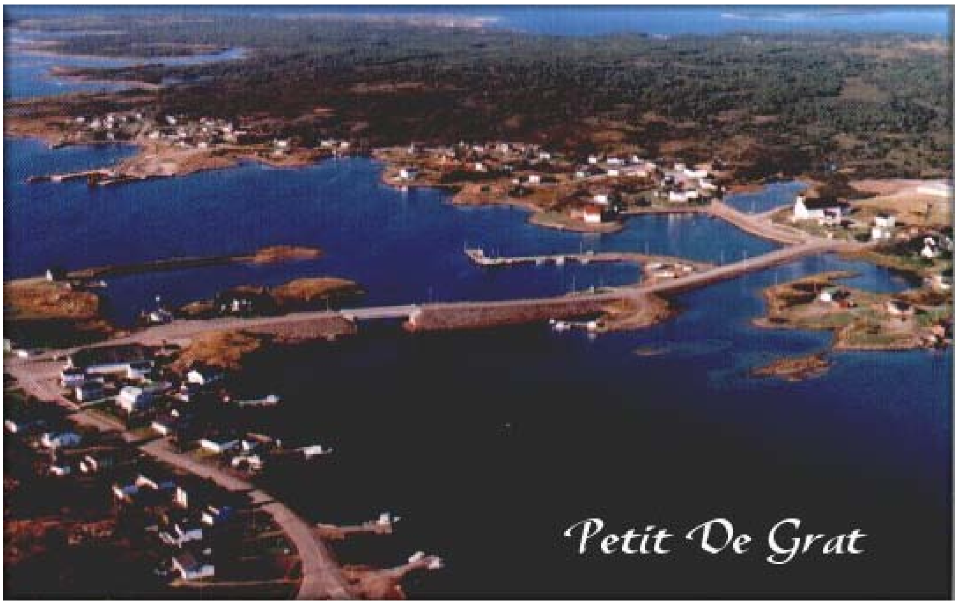

Figure 2.6: Petit de Grat wharf, Isle Madame.

Source: Isle Madame (2004)

2.5.2 Storm surge and sea level rise - data sources for extraction of Storm Scenarios and impacts

In this study, the concept of Storm Scenarios modelling is introduced for Isle Madame. In this section, the sources of data on historical storms are discussed. The main data sources for storms used in this study are:

(i) The North Atlantic Hurricane Database (NOAA 2010) "which is the official record of tropical storms and hurricanes for the Atlantic Ocean, Caribbean Sea and Gulf of Mexico";

(ii) The Environment Canada Canadian Hurricane Centre database (Environment Canada, 2009), and

(iii) The National Oceanic and Atmospheric Administration HURDAT Storm Database (NOAA 2010).

The impact of coastal storms is the consequence of flooding from coastal waters pushed to heights due to high winds and tides. This results in coastal "storm surge". As Webster and Stiff (2008) note:

> "Many coastal communities in Canada and around the world are at risk due to flooding from storm-surge events. A storm surge is an increase in the ocean water level above what is expected from the normal tidal level that can be predicted from astronomical observations and is most often caused by the winds and low pressure of atmospheric storms" (Webster and Stiff 2008).

Storm surge is also a function of the direction, speed, wind, and atmospheric pressure of a storm. This information is captured by the storm databases noted above. Table 2.3 below illustrates the format of data from the HURDAT (NOAA 2010) storm database. Data are provided under each column to illustrate storm information reporting.

Month	Day	Hour	Latitude	Longitude	Direction	Speed	Wind	Pressure	Type
June	15	10 UTC	45 N	61.5 W	34 deg	20 mph or 33kph	85 mph or 140kph	980 mb	Hurricane Category 1

Table 2.3: HURDAT's data layout

Source: NOAA (2010)

The information in Table 2.3 is itemized as follows as defined in NOAA 2010:

- UTC is stands for Universal Coordinated Time.
- Latitude and Longitude are to the nearest tenth of a degree and the Hemispheres are listed as 'N' or 'S' for North or South and 'E' or 'W' for East or West. Wind direction is degrees clockwise from due north (0 deg.)
- Wind speed is given in both miles per hour (mph) and km per hour (kph)
- Central minimum pressure is given in millibars (mb), and
- Storm type can be Tropical Disturbance, Tropical Depression, Tropical Storm, Hurricane, or Major Hurricane reported by category according to the Saffir-Simpson Scale.

Information in the HURDAT database is recorded for historical storms. This information also provides the basis for categorizing storm types that can be used for Storm Scenario modelling.

2.5.3 Isle Madame historical storm profile

The HURDAT database is introduced for extracting the indicators of a storm at the time of impact on or near Isle Madame. Another source of storm data is the National Hurricane Database of NOAA (NHC, 2010). For finding data in the NHC NOAA website, the location (by longitude and latitude) is selected and the date and distance of storm from the location of interest specified. In the case of Isle Madame, the approximate centre of the island is located at Latitude: 45° 32' 60 N, Longitude: 61° 0' 0 W.

Figure 2.7 is the result of a search for all storms happened in Isle Madame in the "Historical Hurricane Tracks" website of NOAA. Figure 2.7 below illustrates all the hurricanes from 1859 to 2010 which had distance of maximum 50 Nautical Miles from Isle Madame. For the purpose of this research, only storms (including hurricanes) from the period 1975 to 2009 are studied.

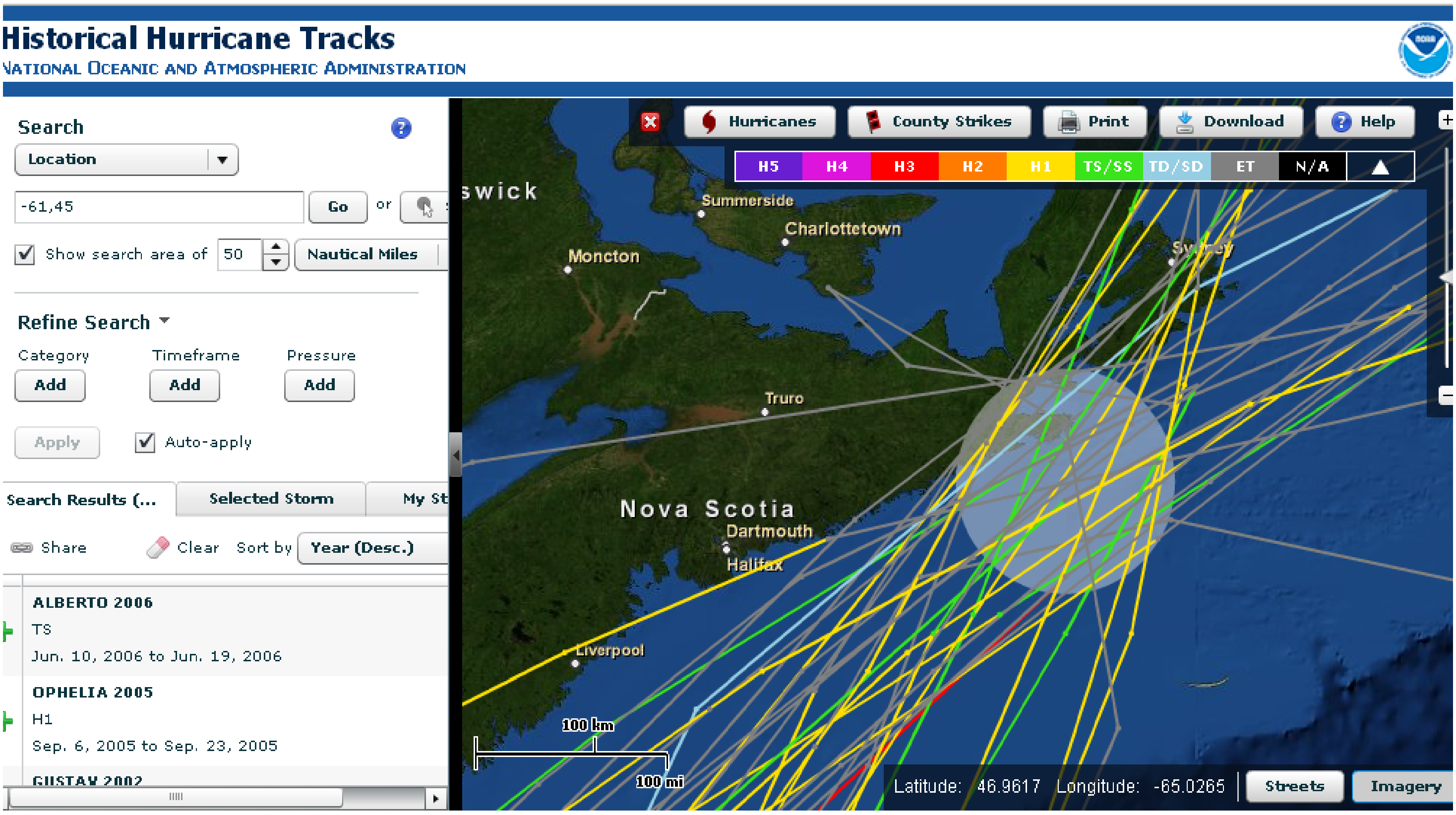

Figure 2.7: Isle Madame historical storms

Sources: Modified by NOAA (2010)

The nearest hurricane from the HURDAT database to Isle Madame within this period 1975 to 2009 is named Hurricane Barry. This Hurricane struck the island on July 9, 1995. The specific storm track of Hurricane Barry is shown Figure 2.8 below. Figure 2.8 is result of search for one storm (Hurricane Barry in July 9, 1995) happened in Isle Madame in the "Historical Hurricane Tracks" website of NOAA.

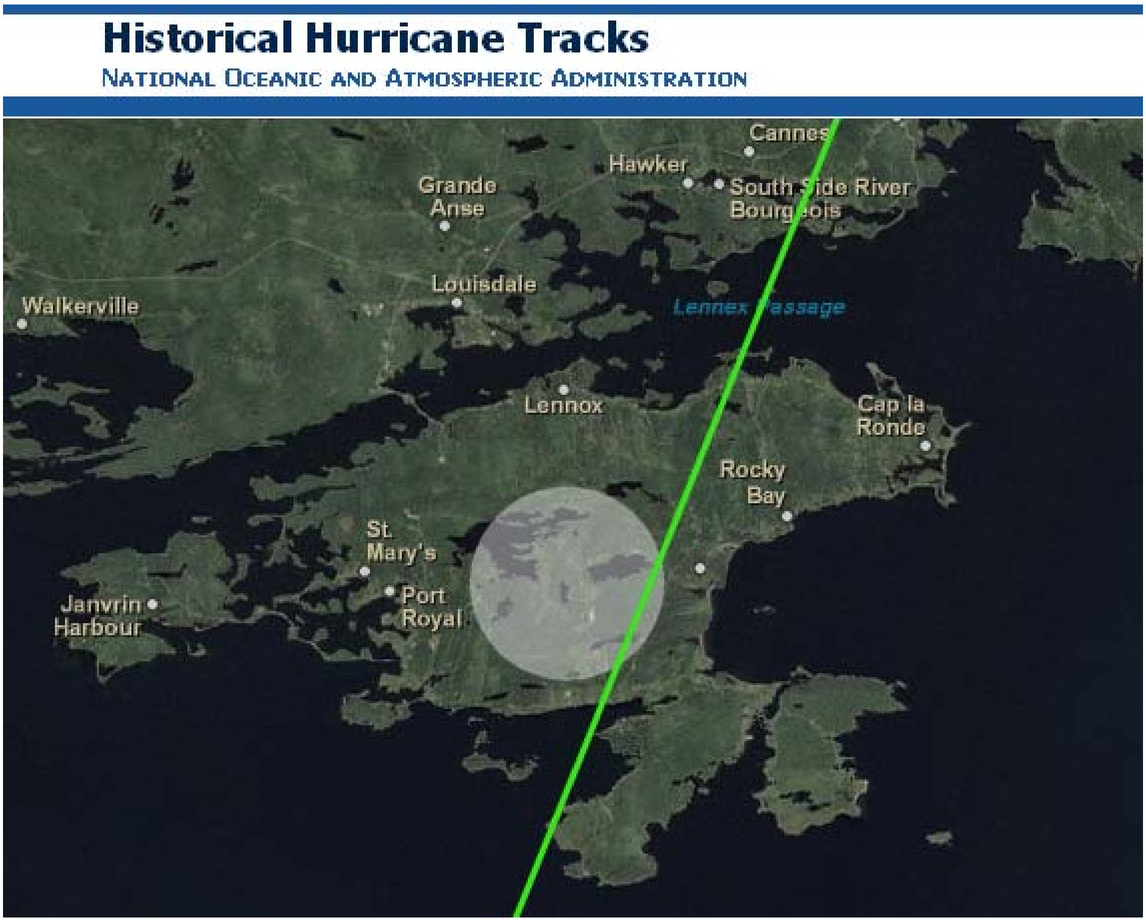

Figure 2.8: Hurricane Barry in July 9, 1995

Source: NOAA (2010)

For finding historical storms from 1975 to 2009 from the NOAA website, all possible historical storms were recognized and then they were matched by the HURDAT database to verify if any storm that may be missed in one of these storm data sources. All storm indicators within the mentioned duration can be extracted from the HURDAT database. This can be done by matching the “Latitude” and “Longitude” columns of the HURDAT database with the community’s coordinates. In cases where a match occurred with the Isle Madame coordinates has not been found, then the closest entry was chosen for recording the storm indicators.

Table 2.4 below presents a summary of Isle Madame’s historical storm profile from 1975 until 2009. The extracted HURDAT file used to identify all 16 historical storms affecting Isle Madame between the mentioned periods, 1975-2009 is found in Appendix G, “HURDAT files of Isle Madame related storms and tracks”. Column “Comment” (Table 2.4) presents the approximate distance of the storm from Isle Madame in Nautical Miles.

No	Storm name	Date	Location	Category	Speed (Kph)	Wind (Kph)	Pressure (MB)	Comment (Nautical Miles)
1	BILL	23Aug 2009	44.4N-62.5W	Hurricane-Category 1	53	120	970	>25,<= 50
2	NOT NAMED	18July 2006	43.7N-60.1W	Tropical Storm	35	65	1007	
3	ALBERTO	16June 2006	44.0N-62.0W	Extratropical Storm	38	100	969	>25,<= 50
4	OPHELIA	18Sept 2005	44.8N-62.6W	Extratropical Storm	42	85	1000	10
5	GUSTV	12Sept 2002	46.5N-59.6W	Hurricane - Category 1	74	140	962	>10, <=25
6	ALLISON	19June 2001	43.5N-61.0W	Extratropical Storm	50	35	1012	
7	SUBTROP	29Oct 2000	44.0N-60.0W	Extratropical Storm	72	95	980	
8	MICHAEL	19Oct 2000	44.0N-58.5W	Hurricane - Category 2	87	160	965	
9	HORTENSE	15Sept 1996	45.5N-61.5W	Hurricane – Category1	31	120	970	10
10	BARRY	9July 1995	44.3N-61.7W	Tropical Storm	40	95	991	10
11	ALLISON	8June 1995	45.2N-61.2W	Extratropical Storm	40	85	989	>10, <=25
12	LILI	15Oct 1990	44.9N-61.0W	Extratropical Storm	70	75	995	>25,<= 50
13	BERTHA	2Aug 1990	44.2N-60.5W	Hurricane-Category 1	35	130	973	>25,<= 50
14	CHRIS	30Aug 1988	46.5N-60.0W	Tropical Depression	68	45	1008	>25,<= 50
15	SUBTROP	20June 1982	44.5N-60.0W	Subtropical Storm	81	110	984	
16	EVELYN	15Oct 1977	45.5N-60.1W	Hurricane-Category 1	59	130	996	>25,<= 50

Table 2.4: Isle Madame’s historical severe storm portfolio (2009-1977)

Source: (NOAA 2010)

2.5.4 Historical storm damages

The sixteen Isle Madame severe storms documented in Table 2.4 are based on the data availability and each storm's indicators including storm wind speed and pressure. The data source for information about historical storms is Environment Canada's Canadian Hurricane Center (Environment Canada 2009) which also provides limited information on the impact reports of those storms affecting Isle Madame. However, it is noted that out of all historical storms in Canada, only a few have an estimated damage cost recorded in the Environment Canada database. In this case of the historical Isle Madame storms, reported damages for these sixteen storms are reported as general damage estimates to the province of Nova Scotia overall and not specifically to Isle Madame. This fact presents a challenge to the modelling efforts for estimating Isle Madame storm impacts including storm damage reporting.

In the case of Isle Madame there is no available data on estimated damage cost for the community. Typically, estimated damages are mostly related to bigger cities or are reported as being for the whole province. Consequently, there is no solid empirical base on which to estimate storm damage for Isle Madame. Accordingly, this research uses the limited province-wide data to establish upper bounds on Isle Madame damage, and the available local Isle Madame information to develop storm damage estimates. Estimated total damage and dynamic storm costs are presented in Chapter 4 and 5.

Anecdotal and other storm damage information about the 16 historical storms in Isle Madame with damage description from the most recent storm to oldest storm in 1977 are listed below in Table 2.5 and are provided by Environment Canada (2009):

Storm name	Date	Damages Reported
BILL	23Aug 2009	• 70 mm rainfall for Nova Scotia. • Spectacular waves that crashed on shore, few branches, twigs and leaves littered roadways throughout the province • Power outages affected a peak of 42,000 customers

		of Nova Scotia Power
NOT NAMED	18July 2006	No significant impacts were reported
ALBERTO	16June 2006	Some trees were damaged and there were local power outages in Nova Scotia
OPHELIA	18Sept 2005	Highest rainfall amounts were recorded in Nova Scotia,
GUSTV	12Sept 2002	• Heavy rain, high winds, and flooding from surge • Broken trees and several car accidents were reported
ALLISON	19June 2001	No report of damage in Canada
SUBTROP	29Oct 2000	• the most damaging storm of the year for Atlantic Canada • It caused extensive coastal flooding and damage in the tens of millions of dollars. • However, for Nova Scotia roads were washed out and fish plant was damaged - estimated cost of damage at the Victoria Co-op Fisheries Ltd. $40,000 **(**HH)
MICHAEL	19Oct 2000	Had impacts mostly in Newfoundland.
HORTENSE	15Sept 1996	• There were many power outages, trees blown down, roofs torn away, and roads damaged • It was estimated that $3 million of damage was reported in Nova Scotia alone. Total property losses approached $5 million
BARRY	9July 1995	• landfall over Nova Scotia with winds of 93 km/h • Large amounts of rain and a few traffic accidents
ALLISON	8June 1995	Rainfall across Nova Scotia between 27 and 64 mm
LILI	15Oct 1990	Rainfall and strong winds in Nova Scotia
BERTHA	2Aug 1990	• heavy rain and high winds caused some damage • High surf along the coast of Nova Scotia resulted in

		several people being washed into the sea (some had injuries ranging from cuts to a sore back no) • Six crewmembers of the cargo ship, Corazon, sailing 560 km south-southwest of Cape Cod were lost • Estimated Cost of Damage: $4.427 million
CHRIS	30Aug 1988	Rainfalls: 47 millimetres in Nova Scotia
SUBTROP	20June 1982	Wind speed of 60 knots, pressure of 998 millibars
EVELYN	15Oct 1977	Provincial rainfalls: 24.5 millimetres in Nova Scotia

Table 2.5: Damages reported of Isle Madame's historical storms (1975-2009)
Source: Environment Canada (2009)

2.5.5 Isle Madame Community Profile Data

Isle Madame data are studied in terms of the four communities' descriptive pillars, namely: (1) Environmental, (2) Economic, (3) Social and (4) Cultural. These four community pillars are defined for the Richmond County Integrated Community Sustainability Plan (ICSP) and represent the key community dimensions by which the community defines itself. As noted in the ICSP document for Richmond County (of which Isle Madame is part):

> "An Integrated Community Sustainability Plan is a long term plan, developed in consultation with community members, which provides direction for the community to realize sustainability objectives it has for the environmental, economic, social, and cultural dimensions of its identity" (Richmond ICSP, 2009).

These four pillars are used in this research to define the status of Isle Madame as well as the impacts of storm damage.

As mentioned above, this research is part of C-Change ICURA Project. The C-Change project itself is part of the International Community-University Research Alliance (ICURA) project, "Managing Adaptation to Environmental Change in Coastal Communities: Canada and the Caribbean". One of the significant objectives of C-Change is to create a framework that all studies for the project can follow. The C-Change community profile data template is this framework and is adopted in this research. The full detailed community profile data template is found in Appendix A, “Community Data Profile – Template”.

Table 2.6 presents the main spatial data sources that are used in this research. The most important dataset used in this research is the DataLocator spatial dataset provided by the Development Isle Madame Association (DIMA) for use in this analysis (GeoNova, 2006). The data sources of Table 2.6 are examined in further detail in Chapter 3 of this thesis.

GeoBase data geodetic datum and projection are measured in North American Datum of 1983. In the case of GeoNova data, “The Coordinate Transformation Web Service supports coordinate transformation among the following reference frames: North American Datum 1983 Canada Spatial Reference System (NAD83CSRS), North American Datum 1983 Original (NAD83 Original), North American Datum 1927 (NAD27), and Average Terrestrial System 1977 (ATS77)” (GeoNova, 2006).

Spatial data source	Type of data	Format
Statistics Canada (2007)	Census data used in Social Pillar, Economic Pillar	Shape file
GeoNova (2006)	Most of the data in Environmental, Economic Pillars and some data in Cultural and Social Pillars	Shape file
DMTI (2009)	Industrial by Type used in Economic Pillar	Shape file
GeoBase (2010)	Isle Madame’s Elevation map	Shape file

Table 2.6: Isle Madame spatial data sources

2.6 Summary of literature review

This section summarizes the literature reviewed for this thesis with a focus on the case of Isle Madame. From the literature reviewed, it is noted that globally, coastal communities including Isle Madame are vulnerable to storm surge and sea level rise. The "common methodology" of community vulnerabilities of Shaw et al (2001), "the physical and socioeconomic vulnerabilities" of Dolan and Walker (2004), and the community breakdown of the C-Change project are used in this research to develop and organize the elements specific to Community Profile using the available data. This analysis assists in identifying Isle Madame areas under threat from storm surge and sea level rise.

From the literature reviewed on geographic information systems, GIS is recognized as a useful tool in modeling climate change especially for well-defined and closed spatial areas such as the island community of Isle Madame. ESRI's ArcMap software is chosen for this research because of its availability at the University of Ottawa and its general ease of use. With the help of ArcMap, a sea level rise tool for Isle Madame is developed as part of this research to determine spatially those vulnerable areas to storm surges and sea level rise.

The literature reviewed on System Dynamics, provides a clear and useful approach for the interaction in this research between the spatial elements of the Isle Madame spatial system and the dynamic system behaviour of storm impacts (Simonovic and Ahmad 2004). There are different ways of integrating GIS with SD. However, the main issue from literature reviewed is the "curse of dimensionality" that arises from large state spaces characterized by large numbers of spatial and temporal units that require functional linkages. As the integration level is more advanced, more linkages are demanded and the issue of dimensionality and parameterization of functional forms in space and time become more important. More spatial indicators and multiple time steps make the dynamic system more complex and difficult to develop and interpret.

Consequently, for the case of Isle Madame, with its different spatial areas (Dissemination Areas, DA) using the Simonovic and Ahmad (2004) SSD methodology is overly complex and data greedy. Therefore, from all the pros and cons of the different integration levels, the low level of integration (Van Duersen 2000, Table 2.2 above) is applied in this research with a very simple one way connection from the spatial analysis of the GIS to the temporal consideration of storm impacts using SD. In this way, data from the GIS will send its information to an Excel spreadsheet file manually, and after some data transformation, the transformed data results are imported from Excel to the temporal STELLA SD model, as specified in Chapter 3 below.

With regard to Isle Madame storm modelling, from the HURDAT file there are sixteen historical storms for Isle Madame from 1975 to 2009. However, the historical storm damage information collected from Environment Canada (2009) shows a nearly complete lack of estimated damages specific to Isle Madame. From all literature reviewed about historical storm data, modelled Storm Scenarios and storm damage estimates need to be developed specifically for Isle Madame in this research. Based on modelled Storm Scenarios, this research estimates the total monetary cost of damages for Isle Madame based on the spatial and sea level rise data. As well, a portion of these estimated cost of damages (immediate damages) are modelled as inputs to the SD model to estimate damage costs over a period of time of modelled storm impacts.

3 Research Methodology

This research studies Isle Madame coastal vulnerability in terms of storm surge and sea level rise. For this purpose, the spatial and temporal aspects of the environmental, social, economic and cultural dimensions of Isle Madame are considered. To this end, the research methodology sets out to determine: (i) a spatial mapping model of Isle Madame developed to model the dimensions as layered maps, and (ii) a system dynamics model developed to estimate temporal storm impacts through a dynamic model of the system's estimated feedbacks and interconnections as a whole, toward modelling Isle Madame damage from modelled Storm Scenarios. Presentation of the research methodology is achieved through the specification of: (1) the spatial model data for describing the community of Isle Madame; (2) the Storm Scenario modelling approach; (3) assets and storm-based assets-at-risk evaluation for Isle Madame; and (4) the system dynamics model for direct and indirect temporal damage impacts. These elements of the research methodology are described in detail in the sections below.

3.1 Model elements

The research model has four major elements. Each is presented in: sub-sections of this chapter as follows:

(3.2) GIS data for the Community Profile;

(3.3) Geographical Information System, Storm Scenarios Modelling, and Total & At Risk Assets Estimation

(3.4) System Dynamics Modelling for Storm Damage

Figure 3.1 illustrates the major methodological model elements as noted above.

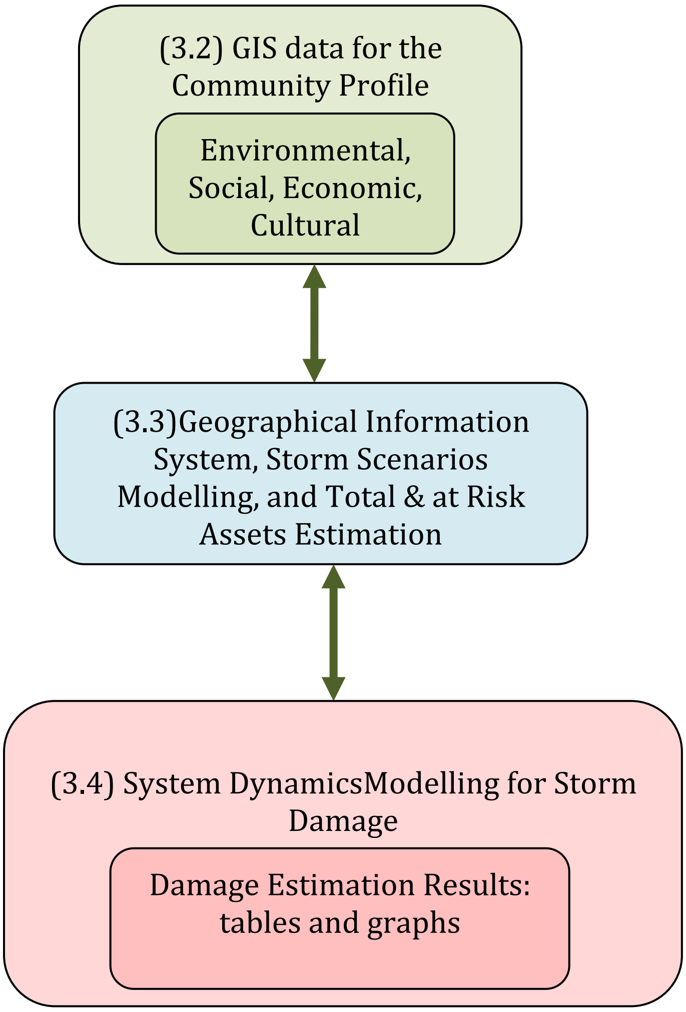

Figure 3.1: Research Methodology Model Elements

3.2 GIS data for the Community Profile

The major resources for the geospatial and socioeconomic data are taken from the following sources: (i) Statistics Canada (2007), 2006 Census Data, (ii) Desktop Mapping Technologies Inc. DMTI (2009); (iii) the GeoNova (2006); and GeoBase (2010). These sources are described in further detail below:

- **Statistics Canada Data**

  Data from Statistics Canada (2007) census are freely available data to the public. Data that are used in this study from Statistics Canada are the census Community Profiles for the 2006 census. Data that are downloaded for this study from this source are presented below in Table 3.1 for the Community Profile pillars:

	Downloaded data from Statistics Canada (2007)				
Cultural Pillar	Language	-	-	-	-
Social Pillar	Transportation or Commuting ways	Employment Rate	Education Statistics	Occupation by Type	Population Statistics (2001-2006)

Table 3.1: Statistics Canada (2007) Data for the Isle Madame Community Profile pillars

- **DMTI**

  Desktop Mapping Technologies Inc (DMTI 2009) includes data about the industry by type for Nova Scotia using the Standard Industrial Code (SIC). These data are collected with the authorization of the University of Ottawa which has access permission to use the DMTI data. All data related to the Industry by Type from the DMTI database are used in the Economic Pillar of the Community Profile.

- **GeoNova (Data Locator)**

  The most important source of data for this study is the DataLocator spatial dataset from the GeoNova Geographic Gateway to Nova Scotia website (GeoNova 2006). Environmental and Economic Pillars data as well as some Cultural and Social Pillar indicators are downloaded in GIS "shape" file formats. This project through the Telfer School of Management of the University of Ottawa was kindly given access to these data by the Development Isle Madame Association, DIMA (2009), the data proprietors, to access and download the data for use in this study. With the exception of the data mentioned above which are downloaded from DMTI and Statistics Canada, the rest of the data are downloaded from Data Locator of GeoNova (2006). The Data Locator application provides data including 1:10,000, 1:50,000, and 1:250,000 mapsheets. In case of Isle Madame, the data access to the 1:10,000 scale have been collected and are presented in this thesis.

- **GeoBase**

  Only elevation data is collected from GeoBase. GeoBase (2010) data are compiled from 1:50,000 scale topographic maps using the North American Datum of 1983 standard consistent with the GeoNova (DataLocator) dataset.

The data collected enable the compilation of a Community Profile for Isle Madame as a snapshot of its status. The major dimensions of the Community Profile for Isle Madame are according to the four pillars: (1) Environmental, (2) Economic, (3) Social, and (4) Cultural. Table 3.2 presents the main items of each pillar. An overview of these four pillars is explained below. The general expression of the Community Profile is provided in Appendix A by major dimension, categories, and indicator items.

Environmental Pillar	Economic Pillar	Social Pillar	Cultural Pillar
Topography	Industry by Type	Population Statistics	Governance Systems
Hydrology	Industry Revenues	Education	Community Dynamics
Coastal Geomorphology	Built Environment	Health Status	Community Groupings
Habitat and Species	Public Works	Occupation by Type	Communications Resources
Land Cover	Real-Estate Values	Employment and Earnings	Language
Land Use	-	-	Places of Significance
Marine Use	-	-	Cultural Events
Climate	-	-	-

Table 3.2: Major Items by Pillar for the Isle Madame Community Profile (Appendix A)

Elements in the pillars are represented table in ArcGIS as a layer in a shape file format with numbers of points or polylines for each element in Isle Madame. All the available data including all items and elements (layers) for Isle Madame are categorized in Appendix B, “Isle Madame Community profile/list of ArcGIS layers”.

3.2.1 Environmental (Natural Capital) Pillar Data

The environmental segment of the Community Profile dataset is the most tangible and obvious aspect to be physically impacted by storm surge and sea level rise.

Environmental data items are defined as: Topography, Hydrology, Coastal Geomorphology, Habitat and Species, Land Cover, Land Use, Marine Use, Habitat and Species, and Climate (Table 3.2, column 1). Individual items of this group contain more specific information and each element is presented as a layer in ArcGIS. For details of the data contents refer to Appendix B.

Under the Topography item, elevation data are the most vital to this research in terms of providing good estimates of the flood plain. As mentioned before, Isle Madame's elevation is an important element in this study.

Ideally, LiDAR elevation should be used for modeling storm surge and sea level rise in ArcGIS. According to Webster and Stiff (2008):

> "LiDAR (Light Detection and Ranging) has been used to construct a high resolution digital elevation model (DEM) and build flood inundation maps for given water levels from storm surges and longer term sea-level rise. This remote sensing technique involves an aircraft equipped with a laser rangefinder that shoots pulses of light towards the earth, and by measuring the two-way travel time, determines the distance or range from the aircraft to the earth's surface. By knowing the precise location of the aircraft with GPS and the distance to the earth's surface, land elevations can be determined. LiDAR measures the earth's surface every 1-2 m on the ground with vertical accuracies within ±0.15 m". (Webster and Stiff 2008, pp.130)

However, in the case of Isle Madame, the only freely available elevation data is not LiDAR. Figure 3.2 presents the Isle Madame's elevation layer which is captured free from the Geobase public website with a scale of 1:50,000 and is the best available elevation data for Isle Madame at the current time. While the lack of detail in the available elevation data for Isle Madame presents a challenge for this research, the development of the methodology and the application of the work to Isle Madame provide a clear applied analysis of the modelling and estimation of storm impacts for the community. This unique contribution of this research – given that storm damage estimates have not been considered previously – seeks to raise the awareness of the extent and importance of more frequent and severe storms, and enhance the capability through knowledge acquisition of the community to be prepared. The ultimate availability of improved data (e.g., LiDAR) in any case will serve to improve the overall estimates within the defined methods developed in this thesis.

As can be seen in Figure 3.2, Isle Madame elevation is characterized by coastlines that are generally less than 2 meters above sea level and therefore potentially vulnerable to storm surges and sea level rise.

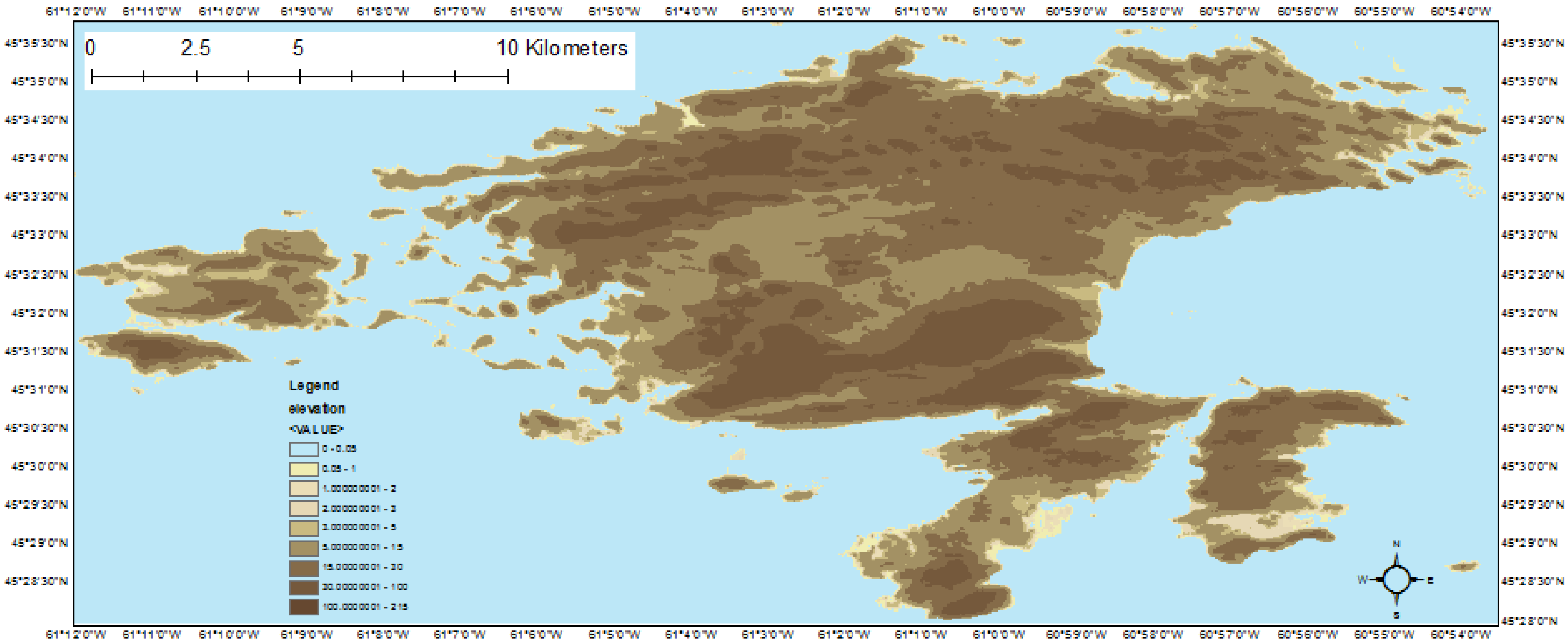

Figure 3.2 Isle Madame's elevation data

Source: GeoBase (2010) and GeoNova (2006)

The environmental pillar also consists of several items represented spatially. Each environmental item has layers which are given in Table 3.3. Item details are found in Appendix B. Figure 3.3 illustrates the Hydrology, Land Use & Land Cover items of the environmental pillar with all related layers as listed in Table 3.3.

Figure 3.3: Isle Madame's Hydrology, Land Use & Land Cover item

Source: Google Earth (2011) and GeoNova (2006)

Table 3.3 presents the environmental layers in the Isle Madame databases and the number of available points or polylines (approximate length and area) in each layer.

Environmental Item	Element (layer)	Number of Points/polylines	Approximate Length /Area
Hydrology, Land Use & Land Cover	Rivers	581	700 km
	Lakes	304	22 sq km
	Break water	3	5 km
	Swamp	661	15 sq km
	Ditch	2	-
	Provincial park, Park, Tree area	1382	90 sq km
	Berries point	8	-
	Cliff line	39	14.3 km
	Culvert	122	-
	Cut line	51	-
	Dump line	5	-
Marine Use	Seal haulout (Habitat)	19	-
	Beaches (Habitat)	13	-
Habitat and Species	Herring (Fish)	24	-
	mackerel (Fish)	25	-
	perch (Fish)	34	-
	Pollock (Fish)	23	-
	flounder (Fish)	24	-
	dogfish (Fish)	12	-
	cod (Fish)	15	-
	Rockweed (Habitat)	301	40.5 km
	Kelp (Habitat)	23	3.8 km
	Squid (Fish)	11	-
	Lobster bottom (Habitat)	16	59 Sq km
	Recreational Clam beds (Habitat)	2	2.3 Sq km
	Shellfish closure (Habitat)	7	14 Sq km

	Scallop bottom (Habitat)	10	7.1 Sq km
	Mussels (Fish)	3	0.2 Sq km
	Sea urchins (Habitat)	10	1.4 Sq km
	EelRichmondCoStdFields (Fish)	67	-
	gaspereau (Fish)	34	-
	salmon (Fish)	18	-
	smelt (Fish)	56	-
	capelin (Fish)	6	-
	trout (Fish)	41	-
	tern nesting (Bird)	2	-
	osprey nesting (Bird)	2	-
	eider nesting (Bird)	17	-
	cormorant nesting (Bird)	3	-
	eagle nesting (Bird)	1	-
	gull nesting (Bird)	1	-
	Heron nesting (Bird)	1	-

Table 3.3: Isle Madame Environmental pillar items
Source: GeoNova (2006)

The Isle Madame total area is approximately 176 sq km. By drawing polygons in ArcMap, approximately 90 sq km of Isle Madame are designated in the Locator dataset as “Tree Area” and “Parks” items. By using the same area estimation method, the area of lakes and swamps are approximately 22 sq km and 15 sq km, respectively. Similarly, the estimate of the total lengths of roads on Isle Madame is approximately 435 km.

The total area of buildings is estimated at approximately 8 sq km (estimated by the total number of buildings (2889), multiplied by the average area of a building in Isle Madame (estimated at 0.003 sq km).

Taking all these land cover elements into account, the estimated detail of total Hydrology, Land Use & Land Cover distribution in Isle Madame is illustrated in Figure 3.4 below.

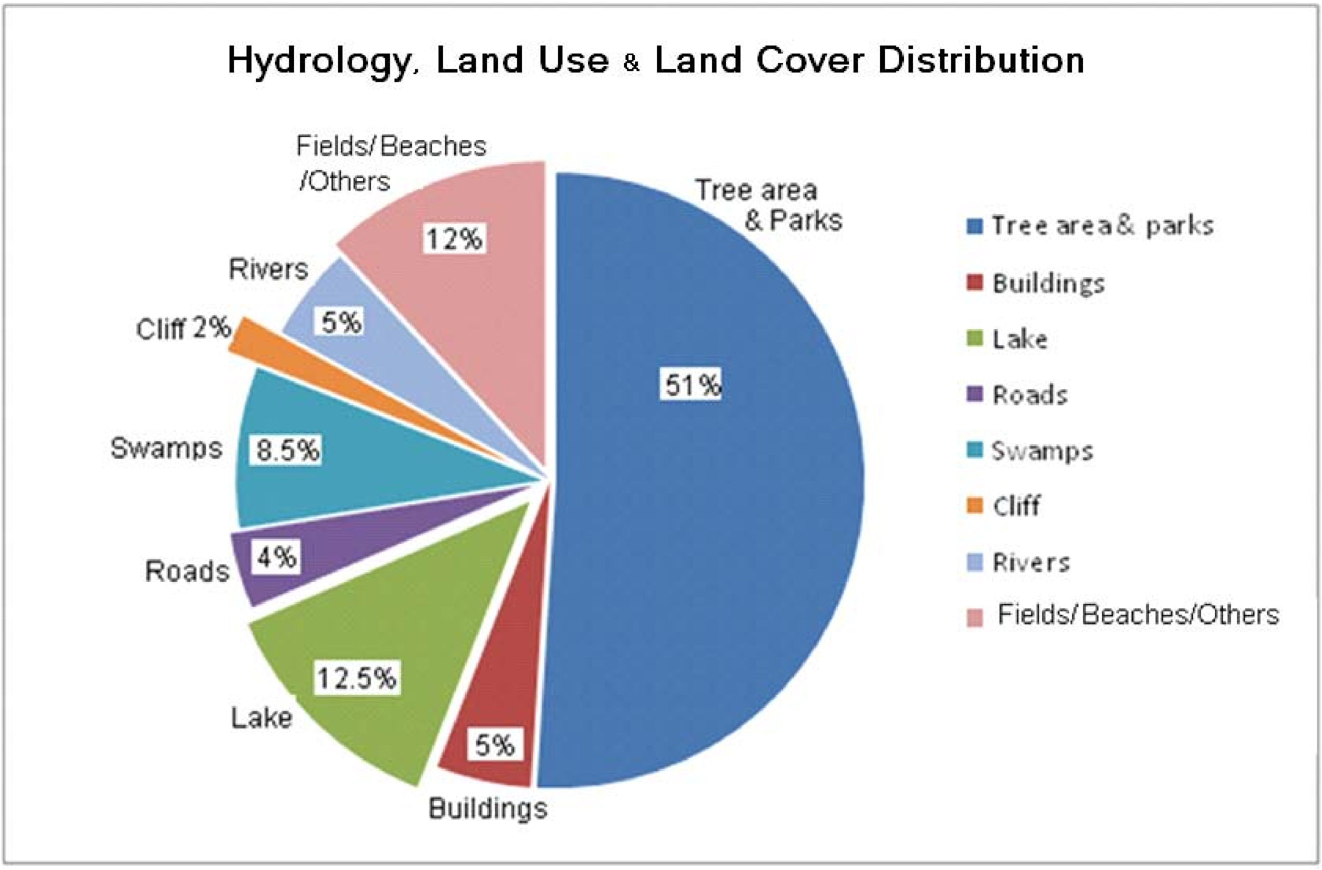

Figure 3.4: Areal Distribution of "Hydrology, Land Use & Land Cover" in Isle Madame
Source: GeoNova (2006)

The Environmental Pillar is also comprised of "Habitat and Species", "Habitat" and "Marine Use". These items have different spatially defined layers for the items: Habitat, Fish, and Birds. Figure 3.5 illustrates all these layers in detail for the Isle Madame map.

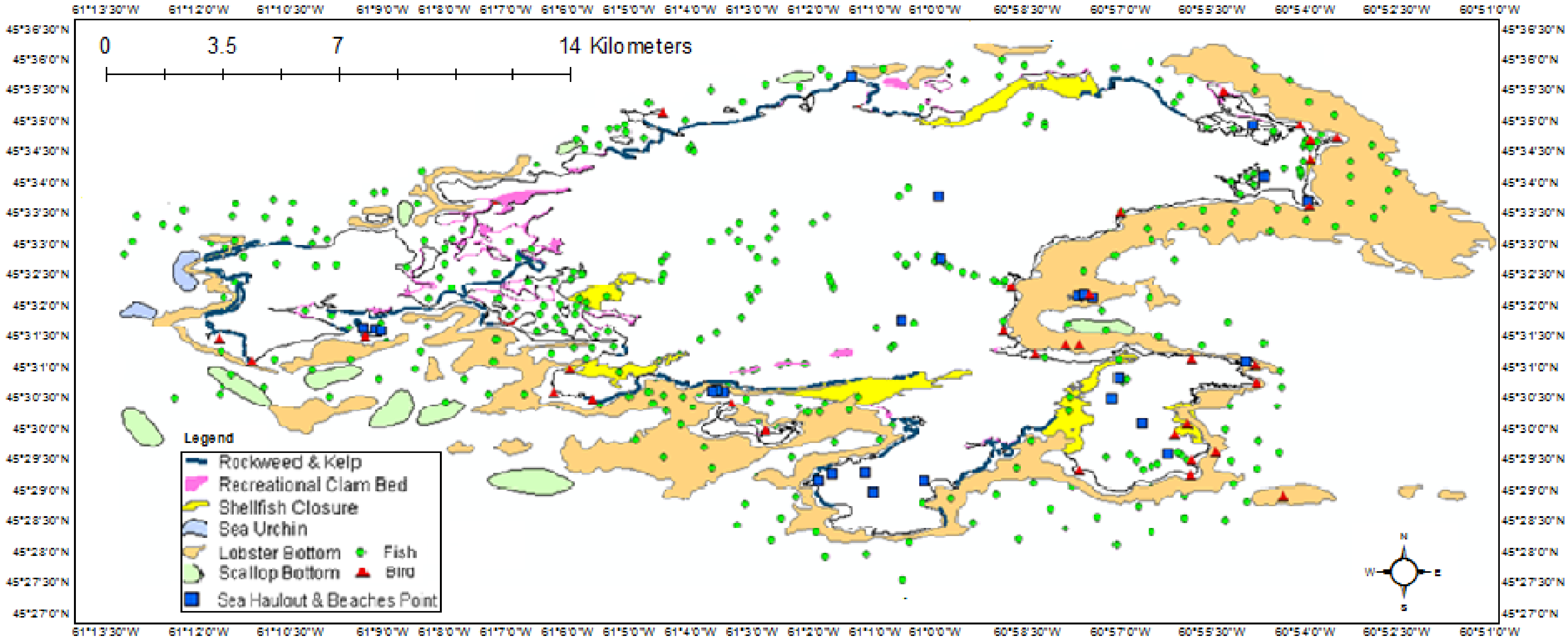

Figure 3.5: Isle Madame's Habitat and Species and Marine Use items with layers

Source: GeoNova (2006)

3.2.2 Economic (Commercial) Pillar

The second pillar of the Community Profile is the Economic or Commercial Pillar (all details of this pillar are found in Appendix A, in general terms, and in Appendix B, specifically for Isle Madame. Under the Economic Pillar are items: (1) Industry by Type, (2) Built Environment (including Real Estate values – see Appendix A), and (3) Public Works. These data are available from the 2006 census, Statistics Canada (2006) and from the GeoNova (2006). Items in the Economic Pillar with detailed layers are presented in Table 3.4. Under the "Built Environment" item there are a number of elements (layers) identified for Isle Madame including; Residential & Non-Industrial Buildings, Fur Farm, Salvage yard, Lobster pounds, Fish processing plants, Herring-mackerel net, Aquaculture lease area (as of April 1998), Plants (factory), Pit, Campground, Tower (microwave), Pool, Restaurant, Accommodation, and Ship wrecks. Figure 3.6 shows different type of Buildings with their attached lands under the "Built Environment" item of the Economic Pillar.

"Public Works" elements include: Sewage treatment plant, Post Office, Wharf, Fire station, Light house stations, Wharves rich, Police station, Roads (local roads, collector highways, wood road, Streets, abandoned road, cart track and loose surface road), Bridges, Culverts, Airstrip, and Parking areas. Each of these elements is a layer in the ArcMap GIS. These elements are shown as points or polylines in ArcMap. The data associated with the points and polylines can be found in its properties table in ArcMap. Figure 3.7 shows layers under the "Public Works" item of the Economic Pillar. There are in total 52 wharves under the "Wharf" layer, and also there is a layer called "Wharves Rich" which includes Breakwaters, Government Wharves, Private Wharves, and Private Service Wharves, Marine, and Small Craft Harbours. Some of the mentioned elements of "Wharves Rich" layer have overlap with "Wharf" layer and "Breakwater" layer that would not be double counted in this research. Therefore, except the redundant element in "Wharves Rich" layer, there are two more breakwaters, one Government Wharf, five Private Service Wharves, and ten Private Wharves which should be considered as part of Isle Madame total assets.

As can be seen in Figure 3.6, the buildings layer in Isle Madame shows how buildings are primarily located very near the waterfront and vulnerable to storm surges and sea level rise.

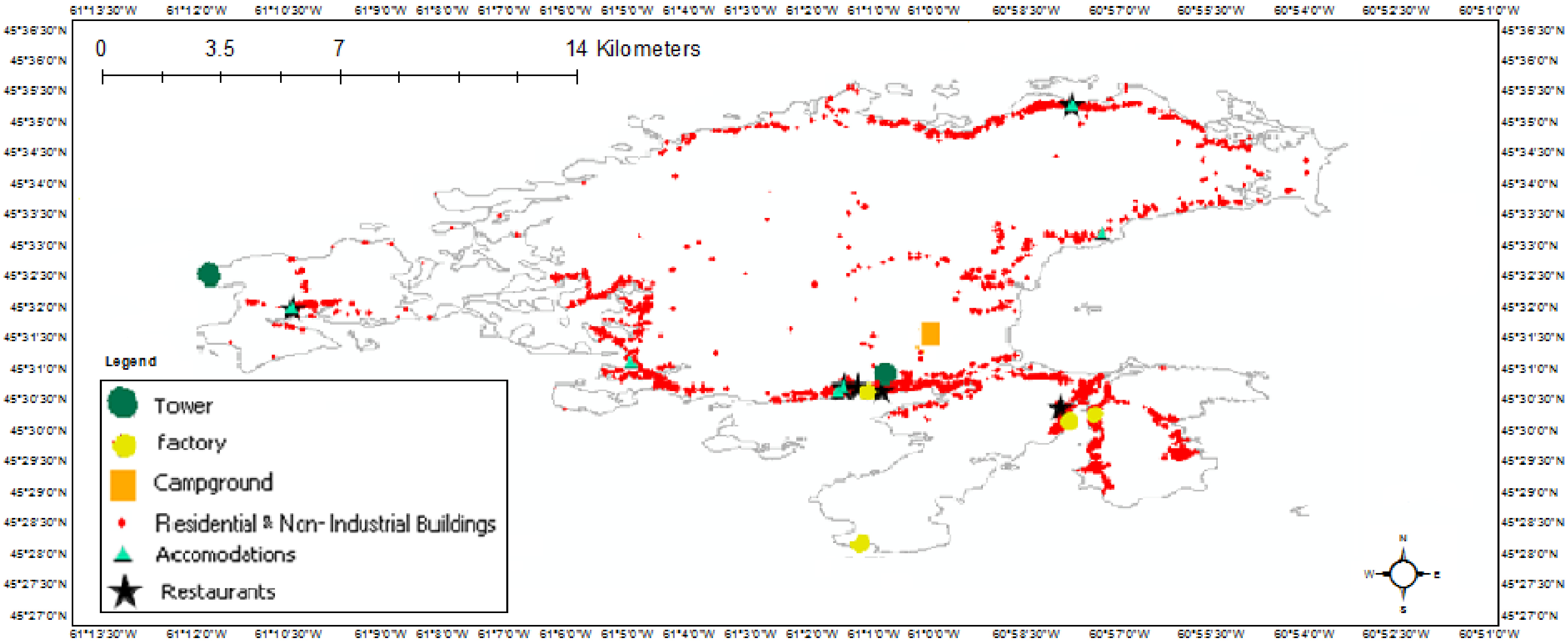

Figure 3.6: Different type of Buildings with their lands in Built Environment Item overlap with Coastline layer

Source: GeoNova (2006)

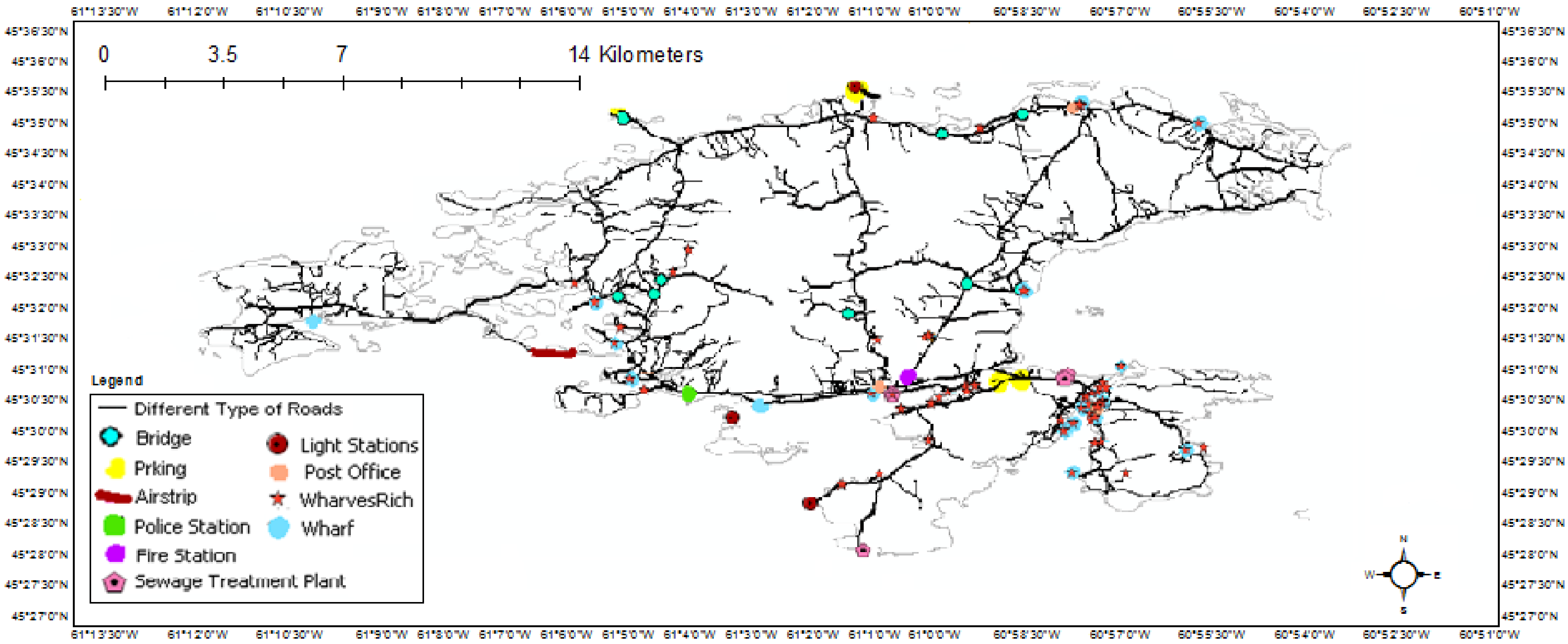

Figure 3.7: Layers of Public Work item of Economic Pillar

Source: GeoNova (2006)

The Economic layers in the Isle Madame Data Locator database are represented by points or polylines. The detail about the number of points or polylines for each layer in the Data Locator database is found in Table 3.4.

Economic Item	Element (layer)	No. of points/polylines	Approximate Length/Area
Built Environment	Residential & Non-Industrial Buildings	2889	-
	Fur Farm	4	-
	Salvage yard	1	-
	Lobster pounds	3	-
	Fish processing plants	4	-
	Herring-mackerel net	12	-
	Aquaculture lease area as April 1998	12	-
	Plants (factory)	4	-
	Pit	61	-
	Tower microwave	10	-
	Pool	2	-
	Campground	3	-
	Restaurant	6	-
	Accommodation	7	-
	Ship wreck	9	-
Public works	Sewage treatment plant	5	-
	Post Office	24	-
	Wharf	52	15m each
	Fire Station	3	-
	Light house stations	3	-
	Wharves rich	60	15m each
	Police Station	9	-
	Local Road	494	130.3 km
	Collector highway	131	33.6 km
	Bridge	12	0.3 km
	wood road	70	20.1 km
	loose surface road	13	5.1 km
	Streets	35	4.8 km
	abandoned road	51	14 km
	cart track	691	214 km
	Culvert	122	8 meters each
	Airstrip	5	1.3 km
	Parking area	18	0.02 sq km

Table 3.4: Isle Madame Economic pillar layers

Source: GeoNova (2006)

The Economic pillar also includes "Industry by Type" data. This information is contained in the DMTI Enhanced Points of Interest (EPOI) dataset (DMTI 2009). These data are recognized by the Standard Industrial Code (SIC) major groups and divisions. The detailed SIC major groups are shown in Appendix C. "Economic Status Quo – Points in Standard Industrial Classification Major Groups". Table 3.5 illustrates the major groups and divisions in SIC and the number of points of different types of industries in Isle Madame.

	Element (layer)	**Percentage**	**Number of points/polylines**
Industry by type Division	A: "Agriculture, Forestry and Fishing"	0.78%	1
	C: "Construction"	3.9%	5
	D: "Manufacturing"	7.8%	10
	E: "Transportation, Communications, Electric, Gas, and Sanitary Services"	9.4%	12
	F: "Wholesale Trade"	4.7%	6
	G: "Retail Trade"	25.8%	33
	H: "Finance, Insurance and Real Estate"	8.6%	11
	I: "Health care and social services educational services"	37.5%	48
	J: "Public Administration"	1.5%	2
	Totals	**100 %**	**128**

Table 3.5: Isle Madame's industry by type based on the SIC division codes
Source: DMTI (2009)

Figure 3.8 illustrates the percentage of economic points in each SIC division for Isle Madame as in is showed Table 3.5. The economic points are the detailed SIC major groups and divisions for Isle Madame as presented in Appendix D, "Detailed Economic Status Quo – Points in Standard Industrial Classification Major Groups and Division – for the Case of Isle Madame". This appendix presents each organization name, address and SICS information for all 128 points and related industries on Isle Madame.

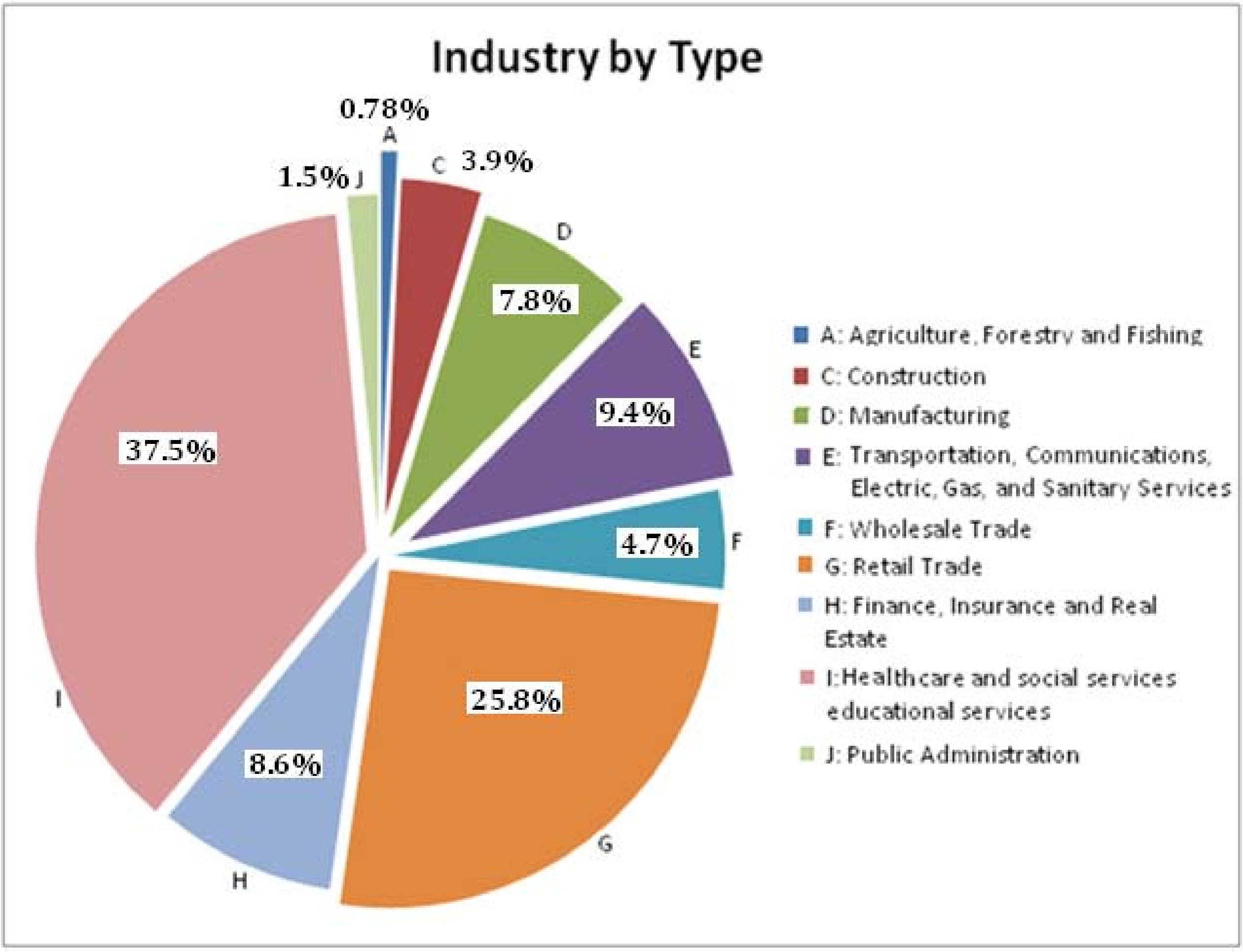

Figure 3.8: Percentage of Industry by Type in the Economic Pillar by SIC division for Isle Madame

Source: DMTI (2009)

Figure 3.9 shows the industry by type points by location on Isle Madame. Points denote different types of industry in Isle Madame as per the SIC divisions A through J. The total number of industries by type is 128 according to GeoNova (2006); however, in Figure 3.9 only 44 of them are identified (to simplify the spatial representation on the map).

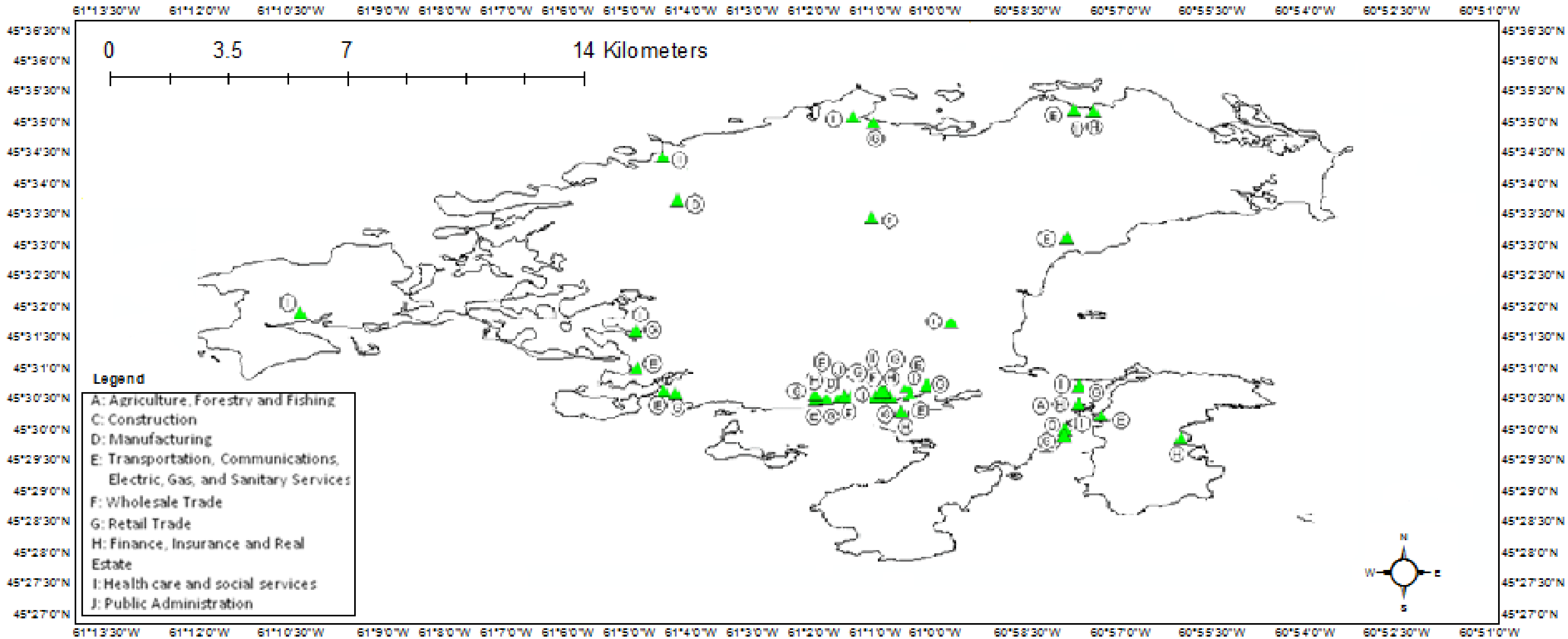

Figure 3.9: Isle Madame's industry by type layer (selected sample)

Source: GeoNova (2006)

3.2.3 Social (Human Capital) Pillar

Social data for Isle Madame are available from Statistics Canada (2007) through the 2006 census. These data are mapped using the dissemination areas, DAs. The Social data items are: Population statistics, Education, Health Status, Occupations by type, and Income.

For mapping these data, Isle Madame's DAs are imported as a base map into ArcGIS. Each DA is assigned property from the census and each of the items, and their elements are mapped as overlapping layers in ArcMap (Statistics Canada 2007). DAs generally have populations of 400 to 900 persons. Figure 3.10 illustrates all six Isle Madame dissemination areas.

Isle Madame's dissemination areas are divided to the six separate areas as can be seen in Figure 3.10. Each of these DAs refers to a code in the 2006 Census database (Statistics Canada 2007) which is noted in Table 3.6.

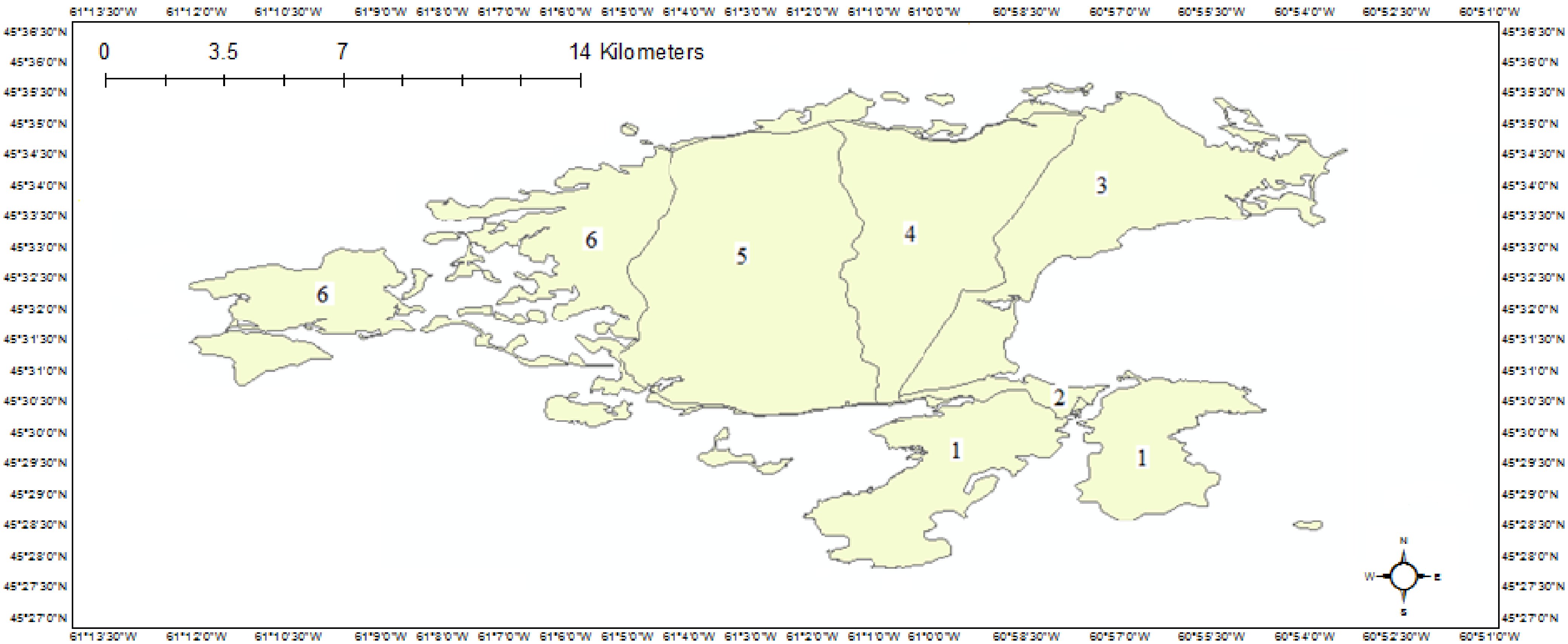

Figure 3.10: Isle Madame's Dissemination Area (DA) map

Source: Statistics Canada (2007)

Dissemination Area	Census Code	Area Description
1	12160010031	Petit De Grat and part of Boudreauville and Cape Auguet
2	12160010032	The Stretch, North of Boudreauville
3	12160010033	Pondville, Poirierville, Rocky Bay, and d'Escousse
4	12160010030	Grandique Road, Lochside and Poulamon
5	12160010029	West Arichat and Martinique
6	12160010028	Saint Marys and Janvrins Island

Table 3.6: Description of Isle Madame's DAs

Source: Statistics Canada (2007)

Each of the four social layers' measures is listed in Table 3.7 which represents graphically Isle Madame DA social statistics.

Social Item	**Layer**	**DA 1**	**DA 2**	**DA 3**	**DA 4**	**DA 5**	**DA 6**	**Total Measures**
Population Statistics	Population less than 14 years of age	115	115	45	80	75	55	485
	Population 15 – 59 years of age	550	385	240	275	305	310	2065
	Population over 60 years of age	275	135	105	110	155	130	910
	Population 2006	945	625	411	468	527	479	3455
Employment Statistics	Pop. In Labour Force	460	290	225	235	235	215	1660
	In Labour Force-Employed	370	270	205	200	210	185	1440
	In Labour Force-Unemployed	90	20	20	35	20	35	220
	Total Number of residents who work (at home, in census division, outside census division)	370	275	210	200	210	185	1450
	Median	$34,970	$53,328	$52,587	$46,062	$49,703	$36,223	Median of

	household income$ (per year)							all DAs= $44,383
	Total number of occupied dwellings	385	235	185	190	195	190	1380
Transportation or Commuting	Car, truck, van, as driver	295	205	155	175	170	135	1135
	Car, truck, van, as passenger	40	45	10	20	15	30	160
	Public transit	10	0	0	0	0	0	10
	Walked	15	15	10	0	20	10	70
Occupation by Type	Management occupations	15	30	10	15	10	0	80
	Business, Finance, or Administration	40	30	50	40	55	45	260
	Natural/Applied Science	15	10	0	25	10	0	60
	Health	25	40	0	0	0	10	75
	Social science, education, government service and religion	10	40	10	15	10	0	85
	Art, culture, recreation and sport	15	0	0	0	0	0	15
	Sales and Services	65	35	45	40	50	45	280
	Trades	115	45	75	50	70	60	415
	Primary Industry	25	0	15	0	10	10	60
	Processing, Manufacturing, or utilities	100	35	10	35	25	25	230
Health	Hospital	-	-	-	-	1	-	1
	Sport field	1	2	1	1	1	-	6
	Senior Citizen Home	-	1	1	-	1	-	3
	Shooting Range	-	-	-	-	1	-	1
	Hiking trail	1	-	-	-	-	-	1
Education Statistics	School	1	1	-	-	1	-	3
	No certificate or degree	395	125	140	150	115	170	1095
	High school certificate or equivalent	130	50	40	60	40	55	375

	College or other non-university certificate or diploma	125	70	70	70	65	70	470
	University, diploma or degree	40	115	80	50	65	45	395
	University certificate or diploma below bachelor level	15	50	20	10	10	25	130
	Bachelor's degree	10	25	20	20	20	25	120
	University certificate or diploma above bachelor level	0	20	30	20	10	0	80
	Master's degree	0	10	20	0	10	0	40

Table 3.7: Measures of Social Layers for Isle Madame's Dissemination Areas (DAs)

Source: Statistics Canada (2007)

Figure 3.11 illustrates the mapable Social layers.

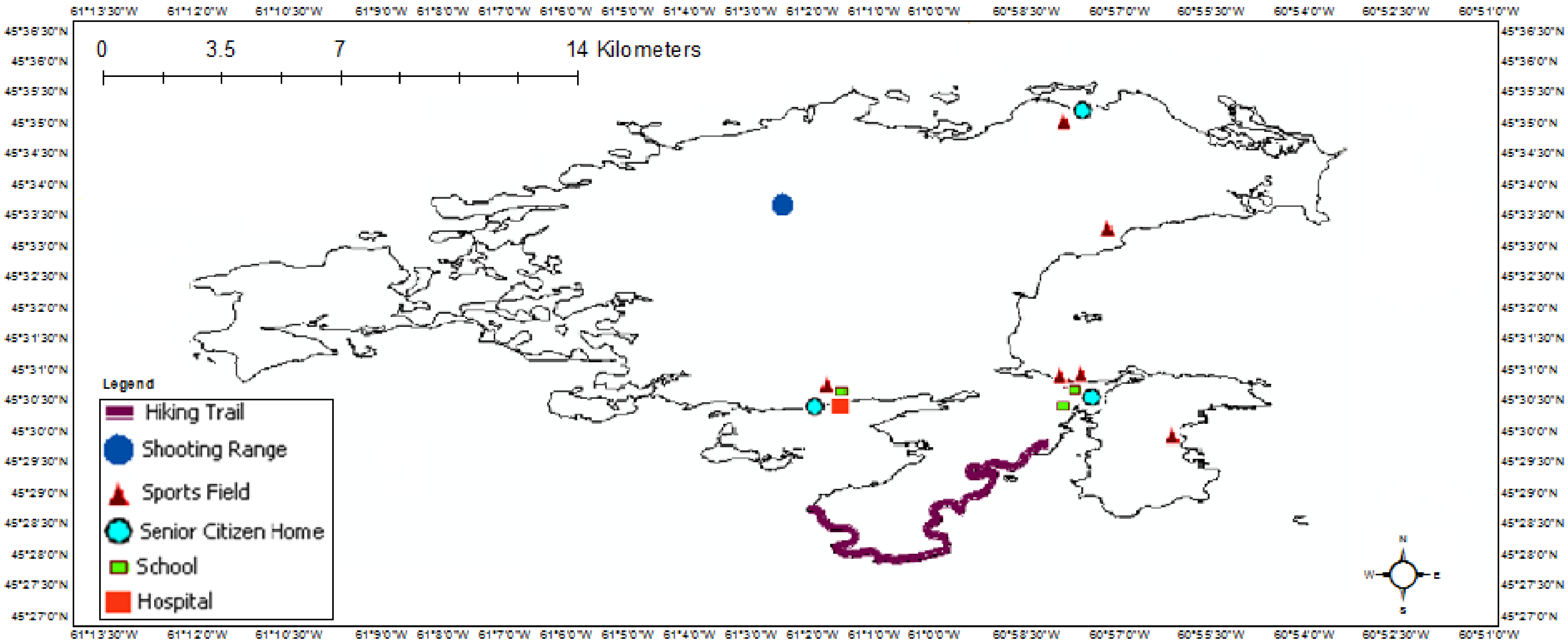

Figure 3.11: Isle Madame's Social layers

Source: GeoNova (2006)

3.2.4 Cultural Capital/Cultural Pillar

The last community profile pillar is the Cultural Pillar. The Isle Madame cultural items include: community dynamics, language, and cultural areas of significance, e.g., museums, and historical sites. Data sources for the cultural pillar are Statistics Canada (2007) 2006 census data, and the GeoNova (2006). Cultural layers under community dynamics and areas of significance are presented as points or polylines on the map. Also, layers for language are presented by DAs.

The cultural pillar of Figure 3.12 presents “Areas of Significance” items in Isle Madame.

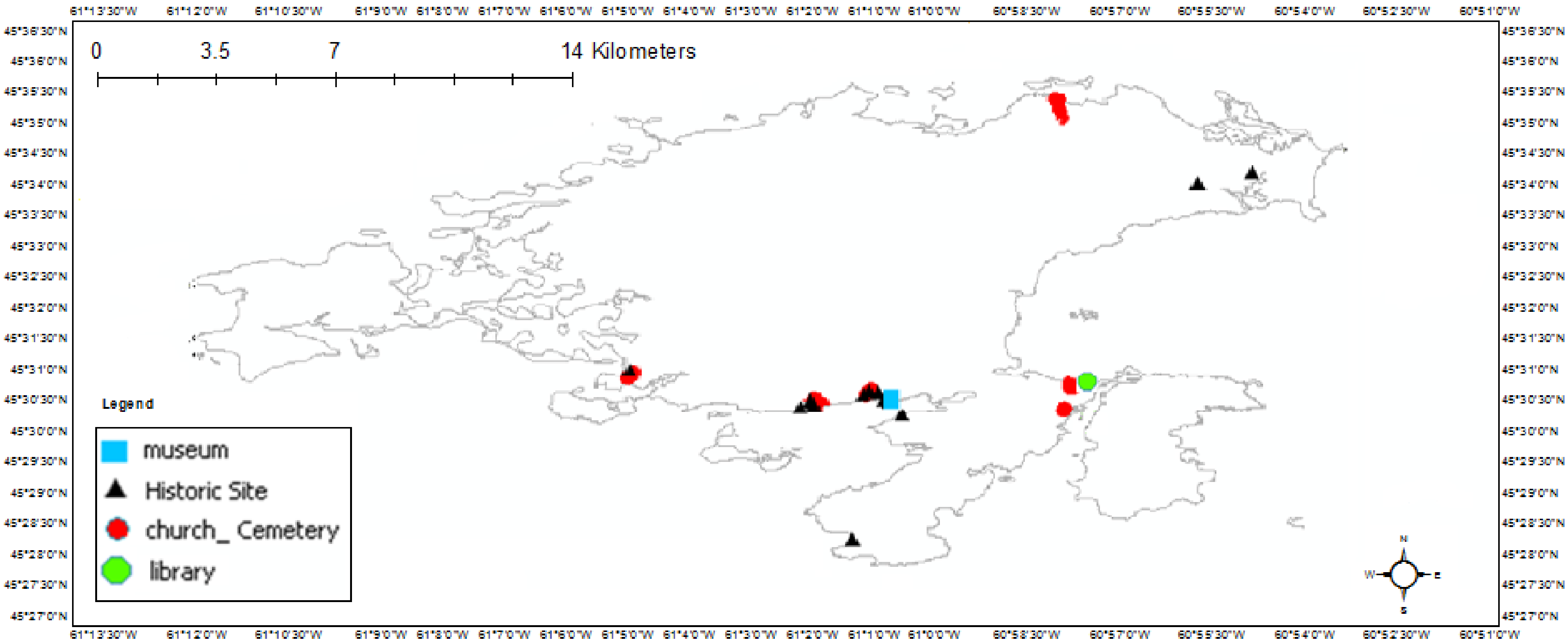

Figure 3.12: Area of Significance item for Isle Madame

Source: GeoNova (2006)

Table 3.8 presents all the cultural layers of Isle Madame.

Cultural Item	Layer	DA 1	DA 2	DA 3	DA 4	DA 5	DA 6	Total Number of points/polylines
Community dynamics	Community center	-	-	-	-	-	-	1
Language	English only Population	320	285	290	340	350	290	1875
	French only Population	600	340	120	130	150	190	1530
	French and English Population	15	0	0	0	0	0	15
Areas of Significance	Museum	-	-	-	1	-	-	1
	Cemetery and Church	1	1	1	2	1	1	7
	Library	1	-	-	-	-	-	1
	Historic site	2	-	2	3	6	1	14

Table 3.8: measures of Cultural Layers for Isle Madame's DAs
Source: Statistics Canada (2007) and GeoNova (2006)

In this section (3.2), data sources are introduced which are used in this research for describing the spatial representation of Isle Madame. Moreover, four pillars with their related items and layers are analyzed for the case of Isle Madame. As a result, collectively, these data create the Isle Madame Community Profile. This descriptive information is used to develop the asset base of Isle Madame and from there to value the community's assets at risk, and expected damages valuation from seal level rise and storm surge events.

3.3 Geographical Information System, Storm Scenarios Modelling, and Total & at Risk Assets Estimation

This section contains mapping information and application of the Geographical information System (GIS) and ArcView9 techniques to prepare Storm Scenarios and to create a tool for finding the most vulnerable Isle Madame areas to storm surge and sea level rise. This section consists of the following subsections: (3.3.1) Storm surge and sea level rise tool, (3.3.2) Severe Storm Scenario models, (3.3.3) Isle Madame historical storms analysis, (3.3.4) Maximum observed water levels, (3.3.5) Lengths of Storm Scenarios, and (3.3.6) Valuation of Isle Madame Total Assets and Assets at Risk from Storm Scenarios.

3.3.1 Storm surge and sea level rise Tool

A Sea Level Rise tool for Isle Madame using the best available elevation data was created for this research and presented at GIS Day, November 15, at the University of Ottawa (Pakdel, S. 2009). The goal of the Sea Level Rise tool (SLRT) is to simulate and illustrate the spatial areas and points of interest (lands, schools, houses, roads, churches, restaurant, etc.,) on the map of Isle Madame that will be impacted by sea water resulting from a specific maximum water level rise from storm surge and sea level rise. This research uses ArcGIS to provide local communities the geographic advantage to become more aware, and more responsive to the vulnerable area of their island subject to severe storms. The ArcMap user interface code for the SLRT is presented in Appendix E, "ArcMap user interface code".

Figure 3.13 presents the user interface of the Sea Level Rise tool. The inputs of the tool are:

1) Select a layer - The specified spatial layer requested by the user to examine the effect of sea level rise (e.g., the pillar layers, or layers for specifics such as public works, schools, residential houses, health units, and, others as described above); and

2) Sea Level rise (meters) - The amount of sea level rise designated by user as the "maximum observed water level" in integer meters, i.e., 0,1,2,3.

Sea level rise tool refers to the "raster calculator" in ArcMap and applies the selected sea level rise amount into the elevation map. It also converts the raster data to polygons that are then used to select assets in Chapter 4.

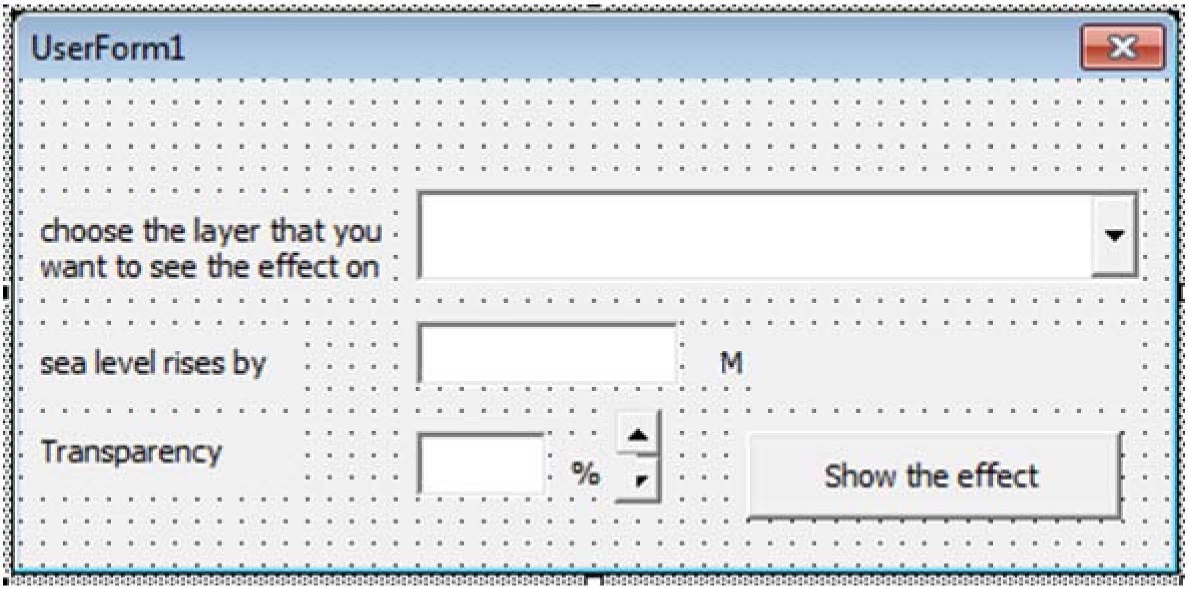

Figure 3.13: User interface of a Sea Level Rise Tool (SLRT)
Source: Pakdel, S. (2009)

Maximum water levels were determined by observing the ranges of maximum water levels of historical storm surges. During severe storms there are factors which result in storm surge. These factors are: (i) strong winds blow onshore pushing water against the coast, (ii) low air pressure which further raises water levels at the coast, and (iii) the underwater slope of the coast which also influences how high a surge can grow (NHC, 2010). "When surge combines with normal tides it creates hurricane storm tides, which can then increase the mean water level. Therefore, storm tides make a further the rise in water level due to the combination of astronomical tide and storm surge" (NHC, 2010). Figure 3.14 illustrates the difference between storm surge and storm tide.

Storm surges are analyzed in terms of meters above Chart Datum (CD) in this research. Chart datum is the base level from which all other measurements are taken. CD is shown in Figure 3.14 as "Mean sea level".

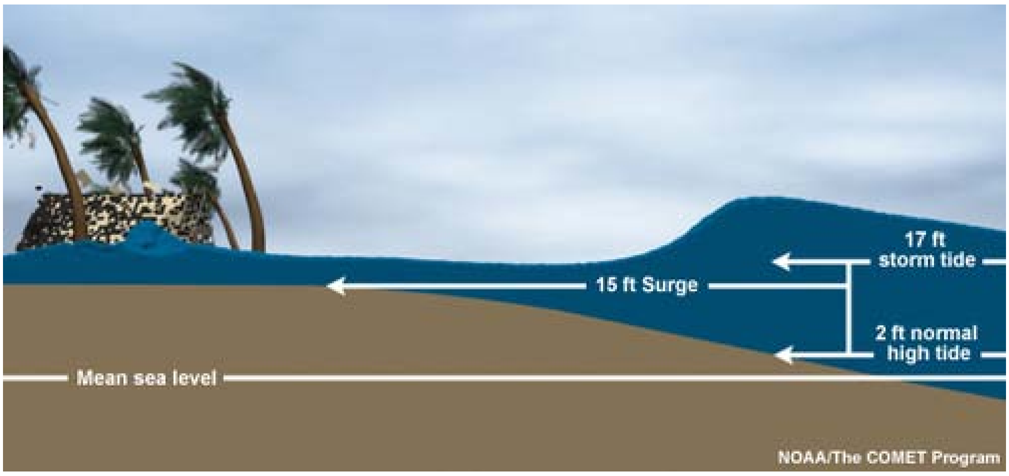

Figure 3.14: Storm surge vs. storm tide

Source: NHC (2010)

As for this research, "maximum observed water level (MOWL) is considered due to the fact that astronomical tides can significantly impact the potential water levels and their subsequent impacts. Therefore, MOWL includes CD + storm tide (includes Storm surge + normal high tide level (or astronomical tide))" (NHC, 2010).

Figure 3.15 shows the two meter rise impact and buffer zones specific to DA 1 and 2 on Isle Madame to illustrate the buffering zone of a two meter storm surge or MOWL.
The shaded area in Figure 3.15 is called the "buffer zone", shows the land area under water after two meters sea level rise. All the area in this zone is considered a vulnerable area and all the spatial layers within the shaded buffer zone are assumed to experience flooding and possible storm damage.

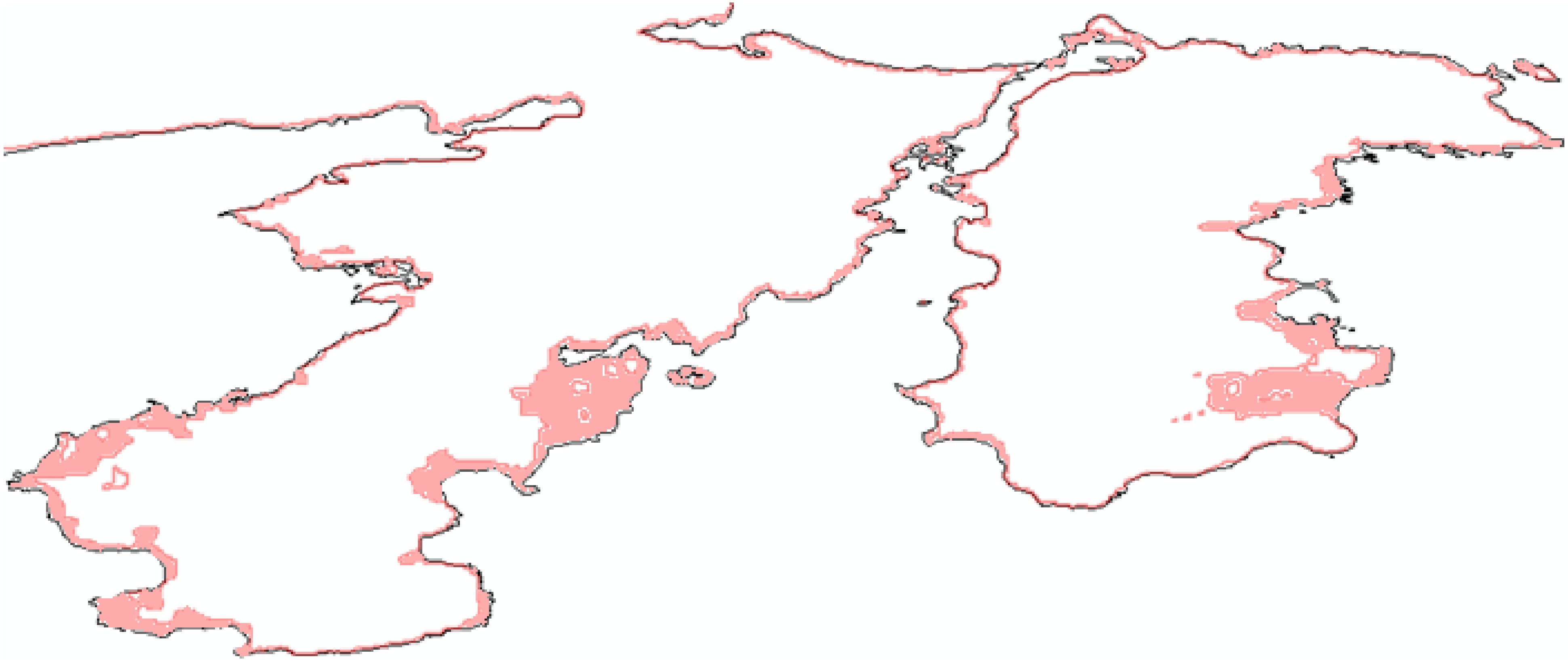

Figure 3.15: DA 1 and 2 and the flooding Buffer zone from a 2 meters sea level rise or storm surge

Source: Google Earth (2011) and Pakdel, S. (2009)

Overall, the Sea Level Rise Tool (SLRT) is dependent on the quality of the available digital elevation map, the descriptive layers and the accuracy of data and points of interest. The tool needs to be as complete and accurate as possible to give precise results for estimating how many roads, houses, schools, churches, hospitals, farms, hotels etc., will be affected and damaged by modelled rising seas and storm surge. Limitations to data, maps, interpretation of information by community partners of Isle Madame are critical issues for understanding the more precise impacts of water damage from storm surge and sea level rise. It is therefore noted that the modelled estimates for storm damage developed here are based on the best available Isle Madame data used in this work.

3.3.2 Storm Scenarios

This item categorizes empirical data on storms and their impacts on Isle Madame. The basis of analysis is based on the Saffir-Simpson Scale of hurricanes categorization by current winds and the expected storm surge (NOAA 2010). The hurricanes categorization consists of five storm groups which show the trend of increasing damages as storm wind speed increases. Figure 3.17 presents the Saffir-Simpson Scale of hurricane categorization.

Abbreviation	Definition	Winds(mph)	Winds(kph)
TD	Tropical Depression	< 39	< 63
TS	Tropical Storm	39 – 73	63 - 118
G	Gale	39-54	63-87
S	Storm	55 – 73	88 - 118
SS1 (S1)	Saffir-Simpson 1	74-95	119-153
SS2 (S2)	Saffir-Simpson 2	96-110	154-177
SS2 (S3)	Saffir-Simpson 3	111-130	178-209
SS2 (S4)	Saffir-Simpson 4	131-155	210-251
SS2 (S5)	Saffir-Simpson 5	>155	>251

Figure 3.16: The Saffir-Simpson Scale for Hurricane Categorization 1-5.

Source: Modified from NOAA (2010)

The approach taken in this research for modelling Storm Scenarios are also based on the storm indicators: storm speed, wind speed and pressure. The speeds and pressure are measured in km per hour and millibars, respectively. The ranges of these indicators are the basis for categorizing storms with increasing severity. Moreover, the format of IPCC's six greenhouse gas emission scenarios (IPCC SRES, 2001) is also observed in this research. The IPCC's six scenarios are categorized for greenhouse gas mitigation and not directly related to storms. However, greenhouse gas has demonstrated impacts on global mean temperatures, and hence on climate change and increased storm frequency. Therefore, what can be seen as six Storm Scenarios in Table 3.9 below are concluded from the Saffir-Simpson Scale and historical storms with especial indicators like wind, speed, and pressure.

In the case of Isle Madame, the maximum and minimum values of these three indicators for the sixteen historical storms are shown in previous section Table 2.5. Among these sixteen storms, Hurricane Hortense in 1996 had the lowest storm speed value of 31 kph. However, Hurricane Michael in 2000 had the highest value of 87kph and 160 kph in storm speed and wind speed, respectively. Extra-tropical storm Alisson in 2001 had the lowest wind speed value of 35 kph and the highest value of 1012 millibars in pressure; whereas, Hurricane Gustave in 2002 had the lowest value of 962 millibars in pressure.

For each indicator (storm speed, wind speed, and pressure) the maximum and minimum values from the sixteen storms were used to define the ranges of six modelled Storm Scenarios by increasing severity across all storm attributes. Once the maximum and minimum values were found, the six Storm Scenarios are categorized by dividing that range into six roughly equal parts.

The input drivers for the six modelled Storm Scenarios affecting Isle Madame are defined as follows:

(1) storm speed with the following range: Minimum 30 and Maximum 89 km/hr,
(2) storm wind speed with the following range: Minimum of 35 and Maximum of 166 km/hr, and
(3) Storm pressure with the following range: Minimum of 960 and Maximum of 1019 millibars.

Table 3.9 defines the six modelled Storm Scenarios developed for this research by monotonically increasing storm attributes.

Storm Scenario	Storm Speed (kph)	Wind Speed (kph)	Pressure (mb)
I	30 – 39	35 – 56	1010 – 1019
II	40 – 49	57 – 78	1000 – 1009
III	50 – 59	79 – 100	990 – 999
IV	60 – 69	101 – 122	980 – 989
V	70 – 79	123 – 144	970 – 979
VI	80 – 89	145 – 166	960 – 969

Table 3.9: General summary of six modelled Storm Scenarios for Isle Madame

3.3.3 Isle Madame historical storms and six Storm Scenarios

The Storm Scenarios are sorted based on the intensity of the storms, meaning that as you move from Storm Scenario I to Storm Scenario VI the storm indicators intensify. The storm and wind speeds increase as the pressure decrease as we move from one more severe Storm Scenario to another. This linearly increasing model of storm scale is consistent with the hurricane the Saffir-Simpson Scale (NOAA 2010) but is specific to the case of Isle Madame and it historical observation set.

The aim is to fit the 16 empirical recent storms (1975-2009) into these six categories. However, as can be anticipated, it may not be a perfect fit and some judgments are needed along the way. Table 3.10 shows the historical storms sorted out based on these the six modelled Storm Scenarios for Isle Madame.

For example, by studying the table you can see that HORTENSE and BILL both have been categorized under Storm Scenario IV, and both have a wind speed within the categorized range, but neither of them are in the corresponding ranges for storm speed and pressure value. According to the table above, only Hurricane MICHAEL 2000 falls precisely into one defined Storm Scenario. The remaining historical storms have one or two matched data with the wind, speed and pressure values as noted in Table 3.10 below.

Storm Scenario	Storm	Maximum Water level	Speed (kph)		Wind (kph)		Pressure (mb)	
			Storm Scenario	Storm	Storm Scenario	Storm	Storm Scenario	Storm
I	ALLISON 2001		**30 – 39**	50	**35 – 56**	35	**1010– 1019**	1012
	CHRIS 1988			68		45		1008
II	NOT NAMED 2006		**40 – 49**	35	**57 – 78**	65	**1000– 1009**	1007
	OPHELIA 2005			42		85		1000
	BERTHA 1990	**1.48**		35		130		973
III	LILI 1990	**1.63**	**50 – 59**	70	**79 – 100**	75	**990– 999**	995
	ALLISON 1195			40		85		989
	BARRY 1995			40		95		991
	ALBERTO 2006			38		100		969
IV	SUBTROP 1982		**60 – 69**	81	**101– 122**	110	**980– 989**	984
	HORTENSE 1996			31		120		970
	BILL 2009			53		120		970
V	EVELYN 1977	**2.05**	**70 – 79**	59	**123– 144**	130	**970– 979**	996
	SUBTROP 2000			75		95		980
	GUSTV 2002			74		140		962
VI	MICHAEL 2000		**80 – 89**	87	**145– 166**	160	**960– 969**	965

Table 3.10: Categorization of historical storm based on the six Storm Scenarios

Source: NOAA (2010)

3.3.4 Maximum Observed Water level and Storm Scenarios

After each historical storm surge, one of the more significant results is the monitoring of the maximum observed water level (MOWL). MOWL refers to:

> "Maximum water level is the rise in water level due to the combination of storm tide (astronomical tide and storm surge) and CD. Such a rise in water level can cause tremendous flooding in coastal areas." (NHC, 2010).

The only available data for maximum water level in all 16 Isle Madame's historical storms are: 1.48 meters for Storm Bertha 1990 (categorized Storm Scenario II), 1.63 meters for Hurricane Lili 1990 (categorized Storm Scenario III), and 2.05 meters for Hurricane Evelyn 1977 (categorized Storm Scenario V). These storm surge data are retrieved from Fisheries and Oceans Canada - Canadian Tides and Water Levels Data Archive, the source of storm maximum water levels (DFO 2010). There is no data freely available for the MOWL for the rest of the historical storms and directly associated with them. Based on the limited data observations, Table 3.7 illustrates the predicted maximum observed water level for each Storm Scenario Storm Scenario II and Storm Scenario V. The maximum observed water levels for the remaining Storm Scenarios are found by interpolating or extrapolating the available data which can be seen in Table 3.11.

Storm Scenario	Maximum Observed Water Level, MOWL (m)	Historical Storm name
I	1- 1.24	ALLISON 2001 & CHRIS 1988
II	1.25 – 1.49	NOT NAMED 2006, OPHELIA 2005, and BERTHA 1990
III	1.5 – 1.74	LILI 1990, ALLISON 1195, BARRY 1995, and ALBERTO 2006
IV	1.75 – 1.99	SUBTROP 1982, HORTENSE 1996, and BILL 2009
V	2.00 – 2.24	EVELYN 1977, SUBTROP 2000, and GUSTV 2002
VI	2.25 and More	MICHAEL 2000

Table 3.11 Maximum Observed Water Levels (MOWL)

Analyzing the storms by the maximum observed water level from Table 3.11 represents increasing severity from Storm Scenario I to VI. Many different reasons can affect the actual impact of a storm such as seasonality, the lunar cycle, and coincidence of a high tide at the time of impact. A higher tide due to the astronomical reasons or a full (e.g., the January 2, 2010 storm that most recently struck Isle Madame) can result in higher water levels and therefore more flooding and storm damage.

3.3.5 Lengths of Storm Scenarios

In this research, the length of the increasing severity of the Storm Scenario is considered as having immediate impacts followed by indirect intermediate impacts. These indirect impacts may include, for example, clean-up, mop up, and repair operations, the loss of income from work stoppages, due to the storm inaccessibility to roads and transportation (e.g., bridges) are all expected to linger after the direct impacts of a severe storm with affects that last longer the more severe the storm. There is limited data available for determining the duration of historical storms in Isle Madame and these indirect storm impacts. Thus, these data are estimated based on historical and anecdotal storm recovery information discovered during the course of this research investigation. The modelled lengths of Storm Scenarios for including indirect effects for this research are shown in Table 3.12. According to the Table 3.12, the lengths of storms become longer as the storm become harsher.

Storm Scenario	Estimated Length of Storm (days)	Historical Storm name
I	1	ALLISON 2001 & CHRIS 1988
II	1.5	NOT NAMED 2006, OPHELIA 2005, and BERTHA 1990
III	2	LILI 1990, ALLISON 1195, BARRY 1995, and ALBERTO 2006
IV	2.5	SUBTROP 1982, HORTENSE 1996, and BILL 2009
V	3	EVELYN 1977, SUBTROP 2000, and GUSTV 2002
VI	3.5	MICHAEL 2000

Table 3.12: Estimated Length of Storms (days) by Storm Scenario

Information on storm length is used in Storm Scenario modelling of dynamic effects using System Dynamics modelling to account for time-based storm damages for Isle Madame. These results are provided in Chapter 5 of this thesis.

3.3.6 Isle Madame Total Asset Valuation

This section estimates the monetary value of total assets for the Isle Madame system as a whole. Valuation indicators for Isle Madame assets are provided in Table 3.13 and follow from the description of the Isle Madame Community Profile presented in Section 3.2 above. Assessing the valuation of the community provides direct evidence for determining those assets that are vulnerable to storm impacts.

The reason behind the valuation of total assets in Isle Madame is to estimate the importance of value and the vulnerable assets to storm surges and sea level rise. Table 3.13 lists the valued physical assets from the Isle Madame Community Profile in summary form below.

Environmental Pillar	Economic Pillar	Social Pillar	Cultural Pillar
• Breakwater • Tree area & Parks • Resources (fish and birds) • Habitat (shore and sea bottom)	• Buildings • Plants (factory) • Light house stations • Sewage treatment plant • Wharves and Petit de Grat marina • Local roads and highways • Bridges • Cart tracks • Culverts • Airstrips • Campgrounds • Post offices • Police stations • Fur farm • Fire stations • Industries by type	• School • Hospital/clinic • Sports fields/ shooting range • Senior citizen homes • Median household income	• Museums • Cemeteries and churches • Historic sites • Community centres • Library • Communication resources

Table 3.13: Layers for valuation of total assets in Isle Madame (Appendix B)

The physical resources of Isle Madame itemized in Table 3.13 above are required to be evaluated to determine the asset base. Itemized evaluations are based on a number of sources (as indicated for each item below) including real estate valuations, land planning valuations, and the work of McCulloch et al (2002) for the case of valuing assets for Atlantic Canada. Valuation estimates and rationale are discussed for Isle Madame items: (1) roads; (2) buildings; (3) public works (including water treatment plants, breakwaters, culverts, and wharves); (4) industry by type; (5) natural resources and habitat (trees and park land, and species); and (6) communication resources. Rationale for the evaluation estimates of the asset layers of Table 3.13 is discussed in the following paragraphs.

1) Valuation of all types of existing Roads in Isle Madame:

The Isle Madame Data Locator dataset (GeoNova 2006) identifies different types of roads in Isle Madame (Table 3.4). Roads for Isle Madame include: Collector highways, local roads, wood roads, loose surface roads, streets, abandoned roads, and cart tracks. To find the asset value of Isle Madame roads, the 2010 replacement cost of constructing a road is used as a proxy value. To this end, the Florida Department of Transportation database (FDT, 2010) is used as a data source. "The FDT database categorizes generic cost per mile based on the type of road, and its context and uses rural, suburban and urban rates" (FDT, 2010). For Isle Madame, all types of roads are assumed to fall under two categories of the FDT database as noted below:

- "New Construction Undivided 2 Lane Rural Road with 5' Paved Shoulders -estimated replacement cost of $1,713,007.35 per mile" (FDT, 2010) (the equivalent of $1,062,064.3 per kilometre); in the case of Isle Madame, as estimate of 60% of this amount ($637,238.58 per km) is applied because the typical road in Isle Madame have no more than 3' Paved Shoulders (i.e., 60% of the 5' Paved Shoulder FDT category). This adjusted FDT category estimate of valuation per km are applied to spatial estimates of Isle Madame road work (taken from Geobase (2006) approximate measure by layer item) as follows:
  - Collector highways - approximate total length of 33.6 km
  - Local Roads, - approximate total length of 130.3 km

- Streets- approximate total length of 4.8 km
- Airstrip- approximate total length of 1.3 km
- Bridges- approximate total length of 0.3 km

- "Rails to Trails project 12' width- estimated replacement cost of $162,515.68 per mile with 5' Paved Shoulders" (FDT, 2010) (equivalent to $100,759.72 per kilometre); in the case of Isle Madame (except for the Cape Auget Hiking trail where the original cost of Rails to Trails project 12' width ($100,759.72 per kilometre) is considered), 10% of this amount is applied ($10,759.72 per km) because of rural, unpaved type of the roads in Isle Madame has only 3' (at most) Paved Shoulders. This adjusted FDT category estimate of valuation per km are applied to unpaved Isle Madame road work (taken from GeoNova (2006) approximate measure by layer item) as follows:
    - Loose Surface Road- approximate total length of 5.1 km
    - Abandoned Road- approximate total length of 14 km
    - Cart Track- approximate total length of 214 km
    - Wood Road- approximate total length of 20.1 km
    - Hiking trail- approximate total length of 12 km

Therefore, the total asset value of all Isle Madame roads are the assumed replacement cost of construction of all types of roads multiplied by the length approximation of roads for a value of $110 million (2010 $CDN) (as reported in Table 3.14 below).

(2) Valuation of all types of existing Buildings in Isle Madame:

The value of the residential buildings and property in Isle Madame are estimated from the average value of a house in Isle Madame multiplied by the total number of buildings in Isle Madame from the Data Locator dataset (Table 3.4, Figure 3.6). "Buildings" refer to structures which are privately owned, including supplemental out buildings such as garages and fish houses. Average house property values are taken from the real state registries (MLS 2010) for Isle Madame and the Property Valuation Service Corporation (PVSC) database (2011). From a sample of 134 houses including their associated land (from the PVSC database), the average value of $84,618 (2010 Canadian Dollars) is estimated for Isle Madame residential (non-industrial) buildings properties for a total asset value of $244,461,402 (2010 $CDN) (as reported in Table 3.14 below).

In the case of layers for buildings and properties such as Sports fields, Senior citizen homes, Museums, Cemeteries and Churches, Historic sites, and Community Centres, the PVSC database is also used to estimate these asset values on a site by site basis as identified in the Isle Madame spatial database (GeoNova, 2006). For these special cases, the exact properties for each of them are found in the map of Isle Madame and the Data Locator dataset (Figure 3.11). The specific PVSC database property value is assigned to the layer. For the case of Sport fields and the shooting range, the average value of a sport field or a shooting range in Isle Madame according to the PVSC database is approximately $22,000 Canadian dollars. There are 8 designated sport fields in Isle Madame that are shown as 50 points in the Data Locator data set (Figure 3.11, GeoNova (2006)).

For the case of Cemeteries and Churches properties (Figure 3.12), the average value per property in Isle Madame according to the PVSC database is approximately $565,000 Canadian dollars.

There are three designated senior citizen homes in Isle Madame (Figure 3.11) according to data from the GeoNova (2006). Their property values from the PVSC database are respectively $1,269,100 Canadian dollars (Petit de Grat site), $606,800 Canadian dollars (Arichat site), and $404,600 Canadian dollars (d’Escousse site).

There are two Museum sites identified in the GeoNova (2006) data (Figure 3.12) and according to the PVSC database, the value for the building and the land of the museum is approximately $118,800 Canadian dollars. The library, “La Picasse” situated in Petit de Grat at the site of the Université Sainte-Anne (Figure 3.12 which is comprised of 7 points according to the data from GeoNova (2006)) has an accessed the value of $294,500 Canadian dollars according to the PVSC database. There are 14 historic sites that are available in Isle Madame in GeoNova (2006) but five of them are churches (these are not double-counted as they are estimated above in the Cemetery and Church layer). The remaining items are spatially identified and valued according to the PVSC database. According to the GeoNova (2006) there is only one Community Centre on Isle Madame valued by PVSC at $246,100. However the GeoNova (2006) database is not up to date, and in 2011 there are approximately 5 community centers in Isle Madame (Arichat, West Arichat, D'Escousse, Rocky Bay, and Petit de Grat). Thus the total estimated asset value for Community Centres are set at 5*$246,100= $1,230,500 (2010 $CDN) (see also Table 3.14).

There are four factories identified in Isle Madame according to GeoNova (2006) data (Figure 3.6). The values of these properties from the PVSC database are $205,600 (Arichat), $1,772,700, $576,100, and $294,500 (2010 Canadian dollars) in Petit de Grat. There is also one campground that is spatially identified with a property value of $26,200 (2010 $CDN) from the PVSC database.

There is one Hospital in Isle Madame, the St. Anne Community and Nursing Care Centre located on the High Road, Arichat (Figure 3.12). The Centre has a property valuation of $620,100 (2010 $CDN) according to the PVSC database.

According to the GeoNova (2006), there are four school buildings on Isle Madame. Elementary school buildings are located in Arichat, d'Escousse, Petit de Grat, with a former regional high school (IMDH) in Arichat (Figure 3.11). In 2011, only one of these schools remains open – the French language school Ecole Beauport in Arichat on the site of the previous elementary and high schools (now closed). For several years now, Isle Madame elementary and high school aged students are bussed to new facilities off island in the nearby village of Louisdale in Richmond County. The estimated valuation of the school properties is valued at a total of $7,427,600 (2010 $CDN) from the PVSC database.

Finally, other buildings layers including public assets for: two Post offices ($50,600 in West Arichat and $102,500 in Arichat), one Police station ($132,600), one Fire station ($431,000), and three Lighthouses (average each worth $12,000 thus three of them are assets worth $36,000) are valued from the PVSC database (Figure 3.6).

(3) Valuation of Public Works in Isle Madame:

Public works building structures include: (i) the sewage treatment; (ii) wharves: (iii) breakwater structures; and (iv) culverts.

The total asset value of the sewage treatment plant in Isle Madame is estimated by the replacement cost of a new sewage treatment plant of the same capacity. Using the recent estimates from Indian and Northern Affairs Canada (2010), the total capital construction cost of 19 village sewage treatment plant projects is $193 million Canadian dollars. Therefore the cost of one sewage treatment plant is approximately $10 million Canadian dollars and there are three sewage treatment plants in Isle Madame. All three sewage treatment plants together in Isle Madame can be considered as a size and capacity comparable to the one of the sewage treatment plant project of Indian and Northern Affairs Canada (2010). Therefore, in this study, the total asset value of all the sewage treatment plants in Isle Madame is assumed to be $10 million Canadian dollars.

In the study by Baird & Associates, Ltd. (2010) the capital cost required for a restored breakwater was estimated to be between the lower bound of $1.1 million 2010 Canadian dollars, to an upper bound of $1.6 million 2010 Canadian dollars. The estimation is based on uncertainty in competition for stone, contractor availability, fuel costs and weather delays. The average value of $1.35 million Canadian dollars is considered for this study for the each breakwater in Isle Madame. There are three breakwaters in Isle Madame; therefore, 3* $1.35 million = $4,050,000

The Petit de Grat marina was recently constructed via an extensive land fill initiative supported by all levels of government as a safe harbour and wharfing area for vessels from the local fishing industry and for marine recreational boating. The total value of the Petit de Grat marina is estimated from government contracts and approximated as $5 million 2010 CDN.

For finding the total assets value of all culverts in Isle Madame, the length of each culvert is assumed as 8 meters (6 meters is the assumed road width and one meter extra from each side of the road). The average capital materials cost of the culvert per meter is assumed to be $200 per culvert. Therefore, each culvert capital is valued at $1600. Assuming culvert installation requires a labour force of 3 workers at $200 labour cost per day, and one backhoe-digger is rented at a cost of $250 per day, then the total value estimate for each culvert is $3,300.

Cost estimation of wharves needs a quantity of capital material, and labour costs. It is recognized that wharf assets differ based on the type and extent or size of the wharf. In this study, it is assumed that the construction cost averages $250 per meter for similar wooden wharves. Also average length of a wharf is considered as 15 meters. There are 52 wharves in "wharf" layer and sixteen in "Wharves Rich" layer so totally 62 wharves are in Isle Madame. Thus the estimated replacement cost of a wharf is $232,500 (2010 $CDN).

(4) Valuation of the Isle Madame Industrial sector by type

According to DMTI (2009), there are a total of 128 industries by type in Isle Madame, as detailed in Table 3.5 and Table D.1 in Appendix D. In this research, the total value of these industries is considered as the industry's property values. Therefore, from the PVSC database the property value of each division of industry by type is as below:

- Division A (Agriculture, Forestry and Fishing) - Total value is $96,700 from 1 site (ALLSEASON AQUATIC FARMS LTD in Arichat)
- Division C (Construction) – there are five sites in Isle Madame in division C. Total property value of them are: $89,700 (for HARBOUR VIEW CONSTRUCTION LTD in West ARICHAT), $140,600 (for SUPERIOR CONTRACTING LTD in ARICHAT), $99,500 (for BAB CONSTRUCTION LTD in ARICHAT), and $126,500 (for TOMMY TUCKER'S ELECTRIC LTD in ARICHAT), and the 5th site property's value in this division was not available in PVSC database, therefore the value of the fifth site is considered as average of the other four industries in division C ($114,075). Therefore total value for division C is equal sum of the all five mentioned sites which is $570,375.
- Division D (Manufacturing) – There are ten sites of division D in Isle Madame, because the property value of all these sites are not available in PVSC database, therefore the average property value of 4 of them (available in PVSC database) is considered as value for each industry in division D in Isle Madame which is $170,000. So Total value of ten sites in division D is 10* $170,000 = $1,700,000
- Division E ("Transportation, Communications, Electric, Gas, and Sanitary Services") – There are 12 sites of division E in Isle Madame, because the property value of all these sites are not available in PVSC database, therefore the average property value of 7 of them (available in PVSC database) is considered as value for each industry in division E in Isle Madame which is $80,000. So Total value of 12 sites in division E is

12* $$80,000 = $ 960,000

- Division F (Wholesale Trade) – There are six sites of division F in Isle Madame, because the property value of all these sites are not available in PVSC database, therefore the average property value of three of them (available in PVSC database) is considered as value for each industry in division F in Isle Madame which is $90,000. So, the Total value of six sites in division F is estimated as (6*$90,000)=$540,000
- Division G (Retail Trade) – There are 33 sites of division G in Isle Madame, because the property value of all these sites are not available in PVSC database, therefore the average property value of 24 of them (available in PVSC database) is considered as value for each industry in division G in Isle Madame which is $160,000. So Total value of ten sites in division G is (33*$160,000)=$5,280,000
- Division H (Finance, Insurance and Real Estate) – There are 11 sites of division H in Isle Madame, because the property value of all these sites are not available in PVSC database, therefore the average property value of 7 of them (available in PVSC database) is considered as value for each industry in division H in Isle Madame which is $90,000. So, the Total value of 11 sites in division H is (11*$90,000)=$990, 000
- Division I (Heath care and social services educational services) – There are 48 sites of division I in Isle Madame, because the property value of all these sites are not available in PVSC database, the average property value of 24 of them (available in PVSC database) is considered as value for each industry in division I in Isle Madame which is $110,000. So Total value of 48 sites in division I is (48*$110,000)=$5,280,000
- Division J (Public Administration) – There are two sites of division J in Isle Madame, only one of them has a property value available in PVSC database which is $120,000, therefore the property value of the other one also is considered as $120,000. So, the Total value of two sites in division J is (2*$120, 000)=$ 240,000

(5) Valuation of the Isle Madame Natural Resources and Habitat

Isle Madame Natural Resources and Habitat include asset valuation for marine, bird and terrestrial resources, and benthic and shoreline resources. The rationale for valuation of these items is presented below.

It is estimated that approximately 51% of total land mass of Isle Madame is covered by trees (Figures 3.3 and 3.4). This estimate was determined by approximating the spatial area of the Google Earth green space. The value of the Tree Area and Parks in Isle Madame is found by determining the average value of a sq kilometre Tree Area in Isle Madame. The full asset valuation of the Tree Area is estimated by multiplying the average value of a square kilometre tree area by total tree and park area in Isle Madame. Five different tree areas in Isle Madame are considered as samples. The approximate area for each sample was estimated by making a polygon in ArcMap, also the land value of each sample was found from the PVSC database. Thus each sample has area size and land price which leads to get the average value of one Sq KM of the tree area. Therefore, the average value of a sq kilometre of Tree Area in Isle Madame is estimated as $180,000 (per sq km). Therefore, the total asset value is the average per sq kilometre value multiplied by the total size of the tree area and parks which is approximately 90 sq km. This value is estimated as $16,200,000 (2010 $CDN) (as reported in Table 3.14 below).

The value of Resources including the value of fish (finfish and shellfish) and birds (including commercial value and non-commercial value) is estimated as $5,000,000 (Figure 3.5). The value of Habitat assets includes the value of scallop and lobster bottom area; sea urchin, and shellfish closure area; rockweed & kelp zones; and recreational clam beds. The approximate area of all marine habitats in Isle Madame is estimated as 70 sq km (Figure 3.5) and the total value is estimated as $2,500,000 (approximately $36 per sq kilometre of marine habitat space). The approximate value of $ 36,000 per sq kilometre of marine habitat space is around one fifth of the estimated value of Isle Madame tree area (or $ 180,000 per sq kilometre) and, the marine habitat in Isle Madame is estimated as 70 sq km, approximately. On the other hand, resources are valued as twice that of their marine habitat, i.e., $ 71,000 per sq km. Given resources of lobster, seals, cod, finfish, whales, and birds (including commercial and non-commercial), estimated value is $10 per kg (e.g. lobster landed value equivalent). This means approximately 7,100 kg resources per sq km which gives a value of approximately $5,000,000 for 70 sq km of marine habitat.

(6) Valuation of the communication resources in Isle Madame:

Total assets of communication resources are estimated as $5,000,000 in this study. Communication resources include towers, cabling, lines, capital infrastructure for radio, TV (the property of the Telile community television in Isle Madame is valued at $70,000 2010 $CDN, according to PVSC database), phones, etc. The total value of these resources is estimated as $5,000,000 in Isle Madame.

Using the valuation information above, Table 3.14 illustrates the calculated Total Asset valuation for each pillar in Isle Madame. For calculating these assets information on Community Profile pillars spatial sites (Data Locator 2006), see also Tables 3.3, 3.4, 3.5, 3.7, and 3.8.

Pillar	**Assets**	**Total Assets**(CND)	**Total Assets**
Environment	Breakwater	$4,050,000	**$27,750,000**
	Habitat	$2,500,000	
	Resources	$5,000,000	
	Tree area and park	$16,200,000	
Economic	Buildings	$244,461,402	**$390,953,067**
	Plants (factory)	$ 2,848,900	
	Light house stations	$36,000	
	Sewage treatment plant	$10,000,000	
	Wharf/WharvesRich/ “Petit de Grat marina”	$5,232,500	
	Different types of roads	$110,226,509	
	Bridge	$191,171	
	Post office	$153,100	
	Police office	$132,600	
	Fur farm	$41,000	
	Pool	$199,100	
	Campground	$111,700	
	Fire station	$431,000	
	Culvert	$402,600	
	Airstrip	$828,410	
	Industry by type	$15,657,075	
Social	Hospital	$620,100	**$72,961,856**
	School	$7,427,600	
	Annual household income	$61,248,540	
	Hiking trail	$1,209,116	
	Sport field and Shooting Range	$ 176,000	

	Senior citizen home	$ 2,280,500	
Cultural	Museum	$ 118,800	**$10,981,300**
	Historic site	$ 1,512,500	
	Community Center	$ 1,230,500	
	Cemetery and Church	$ 2,825,000	
	Communication resources	$5,000,000	
	Library	$ 294,500	
Total			**$502,646,223**

Table 3.14: Summary of the Total Assets for each pillar for the Isle Madame Community Profile

Figure 3.18 presents graphically the total value of Isle Madame by pillar.

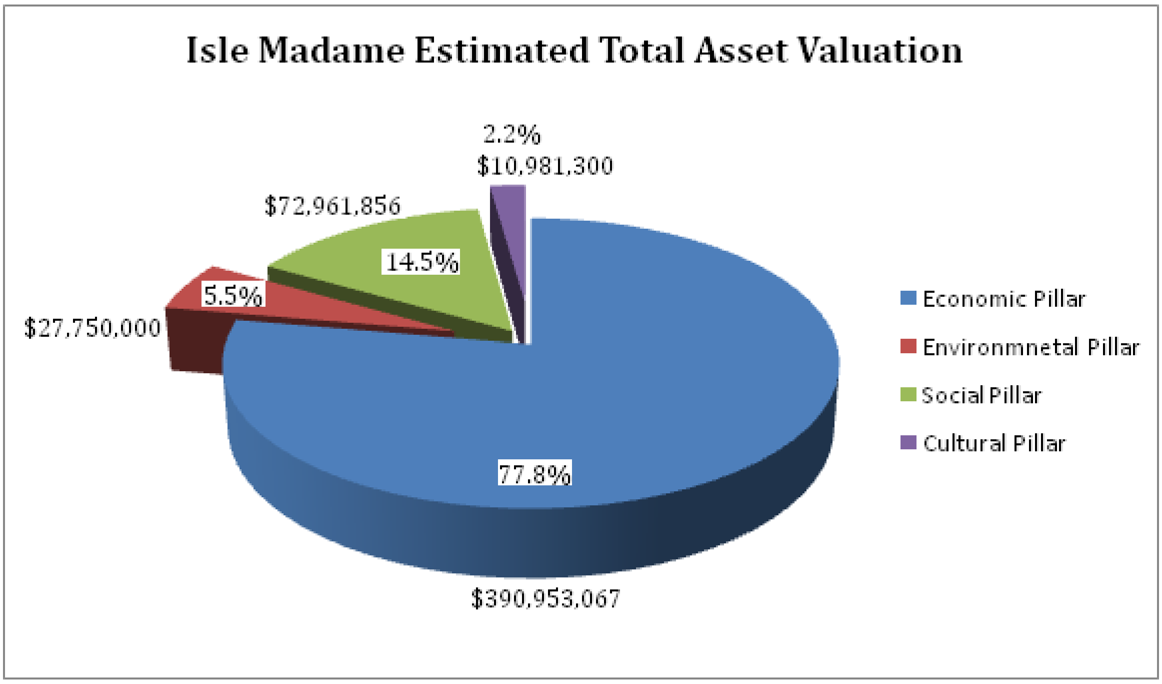

Figure 3.17: Isle Madame Estimated Total Asset Valuation by pillar

3.4 System Dynamics Modelling for Storm Damage

Systems Dynamics modelling is used to describe and link the environmental, economical, cultural, and social dimensions through visual spatial and temporal maps with the direct and indirect (time lagged) storm damage from Storm Scenarios. In this research, the STELLA software modelling technique is applied to the Isle Madame storm damage estimation model. The Isle Madame represents a relatively simple and straightforward problem formulation for which STELLA is well adapted. The challenge for the STELLA model, as noted below (and above) is the lack of an empirical data on which to model the dynamically changing Community Profile arising from the storm surge and sea level rise. The SD model incorporates the feedback loop of direct and indirect damages over time to link environmental, social, cultural, and economical factors.

The four dimensions of the Isle Madame Community profile described above through the GIS data model are inputs for the system dynamics model presented here. Modelled dynamic storm damages and costs are outputs of the SD model. To model the impacts of storm surge and sea level rise over time, the spatial data from the GIS must be combined with the SD model toward an integrated spatial system dynamics (SSD) model of storm damage. The result of moving toward integrating the GIS and SD are dynamic maps, graphs, tables indicating the damage estimates for the community by Storm Scenario.

3.4.1 System Dynamics Model Description

When a storm occurs, it will cause direct damages on each Community Profile pillar which are assumed to occur immediately during the storm. There are also indirect damages (lagged time affects) which are results of and follow from the direct storm damages. The indirect damage is modelled as a storm damage that results from the links and feedback from one Community Profile pillar to another over a relatively short time period extending the storm damages beyond the storm event itself. Therefore, the assumed non-linear SD Model adds time affects for a short period of time, estimated at three weeks, representing these indirect storm damages.

Inputs to the STELLA model include the link between the direct and immediate damage by pillar and the indirect damage on the other pillars, including feedback to itself, e.g., immediate environmental pillar damage from a storm also incurs indirect environmental pillar damages with the three week indirect damage time period.

Direct storm damage to each pillar are inputs to the system dynamics (SD) model as shown in Figure 3.19 below.

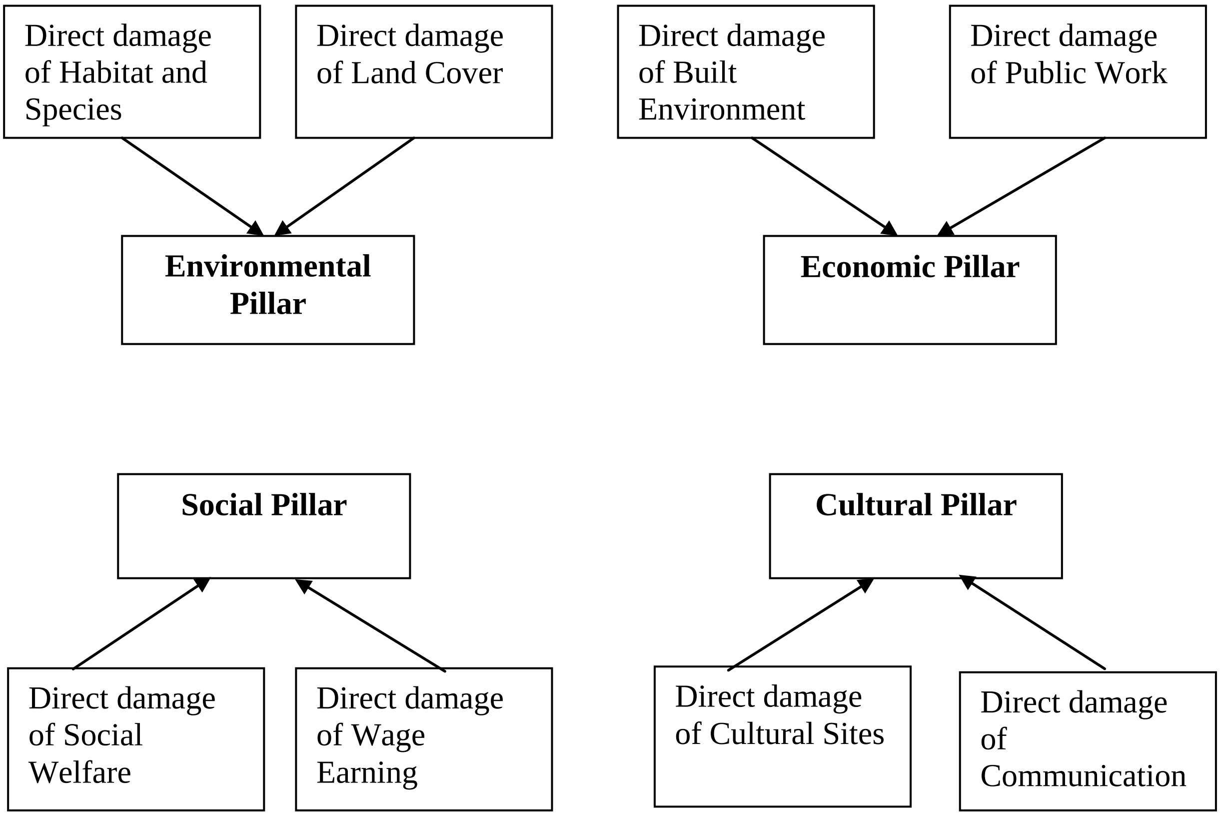

Figure 3.18: Direct damage of items to each pillar as inputs to the SD model

Indirect storm damages for each pillar assumed to be caused by other pillars or the pillar itself. Interactions between pillars which lead to indirect damages are illustrated in Figure 3.20 below.

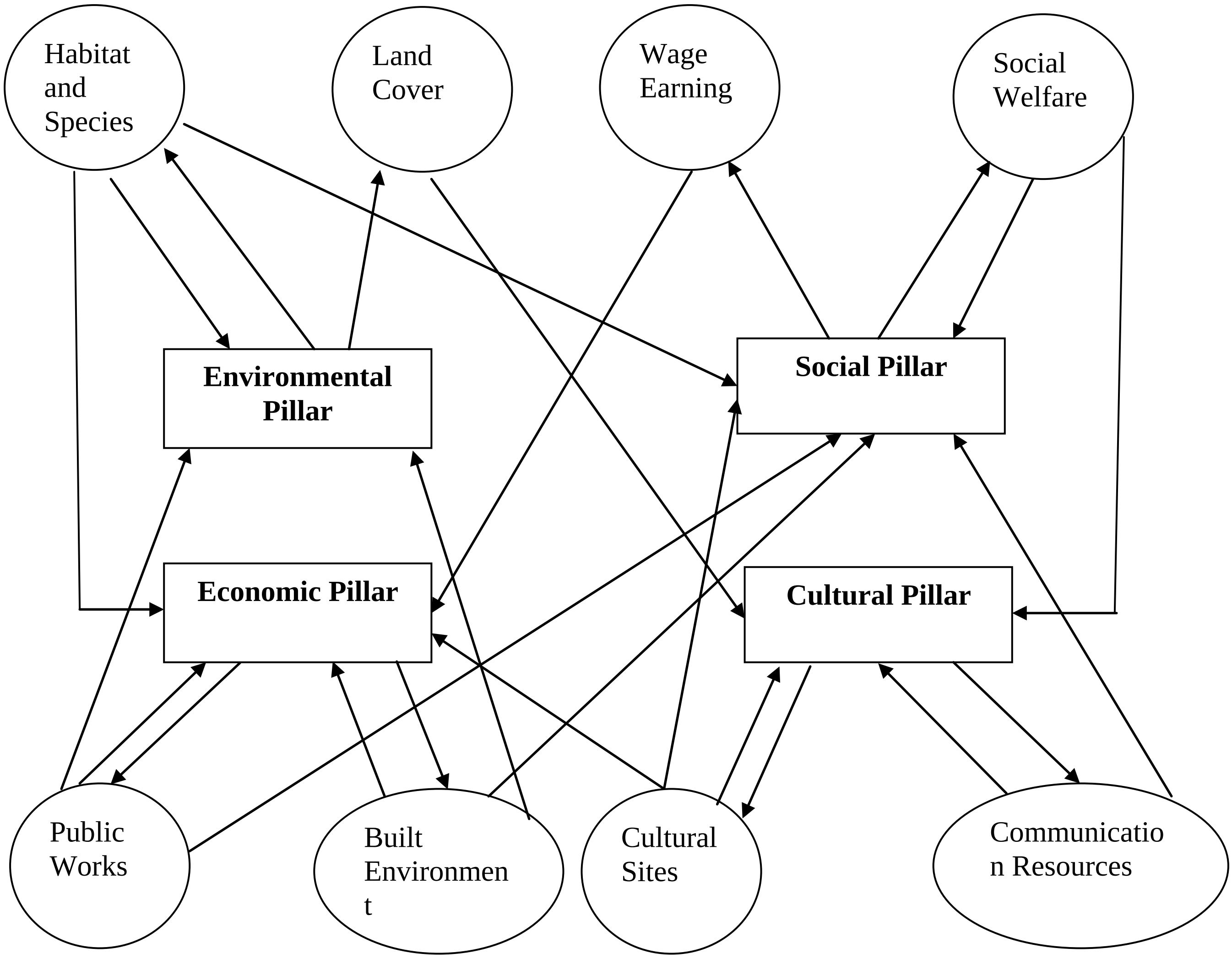

Figure 3.19: Modelled Interaction between the four Community Profile pillars in the SD model

In Figure 3.20, eighteen interactions are considered between the pillars in this model. Descriptions of all these links are discussed in further detail below by pillar. Estimates for direct and indirect storm impacts across the pillars are estimates and valued for SD model illustration in the absence of any such empirical data. This approach is developed from the work of Hartt (2011) who applied a simple SD model to estimating direct and indirect damages for Charlottetown P.E.I. The approach that followed expands the SD modelling formulation for the case of Isle Madame. As in the case of Hartt (2011), percentage damage linkages across the pillars represent best guess estimations without empirical verification. The rationale for these linkages is described below.

Environmental Pillar:

Direct Damages and Indirect Damages for the Environmental Pillar is shown in Figure 3.21.

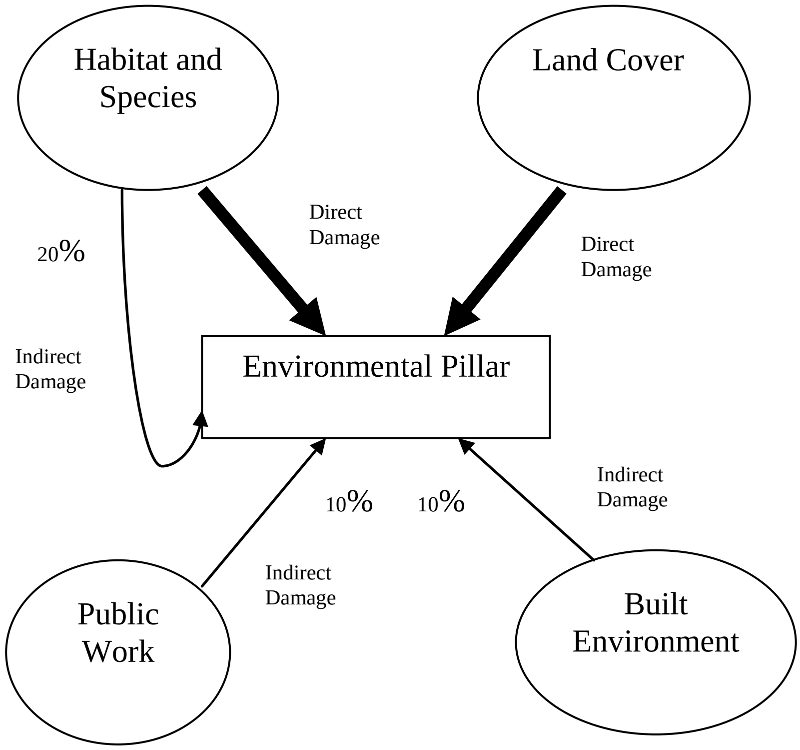

Figure 3.20: Dynamics Interactions in the Environmental pillar in the SD model

Direct Damages. As can be seen in Figure 3.21, the Environmental Pillar has two sources of Direct Damages "Habitat and Species" and "Hydrology, Land Use & Land Cover". The Environmental Pillar also has Indirect Damages over the period of three weeks. Total Damage of the Environmental Pillar is sum of the Direct Damages and Indirect Damages over the weekly period. Each of the Indirect Damages is a portion of Direct Damage from another Pillar or Environmental Pillar itself.

Indirect Damages: The Direct Damage of Habitat and Species has a negative lag affect on the Environmental pillar. It is estimated and modelled that 20% of Direct Damage of Habitat and Species is considered as an Indirect Damage of the first week after the Storm Scenario event for the Environmental Pillar. In subsequent weeks (2 and 3), the Indirect Damage after the Storm Scenario event is estimated and modelled as 20% of the time decay function of the Direct Damage of Habitat and Species, namely, Indirect Damage in week t is 20% *[(Direct Damage of Habitat and Species)^1/t], for t=2,3.

Similarly, the direct impact on the Public Work will have negative indirect and time lag affect on the Environmental pillar. For example, it is expected that there will a negative affect on municipal wastewater systems and storm water collection and disposal systems that will in turn negatively impact the environment in subsequent weeks. The estimated portion of the Direct Damage of Public Works which has affected indirectly on Environmental Pillar is set at 10%.

Finally, the direct impact on the Built Environment will have negative indirect and time lag affect on the Environmental pillar. The estimated portion of the Direct Damage on the Built Environment which indirectly and negatively affects the Environmental Pillar is estimated as 10%.

Social Pillar:

Direct Damages and Indirect Damages for the Social Pillar is shown in Figure 3.22.

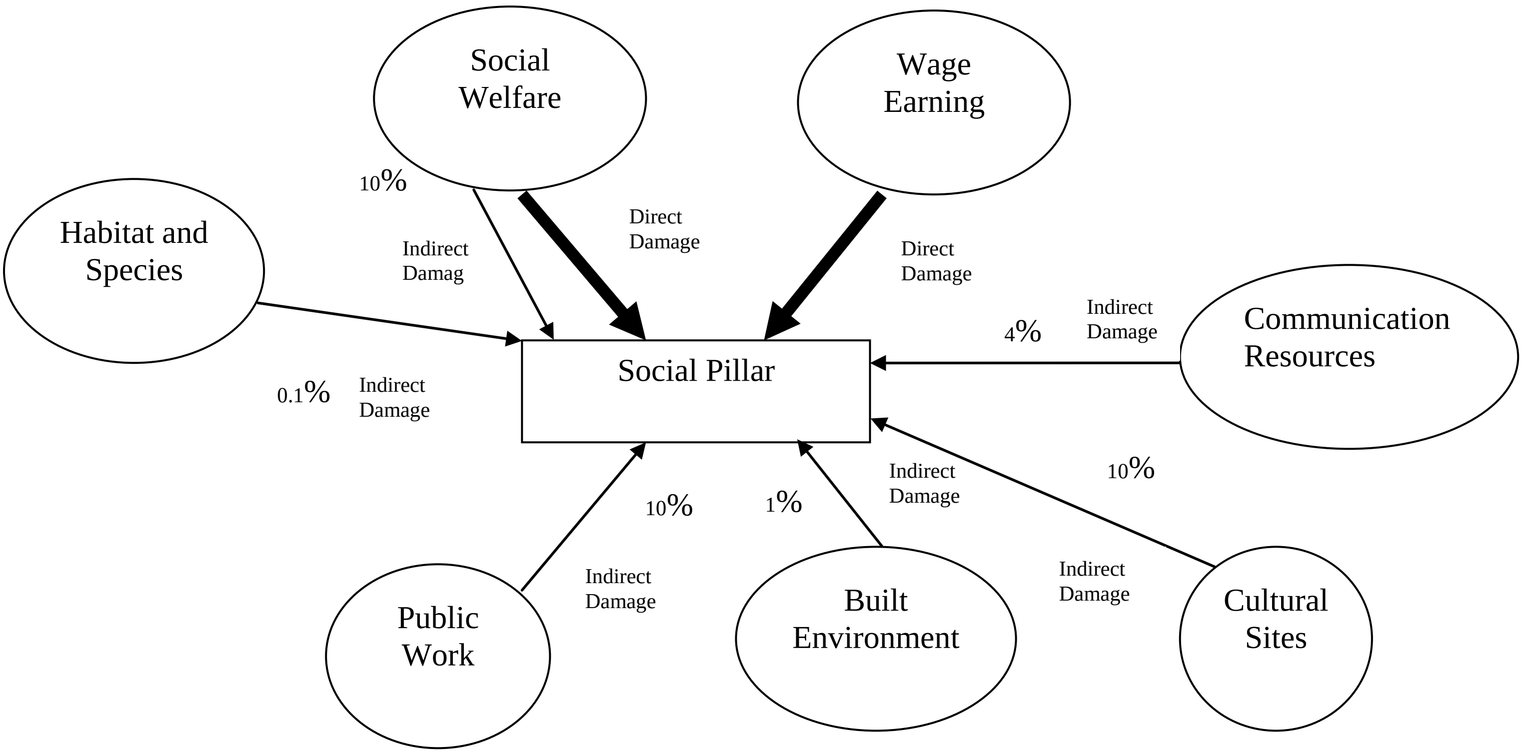

Figure 3.21: Dynamics Interactions in the Social pillar in the SD model

Direct Damages: As can be seen in Figure 3.22, the Social Pillar has two sources of Direct Damages “Social Welfare” and “Wage Earning”. The Social Pillar also has Indirect

Damages over the period of three weeks. Total Damage of the Social Pillar is sum of the Direct Damages and Indirect Damages over the weekly period. Each of the Indirect Damages is a portion of Direct Damage from another Pillar or Social Pillar itself.

Indirect Damages: The Direct Damage of Built Environment has negative lag affect on the Social pillar. It is estimated and modelled that 10% of Direct Damage of Built Environment is considered as an Indirect Damage of the first week after the Storm Scenario event for the Social Pillar. In subsequent weeks, the Indirect Damage after the Storm Scenario event is estimated and modelled as 10% of the time decay function of the Direct Damage of Built Environment, namely, Indirect Damage in week t is 10% *[(Direct Damage of Built Environment)^1/t], for t=2,3.

Similarly, the direct impact on the Cultural Sites will have negative indirect and time lag affect on the Social pillar. The estimated portion of the Direct Damage of Cultural Sites which has affected indirectly on Social Pillar is set at 10%.

Moreover, the direct impact on the Habitat and Species will have negative indirect and time lag affect on the Social pillar. The estimated portion of the Direct Damage of Habitat and Species which has affected indirectly on Social Pillar is set at 0.01%.

Similarly, the direct impact on the Communication Resources will have negative indirect and time lag affect on the Social pillar. The estimated portion of the Direct Damage of Communication Resources which has affected indirectly on Social Pillar is set at 4%.

In addition, the direct impact on the Built Environment will have negative indirect and time lag affect on the Social pillar. The estimated portion of the Direct Damage of Built Environment which has affected indirectly on Social Pillar is set at 1%.

Finally, the direct impact on the Social Welfare will have negative indirect and time lag affect on the Social pillar. The estimated portion of the Direct Damage on the Social Welfare which indirectly and negatively affects the Social Pillar is estimated as 10%.

Economic Pillar:

Direct Damages and Indirect Damages for the Economic Pillar is shown in Figure 3.23.

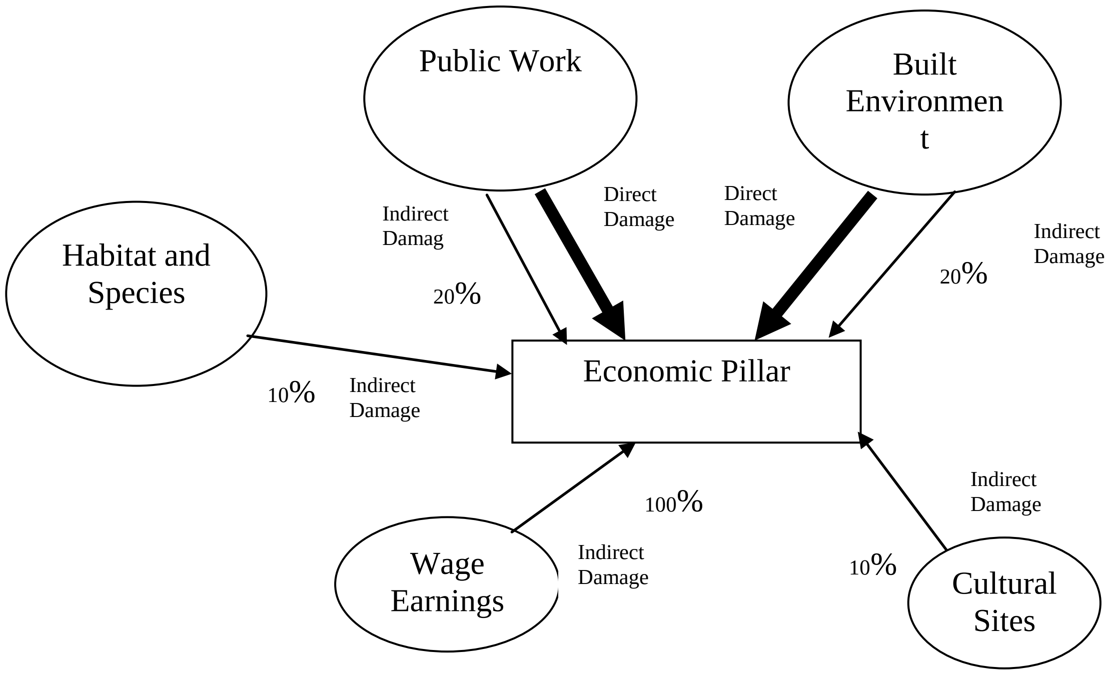

Figure 3.22: Dynamics Interactions in the Economic pillar in the SD model

Direct Damages: As can be seen in Figure 3.23, the Economic Pillar has two sources of Direct Damages “Public Works” and “Built Environment”. The Economic Pillar also has Indirect Damages over the period of three weeks. Total Damage of the Economic Pillar is sum of the Direct Damages and Indirect Damages over the weekly period. Each of the Indirect Damages is a portion of Direct Damage from another Pillar or the Economic Pillar itself.

Indirect Damages: The Direct Damage of Wage Earning has negative lag affect on the Economic pillar. It is estimated and modelled that 100% of Direct Damage of Wage Earning is considered as an Indirect Damage of the first week after the Storm Scenario event for the Economic Pillar. In subsequent weeks, the Indirect Damage after the Storm Scenario event is estimated and modelled as 100% of the time decay function of the Direct Damage of Wage Earning, namely, Indirect Damage in week t is 100% *[(Direct Damage of Wage Earning)^1/t], for t=2,3.

Similarly, the direct impact on the Public Work will have negative indirect and time lag affect on the Economic pillar. The estimated portion of the Direct Damage of Public Work which has affected indirectly on the Economic Pillar is set at 20%.

Moreover, the direct impact on the Built Environment will have negative indirect and time lag affect on the Economic pillar. The estimated portion of the Direct Damage of Built Environment which has affected indirectly on the Economic Pillar is set at 20%.

In addition, the direct impact on the Habitat and Species will have negative indirect and time lag affect on the Economic pillar. The estimated portion of the Direct Damage of Habitat and Species which has affected indirectly on Economic Pillar is set at 10%

Finally, the direct impact on the Cultural Sites will have negative indirect and time lag affect on the Economic pillar. The estimated portion of the Direct Damage on the Cultural Sites which indirectly and negatively affects the Economic Pillar is estimated as 10%.

Cultural Pillar:

Direct Damages and Indirect Damages for the Cultural Pillar is shown in Figure 3.24.

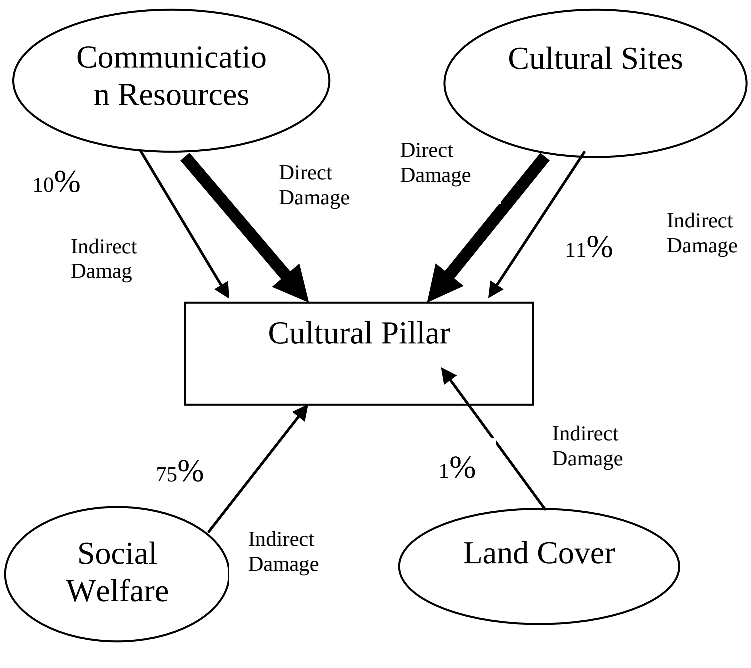

Figure 3.23: Dynamics Interactions in the Cultural pillar in the SD model

Direct Damages: As can be seen in Figure 3.24, the Cultural Pillar has two sources of Direct Damages “Communication Resources” and “Cultural Sites”. The Cultural Pillar also has Indirect Damages over the period of three weeks. Total Damage of the Cultural Pillar is sum of the Direct Damages and Indirect Damages over the weekly period. Each of the Indirect Damages is a portion of Direct Damage from another Pillar or the Cultural Pillar itself.

Indirect Damages: The Direct Damage of Social Welfare has negative lag affect on the Cultural pillar. It is estimated and modelled that 75% of Direct Damage of Social Welfare is considered as an Indirect Damage of the first week after the Storm Scenario event for the Cultural Pillar. In subsequent weeks, the Indirect Damage after the Storm Scenario event is estimated and modelled as 75% of the time decay function of the Direct Damage of Social Welfare, namely, Indirect Damage in week t is 75% *[(Direct Damage of Social Welfare)^1/t], for t=2,3.

Similarly, the direct impact on the “Hydrology, Land Use & Land Cover” will have negative indirect and time lag affect on the Cultural pillar. The estimated portion of the Direct Damage of “Hydrology, Land Use & Land Cover” which has affected indirectly on the Cultural Pillar is set at 1%.

In addition, the direct impact on the Communication Resources will have negative indirect and time lag affect on the Cultural pillar. The estimated portion of the Direct Damage of Communication Resources which has affected indirectly on Cultural Pillar is set at 10%

Finally, the direct impact on the Cultural Sites will have negative indirect and time lag affect on the Cultural pillar. The estimated portion of the Direct Damage on the Cultural Sites which indirectly and negatively affects the Cultural Pillar is estimated as 11%.

3.4.2 Direct Damage Estimation Procedure

As it mentioned above, the input of the STELLA Model is Direct Damages. Direct Damage is a portion of Total Damage and Total Overall Damage (TOD) is the sum of Total Storm Damages (TSD) attributed to each of the four Community Profile pillars:

[3-1] $$\mathrm{TOD} = \sum_{i=1}^{4} \mathrm{TSD}_i$$

Where i = 1,2,3,4 (for Environmental, Economic, Social, and Cultural Pillars)

[3-2] $$TSD_i = TDD_i + TID_i$$

Where i = 1,2,3,4 (for Environmental, Economic, Social, and Cultural Pillars)

[3-3] $$TDD_i = \sum_{k=1}^{2} DD_i \,\hat{}\,(k)$$

Direct Damage (DD) for each pillar (i) with respect to the different indicator layers (k) by pillar is shown in Table 3.15 below:

Indicator (k) / Pillar (i)	Indicator Layer (1)	Indicator Layer (2)
Environmental (1)	Habitat and Species	Land Cover
Economic (2)	Built Environment	Public Works
Social (3)	Wage Earning	Social Welfare
Cultural (4)	Communication Resources	Cultural Sites

Table 3.15: Direct Damage for each pillar with two different sources

[3-4] $$TID_i = \sum_{t=1}^{2} TID_i\,(t)$$

[3-5] $$TID_i(t) = \sum_{j=1}^{4} \sum_{k=1}^{2} C_{ijk} * DD_j \,\hat{}\,(1/t)$$

Where i and j = 1,2,3,4 (for Environmental, Economic, Social, and Cultural Pillars)

And k=*1, 2* for the indicators of Table 3.15

And C is constant for each *ijk* combination as in Table 3.16 below

And t=1, 2, 3 weeks.

The constant values (C) assumed for the ijk combinations are shown in Table 3.16 below:

Pillar (j)	Indicator (k)		Pillar (i)			
			Environmental (1)	Economic (2)	Social (3)	Cultural (4)
Environmental (1)	(1)	Habitat & Species	20%	10%	0.1%	-
	(2)	Land Cover…	1%	-	-	-
Economic (2)	(1)	Built Environment	10%	20%	1%	-
	(2)	Public Works	10%	20%	10%	-
Social (3)	(1)	Wage Earning	-	100%	-	-
	(2)	Social Welfare	-	-	10%	75%
Cultural (4)	(1)	Communication Resources	-	-	4%	11%
	(2)	Cultural Sites	-	10%	10%	10%

Table 3.16: Constant multipliers (C) of Pillar Indicators for Direct Damage

It is noted that the functional forms (Equation 3.6), and the c constant multipliers of Table 3.16 that are assumed in this model are not based on empirical observations or known data (for which there are none). As such, these values have been determined based on "best guess", and reasonable intuition about the dynamics of the various pillar and expected storm damage impacts. These "best guesses" are derived from the limited information of storm histories (section 2.5.3) and their impacts (section 2.5.4) applied across the four pillars in a logical fashion. The presentation of the SD functional forms and model parameters are provided to illustrate the modelling exercise, and to stimulate academic and community feedback and discussion. They are not provided as definitive model valuations but rather as a means to provoke future structured data gathering exercises from observed storm impacts.

In this section indirect damages and their interaction between the four Community Profile pillars are discussed. The result of the STELLA model are the estimated Total Damage of each pillar including the Total Direct Damage, and the Total Indirect Damages for each Community Profile pillar for each Storm Scenario I to VI. These results are compared as graphics and tables for all six Storm Scenarios. The STELLA Model interface is shown in Figure F.1 in Appendix F and all STELLA equations of the Model are available in Appendix F.

4 GIS Total Damage Analysis and Estimation

This chapter and the next present the significant results of this study. In Chapter 4, we present the first phase of the total damage estimates based on the GIS spatial and Community Profile pillar asset valuations methodology described in Chapter 3. In the penultimate chapter, Chapter 5, total damage estimates from the GIS model are the inputs to the dynamic storm impacts of the SSD model to estimate storm damage over time for Isle Madame.

In this chapter, Total damage estimates from Storm Scenarios for Isle Madame are determined. These estimates are based on the GIS spatial information presented in Chapter 3, and Community Profile pillars for Environment, Economics, Social, and Cultural dimensions of Isle Madame. To this end, this chapter is divided into the following sub-sections: (4.1) Impacts of Storm Scenarios; (4.2) Assets at Risk Analysis; and (4.3) Total Damages Estimates.

4.1 Impacts of Storm Scenarios

The Maximum Observed Water Level (MOWL) is used in the sea level rise tool (SLRT) from the ArcGIS spatial model to determine vulnerable spatial assets for the Storm Scenarios. Given the best available digital elevation data for Isle Madame (at the 1:50,000 scale level), only integer-valued sea level rise levels (in meters) can be considered. Of importance to the case of Isle Madame, and based on the historical storm surge data (Section 3.3), MOWLs between 1 meter and 2 meters water level are of interest to this study.

The consequence of the limited elevation data means that only Storm Scenario I (MOWL of 1 meter, Table 3.11) and Storm Scenario V (MOWL of 2 meters, Table 3.11) are explicitly modelled using the ArcGIS to find the line of flooding due to MOWL impacts on the current state of Isle Madame. Interpolating the data found in these two scenarios, the impacts of the other three Storm Scenarios (II through IV) can be found (Storm Scenario VI impacts are found by extrapolating beyond Storm Scenario V). The impacts are categorized into the four Community Profile pillars of this study (Environmental, Economic, Social and Cultural). Immediate or direct physical impacts of the Storm Scenarios are examined in this section including the storm damage to tree areas and parks, buildings, public works, and historic and cultural sites. Indirect storm impacts, such as lingering employment income loss, education stoppages, health impacts from isolation of the aged and the very young over time, are not considered to be solely immediate physical impacts but are treated temporally and discussed further in the SSD model damages results of Chapter 5. These temporal impacts also account for the critical 72 hour post-storm period that is used by first responders as a measure of storm impacts on isolated and vulnerable community members.

The following sub-sections estimate specific Community Profile impacts arising from the storm model “anchors”, Storm Scenarios I and V.

4.1.1 Storm Scenario I

As is mentioned above, Storm Scenario I, the lowest level of severe storms affecting Isle Madame is modelled as a storm with storm speed range of 30 – 39 kph, storm wind range of 35 – 56 kph, storm pressure range of 1010 – 1019 mb, and water level rise (MOWL) of 1 meter (Table 3.11). One meter of maximum observed water level (MOWL) will apply in the ArcGIS SLRT model, and the impacted spatial sites compared against the current state of Isle Madame with respect to the four pillars: environmental, economic, social and cultural.

4.1.1.1 Environmental pillar

All impacts on the designated Environmental pillar layers (Table 3.3) after applying one meter sea level rise in ArcGIS for the case of Isle Madame are summarized in Table 4.1 below. In Table 4.1 “affected” points or polylines from the GeoNova (2006) spatial database indicate the number of items that fall on the water side of the MOWL rise.

Item	Layer	Number of points or polylines affected (approximate space)
Hydrology, Land Use & Land Cover	Breakwater	3
	Tree area and park	420 (5.5 sq km)

Table 4.1: Summary of Environmental items impacted by the one meter sea level rise, Storm Scenario I. Source: GeoNova (2006)

Compared to the Environmental assets (Table 3.14), few Environmental items are impacted, i.e., flooded, as an expected consequence of Storm Scenario I, as noted in Table 4.1 above.

4.1.1.2 Economic pillar

Storm Scenario I spatial impacts on the Economic pillar layers after a one meter sea level rise in ArcGIS for the case of Isle Madame are summarized in Table 4.2 below. In Table 4.2, "affected" points or polylines indicate the number of items that fall on the water side of the MOWL rise.

Item	Layer	No of points or polylines affected (approximate space)
Built Environment	Buildings	166
	Plants (factory)	4
Public works	Light house stations	3
	Sewage treatment plant	3
	Wharf & WharvesRich & "Petit de Grat marina"	50+1"Petit de Grat marina"
	Collector highway	10(1.67 km)
	local road	99(14.1 km)
	Bridge	6(0.6 km)
	Streets	13(0.6 km)
	cart track	56(15.8 km)

	Culvert	19
	Airstrip	1(0.1 km)
Industry by type	D: Manufacturing	1
	H: Finance, Insurance and Real Estate	1
	I: Health care, and social services, educational services	2

Table 4.2: Summary of Economic items impacted by Storm Scenario I
Source: GeoNova (2006) and DMTI (2009)

As can be seen in Figure 4.1 below, the red points illustrate the impacted buildings after a Storm Scenario I, one meter rise of sea level. The affected buildings are denoted by 166 points within the 1m MOWL buffer line. Moreover, there are four points affected in the Industry by type including: (i) the Credit union central of Nova Scotia in Petit de Grat (from division H of SIC database); (ii) Lenoir Forge Museum in Arichat (from division I of SIC database); (iii) Isle Madame Water and Sky Paddling Adventures company in Arichat (from division I of SIC database), and (iv) the Isle Madame Machining company in West Arichat (from division D of SIC database). It is noted that SIC code items "I" are tourist destinations and activities. Along with the storm impacts on the transportation systems (including roads, and streets), coastal storms act as a deterrent to tourism for Isle Madame.

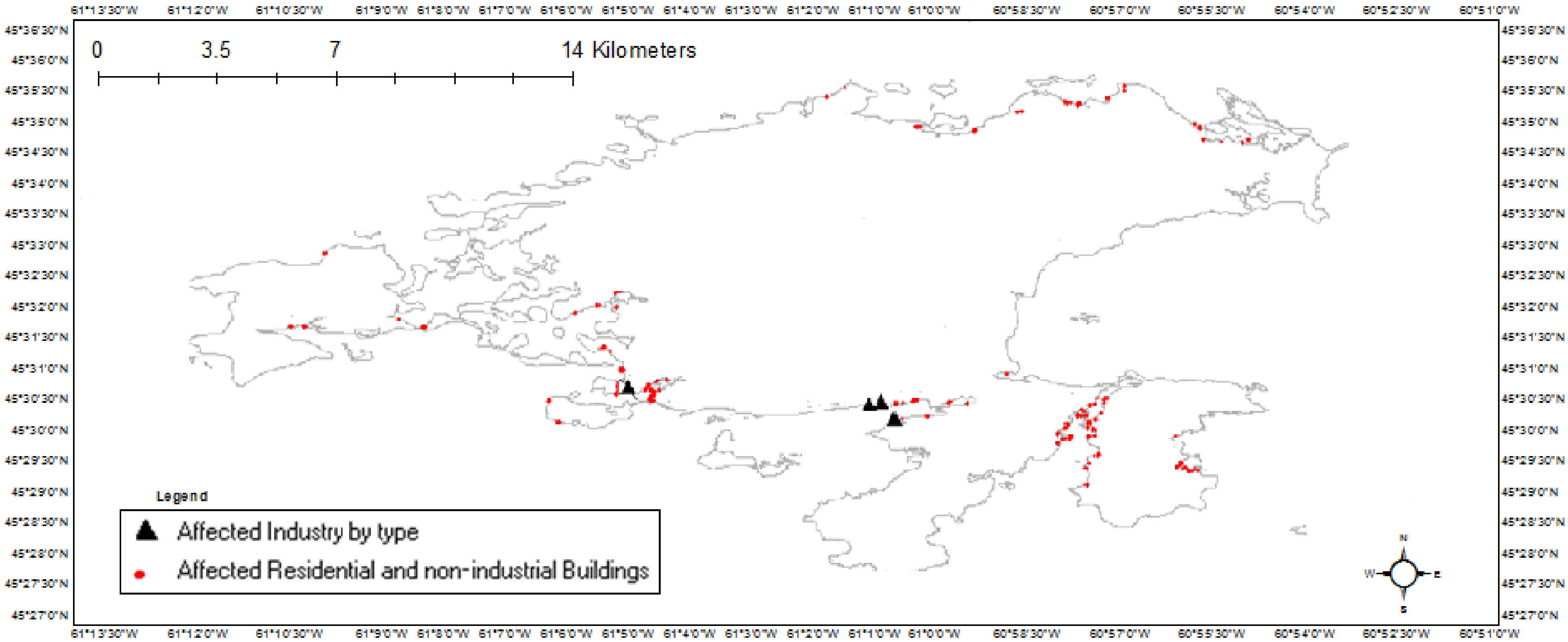

Figure 4.1: Impacted buildings and industries by type after A Storm Scenario I

Source: GeoBase (2010) and GeoNova (2006)

4.1.1.3 Social pillar

The Social impacts associated with Storm Scenario I are determined by examining the population impacts, as follows:

- Population related Storm Scenario I impacts: there are two identified groups of people who are in danger because of their age. These are: people over 60 years old, and children under 14 years old. Data about the number of these people in Isle Madame overall is reported in Table 3.7 above. Moreover, Table 3.7 shows the “total number of families” and the “total number of occupied private dwellings”. Therefore, the estimated number of people in these affected age groups who are in danger is calculated as below:

  (4-1)

  Average number of people over 60 year-old per private dwelling ≈ (Total Population over 60 years of age) / (Total number of occupied private dwellings)

  (4-2)

  Average number of children under 14 year-old per private dwelling ≈ (Total Population under 14 years of age) / (Total number of occupied private dwellings)

From the GeoNova (2006) data, there are a total of 2889 buildings in Isle Madame (Table 3.4). According to the Census 2006 data (Statistics Canada 2007), there are 1380 occupied private dwellings. Therefore, from the equation below, the average number of private dwellings affected by the Storm Scenario I is calculated.

(4-3)

Average number of private dwellings affected by Storm Scenario (i) ≈ (Total number of occupied private dwellings * Number of affected buildings in Isle Madame from Storm Scenario (i)) / (Total number of buildings in Isle Madame)

For (i) =I, II... VI

Finally, the average number of people over 60 years old and children under 14 years old who are vulnerable to Storm Scenario I are found from equations (4-4) and (4-5).

(4-4)

Population of people over 60 years old vulnerable to Storm Scenario(i) ≈ Equation (4.1) * Equation (4.3) for (i) =I, II, to VI

(4-5)

Population of children under 14 years old vulnerable to Storm Scenario(i) ≈ Equation (4.2) * Equation (4.3) for (i) =I, II, to VI

- <u>Lost Employment related impacts:</u> these impacts are related to total lost of income as a result of Storm Scenario I. Table 3.7 gives data for median household income per year and also the total number of occupied private dwellings. Therefore, from all data the total loss of income for each scenario can be calculated. It is assumed that the number of working days per year is assumed 256 days.

(4-6)

Average Income per Day per Household ≈ (Median Household Income per year from all DAs) / (256 working days/year)

From equation (4-6), the average income per day per household on Isle Madame is approximately $173.40 (from Statistic Canada (2007) Median Income per year for all DAs is $44,383 and total working days per year is 256). Now, from equation (4-7), total lost income for each Storm Scenario can be calculated using the statistics by Storm Scenario for length of storm as reported in Table 3.12.

(4-7)

Total Income at risk to lost in Scenario (i) ≈ (Average Income per Day per Household) * (Total number of privet dwelling) * (length of Scenario (i) in days)

For (i) =I, II... VI

An important social layer is the additional health cost incurred as a consequence of the storm from supporting the vulnerable population of the community (the very young and the older age groups) who are expected to require additional health care for an average of 7 days after the storm. Health costs are estimated as $200 per person per day. Therefore, average total health cost can be calculated by equation (4-8) below:

(4-8)

Average Total Health Cost for Storm Scenario (i) ≈ (Population of people over 60 years old vulnerable to Storm Scenario (i)) + (Population of children under 14 years old vulnerable to Storm Scenario (i)) * 200 per day * (7 days) for (i) =I, II, to VI

Table 4.3 illustrates the summary of damage impacts from Storm Scenario I on the Social pillar layers for Isle Madame.

Item	Layer	Number of Points/Amount Affected
Population Statistics	Pop of people over 60 years old vulnerable to Storm Scenario I	52
	Pop of children under 14 years old vulnerable to Storm Scenario I	28
Employment Statistics	Total lost Income at risk in Storm Scenario I	$239,292
Health care	Additional health care cost of Storm Scenario I	$112,000
Health	Hiking trail	3
	Sport field	1
	Senior Citizen Home	1

Table 4.3: Summary of Social items impacted by the one meter sea level rise, Storm Scenario I

Source: GeoNova (2006) and Statistics Canada (2007)

4.1.1.4 Cultural pillar

All impacts on Cultural pillar layers after applying one meter sea level rise in ArcGIS for the case of Isle Madame are summarized in Table 4.4 bellow.

Item	Layer	Number of Points Affected
Areas of Significance	Museum	1
	Cemetery	1
	Historic site	2

Table 4.4: Summary of Cultural items impacted by the one meter sea level rise, Storm Scenario I
Source: GeoNova (2006)

4.1.2 Storm Scenario V

As for the Storm Scenario I impacts analysis presented in the previous subsection, this subsection presents the impacts for Storm Scenario V. Storm Scenario V is defined by storm speed range of 70 – 79 kph, storm wind range of 123 – 144 kph, and storm pressure range 970 – 979 mb. Two meters of maximum observed water level (MOWL) (Table 3.11) are applied in the ArcGIS spatial model to indicate the flooded area and the results are examined against the current state of Isle Madame in terms of the four pillars: Environmental, Economic, Social and Cultural.

4.1.2.1 Environmental pillar

Impacts on environmental layers after applying two meters sea level rise in ArcGIS for the case of Isle Madame are summarized in Table 4.5 below.

Item	Layer	Number of points or polylines affected (approximate space)
Hydrology, Land Use & Land Cover	Breakwater	3
	Tree area and park	461 (6.7 sq km)

Table 4.5: Summary of Environmental pillar items impacted by the two meters sea level rise, Storm Scenario V. Sources: GeoNova (2006)

Compared to the Environmental assets (Table 3.3), few Environmental pillar items are expected to be impacted, i.e., flooded, as an expected consequence of Storm Scenario V.

4.1.2.2 Economic pillar

All impacts on Economic pillar layers after applying two meters MOWL rise in ArcGIS for the case of Isle Madame are summarized in Table 4.6 bellow.

Item	Layer	Number of points/ polylines affected (approximate space)
Built Environment	Buildings	269
	Plants (factory)	4
Public works	Light house stations	3
	Sewage treatment plant	3
	Wharf and WharvesRich& "Petit de Grat marina"	50+1"Petit de Grat marina"
	Collector highway	19 (2.48 km)
	Local road	128 (18 km)
	Bridge	8 (0.8 km)
	Streets	17 (1 km)
	Cart track (unpaved Road)	89(28.7 km)
	Culvert	27
	Airstrip	3 (0.3 km)
Industry by type	D: Manufacturing	1
	G: Retail Trade	1
	H: Finance, Insurance and Real Estate	1
	I: Heatlh care, and social services, educational services	2

Table 4.6: Summary of Economic pillar items impacted by the two meter sea level rise, Storm Scenario V

Source: GeoNova (2006) and DMTI (2009)

According to Table 4.6 there are five points affected in industry by type item which are: (i) Credit union central of Nova Scotia (from division H of SIC database); (ii) Lenoir Forge Museum (from division I of SIC database); (iii) Isle Madame Water and Sky Paddling Adventures company (from division I of SIC database); and (iv) Isle Madame Machining company (from division D of SIC database), and (v) Frank's Marine LTD (from division G of SIC database). Four of these items were included in Storm Scenario I impacts (Table 4. 2).

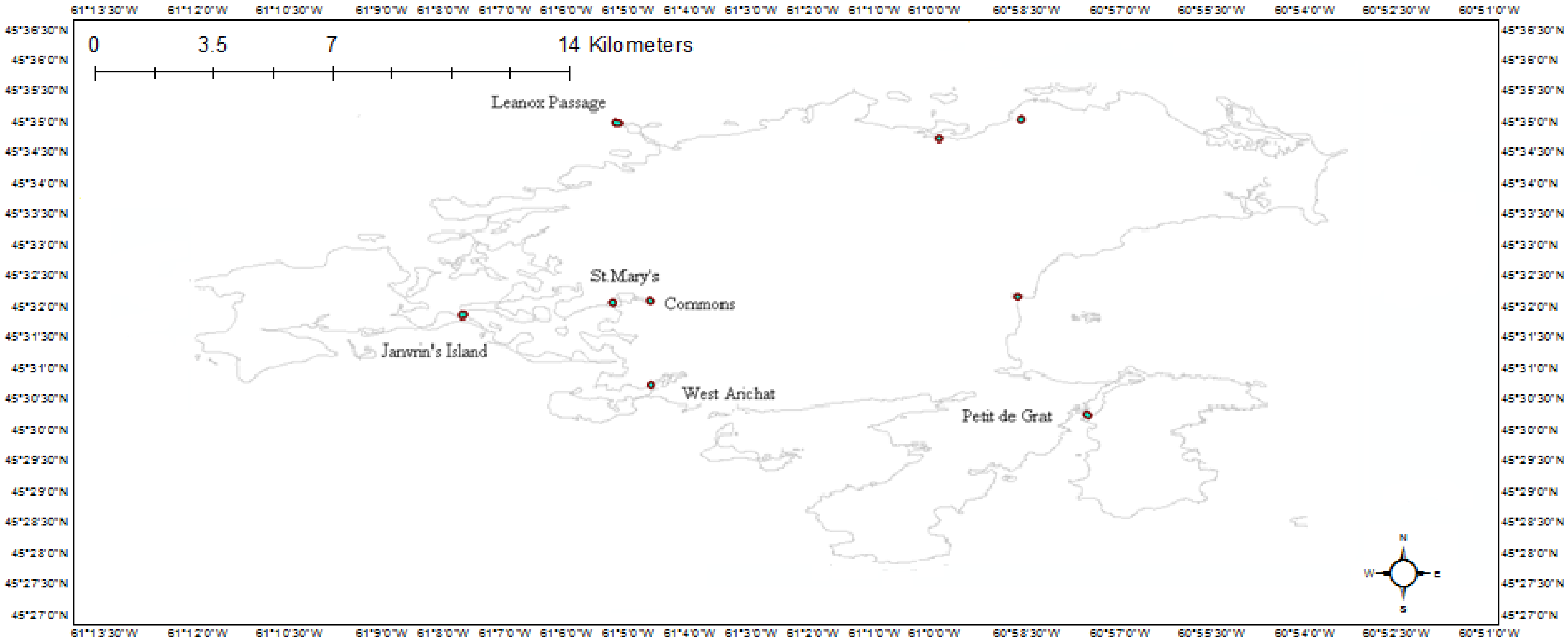

Figure 4.2: Impacted bridges from a Storm Scenario V event

Source: GeoBase (2010) and GeoNova (2006)

Impacts on the Economic pillar after experiencing two meters sea level rise include bridges. As can be seen in Figure 4.2 there are 8 bridges at risk from a two meter rise.

4.1.2.3 Social pillar

Social impacts after a modelled Storm Scenario V include items directly affecting the population within the community of Isle Madame. These impacts are identified as follows:

- Population related Storm Scenario V impacts: there are two identified groups of people who are in more in danger because of their age, people over 60 years old and children under 14 years old. Data about the number of these people in Isle Madame are provided in Table 3.4. Moreover, Table 3.4 shows the total number of families and the total number of occupied private dwellings.
- Lost Employment related impacts: these impacts are related to total loss of income as a result of the modelled Storm Scenario V including people from the community who are unable to travel to their worksite and earn income. Table 3.4 gives data for median household income per year and also the total number of occupied private dwellings. Equations (4-6) and (4-7) are used for the calculation of lost income to isolated individuals who are unable to work because of the storm.

Table 4.7 illustrates the summary of Social pillar impacts of Storm Scenario V on the social layers of Isle Madame.

Item	Layer	Amount / Number
Population Statistics	Pop of people over 60 years old vulnerable to Storm Scenario V	85
	Pop of children under 14 years old vulnerable to Storm Scenario V	45
Employment Statistics	Total Income at risk to loss from Storm Scenario V	$717,876
Health care	Additional health care cost of Storm Scenario V	$182,000
Health	Hiking trail	3
	Sport field	2
	Senior citizen home	1

Table 4.7: Summary of Social items impacted by the two meter sea level rise, Storm Scenario V

Source: GeoNova (2006) and Statistics Canada (2007)

4.1.2.4 Cultural pillar

Cultural impacts due to a modelled Storm Scenario V include items directly affecting the special point of interest to the community. These impacts are attributed to the Cultural pillar layers for a two meters sea level rise in ArcGIS for the case of Isle Madame. These are summarized in Table 4.8 below.

Item	Layer	Affected
Areas of Significance	Museum	1
	Cemetery	2
	Historic site	2

Table 4.8: Summary of Cultural pillar items impacted by the two meters sea level rise, Storm Scenario V

Sources: GeoNova (2006)

Figure 4.3 shows Cultural pillar layers after applying two meters sea level rise to the spatial model. The points on the map below are layers which may be affected or damaged by the storm.

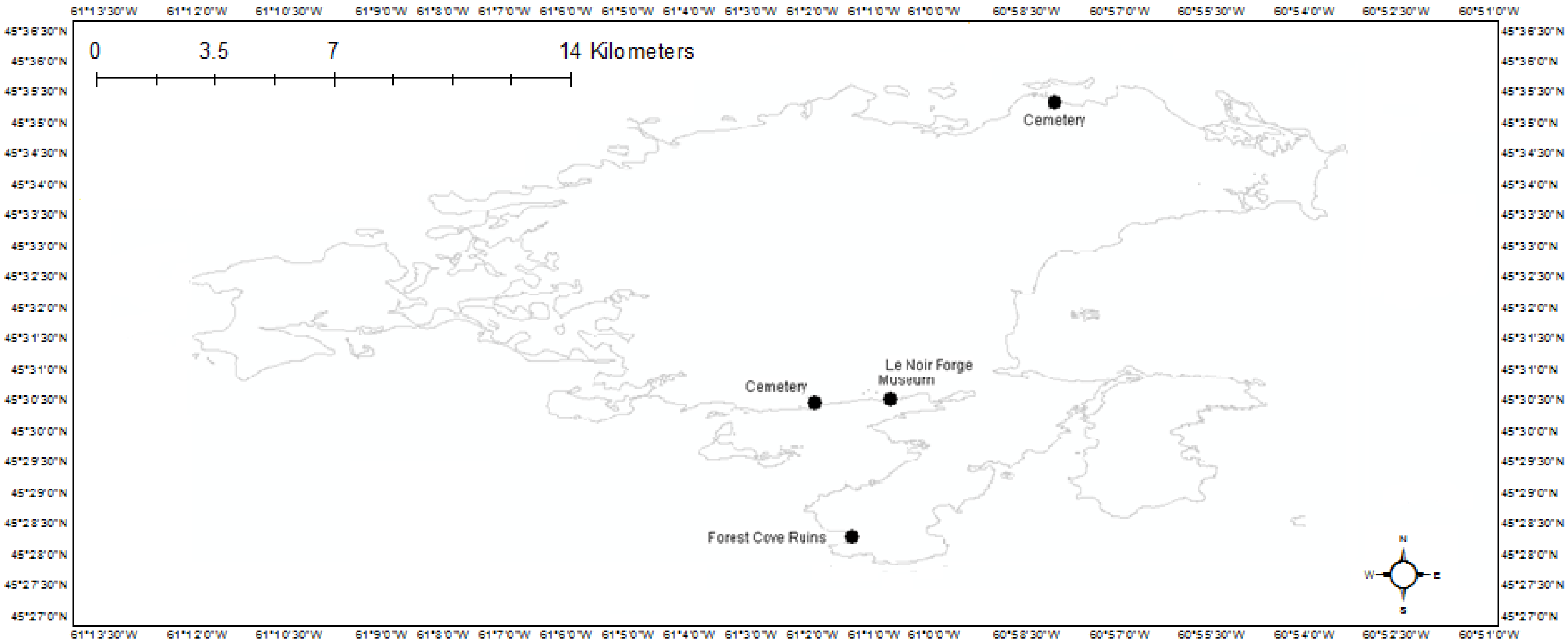

Figure 4.3: Impacted Cultural Pillar after Storm Scenario V

Source: GeoBase (2010) and GeoNova (2006)

4.1.3 Interpolating and Extrapolating Storm Scenario Impacts

In this subsection, the results of the expected impacts of Storm Scenario I and Storm Scenario V are compared. These impacts are then applied to the other modelled Storm Scenarios (II, III, IV, and VI). The impacts are calculated by simple interpolation (or, for the case of Storm Scenario VI, extrapolation) of the impacts results previously described for Storm Scenarios I and V, as described in subsections 4.1.1 and 4.1.2 above.

4.1.3.1 Environmental pillar

In this subsection, the intermediate storm scenario impacts are applied assuming intermediate flooding between one meter and two meters sea level rise on the Environmental pillar layers of Isle Madame. Table 4.9 shows the comparison between Storm Scenarios I and V.

Item	Layer	Storm Scenario I	Storm Scenario V
Hydrology, Land Use & Land Cover	Breakwater	3	3
	Tree area and park	420 (5.5 sq km)	461(6.7 sq km)

Table 4.9: Impacts comparison of environmental layers between Storm Scenario I and V
Source: GeoNova (2006)

After comparison of the Storm Scenario I and V (Table 4.9), the intermediate impacts are applied by taking the simple, equally spaced averages for the other Storm Scenarios. The interpolated (or extrapolated) results are shown in Table 4.10 below.

Item	Layer	Storm Scenario I	Storm Scenario II	Storm Scenario III	Storm Scenario IV	Storm Scenario V	Storm Scenario VI
"Hydrology , Land Use & Land Cover"	Breakwater	3	3	3	3	3	3
	Tree area and park	5.5 sq km	5.8 sq km	6.1 sq km	6.4 sq km	6.7 sq km	7 sq km

Table 4.10: Impacts of Environmental pillar layers for all six Storm Scenarios
Source: GeoNova (2006)

As can be seen in Table 4.10, the three Breakwaters are initially flooded; all Storm Scenarios experience the flooding of these elements. The coastal tree area increases from the spatial estimate of 5.5 sq km to 7 sq km at the most severe storm. Overall, this is a relatively small impact on the tree area (on a total tree asset of 90 sq km, Table 3.3).

4.1.3.2 Economic pillar

In this section, like the previous one, all impacts on the Economic pillar layers for Storm Scenarios I and V are compared. Table 4.11 illustrates this comparison.

Item	Layer	Storm Scenario I	Storm Scenario V
Built Environment	Buildings	166	269
	Plants (factory)	4	4
Public works	Light house stations	3	3
	Sewage treatment plant	3	3
	Wharf and WharfRich and “Petit de Grat marina”	50+1“Petit de Grat marina”	50+1“Petit de Grat marina”
	Collector highway	10 (1.67 km)	19 (2.48 km)
	local road	99 (14.1 km)	128 (18 km)
	Bridge	6 (0.6 km)	8 (0.8 km)
	Streets	13 (0.6 km)	17 (1 km)
	cart track	56 (15.8 km)	89 (28.7 km)
	Culvert	19	27
	Airstrip	1 (0.1 km)	3 (0.3 km)
Industry by type	D: Manufacturing	1	1
	G: Retail Trade	0	1
	H: Finance, Insurance and Real Estate	1	1
	I: Heath care and social services educational services	2	2

Table 4.11: Impacts comparison of Economic pillar layers comparing Storm Scenario I and V
Source: GeoNova (2006) and DMTI (2009)

As before, after simple interpolation and extrapolation of these spatial impacts, the prediction of other Storm Scenarios (II, III, IV, and VI) is shown in Table 4.12 below.

As can be seen in Table 4.12, the four factories, three Light house stations, three Sewage treatment plant, 50 wharves + one Petit de Grat marina are initially flooded; all Storm Scenarios experience the flooding of these elements. Moreover, from industry by type all Storm Scenarios experience the flooding of one element from division D, one element from division H, and two elements from division I. However, one element from Division G is affected by Storm Scenario I to III this number increase to two from Storm Scenario IV to VI. Other elements in Economic Pillar increase from Strom Scenario I to VI gradually.

Item	Layer	Storm Scenario I	Storm Scenario II	Storm Scenario III	Storm Scenario IV	Storm Scenario V	Storm Scenario VI
Built Environment	Buildings	166	192	217	243	269	295
	Plants (factory)	4	4	4	4	4	4
Public works	Light house stations	3	3	3	3	3	3
	Sewage treatment plant	3	3	3	3	3	3
	Wharf/wharvesRich/“Petit de Grat marina”,	50+1“Petit de Grat marina”	50+1“Petit de Grat marina”	50+1“Petit de Grat marina”	50+1“Petit de Grat marina”	50+1“Petit de Grat marina”	50+1“Petit de Grat marina”
	Collector highway	10 (1.67 km)	12(1.86 km)	15(2.1 km)	17(2.3 km)	19 (2.48 km)	21(2.6 km)
	local road	99 (14.1 km)	106(14.8 km)	113(16.1 km)	121(16.8 km)	128 (18 km)	136(18.9 km)
	bridge	6 (0.6 km)	6(0.6 km)	7(0.7 km)	7(0.7 km)	8 (0.8 km)	8 (0.8 km)
	streets	13 (0.6 km)	14(0.7 km)	15(0.8 km)	16(0.9 km)	17 (1 km)	18(1.1 km)
	Unpaved roads	56 (15.8 km)	64 (19.1 km)	72(22.4 km)	81(25.3 km)	89 (28.7 km)	97(31.8 km)
	Culvert	19	21	23	25	27	29
	Airstrip	1 (0.1 km)	1(0.1 km)	2(0.2 km)	2(0.2 km)	3 (0.3 km)	3(0.3 km)
Industry by type	D: Manufacturing	1	1	1	1	1	1
	G: Retail Trade	0	0	0	1	1	1
	H: Finance, Insurance and Real Estate	1	1	1	1	1	1
	I: Health care, and social services, educational services	2	2	2	2	2	2

Table 4.12: Impacts of Economic pillar layers for all Storm Scenarios

Source: GeoNova (2006) and DMTI (2009)

4.1.3.3 Social pillar

This section indicates the Social pillar impacts of all six Storm Scenarios for Isle Madame. Table 4.13 illustrates the summary of impacts of Storm Scenarios I and V on the Social pillar layers of Isle Madame's Community Profile.

Item	Layer	Storm Scenario	Affected Amount / Number by Storm Scenario (Approximate space)
Population Statistics	Vulnerable Pop of people over 60 years old	I	52
		V	85
	Vulnerable Pop of children under 14 years old	I	28
		V	45
Employment Statistics	Lost Total Income	I	$239,292
		V	$717,876
Health care	Additional health care cost of Storm Scenario I	I	$112,000
		V	$182,000
Health	Hiking trail	I	3(4.6 km)
		V	3(4.6 km)
	Sport field	I	1
		V	2
	Senior citizen home	I	1
		V	1

Table 4.13: Summary of impacts of Storm Scenario I and V on Social pillar layers of Isle Madame

Source: Statistics Canada (2007)

Table 4.14 shows the comparison of impacts from all six Storm Scenarios on the Social pillar layers of Isle Madame.

Item	Layer	Storm Scenario	Affected Amount / Number by Storm Scenario
Population Statistics	Vulnerable Pop of people over 60 years old	I	52
		II	60
		III	68
		IV	76
		V	85
		VI	93
	Vulnerable Pop of children under 14 years old	I	28
		II	32
		III	36
		IV	41
		V	45
		VI	49
Employment Statistics	Lost Total Income	I	$239,292
		II	$358,938
		III	$478,584
		IV	$598,230
		V	$717,876
		VI	$837,522
Health care	Additional health care cost	I	$112,000
		II	$128,800
		III	$145,600
		IV	$163,800
		V	$182,000
		VI	$198,800
Health	Hiking trail	I	3 (4.6 km)
		II	3(4.6 km)

		III	3(4.6 km)
		IV	3(4.6 km)
		V	3(4.6 km)
		VI	3 (4.6 km)
	Sport field	I	1
		II	1
		III	1
		IV	2
		V	2
		VI	2
	Senior citizen home	I	1
		II	1
		III	1
		IV	1
		V	1
		VI	1

Table 4.14: Impacts of all six Storm Scenarios on Social pillar layers of Isle Madame
Source: Statistics Canada (2007)

As can be seen in Table 4.14, the one Senior citizen home and 4.6 km hiking trail are initially flooded; all Storm Scenarios experience the flooding of these elements. The only one Sport field affected by first three Storm Scenarios but this number increases to two for last three Storm Scenarios. The number of vulnerable people and additional health cost grow from Storm Scenario I to VI. Moreover, more income is lost from Storm Scenario I to VI.

4.1.3.4 Cultural pillar

This section indicates the Cultural pillar impacts of all six Storm Scenarios for Isle Madame. Table 4.15 presents the summary of impacts of Storm Scenarios I and V on the Cultural pillar layers of Isle Madame's Community Profile.

Item	Layer	Storm Scenario I	Storm Scenario V
Areas of Significance	Museum	1	1
	Cemetery	1	2
	Historic site	2	2

Table 4.15: Summary of impacts of Storm Scenario I and V on Cultural pillar layers of Isle Madame
Source: GeoNova (2006)

By interpolating and extrapolating the available data on impacts of Storm Scenarios I and V on the Cultural pillar impacts, the impacts for the other Storm Scenarios are predicted and illustrated in Table 4.16.

Item	Layer	Storm Scenario I	Storm Scenario II	Storm Scenario III	Storm Scenario IV	Storm Scenario V	Storm Scenario VI
Areas of Significance	Museum	1	1	1	1	1	1
	Cemetery	1	1	1	2	2	2
	Historic site	2	2	2	2	2	2

Table 4.16: Impacts of all six Storm Scenarios on Cultural pillar layers of Isle Madame
Source: GeoNova (2006)

4.2 Assets at Risk Analysis

In this section, monetary values are assigned to the vulnerable assets at risk from storms as modelled Storms Scenarios I through VI (i.e., within the storm and flooded areas). Subsections include: (1) Subsection (4.2.1) compares all six Storm Scenarios to determine their monetary "assets at risk" value by each of the four pillars of the community profile, and (2) Subsection (4.2.2) provides a summary of the total "assets at risk" for each of the four Community Profile pillars. In this study, the approach of "cost at risk" of community assets used McCulloch et al. (2002) is the basis for the "assets at risk" estimates provided in this research.

The "Assets at Risk" values for Storm Scenario I and V are estimated and presented in Table 4.17 below. Based on the information in Table 4.17 for Storm Scenarios I and V, estimates for the remaining Storm Scenarios II, III, IV, and VI are calculated based on the unit valuations applied to Tables 4.10, 4.12, 4.14, and 4.16 for each of the Community Profile pillars.

4.2.1 Assets at Risk: Environmental Pillar

As can be seen in Table 4.17, the "Asset at Risk" value of Isle Madame "Breakwater" (Environmental pillar item) is the same for all Storm Scenarios I through VI. All (3) identified Breakwaters in Isle Madame (GeoNova 2006) are in the vulnerable area (buffer zone) after a one meter MOWL rise. Breakwaters have estimated replacement value of $1,350,000 (Section 3.3.6 above.)

Similarly the "Asset at Risk" value of "Habitat", and "Resources" remain the same in both Storm Scenarios I and V, since all elements of these layers are at risk and vulnerable to a MOWL rise of one (and greater) meter. The "Asset at Risk" value of Tree area and Parks increased from Storm Scenario I to VI, as the size of the flooded Tree area became larger as the storms scenario (and sea level rise, storm surge) increased with larger MOWL rise from one metre to two meters (refer to Table 4.9). And the value is calculated based on $180,000 per sq km.

4.2.2 Assets at Risk: Economic Pillar

According to Table 4.17 below, the "Assets at Risk" values of Plants (factories), Light house stations, Sewage treatment plant, and Wharf and WharvesRich (including the Petit de Grat marina), layers remain the same in both Storm Scenario I and V, because the same number of elements of these layers are at risk and vulnerable to the MOWL rise of one (Table 4.11). Therefore the valuations of Assets at Risk for these items apply equally to all Storm Scenarios I through VI (Table 4.18).

The "Assets at Risk" values of other items under the Economic pillar have increased from Storm Scenario I to V, as the number of measurable vulnerable elements (e.g., space, numbers of units, etc.) of these layers increase within the expanding flood lines due to the MOWL rise from one meter to two meters (refer to Table 4.11) and the values are calculated from Section 3.3.6. For example, in the case of Isle Madame Culverts, two times more culverts are flooded for Storm Scenario I (19) versus VI (29).

4.2.3 Assets at Risk: Social Pillar

Under the Social Pillar in Table 4.17, the "Asset at Risk" values of "Senior citizen home" and "Hiking trail" layers remain the same in both Storm Scenario I and V, because the same number of elements of these layers are at risk and vulnerable to MOWL rise from a one meter MOWL (refer to Table 4.13). The "Asset at Risk" values of the Sport field layer increased from Storm Scenario I (1) to V (2), because the number of vulnerable elements on the Sport field layer becomes more due to MOWL rise from one metre to two meters (refer to Table 4.13).

On the Social Pillar there is a modelled health safety risk which reflects the vulnerability of part of the community population who are over 60 years old and under 14 years old. Therefore, the "Asset at Risk" values of "Additional Health Care Cost" for Storm Scenario I and V is calculated from equation (4-8) under subsection (4.1.1.3).

Moreover, all households' income is at risk in the case of the Storm Scenarios. The "Asset at Risk" value of Total Lost Income increases from Storm Scenario I to V because the length of Storm Scenario increases from Storm Scenario I to V (Table 3.12). The "Asset at Risk" value of "Total lost Income" for Storm Scenario I to V is calculated from equations (4-7) under sub-section (4.1.1.3).

4.2.4 Assets at Risk: Cultural Pillar

According to Table 4.17, the "Asset at Risk" values of "Historic sites" and "Museum" layers remain the same in both Storm Scenario I and V, because the same number of elements of these layers are at risk and vulnerable to MOWL rise of one and two meters (refer to Table 4.15).

The "Asset at Risk" values of Cemetery and Church layer increased from Storm Scenario I to V, because the number of vulnerable elements on Cemetery and Church layer is more due to the MOWL rise from one metre to two meters (refer to Table 4.15).

In addition, the "Asset at Risk" value of "Communication resources" layer remains the same in both Storm Scenario I and V, because the all elements of "Communication resources" layers are considered to be at risk and vulnerable to the MOWL rise of one meter and greater.

Pillar	**At Risk**	**Assets at Risk Value** (Canadian Dollars)	
		I	**V**
Environment	Breakwater	$4,050,000	$4,050,000
	Habitat	$2,500,000	$2,500,000
	Resources	$5,000,000	$5,000,000
	Tree area and park	$990,000	$1,206,000
Economic	Buildings	$14,046,588	$22,762,242
	Plants (factory)	$2,848,900	$2,848,900
	Light house stations	$36,000	$36,000
	Sewage treatment plant	$10,000,000	$10,000,000
	Wharf & WharvesRich & Petit de Grat marina	$5,187,500	$5,187,500
	Collector highway	$1,066,737	$1,580,351
	local road and streets	$9,367,407	$12,107,533
	Bridge	$382,343	$637,238
	Unpaved roads	$170,003	$308,803
	Culvert	$62,700	$89,100
	Airstrip	$63,723	$191,171
	Industry by Type	$480,000	$640,000
Social	Total lost Income	$239,292	$717,876
	Additional Health Care Cost	$112,000	$182,000
	Hiking trail	$468,532	$468,532
	Sport field	$22,000	$44,000
	Senior citizen home	$ 404,600	$404,600
Cultural	Museum	$ 118,800	$118,800
	Communication resources	$5,000,000	$5,000,000
	Historic sites	$ 1,512,500	$1,512,500
	Cemetery and Church	$565,000	$1,130,000
Total		**$64,694,627**	**$78,723,146**

Table 4.17: Estimated "Assets at Risk" values for each community pillar for the anchor Storm Scenarios I (MOWL of 1m) and V (MOWL of 2m)

4.2.5 Storm Scenarios Assets at Risk

The Assets at Risk values for all six Storm Scenarios by pillar are shown in Table 4.18. Valuation details are discussed in the methodology and assets valuation of Chapter 3. Values for Table 4.18 are calculated from the information in Tables 4.10, 4.12, 4.14 and 4.16 provided above for identified special assets at risk.

As can be seen in Table 4.18, “Asset at Risk” values of “breakwater”, “Plants (factory)”, “Light house stations”, “Sewage treatment plant”, “Wharf and WharvesRich and Petit de Grat marina”, “Senior citizen home”, “Hiking trail”, “Historic sites” and “Museum” remain the same in all six Storm Scenarios, because the same number of elements of these layers are at risk and vulnerable to MOWL rise of one meter and greater.

Similarly, the “Asset at Risk” values of “Habitat”, and “Resources” and “Communication resources” layers remain the same in all six Storm Scenarios. The assumption is all elements of these layers are at risk and vulnerable to an MOWL rise of one meter and greater.

The “Asset at Risk” values of the other items including “Tree area”, “Sport field”, “Cemetery and Church”, “Buildings”, “Industrial by Type”, “Collector highway”, “Local road and streets”, “Bridges”, “Unpaved roads”, and “Culverts” layers increase as the Storm Scenario increases from I to VI. As noted above, this is due to the increasing number of vulnerable elements in each of these layers as the MOWL rises from one metre to two meters and more.

With respect to the Social Pillar, the asset at risk models the health and safety at risk from the severe storms. This reflects the vulnerability of part of the community population who are over 60 years old and under 14 years old. Therefore, the “Asset at Risk” values of “Additional Health Care Cost” for all six Storm Scenarios are calculated from equation (4-8) under sub-section (4.1.1.3). Moreover, all households’ income is at risk in case of Storm Scenarios but the “Asset at Risk” value of Total lost Income increases from all six Storm Scenarios because the length of Storm Scenario increases over Storm Scenario I to VI. Therefore, the “Asset at Risk” value of “Total lost Income” for all six Storm Scenarios is calculated from equations (4-7) under sub-section (4.1.1.3).

Pillar	At Risk	Assets at Risk Value (Canadian Dollars)					
		I	II	III	IV	V	VI
Environment	Breakwater	$4,050,000	$4,050,000	$4,050,000	$4,050,000	$4,050,000	$4,050,000
	Habitat	$2,500,000	$2,500,000	$2,500,000	$2,500,000	$2,500,000	$2,500,000
	Resources	$5,000,000	$5,000,000	$5,000,000	$5,000,000	$5,000,000	$5,000,000
	Tree area and park	$990,000	$1,044,000	$1,098,000	$1,152,000	$1,206,000	$1,260,000
Economic	Buildings	$14,046,588	$16,246,656	$18,362,106	$20,562,174	$22,762,242	$24,962,310
	Plants (factory)	$2,848,900	$2,848,900	$2,848,900	$2,848,900	$2,848,900	$2,848,900
	Light house stations	$36,000	$36,000	$36,000	$36,000	$36,000	$36,000
	Sewage treatment plant	$10,000,000	$10,000,000	$10,000,000	$10,000,000	$10,000,000	$10,000,000
	Wharf and WharvesRich and Petit de Grat marina	$5,187,500	$5,187,500	$5,187,500	$5,187,500	$5,187,500	$5,187,500
	Collector highway	$1,066,737	$1,185,263	$1,338,201	$1,548,448	$1,580,351	$1,750,420
	local road and streets	$9,367,407	$9,877,197	$10,769,332	$11,279,122	$12,107,533	$12,744,771
	Bridge	$382,343	$446,067	$509,790	$573,514	$637,238	$700,962
	Unpaved roads	$170,003	$205,510	$241,017	$272,220	$308,803	$342,159
	Culvert	$62,700	$69,300	$75,900	$82,500	$89,100	$95,700
	Airstrip	$63,723	$63,723	$127,447	$127,447	$191,171	$191,171
	Industrial by Type	$480,000	$480,000	$480,000	$640,000	$640,000	$640,000
Social	Total Income at risk to lost	$239,292	$358,938	$478,584	$598,230	$717,876	$837,522
	Additional Health Care Cost	$112,000	$128,800	$145,600	$163,000	$182,000	$198,800
	Hiking trail	$468,532	$468,532	$468,532	$468,532	$468,532	$468,532
	Sport field	$22,000	$22,000	$22,000	$44,000	$44,000	$44,000
	Senior citizen home	$404,600	$404,600	$404,600	$404,600	$404,600	$404,600
Cultural	Museum	$118,800	$118,800	$118,800	$118,800	$118,800	$118,800
	Communication resources	$5,000,000	$5,000,000	$5,000,000	$5,000,000	$5,000,000	$5,000,000
	Historic sites	$1,512,500	$1,512,500	$1,512,500	$1,512,500	$1,512,500	$1,512,500
	Cemetery and Church	$565,000	$565,000	$565,000	$1,130,000	$1,130,000	$1,130,000
Total		**$64,694,625**	**$67,819,286**	**$71,339,809**	**$75,299,487**	**$78,723,146**	**$82,024,647**

Table 4.18: Assets at Risk of layers in each pillar in Isle Madame by Storm Scenario I – VI

4.2.6 Summary

The "assets at risk" values for Isle Madame relative to the all six Storm Scenarios I-VI have been found for all four pillars of the Community Profile. This section compares the values of "assets at risk" for all pillars by Storm Scenario. The summary of the monetary comparison of "assets at risk" of all six Storm Scenarios is provided in Table 4.19. The graphical display of the summary is presented in Figure 4.4.

Storm Scenario / Pillar	I	II	III	IV	V	VI
Environmental	$12,540,000	$12,594,000	$12,648,000	$12,702,000	$12,756,000	$12,810,000
Economic	$43,711,901	$46,646,116	$49,976,193	$53,157,825	$56,388,838	$59,499,893
Social	$1,246,424	$1,382,870	$1,519,316	$1,678,362	$1,817,008	$1,953,454
Cultural	$7,196,300	$7,196,300	$7,196,300	$7,761,300	$7,761,300	$7,761,300
Total	**$64,694,625**	**$67,819,286**	**$71,339,809**	**$75,299,487**	**$78,723,146**	**$82,024,647**

Table 4.19: 'Assets at risk' monetary comparison of six Storm Scenarios

Figure 4.4 illustrates the comparison of "assets at risk" of the all six Storm Scenarios by the four pillars graphically. As can be seen from Table 4.19 and Figure 4.4, the Economic pillar for Isle Madame has by far the largest "Assets at Risk" valuation in all six Storm Scenarios at around $50million. The valuations for the Environmental ($12 million) and the Cultural ($7 million) pillars are similar. The "Assets at Risk" valuations for the Social pillar (less than $2 million) is relatively low at about 2.4% of the total estimated Assets at Risk from severe storms.

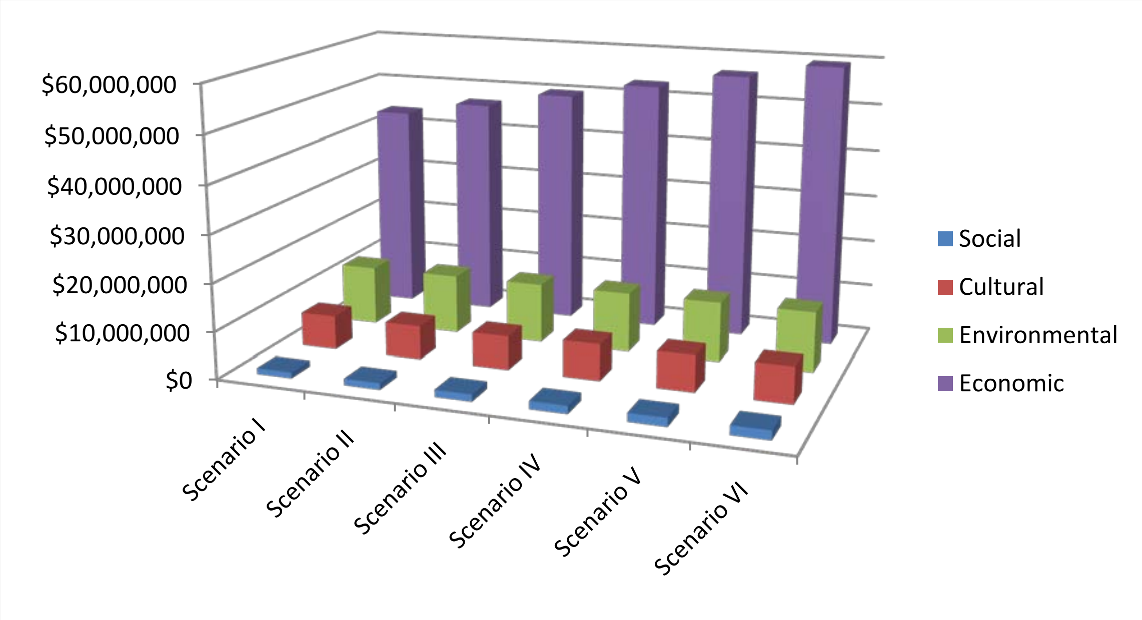

Figure 4.4: Comparison of the six Storm Scenarios' 'Assets at Risk' values

4.3 Total Damage Estimation

In this section, the estimated total damage valuation for each modelled Storm Scenario I through VI is estimated from the determined "Assets at Risk". These estimated values for storm damage approximation differ from the value of everything that could be potentially damaged by a severe storm as captured by the "Assets at Risk" estimate of vulnerability (Table 4.19 and Figure 4.4). Actual estimated storm damages are expected to be a fraction of the "Assets at Risk" evaluations. The estimation of total actual damages for each Storm Scenario I through VI and by Community Profile pillar is discussed in the following subsections that examine the four pillars individually.

4.3.1 Damage Estimation for the Environmental Pillar

In this section, costs of damages for the Environmental Pillar (including: Breakwater, Habitat, Resources, and Tree area and park) are estimated as below.

The estimated damage cost to the Habitat and Resources layer of the Environmental pillar are considered as ranging from 10% and 15% of the valued Habitat and Resources layer "Assets At Risk" ($7.5 million 2010 $CDN for all Storm Scenarios, Table 4.18) for Storm Scenarios I to VI respectively. Therefore, the range of actual estimated loss to the Habitat and Resources layer is between $750 thousand to $1.125million (Table 4.20 below).

The estimate of damage of the Isle Madame breakwaters assigns damages to the total asset value of the breakwater as the result of each Storm Scenario. The most exposed part of breakwaters, e.g., such as the breakwater at Little Anse, to a storm event is its Armour stone. Therefore, quantities of Armour stones core and filter material for the current breakwater and estimated annual breakwater maintenance costs are used to estimate breakwater damage estimation in this research. The annual maintenance cost for a breakwater in Isle Madame is estimated at $42,000 (2010 Canadian Dollars). According to historical storms in the area, normally two severe storms occur yearly. If the maintenance cost of the breakwater is divided by two storms annually, then every storm has an assumed maintenance cost of $21,000 which is considered as its damage cost in this study. However, as Storm Scenarios become harsher (I through VI), breakwater damage is larger as stronger surges cause more damage to the breakwater. Accordingly, the modelled breakwater maintenance cost of 1/3 for Storm Scenario I, and 2/3 for Storm Scenario V. This implies breakwater damages of $14,000 damage cost for Storm Scenario I, and $28,000 damage cost for Storm Scenario V. Estimated damages for the intermediate Storm Scenarios are determined by interpolation (and extrapolation for Storm Scenario VI). There are three breakwaters in Isle Madame so all the estimated costs of damages are multiplied by three and the final breakwater damage estimate value is shown in Table 4.20.

The estimated damage for the vulnerable Tree Area and Parks is estimated as ranging between 15% and 20% of the total Tree Area and Parks "asset at risk" value ($990 thousand to $1.26 million 2010 CDN) for Storm Scenario I and Storm Scenario VI, respectively. The resulting damage estimations of Tree Area and Parks in Isle Madame for all six Storm Scenarios are found in Table 4.20.

4.3.2 Damage Estimation for Economic Pillar

In this section costs of damages for the Economic pillar (including items: Wharf, WharvesRich and Petit de Grat marina, Buildings, Plants (factory), Light house stations, Sewage treatment plant, Collector highway, Local road and streets, Bridges, Airstrip, Unpaved roads, Culverts and Industry by Type) are estimated below.

Damages to buildings as a result of a storm surge follows primarily from flooding to basements and foundations (Canada Mortgage and Housing Corporation, CMHC 2011). In this research, wind damage is considered peripherally to the principle damage from flooding. Estimation of damage to buildings in Isle Madame is based on the costs per flooding occurrence to a basement which is between $3,000 and $5,000 2010 Canadian dollars (CMHC 2011). In this research, the average basement damage of $4,000 is considered as the damage attributed to buildings that are within the buffer (flooded) zone for the Storm Scenario in question. The total damage estimation of flooded buildings (Table 4.12) in Isle Madame by Storm Scenario can be seen in Table 4.20.

The estimated damage to "Plants (Factories)" is estimated at five times more than the damage attributed to a residential house based on the estimated average size differentials between industrial and living are buildings. Storm damage estimates to Plants vary between (5*$2,000=) $10,000 (Storm Scenario I) and (5*$4,000=) $ 20,000 for Storm Scenario VI (Table 4.20).

Estimating storm damage to Isle Madame roads is based on the length of flooded roads (within the buffer zones) and the cost of damaged road repairs. Information about the length of flooded roads for each Storm Scenario is provided from the ArcGIS spatial model as reported in Table 4.12. Further, the Florida Department of Transportation database (FDT 2010) estimates the cost of road repair as follows:

- "Milling and Resurfacing 2 Lane Rural Road with 5' Paved Shoulders", FDT estimated replacement costs are $416,437.91 per mile which is equivalent to $258,191.5 per kilometre. However for the case of Isle Madame, damage estimates of between 10% and 60% of this amount will be considered for Storm Scenario I and VI, respectively.

For highways, the estimates are between 5% and 50% for Storm Scenario I and VI respectively for roads and streets because of type of the roads in Isle Madame are 5' Paved Shoulders. "Roads" included under this group include; Collector highway, Local Roads, Streets, Airstrip, and Bridges.

- Rails to Trails project 12' width with 5' Paved Shoulders. The damage cost of this group is considered as 10% of its "Assets at Risk" valuations (Table 4.18).

The damage estimation of different type of roads in Isle Madame can be seen in Table 4.20. All values in the FDT (2010) database are in US dollars. (In this study, 2010 Canadian dollars are considered to be at par with US dollars.)

For damage estimation of flooded culverts, it is assumed that it takes two days to replace and repair a damaged flooded out (or "blown out") culvert and that this work requires 3 people (labour force) each working at a rate of $200 per day over two days. The estimated capital cost of a replacement culvert is $1600 (as calculated in the Total Asset valuation for Culverts, Table 3.4). Finally, the cost of a power digger (backhoe) machine is assumed at a rental cost of $250 per day. Therefore, the total estimation of damage for flooded culverts is $3,300 per culvert. Finally, damage costs for culverts depend on the flooded incidence that is Storm Scenario dependent (Table 4.12). Total damage costs are reported in Table 4.20.

The estimated damage cost to the Petit de Grat marina layer of the Economic pillar is considered as ranging from 1% and 4% of the valued Petit de Grat marina layer "Assets At Risk" ($5 million (2010 $CDN) for all Storm Scenarios, Table 4.18) for Storm Scenarios I to VI respectively. Therefore, the range of actual estimated loss to the Petit de Grat marina (still under construction) is between $50 thousand to $200 thousand which are added to the "Wharf and WharvesRich" item, and considered as one layer together (Table 4.20 below).

The average cost of a wooden wharf is estimated in Section 3.4.6. This estimate, it is recognized, does not consider accurate engineering inputs. With regard to the estimated damage cost to the Wharf/WharvesRich layer of the Economic pillar, it is subjectively considered as ranging from 20% and 30% of the valued wharf/WharvesRich layer

"Assets At Risk" ($187,500 (2010 $CDN) for all Storm Scenarios, Table 4.18) for Storm Scenarios I to VI respectively. The damage estimation of Wharf/WharvesRich with Petit de Grat marina (all as one layer) can be seen in Table 4.20.

The damage cost to Isle Madame light houses are estimated at $5,000 for each light house. Lighthouse damage requires a helicopter service and repair man (half a day of labour) plus the cost of all needed materials. There are three vulnerable light house stations for all six Storm Scenarios. The damage estimation of light house stations in Isle Madame for all six Storm Scenarios is $15,000 (Table 4.20).

The estimated damage cost to the sewage treatment plants layer of the Economic pillar are considered as ranging from 0.5% and 5% of the valued sewage treatment plants layer "Assets At Risk" ($10 million 2010 $CDN for all Storm Scenarios, Table 4.18) for Storm Scenarios I to VI respectively. Therefore, the range of actual estimated loss to the sewage treatment plants layer is between $50 thousand to $500 thousand for the range of increasing Storm Scenarios I to VI (Table 4.20 below).

Estimation of damage costs of Industry by type is considered as damage estimation to normal residential buildings, as the asset value of industry is considered the asset value of the property. Therefore the average basement damage ($4000) is considered for cost of damage for each industry by type in the flooded zone.

4.3.3 Damage Estimation for Social Pillar

In this section, the costs estimations of damages for the Social pillar layers (including: hiking trail, Total lost Income, Sport field, Senior citizen home, and Additional Health Care Cost) are estimated.

For damage estimation of a flooded hiking trail, it is assumed that it takes ten days to repair and maintenance damaged parts of hiking trail and that this work requires 2 people (labour force) at a cost of $100 each per day plus the cost of transportation (e.g., gas) as $1000 per kilometre to be repaired. Finally, damage costs for the hiking trail depend on the flooded incidence that is Storm Scenario dependent (4.6 km for all Storm Scenarios, Table 4.14). Total damage costs are reported in Table 4.20.

The estimated damage cost to Isle Madame Sport Fields layer of the Social pillar are considered as 10% of the valued sport field layer "Assets at Risk" ($22,000 (2010 $CDN), for Storm Scenarios I, II, III and $44,000 (2010 $CDN) for Storm Scenarios IV, V, VI, Table 4.18). Therefore, the range of actual estimated loss to the Sport Field layer is $2,200 for first three Storm Scenarios and to $4,400 for last three Storm Scenarios (Table 4.20 below).

For estimating the total income lost per Storm Scenario equation (4-9) is used. The calculated values from the equation are doubled for each Storm Scenario because there are expected to be community members who work in offices that are damaged but their houses are safe.

(4-9)

Total Lost Income Storm Scenario (i) $\approx$ (Average Income per Day per Household) * (Average number of privet dwelling affected by Storm Scenario (i)) * (length of Storm Scenario (i)in days)

For (i) =I, II… VI

4.3.4 Damage Estimation for Cultural Pillar

In this section costs of damages for the Cultural pillar (including: Museum, Communication resources, Historic sites, and Cemetery and Church) are estimated.

The estimated damage cost to the Communication resources layer of the Cultural pillar are considered as ranging from 1% and 20% of the valued communication resources layer "Assets At Risk" ($5 million 2010 $CDN for all Storm Scenarios, Table 4.18) for Storm Scenarios I to VI respectively. Therefore, the range of actual estimated loss to the communication resources layer is between $50 thousand to $1million (Table 4.20 below).

The estimated damage cost to the Historic sites layer of the Cultural pillar are considered as ranging from 5% and 10% of the valued Historic sites layer "Assets At Risk" ($1,512,500 (2010 $CDN) for all Storm Scenarios, Table 4.18) for Storm Scenarios I to VI respectively. Therefore, the range of actual estimated loss to the Historic sites layer is between $75,625 to $151,250 (Table 4.20).

The estimated damage cost to the cemetery and churches layer of the Cultural pillar are considered as ranging from 5% and 10% of the valued cemetery and churches layer "Assets At Risk" ($565,000 (2010 $CDN), for Storm Scenarios I, II, III and $1,130,000 (2010 $CDN) for Storm Scenarios IV, V, VI, Table 4.18) for Storm Scenarios I to VI respectively. Therefore, the range of actual estimated loss to the cemetery and churches layer is $28,250 for first three Storm Scenarios and to $113,000 for last three Storm Scenarios (Table 4.20).

Museum and Senior citizen homes are treated like other buildings but because they are larger, damage estimates (to basement, foundations, etc.) are estimated as five times that of a normal building (5*$4,000=$20,000).

Pillar	Damaged Layer	Total Damage Estimation by Storm Scenario					
		I	II	III	IV	V	VI
Environment	Breakwater	$42,000	$42,000	$42,000	$84,000	$84,000	$84,000
	Habitat	$250,000	$275,000	$300,000	$325,000	$350,000	$375,000
	Resources	$500,000	$550,000	$600,000	$650000	$700,000	$750,000
	Tree area and park	$148,500	$167,040	$186,660	$207,360	$229,140	$252,000
Economic	Buildings	$664,000	$768,000	$868,000	$972,000	$1,076,000	$1,180,000
	Plants (factory)	$10,000	$12,000	$14,000	$16,000	$18,000	$20,000
	Light house stations	$15,000	$15,000	$15,000	$15,000	$15,000	$15,000
	Sewage treatment plant	$50,000	$100,000	$200,000	$300,000	$400,000	$500,000
	Wharf/WharvesRch/ Petit de Grat marina	$277,500	$302,500	$327,500	$566,250	$591,250	$616,250
	Collector highway	$43,221	$98,112	$162,660	$237,536	$335,648	$402,778
	local road and streets	$189,770	$400,196	$872,687	$1,355,505	$1,962,255	$2,581,914
	Bridge	$9,294	$9,294	$10,844	$10,844	$12,393	$12,393
	Airstrip	$1,549	$1,549	$3,098	$3,098	$4,647	$4,647
	Industrial by Type	$16,000	$16,000	$16,000	$20,000	$20,000	$20,000
	Unpaved roads	$17,000	$20,551	$24,101	$27,222	$30,880	$34,215
	Culvert	$62,700	$69,300	$75,900	$82,500	$89,100	$95,700
Social	Total lost Income	$28,784	$43,176	$57,568	$71,961	$86,352	$100,744
	Hiking trail	$2,120	$2,120	$2,120	$2,120	$2,120	$2,120
	Sport field	$2,200	$2,200	$2,200	$4,400	$4,400	$4,400
	Senior citizen home	$20,000	$22,000	$24,000	$26,000	$28,000	$30,000
	Additional Health Care Cost for Storm Scenario	$112,000	$128,800	$145,600	$163,000	$182,000	$198,800
Cultural	Museum	$12,000	$12,000	$12,000	$12,000	$12,000	$12,000
	Communication resources	$50,000	$100,000	$175,000	$250,000	$500,000	$1,000,000
	Historic sites	$ 75,625	$90,750	$ 105,875	$121,000	$ 136,125	$ 151,250
	Cemetery and Church	$28,250	$33,900	$39,550	$ 90,400	$ 101,700	$ 113,000
Total		**$2,627,513**	**$3,281,488**	**$4,282,363**	**$5,613,196**	**$6,971,010**	**$8,556,211**

Table 4.20: Isle Madame's Total Damage estimations for all six Storm Scenarios by Community Profile pillar

As can be seen from Table 4.20, the estimated damage costs of “Museum”, “Hiking trail” and “Light house stations” layers remain the same from Storm Scenario I to IV, because the same number of elements of these layers are at risk and vulnerable to MOWL rise of one and two meters and more. However, the estimated damage costs of most of the other layers are assumed to have a linear increasing trend dependent on storm scenario severity.

4.3.5 Summary

Total estimated storm damage values relative to the all six modelled Storm Scenarios I to VI have been found for all four pillars of the Community Profile for Isle Madame. This section summarizes these results and compares the estimated damage values for all pillars by Storm Scenario. The summary of the monetary damage estimates can be seen in Table 4.21.

Storm Scenario / Pillar	I	II	III	IV	V	VI
Environmental	$940,500	$1,034,040	$1,128,660	$1,266,360	$1,363,140	$1,461,000
Economic	$1,356,034	$1,812,502	$2,589,790	$3,605,955	$4,555,173	$5,482,897
Social	$165,104	$198,296	$231,488	$267,481	$302,872	$336,064
Cultural	$165,875	$236,650	$332,425	$473,400	$749,825	$1,276,250
Total	**$2,627,513**	**$3,281,488**	**$4,282,363**	**$5,613,196**	**$6,971,010**	**$8,556,211**

Table 4.21: Total Estimated Damage monetary comparison for the six Storm Scenarios

Figure 4.5 illustrates the comparison of total estimated damage of all the six Storm Scenarios by the four pillars graphically.

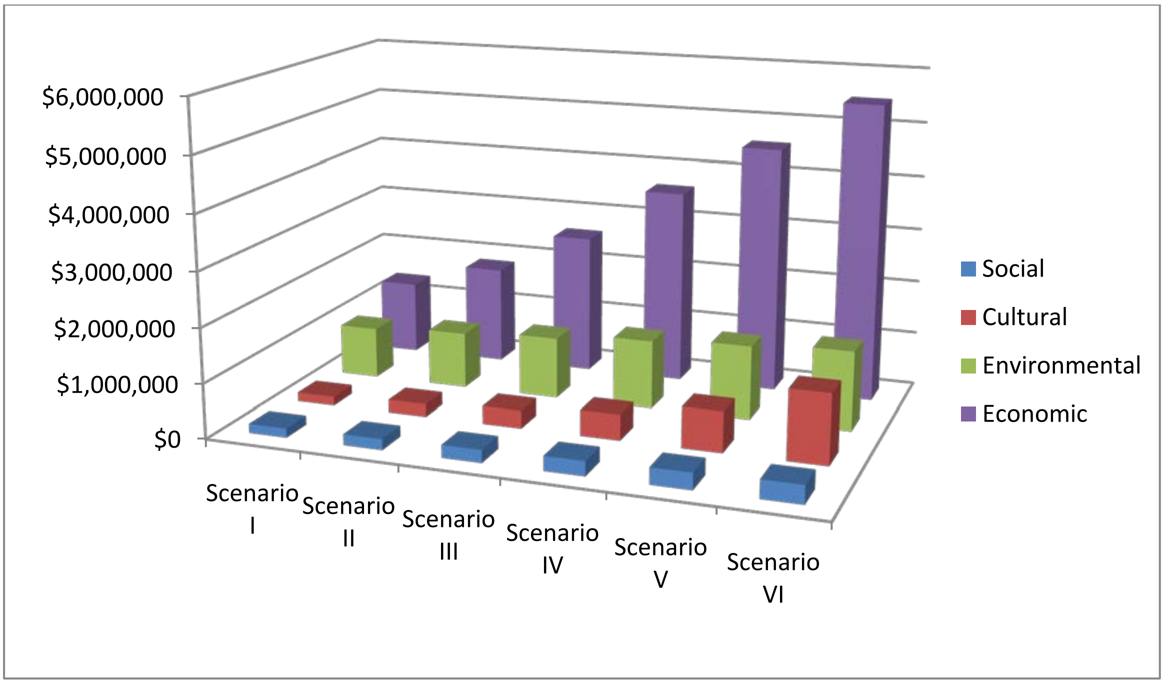

Figure 4.5: Total estimated damage costs for the six Storm Scenarios

Table 4.21 and Figure 4.5 are comparable to the Assets at Risk estimations of Table 4.19 and Figure 4.4. As can be seen from Table 4.21 and Figure 4.5, the Economic pillar for Isle Madame has by far the largest "Total Damage" valuation element in all six Storm Scenarios ranging from $1 to $5million or 65% of the estimated Total Damages. The damage valuations for the Environmental (approximately $1 million) and the Cultural (from $165thousand to $1,3million) pillars are similar. The "Total Damage" estimates for the Social pillar (less than $500thousand) is a relatively low proportion, about 7% to 14% of the total estimated Total Damage estimates from severe storms.

Table 4.21 and Figure 4.5 provide static, one-time total storm damage estimates for Isle Madame. As noted above, Total Storm Damage includes a Total Direct Damages (from the storm event) and Total Indirect Damages attributed to clean-up and repair operations, and lingering damages to the members of the community. Completing the temporal (immediate, direct, and timed indirect) damages is the subject of the next chapter that uses the spatial model Total Direct Damage estimates of Table 4.21 as input to a formulated System Dynamics Model to determine the temporal aspects of storm damage on Isle Madame.

5 System Dynamics Damage Estimation and Results

In this chapter, the interaction between all four pillars and the application of estimating temporal storm damages is carried out for Isle Madame using the STELLA software methodology presented in Chapter 3. Total overall storm damages estimates are calculated for Isle Madame based on the original total storm estimate of the spatial model (Chapter 4 results), and STELLA determined total direct damages, and total indirect damages for each Storm Scenario by pillar.

This chapter is divided into the following subsections:

(5.1) Calculated STELLA Total Damage Equivalents

(5.2) System Dynamics Trials and Results for Storm Scenario I

(5.3) System Dynamics Results for all Storm Scenarios

(5.4) Comparative Analysis: ArcGIS vs. STELLA Results

(5.5) Policy Implications

These results provide initial estimates for estimated spatial and temporal storm damage impacts for Isle Madame to be used in the community for strategic planning and preparedness.

5.1 Calculated STELLA Total Damage Equivalents

Total overall storm damage estimates for each pillar by the different Storm Scenarios is estimated in Chapter 4 using the ArcGIS model and spatially defined data from the SLRT and flood lines. The resulting total storm damages of Table 4.21 are used as inputs to the SD Model. The summary version of Total Damage estimations reported in Table 4.21 is shown in Table 5.1. This table groups the principle items of the Community Profile pillar values in reporting the total damage estimates by Storm Scenario for Isle Madame.

Pillar	Item	Total Estimated Storm Damage					
		Storm Scenario I	Storm Scenario II	Storm Scenario III	Storm Scenario IV	Storm Scenario V	Storm Scenario VI
Environment	Habitat and Species	$792,000	$867,000	$942,000	$1,059,000	$1,134,000	$1,209,000
	"Hydrology, Land Use & Land Cover"	$148,500	$167,040	$186,660	$207,360	$229,140	$252,000
Economic	Built Environment & Industry by Type	$1,004,240	$1,385,708	$2,036,446	$2,713,861	$3,536,530	$4,339,254
	Public Work	$351,794	$426,794	$553,344	$892,094	$1,018,643	$1,143,643
Social	Social Welfare	$136,320	$155,120	$173,920	$195,520	$216,520	$235,320
	Wage Earning	$28,784	$43,176	$57,568	$71,961	$86,352	$100,744
Cultural	Cultural Sites	$115,875	$136,650	$157,425	$223,400	$249,825	$276,250
	Communication Resources	$50,000	$100,000	$175,000	$250,000	$500,000	$1,000,000
Total		**$2,627,513**	**$3,281,488**	**$4,282,363**	**$5,613,196**	**$6,971,010**	**$8,556,211**

Table 5.1: Total Estimated Storm Damage costs by Principle Items of the Community pillars and Storm Scenario I to VI

As mentioned previously in Chapter 3, Direct Damages (equation (3-2)) are modelled as a fraction of Total Estimated Storm Damages (Table 4.20). This means that the Direct Damages inputs to the STELLA model is a portion of estimated Total Damage. This portion of Total Estimated Storm Damages for each Storm Scenario assigned to the STELLA inputs for total Direct Damages over all pillars (equation (3-3) and Table 3.16) are determined by searching for the constant values such that the STELLA total overall damages (TOD, equation (3-1)) equal the given Total Estimated Storm Damage values (Table 4.21) for each Storm Scenario. Equation (5-1) expresses the objective of the search by Storm Scenario I through VI for the constant fraction denoted as *x* (Table 5.2).

[5-1]

$$x = \frac{(\sum_{n=1}^{\infty} TDD_i)}{\text{Total Estimated Storm Damge}}$$

The search for x is carried out numerically for each Storm Scenario separately using Excel and based on the function forms defined in equations 3-1 through 3-6 for determining the temporal distribution of total storm damage estimates into immediate (direct) and indirect damages over time.

The value of x for each Storm Scenario I through VI is estimated using a Newton–Raphson method for "finding successively better approximations to the zeroes (or roots) of a real-valued function" (William H. Press et al 1992). Through the numerical search process, different values for x are used to determine Direct Damage input values (equation 3-3 to 3-6) for the SD Model. The results of different x values are compared to the Total Estimated Storm Damage for each Storm Scenario (Table 4.21). The search results are presented in Table 5.2 for all six Storm Scenarios.

Storm Scenario	*x* Value
I	0.7489582
II	0.74962
III	0.7510764
IV	0.7506783
V	0.7543033
VI	0.75974

Table 5.2: *x* Value Search Results by Storm Scenario

5.2 System Dynamics Trials and Results for Storm Scenario I

In this section, the STELLA SD model is presented for Storm Scenario I over a period of three weeks (t=0,1,2,3) and T=3. The results are presented below in Table 5.3 and Figure 5.1.

5.2.1 Model Timing

The period of the STELLA temporal model for determining direct and indirect storm impacts is considered in this research as three weeks, i.e., t=0,1,2,3 and T=3 in the model for determining the timing of Indirect Damage affects from severe storms. When severe storms happen, there is an immediate (t=0) Direct Damage Subsequently, over time there are Indirect Damages that are assumed to occur in t=1, 2, 3. The rationale for considering T=3, three weeks, is estimated that this the best estimate of the time for immediate and required repair and recovery from immediate damages of a severe storm. However, this estimate is subjective. There are currently no empirical data or evidence about this matter for the case of severe storms on Isle Madame.

5.2.2 Storm Scenario I Trial and Results

In this section, the Storm Scenario I STELLA model temporal storm estimates are provided for the Community Profile pillars. Table 5.3 presents the results of the model for Storm Scenario I and assuming the duration of three weeks for indirect storm damages. The detailed presentation of these results is found in Appendix H, "Results of the System Dynamics Model for each Storm Scenario".

End of week	Damage Type	Environment	Economic	Social	Cultural	Total Damage of Storm Scenario I
0	Direct	$704,395	$1,015,613	$123,656	$124,233	$1,967,897
1	Indirect	$220,196	$292,677	$54,849	$90,484	$658,205
2	Indirect	$292	$529	$130	$294	$1,245
3	Indirect	$32	$72	$18	$44	$165
	Total	**$924,916**	**$1,308,890**	**$178,652**	**$215,054**	**$2,627,513**

Table 5.3: Results of SD Model for Storm Scenario I

Table 5.3 presents the results of the SD Model for Storm Scenario I. This result uses the best value of *x* for each Storm Scenario I through VI (Table 5.2) to obtain the same total damage values as was calculated in Table 4.21 for the spatial model. Moreover, from the Table 5.3, the minimal contribution of t=3 is noticeable in all four pillars. On the other hand, Economic and Environmental pillars are dominant; whereas, Social and Cultural pillars have minimal contribution in the Total Direct Damage in t=0 and relatively in the Overall Total of all four Pillars at the end of the three-week period.

The graphical results from the STELLA model outputs for Storm Scenario I is illustrated in Figure 5.1.

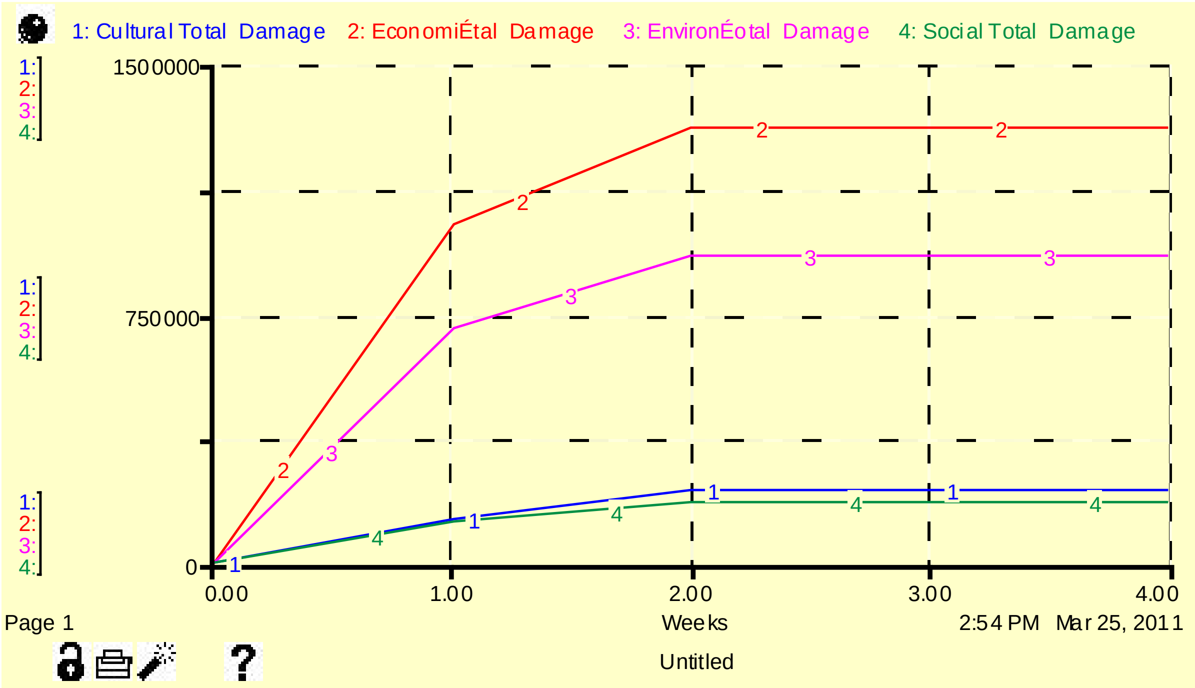

Figure 5.1: STELLA Output for Total Temporal Storm Damage Estimates by four pillars for Storm Scenario I

5.3 System Dynamics Trials and Results for all Storm Scenarios

The STELLA model estimates for the total temporal storm damage estimates by Community Profile pillar for all six Storm Scenarios are presented below in Figures 5.2 through 5.5. These figures illustrate the STELLA model storm damage estimates respectively for time periods t=0 (direct, immediate storm damages, Figure 5.2), after one week (t=1), Figure 5.3; after two weeks (t=2), Figure 5.4, and, finally, after three weeks (t=3), Figure 5.5. The detailed presentations of these results are found in the tables and STELLA graphics of Appendix H, "Results of the System Dynamics Model for each Storm Scenario".

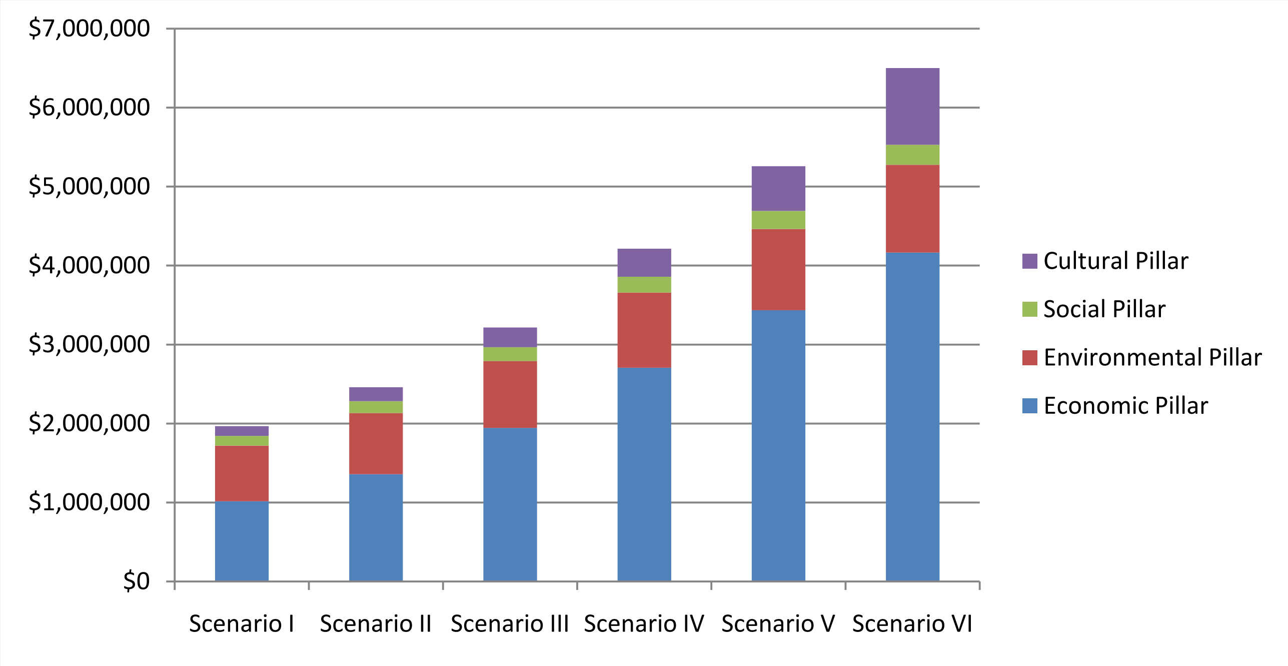

Figure 5.2: Direct Damage Comparison of four pillars of all six Storm Scenarios in time zero from SD Model results

As can be seen from the Figure 5.2, there is a significant increase in each pillar from Storm Scenario I to VI, especially in the more prominent Economic and Environmental pillars.

The Indirect Damages results comparison in time one, two, and three of four pillars of all six Storm Scenarios are presented in Figures 5.3, 5.4, and 5.5 respectively.

As can be seen from the Figure 5.3, there is a significant increase in each pillar from Storm Scenario I to VI. However, Economic and Environmental pillars are dominant; whereas, Social and Cultural pillars have minimal contribution in the in the Overall Total of all four Pillars in each Storm Scenario for t=1. On the other hand, in Figure 5.4 and Figure 5.5 the contribution of Social and Cultural pillars are become more. In Figure 5.4 contribution of Cultural pillar is almost equal to contribution of Environmental pillar, and in Figure 5.5 Cultural Pillar has more contribution than Environmental Pillar. Economic and Social Pillars have respectively the biggest and smallest contribution in all three Figures (5.3, 5.4, and 5.5) which presents t=1, 2, 3 respectively.

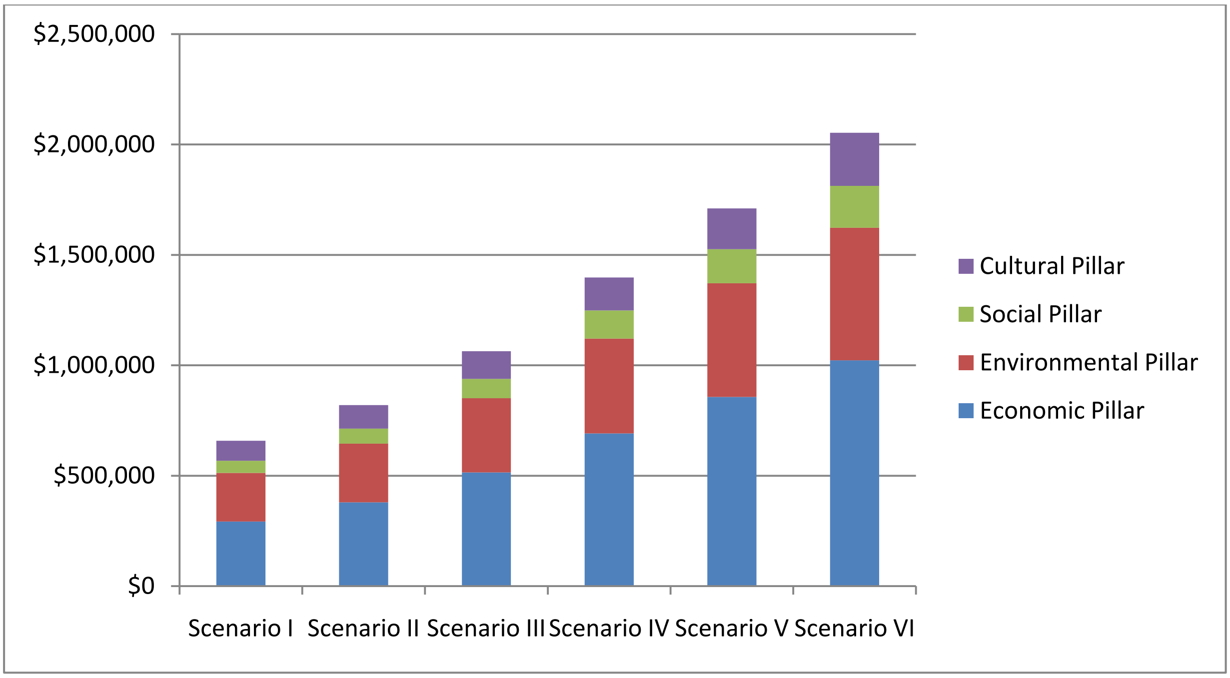

Figure 5.3: Indirect Damages Comparison in time one of four pillars of all six Storm Scenarios from SD Model results

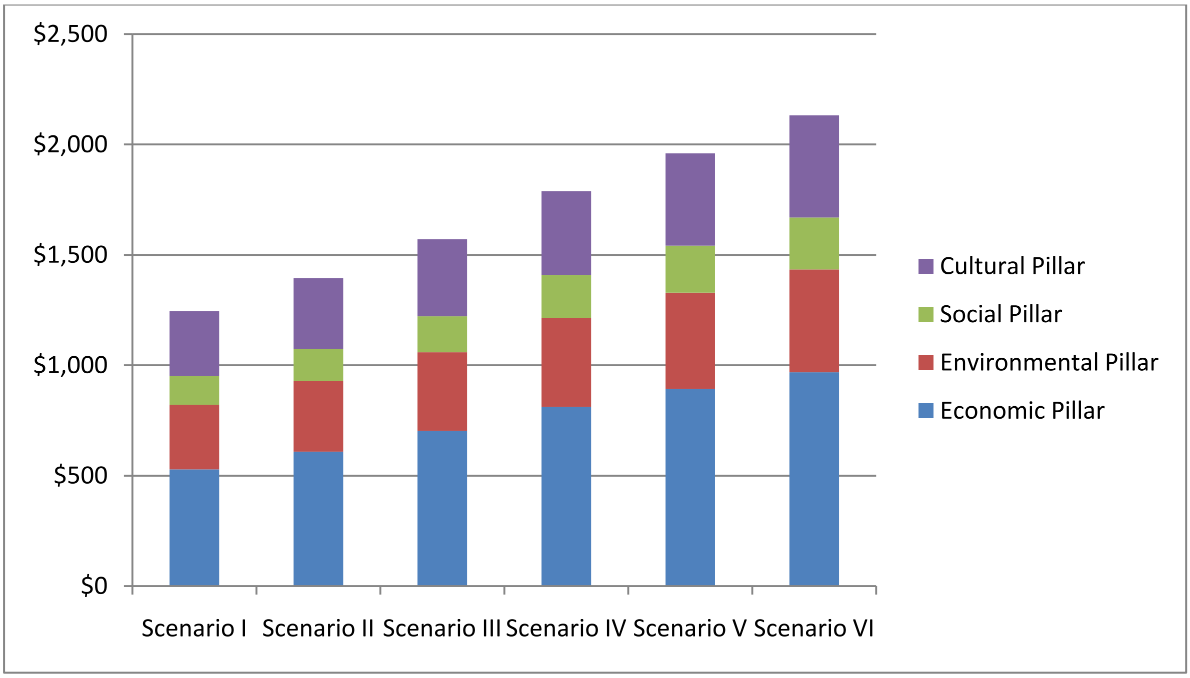

Figure 5.4: Indirect Damages Comparison in time two of four pillars of all six Storm Scenarios from SD Model results

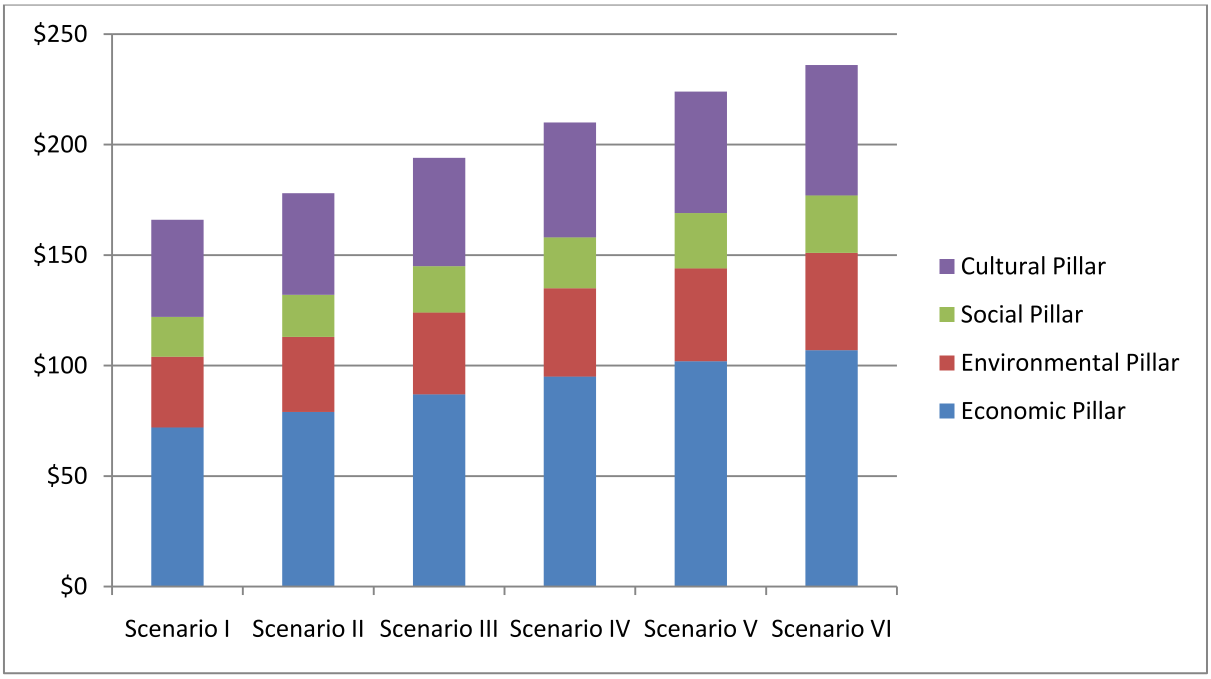

Figure 5.5: Indirect Damages Comparison in time three of four pillars of all six Storm Scenarios from SD Model results

5.4 Comparative Analysis: ARCGIS vs. STELLA Results

In this section, all the total damage results from the SD Model are summarized and compared to the Total Storms Damage Estimates by pillar for the ArcGIS spatial model (Table 4.21) for all six-Storm Scenarios. The summarized and totalled SD model results are presented in Table 5.4. The comparative summaries are presented in Table 5.5 below. The comparison of Total Damages of all six Storm Scenarios by four pillars is also illustrated in Figure 5.6.

Storm Scenario / Pillar	I	II	III	IV	V	VI
Environmental	$924,916	$1,041,344	$1,184,119	$1,380,757	$1,543,373	$1,710,753
Economic	$1,308,890	$1,738,715	$2,460,759	$3,399,488	$4,293,691	$5,189,146
Social	$178,652	$216,711	$261,756	$328,098	$383,326	$445,611
Cultural	$215,054	$284,718	$375,729	$504,853	$750,620	$1,210,700
Total Damage at the end of the three-week-period	**$2,627,513**	**$3,281,488**	**$4,282,363**	**$5,613,196**	**$6,971,010**	**$8,556,211**

Table 5.4: Summarized Total Damage Estimates by pillar for all six-Storm Scenarios from the STELLA Model

As noted in Table 5.5 below, there are differences between estimated "total damage" by pillar from the ArcGIS spatial model (Table 4.21) and the "total damages" by pillar from the SD Model (Table 5.4). Table 5.5 reports on these differences.

	Total Damage Estimates Difference between the Spatial and the Temporal Models					
	Storm Scenario I	Storm Scenario II	Storm Scenario III	Storm Scenario IV	Storm Scenario V	Storm Scenario VI
Environmental	$15,584 **(+0.6%)**	-$7,304 **(-0.2%)**	-$55,459 **(-1.3%)**	-$114,397 **(-2%)**	-$180,233 **(-2.3%)**	-$249,753 **(-2.9%)**
Economic	$47,144 **(+1.8%)**	$73,787 **(+2.2%)**	$129,031 **(+3.0%)**	$206,467 **(+3.7%)**	$261,482 **(+3.75%)**	$293,751 **(+3.4%)**
Social	-$13,548 **(-0.5%)**	-$18,415 **(-0.6%)**	-$30,268 **(-0.7%)**	-$60,617 **(-1.1%)**	-$80,454 **(-1.15%)**	-$109,547 **(-1.3%)**
Cultural	-$49,179 **(-1.9%)**	-$48,068 **(-1.4%)**	-$43,304 **(-1%)**	-$31,453 **(-0.6%)**	-$795 **(-0.2%)**	$65,550 **(+0.8%)**
Total	**$0**	**$0**	**$0**	**$0**	**$0**	**$0**

Table 5.5: Comparative Report on estimated Total Storm Damages (Table 4.21) versus estimated Total Storm Damage from SD Model (Table 5.4) by Storm Scenario and percentage differences from the Total Damage Estimations

Table 5.5 presents no difference (zero) between estimated Total Storm Damage estimates from the Chapter 4 (Table 4.21) spatial model and Total Storm Damage estimates from the SD Model (Table 5.4). This is because of the chosen model search (equation 5-1). However, the differences between each pillar by Storm Scenarios are not zero.

As can be seen from Table 5.5, the total damages of the Economic pillar damages (Table 4.21) are higher than the Total Damage of the Economic pillar from the SD Model (Table 5.4) for all Storm Scenarios. This is the opposite for the Social, Cultural (except for Storm Scenario VI), and the Environmental pillars (with the exception of Storm Scenario I).

In overall, these differences are not significant as most of them are under $100,000 on totals of nearly $3 million or more. Some of them have higher differences especially in Economic Pillar for the last three Storm Scenarios (IV-VI), but compared to the large amount as Overall Total in last three Storm Scenarios these differences are not really big.

6 Conclusions and Recommendations for Future Research

This chapter discusses the thesis results for estimating expected damages from severe storms for the case of Isle Madame, Cape Breton. A summary of the research relative to the stated research objectives of the thesis is presented. Finally, the chapter concludes with a discussion of the critical aspects of the research and the potential for future research.

6.1 Conclusion – Summary of Results

The community of Isle Madame was profiled according to the Community Profile identified as dimensions: environmental, economic, social, and cultural values. Assets for the Community Profile dimensions were valued for Isle Madame and estimated at a total valuation of approximately $500 million 2010 $CDN based on a careful analysis of the spatial assets of the community and using the ArcGIS model. This overall valuation is useful for identifying the importance of the community status quo and those spatial elements under risk from severe storms.

Six severe Storm Scenarios are modeled based on sixteen historical storms experienced in Isle Madame from 1975 to 2009. Categorizing of the six Storm Scenarios is based on the severity of the historical storms with respect to wind speed, storm speed, and storm pressure. Using the spatial model and the ArcGIS tool developed for this purpose, the flooding impacts from modelled storm surge are developed to identify vulnerable Isle Madame assets that are recognized as "assets at risk" for the community. Assets at Risk for Isle Madame in the face of storms ranged from estimates of $64 million (2010 $CDN) for low severity storms to estimates of $82 million for the highest severity storm.

While "assets at risk" can be identified, actual storm damage and the estimated cost of this damage is calculated as a fraction of assets at risk. For Isle Madame, total damage from modelled severe storms is estimated as being between under $3million for low severity storms to almost $9 million (2010 $CDN) for the highest severity modelled storm.

Total storm damage is modelled temporally as having a direct damage impact, and indirect damage impacts over time. System Dynamics are used to determine the split between temporally defined direct and indirect damages. Input to the SD model is based on initial total spatially defined total storm damage estimates. Total temporal storm damage estimates provide Direct Damage (Immediate damage) in time zero, and Indirect Damages (lagged impacts) over a post-storm three week time period.

Isle Madame damage estimates by Community Profile are designed to provide spatial and temporal insight into vulnerabilities of the community. These vulnerabilities provide the focus for adapting to the pending change. For example, the dominance of the Economic and Environmental dimensions also provides evidence of the largest estimated indicators in each dimension. This information ultimately provides important evidence to the community about its most vulnerable assets thereby enabling it to be better aware of how it can prepare for the storm event.

6.2 Research Objectives and Results

In this section the objectives of this research are analyzed in response to the research questions as below:

1- Description of the spatial characteristics of Isle Madame through the Community Profile: By using maps and ArcGIS software all available data in Isle Madame were described and analyzed spatially with respect to its environmental, economic, social, and cultural components.

2- Determination of the Isle Madame's vulnerable areas to storm surge and sea level rise: The Sea Level Rise Tool (SLRT) was created via ArcGIS to find the vulnerable area (buffer zone) in Isle Madame by applying different Storm Scenario (with different MOWL based on the historical storms information in Isle Madame). In addition, the Sea Level Rise Tool helps to find information about how many elements (with all details of the elements) of each data layer is on vulnerable area (buffer zone) regarding to each Storm Scenario. On the other hand, all assets values of available data in Isle Madame were evaluated with respect to its environmental, economic, social, and cultural components.

In next step, the "Assets at Risk" values for each Storm Scenario were estimated by knowing a number of affected elements for each Storm Scenario and the assets value of each element. The asset at risk basically refers to all assets in the buffer zone (vulnerable area).

3- Estimation of the expected impacts/damage from storm surge and sea level rise Scenarios on Isle Madame: Obviously not all the assets at risk will damage due to Storm Surges. Therefore, the damage costs of the all affected elements were estimated with respect to its environmental, economic, social, and cultural components. These valuated Damage costs are Total Damage for each Storm Scenario in Isle Madame based on the ArcGIS and Sea Level Rise Tool information.

Finally the Total Damage, Direct Damage, and Indirect Damage were calculated via System Dynamics Model. The input to the SD Model is considered as Direct Damage (Immediate Damage after storm surge in time zero) which is a fraction of estimated Total Damage in the previous step. Moreover, there are lag damages (Indirect Damages) which are modeled and calculated in SD Model in time one, two, and three. Therefore, the result of SD Model is Total damage consist of Direct Damage (t=0) and Indirect Damages (t=1, 2, 3). At the end the estimated Total Damage based on ArcGIS was compared with the calculated Total Damage from SD Model for all six Storm Scenarios.

The objectives of this research were fulfilled although data observation on Isle Madame storms impacts is limited. In this research four pillars (which were created by members of the C-Change team) and related layers in each pillar as community profile were evaluated (refer to Appendix A). All possible data for layers of each pillar in the case of Isle Madame were collected (refer to Appendix B).

6.3 Recommendations for Future Research

Recommendation for future study focuses on the area of this research that could lead to more complete and more accurate future research based on more and structured storm analysis and observations in the future. Future study opportunities for this research include:

- **Elevation Data**. The ArcGIS SLRT tool is applied to simulate a flood to the Isle Madame elevation map to find a vulnerable area and number of points of each layer in that area (buffer zone). Everything in the vulnerable area is considered as "Assets at Risk". Because of the poor quality of available digital elevation for Isle Madame, only Storm Scenario I and V which have integer maximum observed water levels can be applied in ArcGIS tool. Therefore, "Assets at Risk" monetary values for each layers of each pillar for these two Storm Scenarios were estimated and for the rest of Storm Scenarios interpolation and extrapolation were used. Moreover, the digital elevation data that is used in this research considers only integer number for maximum observed water levels. Therefore, Storm Scenario I and V with the integer maximum observed water level were applied in this research and for the rest of the Storm Scenarios interpolation and extrapolation were used. However, it is recognized that the GeoBase digital elevation data are compiled from 1:50,000 scale topographic maps which have 12 meter horizontal error and a 10 meter vertical error 90% of the time. Using better quality digital elevation data (especially LiDAR data) would be an opportunity to find the correct buffer line for each individual Storm Scenario. The Isle Madame community would benefit from such research with correct estimation of threats from storm surges. As noted previously in the thesis, the acknowledged lack of precision in the available elevation data for Isle Madame presents a challenge for this research. Nevertheless, the development of the methodology and the application of the work to Isle Madame provide a clear applied analysis of the modelling and estimation of storm impacts for the community. This contribution of the current research – given that storm damage estimates have not been considered previously – seeks to raise the awareness of the extent and importance of more frequent and severe storms, and enhance the capability through knowledge acquisition of the community to be prepared. The ultimate availability of improved spatial elevation data (e.g., LiDAR) in any case will serve to improve the overall estimates within the same defined methods developed and applied in this thesis. Future studies can readily be done – and estimations thereby improved upon - using more precise elevation data for Isle Madame but without gain or loss of the intent of the research

- **Isle Madame Spatial Data**. A review of relevant and more accurate and up-to-date related data for Isle Madame would improve model estimates. As mentioned before, some of the data used in this research were taken from freely available sources such as Geobase, Census of Canada, and DMTI and the rest of the data were downloaded from GeoNova (2006).

- **System Dynamics Model Data**. More accurate data the System Dynamics Model would also benefit and provide more accurate estimates via the SD Model for temporal storm damages. Historical storms and maximum observed water levels of them has been poorly reported in freely available sources. Total Damages of these storms were not reported especially in case of Isle Madame. The objective of damages estimation in this research is a first step toward predicting and eventually preparing for extreme storm events. This research used four pillars (Environmental, Economic, Social, and Cultural) with small portion of these components especially in System Dynamics Model. However, using different data sets of the community could change the scope of study and extend it in different directions. As noted previously, the functional forms, and the parameters assumed in the SD model are not based on empirical observations or known data (for which there are none). As such, these values have been determined based on "best guesses", and reasonable intuition about the dynamics of the various pillar and expected storm damage impacts. The presentation of the SD functional forms and model parameters are provided to illustrate the modelling exercise, and to stimulate academic and community feedback and discussion. They are not provided as definitive model valuations but rather as a means to provoke future structured data gathering exercises from observed storm impacts. Moreover, SD model needs more developed feedback loops due to each pillar's impacts, for example using the "logical loop" tool in STELLA would be one option. More elaboration of storms events on individual and family unit mobility and communication affecting work routines constitutes damages not easily recorded.

- **Development of Storm Related Data Collection**. This research used considerable estimation due to the lack of available data and observations. These estimations mainly were done in finding total assets value, "assets at risk" value, costs of damages, and percentage of Total Damages in Chapter five, also constant parameters in STELLA. However, there is a opportunity for future studies to calculate these estimations with a directed program of storm impacts data collection and more specific and precise findings of the right values for calculation and modelling.

- **Integration of System Dynamics with Geographical Information Systems**. This research uses a simple method (low level) of integration of SD and GIS and there is much to be done in this area. The simple method that is used in this research is described as a one way connection, meaning estimated total damages with results from GIS go to a separate Excel spreadsheet file manually and from there imports the portion of total damages as direct damage to the SD Model. As such, there is no loop between SD Model and GIS. Integration of SD and GIS in a preferred and integrated fashion could be an opportunity for future study.

- **Management Adaptation and Alternative Evaluation**. Use of the assets at risk and total damage estimates by dimension can be used to direct strategies to adapt to the more serious Community Profile pillars and associated important layers/indicators.

- **Sensitivity of results.** Assets at risk damages; assuming flood lines are sensitive to change, these affected assets at risk and damages. In addition most sensitive variables are: economic pillar values especially local industry and public works. Social and cultural estimates (for assets and damages) reflect only spatial and demographic characteristics; these pillars are also sensitive to subjective valuation to reflect social resilience not easily quantifiable. Future work requires more precise spatial data (as noted above) and further analyse.

- **Policy Implications:** Total Damage (direct and indirect) estimates are consequences of vulnerable areas as discovered and presented according to the four pillars. This information about the relative damage estimates costs by pillar will allow local governments to focus storm preparedness and storm recovery on those pillars that are expected to be most affected. The evaluation of strategic adaptive options in the face of storm damage estimates by pillar can be adjusted to focus on the community's main concerns. Thus, this damage information is indispensible for the future application of policy decision making based on attempts to reduce community costs from anticipated storm impacts.

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Appendix A: Community Data Profile – Template

The SSHRC-IDRC ICURA project "Community Profile Metadata set" is shown below in details, which will used for mapping and modeling (SD) for project community data. Elements of each dimension can be seen in table A.1 in below:

	Main Dimensions		Level 1 Categories		Items
1	Environmental	A	Topography	I	Land Area
				II	Mean Elevation
				III	Lowest Point

				IV	Highest Point
				V	Slope
		B	Hydrology	I	Watershed Boundaries
				II	Lakes, Rivers, Streams
		C	Coastal Geomorphology	I	Length
				II	Physical Composition
				III	Bathymetry
				IV	Ports and Harbours
				V	Wave Climate
				VI	Sedimentation and Erosion
		D	Habitat and Species	I	Terrestrial
				II	Fresh and salt water wetlands
				III	Aquatic
				IV	Migratory species and routes
				V	Rare/Endangered
		E	Land Cover	I	Forests
				II	Wetlands
				III	Barrens
				IV	Grasslands and Pastures
				V	Flood Plains and Hazard Lands
		F	Land Use	I	Town Centers
				II	Industrial
				III	Commercial
				IV	Residential
				V	Agriculture
				VI	Forestry
				VII	Mineral extraction
				VIII	Transportation and utilities
				IX	Energy production

				X	Parks and open space
				XI	Beaches
				XII	Protected Areas
				XIII	Scenic/historical/cultural areas
				XIV	Tourism
		G	Marine Use	I	Aquaculture
				II	Marine Benthic
				III	Recreational Fishing
				IV	Commercial Fishing
				V	Recreational Boating
				VI	Transportation routes
				VII	Tourism
				VIII	Protected areas
				IX	Scenic/historical/cultural areas
		I	Climate	I	Mean temperatures
				II	Mean precipitation
				III	Prevailing winds and wind speed
				IV	Storm events
				V	High tides and storm surges
2	<u>Economic</u>	A	Industry by Type	I	Agriculture and other resourced based occupations
				II	Constructions
				III	Manufacturing
				IV	Wholesale trade
				V	Retail
				VI	Finance and real estate
				VII	Heath care and social services educational

					services
				VIII	Other services
		B	Industry Revenues	I	Natural resources
				II	Tourism
				III	Commercial
				IV	Industrial
		C	Built Environment	I	Private dwellings
				II	Industrial structures
				III	Commercial structures
				IV	Retail structures
				V	Coastal structures
				VI	Fuel storage
		D	Public Works	I	Government buildings
				II	Fire fighting
				III	Policing
				IV	Hospitals
				V	Solid waste management systems
				VI	Municipal wastewater systems
				VII	Storm water collection and disposal systems
				VIII	Potable water source, treatment and supply systems
				IX	Energy generation and supply systems
				X	Transportation systems
		E	Real-Estate Values	I	Residential property
				II	Coastal residential property
				III	Coastal tourism property
				IV	Commercial property value

				V	Industrial property value
				VI	Municipal tax base
				VII	Average value of owned dwellings
3	Social	A	Population Statistics	I	Population in 2006
				II	Population in 2001
				III	Population density per sq. Km
				IV	Median age of the population
				V	Population change (%)
				VI	Aboriginal population
				VII	Population less than 14 years of age
				VIII	Population 15 – 59 years of age
				IX	Population over 60 years of age
		B	Education	I	School
				II	No certificate, diploma, degree
				III	High school certificate
				IV	College or non-university certificate
				V	University diploma below Bachelors
				VI	University certificate, diploma, degree
		C	Health Status	I	Morbidity rates
				II	Mortality rates/average age
				III	# of hospitals/clinics/hospices/

					other health care centers per capita
				IV	Number of residences without family doctor
				V	How does the community perceive their health/happiness
				VI	Recreation Places (sport field, shooting range…)
				VII	Hospitals/clinics…
		D	Occupation by Type	I	Management
				II	Business, finance, or administration
				III	Natural/applied sciences
				IV	Social science, education, government, religion
				V	Sales and service
				VI	Trades, transport, and equipment
				VII	Unique to primary industry
				VIII	Processing, manufacturing, or utilities
		E	Employment and Earnings	I	Total population (over age 15) in labor force
				II	Employment/unemployment rate
				III	Median income (all census families)
				IV	Median income (all private households)
				V	Median earnings (age 15 and over)

4	Cultural	A	Governance Systems	I	Government agencies (federal, provincial, municipal, EMR, other)
				II	First Nations, aboriginal, Métis
				III	Other non-government organizations (co-management, advisory boards)
				IV	Enabling legislation (Planning Acts, Municipal By-laws, Environmental Protection Acts)
				V	Decision-making processes
		B	Community Dynamics	I	Community leaders
				II	Business leaders
				III	Important Families
				IV	Other traditional/significant people
		C	Community Groupings	I	Religious
				II	Language
				III	Family organization
				IV	Traditions/heritage
		D	Communications Resources	I	Community newspapers, other print media/news
				II	Local access cable TV Channel
				III	Local radio stations
				IV	Television (homes with television)
				V	Telephones (homes with,

					cell phone users)
				VI	Internet Access (homes with, schools with, public access)
		E	Language	I	English only
				II	French only
				III	French and English
				IV	No French or English
		F	Places of Significance	I	Sacred sites
				II	Historical sites
				III	Museum
				IV	Church and Cemetery
				V	library
				VI	Historic site
				VII	Archaeological and anthropological Sites
		G	Cultural Events		

Table A.1: Dimensions, Level 1 Categories and Items of the Community Profile Template

Appendix B: Isle Madame Community profile/list of ArcGIS layers

Descriptive narrative of the community profile is listed in this Appendix based on historical and current facts of the Isle Madame, Cape Breton, Nova Scotia. In Tables B.1, B.2, B.3, and B.4, each element represents a layer in ArcGIS with its source and type.

1. Natural Capital/Environmental Pillar

Table B.1 presents all layers for the Environmental Community Profile dimension.

Environmental Pillar				
ITEM	**Layer**	**Source**	**Type**	**Others**
Topography	Elevation	Geobase	Raster date	scale 1:50,000
Hydrology, Land use and Land Cover	Rivers	GeoNova	Shape file	Polyline
	lakes	GeoNova	Shape file	Polyline
	Break water	GeoNova	Shape file	Polyline
	Swamp	GeoNova	Shape file	Polyline
	Beaver damp	GeoNova	Shape file	Polyline
	Ditch	GeoNova	Shape file	Polyline
	Provincial park	GeoNova	Shape file	Front-point
	Berries point	GeoNova	Shape file	Front-point
	Cliff line	GeoNova	Shape file	Polyline
	park	GeoNova	Shape file	Polyline
	Tree area	GeoNova	Shape file	Polyline
	Tree row	GeoNova	Shape file	Polyline
	Tree individual	GeoNova	Shape file	Polyline
	Cut line	GeoNova	Shape file	Polyline
Marine Use	seal haulout	GeoNova	Shape file	Front point

	Beaches point	GeoNova	Shape file	Front point
Habitat and Species	herring	GeoNova	Shape file	Front point
	mackerel	GeoNova	Shape file	Front point
	perch	GeoNova	Shape file	Front point
	Pollock	GeoNova	Shape file	Front point
	flounder	GeoNova	Shape file	Front point
	dogfish	GeoNova	Shape file	Front point
	cod	GeoNova	Shape file	Front point
	rockweed	GeoNova	Shape file	Polyline
	kelp	GeoNova	Shape file	Polyline
	squid	GeoNova	Shape file	Front point
	lobster bottom	GeoNova	Shape file	Region
	recreational clam beds	GeoNova	Shape file	Polyline, region
	shellfish closure	GeoNova	Shape file	Region
	scallop bottom	GeoNova	Shape file	Region
	mussels	GeoNova	Shape file	Region
	sea urchins	GeoNova	Shape file	Polyline, region
	eelRichmondCoStdFields	GeoNova	Shape file	Front point
	gaspereau	GeoNova	Shape file	Front point
	salmon	GeoNova	Shape file	Front point
	smelt	GeoNova	Shape file	Front point
	capelin	GeoNova	Shape file	Front point
	trout	GeoNova	Shape file	Front point
	tern nesting	GeoNova	Shape file	Front point
	osprey nesting	GeoNova	Shape file	Front point

	eider nesting	GeoNova	Shape file	Front point
	cormorant nesting	GeoNova	Shape file	Front point
	eagle nesting	GeoNova	Shape file	Front point
	gull nesting	GeoNova	Shape file	Front point
	Heron nesting	GeoNova	Shape file	Front point

Table B.1: Isle Madame Environmental data/layers

Source: GeoNova (2006) and Geobase (2010)

2. Economic (Commercial) Pillar

Table B.2 presents all layers for the Economic Community Profile dimension.

Economical **Pillar**				
ITEM	**Layer**	**Source**	**Type**	**Others**
Industry by type	Agriculture and other resourced based occupations	DMTI	Shape file	Point
	Constructions	DMTI	Shape file	Point
	Manufacturing	DMTI	Shape file	Point
	Wholesale trade	DMTI	Shape file	Point
	Retail	DMTI	Shape file	Point
	Finance and real estate	DMTI	Shape file	Point
	Heath care and social services educational services	DMTI	Shape file	Point
Built Environment	Buildings	GeoNova	Shape file	Polyline
	Fur Farm	GeoNova	Shape file	Polyline
	Salvage yard	GeoNova	Shape file	Polyline
	(Fish industry) Lobster pounds	GeoNova	Shape file	font point

	(Fish industry) fish processing plants	GeoNova	Shape file	font point
	(Fish industry) herring-mackerel net	GeoNova	Shape file	Region
	(Fish industry) aquaculture lease area as April 1998	GeoNova	Shape file	Region
	Plants (factory)	GeoNova	Shape file	Polyline
	Tower microwave	GeoNova	Shape file	
	pool	GeoNova	Shape file	Polyline
	Pit	GeoNova	Shape file	Polyline
	Ship wreck	GeoNova	Shape file	font point
	Accommodation	GeoNova	Shape file	font point
	Restaurant	GeoNova	Shape file	font point
	campground	GeoNova	Shape file	Polyline
Public works	wharf	GeoNova	Shape file	Polyline
	Sewage treatment plant	GeoNova	Shape file	font point
	Wharves rich	GeoNova	Shape file	font point
	police station	GeoNova	Shape file	Polyline
	fire station	GeoNova	Shape file	Polyline
	post office	GeoNova	Shape file	Polyline
	Light stations	GeoNova	Shape file	font point
	(Transportation)Collector highway	GeoNova	Shape file	Polyline
	(Transportation)local road	GeoNova	Shape file	Polyline
	(Transportation)bridge	GeoNova	Shape file	Polyline
	(Transportation)wood road	GeoNova	Shape file	Polyline
	(Transportation)loose surface road	GeoNova	Shape file	Polyline

	(Transportation)streets	GeoNova	Shape file	Text
	(Transportation)abandoned road	GeoNova	Shape file	Polyline
	(Transportation)cart track	GeoNova	Shape file	Polyline
	(Transportation)Culvert	GeoNova	Shape file	Polyline
	(Transportation)Airstrip	GeoNova	Shape file	Polyline
	(Transportation)Parking area	GeoNova	Shape file	Polyline

Table B.2: Isle Madame Economical data/layers

Source: GeoNova (2006) and DMTI(2009)

3. Human Capital/Social Pillar

Table B.3 presents all layers for the Social Community Profile dimension.

Social **Pillar**				
ITEM	**Layer**	**Source**	**Type**	**Others**
Population Statistics (2001-2006)	Population in 2006	Census Canada	Shape file	-
	Population in 2001	Census Canada	Shape file	-
	Population density per sq. km	Census Canada	Shape file	-
	Median age of the population	Census Canada	Shape file	-
	Population change (%)	Census Canada	Shape file	-
	Aboriginal population	Census Canada	Shape file	-
	Population less than 14 years of age	Census Canada	Shape file	-
	Population 15 – 59 years of age	Census Canada	Shape file	-
	Population over 60 years of age	Census Canada	Shape file	-
	Management	Census Canada	Shape file	-
	Business, finance, or administration	Census Canada	Shape file	-

Occupations by type	Natural/applied sciences	Census Canada	Shape file	-
	Social science, education, government, religion	Census Canada	Shape file	-
	Sales and service	Census Canada	Shape file	-
	Trades, transport, and equipment	Census Canada	Shape file	-
	Unique to primary industry	Census Canada	Shape file	-
	Processing, manufacturing, or utilities	Census Canada	Shape file	-
Health Status	hospital	GeoNova	Shape file	Polyline
	Hiking trail	GeoNova	Shape file	Polyline
	Sport field	GeoNova	Shape file	Polyline
	Shooting range	GeoNova	Shape file	Polyline
	Senior citizen home	GeoNova	Shape file	Polyline
Education	school	GeoNova	Shape file	Polyline
	No certificate, diploma, degree	Census Canada	Shape file	-
	High school certificate	Census Canada	Shape file	-
	College or non-university certificate	Census Canada	Shape file	-
	University diploma below Bachelors	Census Canada	Shape file	-
	University certificate, diploma, degree	Census Canada	Shape file	-
Employment Rate	Number of residents who work (at home, in census division, outside census division)	Census Canada	Shape file	-
	Mode of transportation to work (# of residents) (private automobile, public transit, walk/bike)	Census Canada	Shape file	-

Table B.3: Isle Madame Social data/layers

Source: GeoNova (2006) and Statistics Canada (2007)

4. Culture Capital/Cultural Pillar

Table B.4 presents all layers for the Cultural Community Profile dimension

Cultural **Pillar**				
ITEM	**Layer**	**Source**	**Type**	**Others**
Community dynamics	Community center	GeoNova	Shape file	Polyline
	Town Hal	GeoNova	Shape file	Polyline
Communication Resources	Community newspapers, other print media/news	Census Canada	Shape file	-
	Local access cable TV Channel	Census Canada	Shape file	-
	Local radio stations	Census Canada	Shape file	-
	Television (homes with television)	Census Canada	Shape file	-
	Telephones (homes with, cell phone users)	Census Canada	Shape file	-
	Internet Access (homes with, schools with, public access)	Census Canada	Shape file	-
Language	English only	Census Canada	Shape file	-
	French only	Census Canada	Shape file	-
	French and English	Census Canada	Shape file	-
	No French or English	Census Canada	Shape file	-
Areas of Significance	Museum	GeoNova	Shape file	Polyline
	Cemetery	GeoNova	Shape file	Polyline
	church	GeoNova	Shape file	Polyline
	library	GeoNova	Shape file	Polyline
	Historic site	GeoNova	Shape file	Front point

Table B.4: Isle Madame Cultural data/layers

Source: GeoNova (2006) and Statistics Canada (2007)

Appendix C: Economic Status Quo – Points in Standard Industrial Classification Major Groups

Table C.1 presents the Standard Industrial Classification (SIC) by major groups from the Desktop Mapping Technologies Inc (DMTI 2009) data source.

Major Group	Name
01	Agricultural Production Crops
02	Agricultural Production Livestock And Animal Specialties
07	Agricultural Services
09	Fishing, Hunting, And Trapping
13	Oil And Gas Extraction
15	Building Construction General Contractors And Operative Builders
16	Heavy Construction Other Than Building Construction Contractors
17	Construction Special Trade Contractors
20	Food And Kindred Products
23	Apparel And Other Finished Products Made From Fabrics And Similar
24	Materials
25	Furniture And Fixtures
26	Paper And Allied Products
27	Printing, Publishing, And Allied Industries
28	Chemicals And Allied Products
30	Rubber And Miscellaneous Plastics Products
32	Stone, Clay, Glass, And Concrete Products
34	Fabricated Metal Products, Except Machinery And Transportation Equipment
35	Industrial And Commercial Machinery And Computer Equipment
36	Electronic And Other Electrical Equipment And Components, Except Computer Equipment
37	Transportation Equipment
38	Measuring, Analyzing, And Controlling Instruments; Photographic, Medical And Optical Goods; Watches And Clocks
39	Miscellaneous Manufacturing Industries

41	Local And Suburban Transit And Interurban Highway Passenger Transportation
42	Motor Freight Transportation And Warehousing
43	United States Postal Service
44	Water Transportation
45	Transportation By Air
47	Transportation Services
48	Communications
49	Electric, Gas, And Sanitary Services
50	Wholesale Trade-durable Goods
51	Wholesale Trade-non-durable Goods
52	Building Materials, Hardware, Garden Supply, And Mobile Home Dealers
53	General Merchandise Stores
54	Food Stores
55	Automotive Dealers And Gasoline Service Stations
56	Apparel And Accessory Stores
57	Home Furniture, Furnishings, And Equipment Stores
58	Eating And Drinking Places
59	Miscellaneous Retail
60	Depository Institutions
61	Non-depository Credit Institutions
62	Security And Commodity Brokers, Dealers, Exchanges, And Services
63	Insurance Carriers
64	Insurance Agents, Brokers, And Service
65	Real Estate
70	Hotels, Rooming Houses, Camps, And Other Lodging Places
72	Personal Services
73	Business Services
75	Automotive Repair, Services, And Parking
76	Miscellaneous Repair Services
78	Motion Pictures
79	Amusement And Recreation Services
80	Health Services
81	Legal Services

82	Educational Services
83	Social Services
84	Museums, Art Galleries, And Botanical And Zoological Gardens
86	Membership Organizations
87	Engineering, Accounting, Research, Management, And Related Services
89	Services, not elsewhere classified
91	Executive, Legislative, And General Government, Except Finance
92	Justice, Public Order, And Safety
93	Public Finance, Taxation, And Monetary Policy
99	No classifiable Establishments

Table C.1: Economic Status Quo Points in SIC Major Groups

Source: DMTI (2009)

Appendix D: Detailed Economic Status Quo – Points in Standard Industrial Classification Major Groups and Division – for the Case of Isle Madame

Table D.1 and D.2 present Isle Madame's standard industrial classification in detailed; name of the industry or company, its address, SIC major group and division. Table D.1 presents the Isle Madame-Retiree's Industry by Type and Table D.2 presents the Isle Madame Industry by Type. The source of the data in this appendix is from DMTI(2009).

NAME	ADDRESS	DELIV_MODE	CITY	PROV	POST_CODE	SIC Major Groups	SIC Division
GULLIVER'S KITCHEN	677 LOWER RD		ARICHAT	NS	B0E 1A0	58	G
SEARS CANADA INC.	2341 320 HIGHWAY		ARICHAT	NS	B0E 1A0	59	G
DIGGDON'S FREIGHT SERVICE	16 CREIGHTON RD	PO BOX 389	WEST ARICHAT	NS	B0E 3J0	42	E
ST JOSEPH'S CREDIT UNION LTD	3552 206 HIGHWAY	PO BOX 159	PETIT DE GRAT	NS	B0E 2L0	60	H
ISLE MADAME DENTAL CENTRE	2288 206 HIGHWAY	PO BOX 300	ARICHAT	NS	B0E 1A0	80	I
BOUDREAU C H FUNERAL HOME LTD	633 LOWER RD	PO BOX 99	ARICHAT	NS	B0E 1A0	32	D
CHARLES FOREST CO-OP	2743 206 HIGHWAY		ARICHAT	NS	B0E 1A0	54	G
BOUDREAU'S FUELS LTD	5154 320 HIGHWAY	PO BOX 205	ARICHAT	NS	B0E 1A0	51	F
UNIVERSIT╔ SAINTE-ANNE	3433 206 ROUTE	PO BOX 45	PETIT DE GRAT	NS	B0E 2L0	82	I
WILSON GAS STOP	1665 206 HIGHWAY		WEST ARICHAT	NS	B0E 3J0	55	G

LA PICASSE	3435 206 ROUTE	PO BOX 70	PETIT DE GRAT	NS	B0E 2L0	83	I
DUKE OF YORK CRANBERRY FARM	1198 GRANDIQUE RD	PO BOX 263	ARICHAT	NS	B0E 1A0	51	F
NOVA SCOTIA LIQUOR CORPORATION	2392 206 HIGHWAY		ARICHAT	NS	B0E 1A0	59	G
SAMPSON ARTHUR TV & APPLIANCES SALES & SERVICE	42 ANTHONY RD		L'ARDOISE	NS	B0E 1S0	57	G
CONSEIL SCOLAIRE ACADIEN PROVINCIAL	2359 206 ROUTE	PO BOX 1500	ARICHAT	NS	B0E 1A0	82	I
NOTRE-DAME-DE-L'ASSOMPTION	2316 206 HIGHWAY	PO BOX 60	ARICHAT	NS	B0E 1A0	86	I
ISLE OF MADAME HISTORICAL SOCIETY (THE)	2543 206 HIGHWAY	PO BOX 223	ARICHAT	NS	B0E 1A0	83	I
DELOREY'S PIZZERIA & CAFE	2374 206 HIGHWAY		ARICHAT	NS	B0E 1A0	58	G
TOMMY TUCKER'S ELECTRIC LTD	691 LOWER RD	PO BOX 420	ARICHAT	NS	B0E 1A0	17	C
SERVICE CANADA	3435 206 ROUTE		ARICHAT	NS	B0E 1A0	83	I
SAMSON ENTERPRISES LTD	179 BOUDREAUVILLE	PO BOX 72	ARICHAT	NS	B0E 1A0	37	D
PROXIM	2374 HIGH RD		ARICHAT	NS	B0E 1A0	59	G
VOLLMER ISLAND PARADISE	1489 JANVRINS ISLAND		ARICHAT	NS	B0E 1A0	70	I
CANDY SHOP (THE)	2372 HIGH RD		ARICHAT	NS	B0E 1A0	59	G
BABIN'S SERVICE CENTRE SALES & SERVICE	7 INDUSTRIAL RD		ARICHAT	NS	B0E 1A0	55	G
MARY ANN'S WEDDING SHOPPE	326 CAP LA RONDE RD		ARICHAT	NS	B0E 1A0	59	G

CULLEY'S CANTEEN	58 BENIES LN		ARICHAT	NS	B0E 1A0	58	G
LEBLANC U J PRO HOME CENTRE	775 MAIN ST	PO BOX 270	ARICHAT	NS	B0E 1A0	52	G
ST ANNE COMMUNITY & NURSING CARE CENTRE	2313 MAIN	PO BOX 30	ARICHAT	NS	B0E 1A0	80	I
BAB CONSTRUCTION LTD	89 ROCKY RD BAY		ARICHAT	NS	B0E 1A0	15	C
CORNER BRIDGE STORE			PETIT DE GRAT	NS	B0E 2L0	54	G
EAST COAST CREDIT UNION	9 CAP LA RONDE RD	PO BOX 552	D'ESCOUSSE	NS	B0E 1K0	60	H
JEANTIE'S MINI-MART	2341 MAIN ST	PO BOX 329	ARICHAT	NS	B0E 1A0	54	G
WINTER IVO		PO BOX 180	ARICHAT	NS	B0E 1A0	81	I
EASTERN COUNTIES REGIONAL LIBRARY			PETIT DE GRAT	NS	B0E 2L0	82	I
CLEARWATER MANAGEMENT SERVICES LTD		PO BOX 2000	ARICHAT	NS	B0E 1A0	20	D
BONIN AUTOMOTIVE			PETIT DE GRAT	NS	B0E 2L0	55	G
RICHMOND (MUNICIPALITY OF THE COUNTY OF)	2357 MAIN ST	PO BOX 120	ARICHAT	NS	B0E 1A0	93	J
DEVELOPMENT ISLE MADAME ASSOCIATION		PO BOX 57	ARICHAT	NS	B0E 1A0	86	I
IML FUNERAL SERVICES		PO BOX 138	PETIT DE GRAT	NS	B0E 2L0	72	I
PETIT DE GRAT PACKERS LTD		PO BOX 40	PETIT DE GRAT	NS	B0E 2L0	20	D
COOPERATIVE RADIO		PO BOX 250	PETIT DE GRAT	NS	B0E 2L0	48	E

RICHMOND LTD (LA)							
PREMIUM GROUP		PO BOX 39	ARICHAT	NS	B0E 1A0	51	F
RONA HOME & GARDEN	775 LOWER ROAD		ARICHAT	NS	B0E 1A0	52	G
ARICHAT (ST. ANNE LADIES AUXILIARY HOSP)			RICHMOND, SUBD. C	NS		45	E
╔COLE BEAU-PORT	2359 ROUTE 206		ARICHAT	NS	B0E 1A0	82	I
RBC ROYAL BANK OF CANADA	668 LOWER ST	PO BOX 240	ARICHAT	NS	B0E 1A0	60	H
CREDIT UNION CENTRAL OF NOVA SCOTIA		PO BOX 485	D'ESCOUSSE	NS	B0E 1K0	60	H
CREDIT UNION CENTRAL OF NOVA SCOTIA	3552 HWY 206	PO BOX 159	PETIT DE GRAT	NS	B0E 2L0	60	H
ST JOSEPHÆS CREDIT UNION LTD	3552 HIGHWAY 206	PO BOX 159	PETIT DE GRA	NS	B0E 2L0	60	H
ST JOSEPHÆS CREDIT UNION LTD	3552 HIGHWAY 206	PO BOX 159	PETIT DE GRAT	NS	B0E 2L0	60	H
ST ANNE COMMUNITY AND NURSING HOME CENTRE		PO DRAWER 30	ARICHAT	NS	B0E 1A0	80	I
ST ANNE COMMUNITY & NURSING CARE CENTRE		PO DRAWER 30	ARICHAT	NS	B0E 1A0	80	I
RICHMOND DIST - ARICHAT		BOX 9	ARICHAT	NS	B0E 1A0	92	J
ARICHAT PO	2541 HIGH RD		ARICHAT	NS	B0E 1A0	43	E
D'ESCOUSSE PO	3280 HWY 320		D'ESCOUSSE	NS	B0E 1K0	43	E
PEIT DE GRAT PO	3648 MAIN ST		PETIT DE GRAT	NS	B0E 2L0	43	E

WEST ARICHAT PO	1531 MAIN ST		WEST ARICHAT	NS	B0E 3J0	43	E
ALONGSHORE SAILING VACATIONS		PO BOX 2000	D'ESCOUSSE	NS	B0E 1K0	44	E
LENNOX PASSAGE YACHT CLUB			D'ESCOUSSE	NS	B0E 1K0	44	E
LENOIR FORGE MUSEUM		PO BOX 206	ARICHAT	NS	B0E 1A0	84	I
ISLE MADAME WATER AND SKY PADDLING ADVENTURES		PO BOX 228	ARICHAT	NS	B0E 1A0	79	I
LENNOX PASSAGE PROVINCIAL PARK				NS		79	I
PONDVILLE BEACH PROVINCIAL PARK				NS		79	I
BURNT ISLAND PROVINCIAL PARK				NS		79	I

Table D.1: Isle Madame-Retiree’s Economic Status Quo Points in SIC Major Groups and SIC Division

Source: DMTI (2009)

NAME	ADDRESS	CITY	PROV	POST_CODE	PHONE	SIC Major Group	SIC Decision
MARTELL JOSEPH		ARICHAT	NS	B0E 1A0	902-226-9681	87	I
D'ESCOUSSE CIVIC IMPROVEMENT SOCIETY		D'ESCOUSSE	NS	B0E 1K0	902-226-3202	86	I
SONIA'S BEAUTY BOUTIQUE		ARICHAT	NS	B0E 1A0	902-226-3578	72	I

PR╔SCHOLAIRE DE LA PICASSE		PETIT DE GRAT	NS	B0E 2L0	902-226-3319	82	I
TELILE		ARICHAT	NS	B0E 1A0	902-226-1928	48	E
ISLE MADAME DAY CARE CENTRE		D'ESCOUSSE	NS	B0E 1K0	902-226-2481	83	I
SAMSON'S J L INSURANCE AGENCY		ARICHAT	NS	B0E 1A0	902-226-2707	64	H
SUNRISE MONUMENTS		ARICHAT	NS	B0E 1A0	902-226-0006	32	D
AUBERGE ACADIENNE (L')		ARICHAT	NS	B0E 1A0	902-226-2200	70	I
BLUEWAVE ENERGY		ARICHAT	NS	B0E 1A0	902-226-2172	51	F
MACNEIL LAURIE DR		ARICHAT	NS	B0E 1A0	902-226-1674	80	I
ISLAND NEST (THE)		ARICHAT	NS	B0E 1A0	902-226-0033	58	G
GORD'S IRVING		ARICHAT	NS	B0E 1A0	902-226-2103	55	G
AFL TANK MANUFACTURING DISTRIBUTOR		ARICHAT	NS	B0E 1A0	902-226-0055	34	D
FUNERAL SERVICE ASSOCTIATION OF NOVA SCOTIA		ARICHAT	NS	B0E 1A0	902-226-3301	86	I
ARICHAT BIBLE CHURCH		ARICHAT	NS	B0E 1A0	902-226-1444	86	I
RICHMOND COUNTY LITERACY NETWORK		D'ESCOUSSE	NS	B0E 1K0	902-226-0383	82	I
MARITIME SOLAR REFLECTION SYSTEMS LTD		ARICHAT	NS	B0E 1A0	902-226-0542	50	F
SHIRLEY'S SPUD WAGON		ARICHAT	NS	B0E 1A0	902-226-0293	58	G

WEST ARICHAT FIBREGLASS INC.		WEST ARICHAT	NS	B0E 3J0	902-226-0629	30	D
GRECO EXPRESS		WEST ARICHAT	NS	B0E 3J0	902-226-0354	58	G
FAMILY TREASURES CLOTHING		ARICHAT	NS	B0E 1A0	902-226-2569	59	G
RURAL LINX MARKETING		ARICHAT	NS	B0E 1A0	902-226-0624	73	I
STRAIT AREA PEST CONTROL		ARICHAT	NS	B0E 1A0	902-226-2083	28	D
SAMSON O J MOBILE CLOTHING		ARICHAT	NS	B0E 1A0	902-226-2328	56	G
ROCKY BAY ATHLETIC CLUB		ARICHAT	NS	B0E 1A0	902-226-3463	79	I
ARICHAT CEMENT FINISHING LTD		ARICHAT	NS	B0E 1A0	902-226-9801	17	C
SUPERIOR CONTRACTING LTD		ARICHAT	NS	B0E 1A0	902-226-3391	15	C
OCEAN VIEW DRAFTING		ARICHAT	NS	B0E 1A0	902-226-3222	87	I
A A MUNRO INSURANCE BROKERS INC.		PETIT DE GRAT	NS	B0E 2L0	902-226-2701	63	H
VINA MOTEL		ARICHAT	NS	B0E 1A0	902-226-2662	70	I
BRITTEN'S SERVICE CENTRE & TIRE SHOP		ARICHAT	NS	B0E 1A0	902-226-2953	55	G
HARBOUR VIEW CONSTRUCTION LTD		WEST ARICHAT	NS	B0E 3J0	902-226-3528	17	C
ST ANNE COMMUNITY & NURSING CARE CENTRE	2313 MAIN	ARICHAT	NS	B0E 1A0	902-226-2826	80	I
RICHMOND REGIONAL HOUSING AUTHORITY		ARICHAT	NS	B0E 1A0	902-226-3368	65	H

ISLE MADAME DAY CARE CENTRE		ARICHAT	NS	B0E 1A0	902-226-0399	83	I
FLAT CALM COUNTRY INN	3281 HIGHWAY 320	D'ESCOUSSE	NS	B0E 1K0	902-226-0422	70	I
FAMILY PLACE RESOURCE CENTRE	677 LOWER RD	ARICHAT	NS	B0E 1A0	902-226-0512	86	I
LENOIR FORGE MUSEUM	712 LOWER RD	ARICHAT	NS	B0E 1A0	902-226-9364	84	I
FRANK'S MARINE LTD	90 SHORE RD	ARICHAT	NS	B0E 1A0	902-226-0079	55	G
ACTIVE LIVING CENTRE	677 LOWER RD	ARICHAT	NS	B0E 1A0	902-226-0403	86	I
ISLE MADAME MACHINING	71 SHORE	ARICHAT	NS	B0E 1A0	902-226-0210	35	D
ROYAL BANK OF CANADA		ARICHAT	NS	B0E 1A0	902-226-2552	60	H
GREEN ISLAND DISTRIBUTORS		ARICHAT	NS	B0E 1A0	902-226-2633	51	F
CLAIRE'S CAFE (1998) LTD		D'ESCOUSSE	NS	B0E 1K0	902-226-1432	58	G
POIRIER'S GARAGE		D'ESCOUSSE	NS	B0E 1K0	902-226-3034	55	G
PRODUCTION PICASSE LTD		PETIT DE GRAT	NS	B0E 2L0	902-226-0002	59	G
FAMILY SERVICE OF ARICHAT		ARICHAT	NS	B0E 1A0	902-226-2473	83	I
CHEZ GUSTAVE		PETIT DE GRAT	NS	B0E 2L0	902-226-3458	58	G
ECOLE SECONDAIRE DE L'ILE MADAME		ARICHAT	NS	B0E 1A0	902-226-3353	82	I
TOUCH WITH A BRUSH		ARICHAT	NS	B0E 1A0	902-226-3794	59	G
BRITTEN'S SERVICE CENTRE & TIRE SHOP -		ARICHAT	NS	B0E 1A0	902-226-3292	55	G

IF BUSY CALL							
DEBBIE'S CANTEEN		WEST ARICHAT	NS	B0E 3J0	902-226-9574	58	G
ECOLE SECONDAIRE DE L'ILE-MADAME		ARICHAT	NS	B0E 1A0	902-226-5220	82	I
GRECO EXPRESS		ARICHAT	NS	B0E 1A0	902-226-3200	58	G
RADIO COMMUNAUTAIRE (LE)		ARICHAT	NS	B0E 1A0	902-226-0025	48	E
SAMSON ENTERPRISES LTD		ARICHAT	NS	B0E 1A0	902-226-0095	44	E
UNIVERSIT╔ SAINTE-ANNE		ARICHAT	NS	B0E 1A0	902-226-3919	82	I
ALLSEASON AQUATIC FARMS LTD	GENERAL DELIVERY	ARICHAT	NS	B0E 1A0	902-226-0337	02	A
ALLAN SAVOURY SCALLOP & MUSSELL FARMS INC.	160 DUCAN RD	D'ESCOUSSE	NS	B0E 1K0	902-345-2996	20	D
CMA2004	34256 HIGHWAY 206	ARICHAT	NS	B0E 1A0	902-226-0338	82	I
CONGRES MONDIAL ACADIEN 2004	3435 ROUTE 206	ARICHAT	NS	B0E 1A0	902-226-1013	83	I
PICASSE (LA) - GENEALOGIE BUREAU	3435 ROUTE 206	ARICHAT	NS	B0E 1A0	902-226-0185	83	I

Table D.2: Isle Madame’s Economic Status Quo Points in SIC Major Groups and SIC Division

Source: DMTI (2009)

Appendix E: ArcMap User Interface Code

The Sea-Level Rise Tool (SLRT) (Pakdel, S., 2009) developed for this research in ArcGIS uses Visual Basics for Applications (Burke, R. 2003). The Sea Level Rise Tool was made via ArcGIS to find the vulnerable area (buffer zone) in Isle Madame by applying different Storm Scenarios with different MOWL based on the historical storms information in Isle Madame. In addition, the Sea Level Rise Tool helps to find information about how many elements (with all details of the elements) of each data layer is on vulnerable area (buffer zone) regarding to each Storm Scenario. The tool is described in details in chapter three and a screenshot of the graphical user interface is provided in Section 3.4.1. Below is the VBA code for the tool:

```
Private Sub ListBox1_Click()
ListBox2.Clear
Dim dblValue As Double
Dim bolTest As Boolean
bolTest = IsNumeric(TextBox1.Value)
dblValue = TextBox1.Value

End Sub
Private Sub spnTr_Change()
txtTr.Text = spnTr.Value
End Sub

Private Sub txtTr_Change()
If IsNumeric(txtTr.Text) Then spnTr.Value = txtTr.Text
End Sub

Private Sub UserForm_Initialize()
Dim pMxdoc As IMxDocument 'get entry to arcobjects
Set pMxdoc = ThisDocument

Dim pMap As IMap ' map is the dataframe holding layers etc
Set pMap = pMxdoc.FocusMap
lcount = pMap.LayerCount
Dim player As ILayer
   For I = 0 Tolcount - 1
   Set player = pMap.Layer(I)
   ComboBox1.AddItem player.Name
   Next
ComboBox1.Text = ComboBox1.List(0, 0)
End Sub

Function getLayerByName(inName As String) As ILayer
Dim pMxdoc As IMxDocument
Set pMxdoc = ThisDocument
```

```
Dim pMap As IMap ' map is the dataframe holding layers etc
Set pMap = pMxdoc.FocusMap
lcount = pMap.LayerCount
Dim player As ILayer
  For I = 0 Tolcount - 1
  Set player = pMap.Layer(I)
    If inName = player.Name Then
    Set getLayerByName = player
    Exit Function
    End If
  Next
End Function


Private Sub RasterQuery()
' define the for query
Dim pMxdoc As IMxDocument
Set pMxdoc = ThisDocument
Dim pMap As IMap
Set pMap = pMxdoc.FocusMap

' Set player to the bottom of the list
Dim player As IRasterLayer
Set player = pMap.Layer(pMap.LayerCount - 1)

Dim pTopLayer As IRasterLayer
Set pTopLayer = pMap.Layer(0)

Dim pRaster As IRaster
Set pRaster = player.Raster

' If the name of the top layer is Eval... (Meaning there has already been a calculation), then
If pTopLayer.Name = "EvaluationResult" Then
' Make an effect object and set it to player (top layer)
  Dim fakeDeleteEffect As ILayerEffects
  Set fakeDeleteEffect = pTopLayer
' player property of transparency to 100
fakeDeleteEffect.Transparency = 100

End If

' PERFORM RASTER QUERY prepare a query filter
' prepare a query filter
Dim pQFilter As IQueryFilter
Set pQFilter = New QueryFilter
pQFilter.WhereClause = "value > " + txtLevel.Text
Dim pRasDes As IRasterDescriptor
Set pRasDes = New RasterDescriptor
pRasDes.CreatepRaster, pQFilter, "value"

' prepare a raster descriptor
Dim pLogicalOp As ILogicalOp
Set pLogicalOp = New RasterMathOps

' run a logical operation
Dim pOutputRaster As IGeoDataset
Set pOutputRaster = pLogicalOp.Test(pRasDes)

' creat the output raster layer and add the layer to the active map
```

```
Dim pOutputLayer As IRasterLayer
Set pOutputLayer = New rasterLayer
pOutputLayer.CreateFromRasterpOutputRaster
pOutputLayer.Name = "EvaluationResult"


Dim pLayerEffects As ILayerEffects
Set pLayerEffects = pOutputLayer
pLayerEffects.Transparency = txtTr.Value
pMap.AddLayerpOutputLayer
End Sub

Private Sub CommandButton1_Click()
Dim bolTest As Boolean
bolTest = IsNumeric(txtLevel.Text) And IsNumeric(txtTr.Text)
If bolTest Then
txtError.Caption = ""
  Call RasterQuery
Else
txtError.Caption = "Please enter a numeric value"
End If
End Sub
```

Appendix F: System Dynamics Model and STELLA equation code for the temporal estimation of the storm damage model

In 2011, the author created a System Dynamics Model with STELLA for this research. Total Damage, Direct Damage, and Indirect Damage were calculated via System Dynamics Model. The input to the SD Model is considered as Direct Damage (Immediate Damage after storm surge in time zero) which is a fraction of estimated Total Damage in previous step. Moreover, there are lag damages (Indirect Damages) which are modeled and calculated in SD Model in time one, two, and three. Therefore, the result of SD Model is Total damage consist of Direct Damage (t=0) and Indirect Damages (t=1, 2, 3). At the end the estimated Total Damage based on ArcGIS was compared with the calculated Total Damage from SD Model for all six Storm Scenarios. The Model is described in chapter five of this research and a screenshot of the Model Map is provided in this section too. Below is the Equation code for the Model:

Cultural_Total__Damage(t) = Cultural_Total__Damage(t - dt) + (TotalDDCu + TotalInDDCu) * dt
INIT Cultural_Total__Damage = 0

INFLOWS:
TotalDDCu = DirectDamage_of_Communication_Resource+Direct_Damage_of_Cultural_Sites
TotalInDDCu = Communication_Resource2+Cultural__Sites_Cu+Land_Cover+Social__Welfare_Cu

Economic_Total__Damage(t) = Economic_Total__Damage(t - dt) + (TotalDDEc + TotalInDDEc) * dt
INIT Economic_Total__Damage = 0

INFLOWS:
TotalDDEc = DirectDamage_of_Built_Environment+Direct_Damage__of_Public_Works
TotalInDDEc = Built__Environmen& industrial by type_Ec+Cultural_Sites_Ec+ Habitat and Species +Public__Work_Ec+Wage_Earning

Environment_Total__Damage(t) = Environment_Total__Damage(t - dt) + (TotalDDEn + TotalInDDEn) * dt
INIT Environment_Total__Damage = 0

INFLOWS:
TotalDDEn = Direct_Damage__Land_cover+DirectDamage__of_ Habitat and Species
TotalInDDEn = Built__Environmen& industrial by type_En+Natural__Resource_En+PublicWork_En

Social_Total__Damage(t) = Social_Total__Damage(t - dt) + (TotalDDSo + TotalInDDSo) * dt
INIT Social_Total__Damage = 0

INFLOWS:
TotalDDSo = DirectDamage_of_Socila_Welfare+Direct_Damage_of_Wage_Earning
TotalInDDSo = Built_Environment& industrial by type __So+Communication_Resource1+Cultural_Sites_So+ Habitat and Species _So+PublicWork_So+social__Welfare_So

(Direct Damages that are inputs to the Model)
Total_DirectDamage_of_Built_Environment& industrial by type = 760945
Total_DirectDamage_of_Communication_Resource = 38500
Total_DirectDamage_of_Socila_Welfare = 104966
Total_DirectDamage__of_ Habitat and Species = 626780
Total_Direct_Damage_of_Cultural_Sites = 192962
Total_Direct_Damage_of_Wage_Earning = 9037
Total_Direct_Damage__Land_cover = 374220
Total_Direct_Damage__of_Public_Works = 213132

(Lag affects of each Total Direct Damages on other pillars)
Built_Environment__So = constant8*Use_of_DirectDamage_of_Built_Environment& industrial by type
Built__Environmen_Ec = Constant_16*Use_of_DirectDamage_of_Built_Environment& industrial by type
Built__Environmen_En = constant7*Use_of_DirectDamage_of_Built_Environment& industrial by type

Communication_Resource1 = constant6*Use_of_DirectDamage_of_Communication_Resource
Communication_Resource2 = constant4*Use_of_DirectDamage_of_Communication_Resource

Cultural_Sites_Ec = Constant_13*use_of_Direct_Damage_of_Cultural_Sites
Cultural_Sites_So = constant_12*use_of_Direct_Damage_of_Cultural_Sites
Cultural__Sites_Cu = constant_18*use_of_Direct_Damage_of_Cultural_Sites

Land_Cover = constant1*use_ofDirect_Damage_Land_Cover

Natural_ResourceEc = constant3*Use_of_DirectDamage__of_ Habitat and Species
Natural_Resource_So = constant2*Use_of_DirectDamage__of_ Habitat and Species
Natural__Resource_En = Constant_14*Use_of_DirectDamage__of_ Habitat and Species

PublicWork_En = contant_10*Use_of_Direct_Damage__of_Public_Works
PublicWork_So = contant_11*Use_of_Direct_Damage__of_Public_Works
Public__Work_Ec = Constant_17*Use_of_Direct_Damage__of_Public_Works

Social__Welfare_Cu = constant5*Use_ofl_Direct_Damage_of_Socila_Welfare
social__Welfare_So = Constant_15*Use_ofl_Direct_Damage_of_Socila_Welfare

Wage_Earning = constant9*Use_of_Direct_Damage_of_Wage_Earning

(Constants amounts that are used above)
constant1 = .01
constant2 = .001
constant3 = .1
constant4 = .11
constant5 = .75
constant6 = .04
constant7 = .1
constant8 = .01
constant9 = 1
constant_12 = .1
Constant_13 = .1
Constant_14 = .2
Constant_15 = .1
Constant_16 = .2
Constant_17 = .2
constant_18 = .1
contant_10 = .1
contant_11 = .1

(Direct Damages of each item that are considered in tome zero and they are immediate damage)

DirectDamage_of_Built_Environment & industrial by type = IF (TIME=0) THEN Total_DirectDamage_of_Built_Environment & industrial by type ELSE 0

DirectDamage_of_Communication_Resource = IF (TIME=0) THEN Total_DirectDamage_of_Communication_Resource ELSE 0

DirectDamage_of_Socila_Welfare = IF (TIME=0) THEN Total_DirectDamage_of_Socila_Welfare ELSE 0

DirectDamage__of_ Habitat and Species = IF (TIME=0) THEN Total_DirectDamage__of_ Habitat and Species ELSE 0

Direct_Damage_of_Cultural_Sites = IF (TIME=0) THEN Total_Direct_Damage_of_Cultural_Sites ELSE 0

Direct_Damage_of_Wage_Earning = IF (TIME=0) THEN Total_Direct_Damage_of_Wage_Earning ELSE 0

Direct_Damage__Land_cover = IF (TIME=0) THEN Total_Direct_Damage__Land_cover ELSE 0

Direct_Damage__of_Public_Works = IF (TIME=0) THEN Total_Direct_Damage__of_Public_Works ELSE 0

(Use of direct damages for lag affects)
use_ofDirect_Damage_Land_Cover = IF (TIME=0) THEN 0 ELSE (Total_Direct_Damage__Land_cover)^(1/TIME)
Use_ofl_Direct_Damage_of_Socila_Welfare = IF (TIME=0) THEN 0 ELSE (Total_DirectDamage_of_Socila_Welfare)^(1/TIME)
Use_of_DirectDamage_of_Built_Environment $ Industrial by type = IF (TIME=0) THEN 0 ELSE (Total_DirectDamage_of_Built_Environment$ Industrial by type)^(1/TIME)
Use_of_DirectDamage_of_Communication_Resource = IF (TIME=0) THEN 0 ELSE (Total_DirectDamage_of_Communication_Resource)^(1/TIME)
Use_of_DirectDamage__of_ Habitat and Species = IF (TIME=0) THEN 0 ELSE (Total_DirectDamage__of_ Habitat and Species)^(1/TIME)
use_of_Direct_Damage_of_Cultural_Sites = IF (TIME=0) THEN 0 ELSE (Total_Direct_Damage_of_Cultural_Sites)^(1/TIME)
Use_of_Direct_Damage_of_Wage_Earning = IF (TIME=0) THEN 0 ELSE (Total_Direct_Damage_of_Wage_Earning)^(1/TIME)
Use_of_Direct_Damage__of_Public_Works = IF (TIME=0) THEN 0 ELSE (Total_Direct_Damage__of_Public_Works)^(1/TIME)

(Final results for each Storm Scenario)
TotalDamage_for_scenario_x = Social_Total__Damage+Environment_Total__Damage+Economic_Total__Damage+Cultural_Total__Damage

TotalDirectDamage__for_scenario_x = TotalDDCu+TotalDDEc+TotalDDEn+TotalDDSo

Total_IndirecDamage_for_scenario_x = TotalInDDCu+TotalInDDEc+TotalInDDEn+TotalInDDSo

In the STELLA model which is shown in Figure F.1, there are four pillars (Economic, Environmental, Social, and Cultural) and each of them is shown in a sector frame with its name above the frame. In each frame there is a stock shown by a sq. Stocks' names are: Environmental Total Damage, Cultural Total Damage, Social Total Damage, and Economic Total Damage. These stocks present Total Damage of each pillar and they have initial value of zero then they are showing sum of the Total Direct Damage and Total Indirect Damage after each period. For each stock there are two inflow; Total Direct Damage of that pillar and Total Indirect Damage of that pillar, these are shown as TotalDD and TotalInDD respectively. Also in each frame there are two Total Direct Damage converters and each of them presents one of the two selected items in each pillar. These converters are the inputs to the Model; they have constant values from table 3.15 regarding to different Storm Scenario and these numbers will import to the model from an excel file. These converters are as bellow:

Total Direct Damage of Habitat and Species and Total Direct Damage of "Hydrology, Land Use & Land Cover" for Environmental Pillar, Total Direct Damage of Built Environment and Total Direct Damage of Public Works for Economic Pillar, Total Direct Damage of Cultural Sites and Total Direct Damage of Communication Resources for Cultural Pillar, and Total Direct Damage of Wage Earning and Total Direct Damage of Social Welfare for Social Pillar.

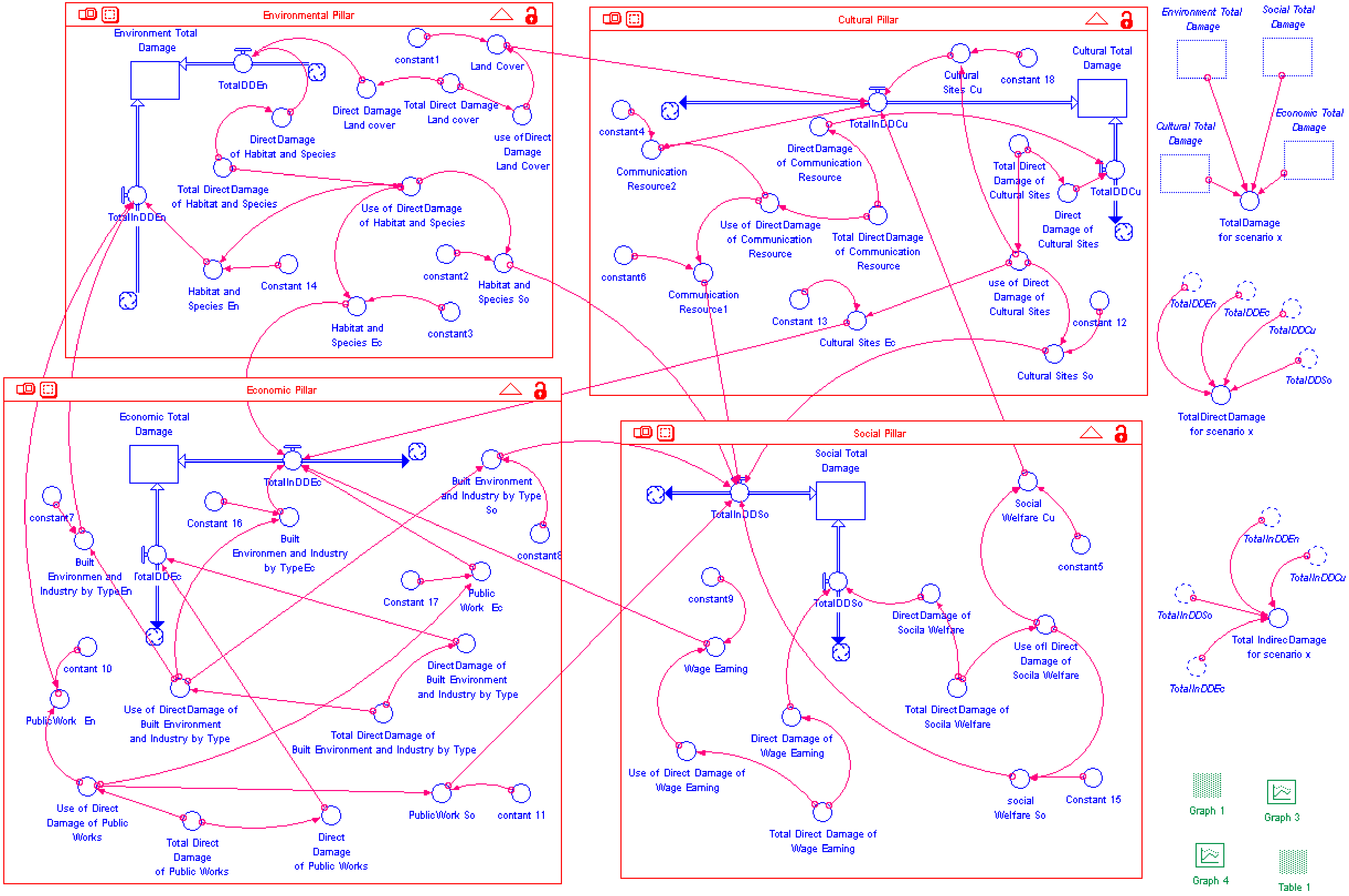

Figure F.1: System Dynamics Model

Each of the Total Direct Damage converters has two branches and each branch has different condition. All these branches with their conditions are shown in table F.1. One of these branches helps to take a value of Total Direct Damage converter and put a condition along with use a function for it to make it ready for use in one of the 18 mentioned interactions. The other branch takes a value of Total Direct Damage converter and put a condition for it and sends it to Total Direct Damage inflow (or TotalDD).

Total Direct Damage converter	**Branch**	**Condition and Equation related to the Branch**
Total Direct Damage of Habitat and Species	Use of Direct Damage of Habitat and Species	IF (TIME=0) THEN 0 ELSE Total Direct Damage of Habitat and Species ^1/(TIME)
	Direct Damage of Habitat and Species	IF (TIME=0) THEN Total Direct Damage of Habitat and Species ELSE 0
Total Direct Damage of "Land Cover"	Use of Direct Damage of "Land Cover"	IF (TIME=0) THEN 0 ELSE Total Direct Damage of "Land Cover" ^1/(TIME)
	Direct Damage of "Land Cover"	IF (TIME=0) THEN Total Direct Damage of "Land Cover" ELSE 0
Total Direct Damage of Built Environment & Industry by Type	Use of Direct Damage of Built Environment & Industry by Type	IF (TIME=0) THEN 0 ELSE Total Direct Damage of Built Environment & Industry by Type ^1/(TIME)
	Direct Damage of Built Environment & Industry by Type	IF (TIME=0) THEN Total Direct Damage of Built Environment & Industry by Type ELSE 0
Total Direct Damage of Public Works	Use of Direct Damage of Public Works	IF (TIME=0) THEN 0 ELSE Total Direct Damage of Public Works ^1/(TIME)
	Direct Damage of Public Works	IF (TIME=0) THEN Total Direct Damage of Public Works ELSE 0
Total Direct Damage of Cultural Sites	Use of Direct Damage of Cultural Sites	IF (TIME=0) THEN 0 ELSE Total Direct Damage of Cultural Sites ^1/(TIME)
	Direct Damage of Cultural Sites	IF (TIME=0) THEN Total Direct Damage of Cultural Sites ELSE 0
Total Direct Damage of Communication Resources	Use of Direct Damage of Communication Resources	IF (TIME=0) THEN 0 ELSE Total Direct Damage of Communication Resources ^1/(TIME)
	Direct Damage of Communication Resources	IF (TIME=0) THEN Total Direct Damage of Communication Resources ELSE 0

Total Direct Damage of Wage Earning	Use of Direct Damage of Wage Earning	IF (TIME=0) THEN 0 ELSE Total Direct Damage of Wage Earning ^1/(TIME)
	Direct Damage of Wage Earning	IF (TIME=0) THEN Total Direct Damage of Wage Earning ELSE 0
Total Direct Damage of Social Welfare	Use of Direct Damage of Social Welfare	IF (TIME=0) THEN 0 ELSE Total Direct Damage of Social Welfare ^1/(TIME)
	Direct Damage of Social Welfare	IF (TIME=0) THEN Total Direct Damage of Social Welfare ELSE 0

Table F.1: Total Direct Damage converters and their branches

Appendix G: HURDAT files of Isle Madame related storms and tracks

Tables G.1 to G.16 present all sixteen historical storms in Isle Madame with details including name of the storm, date, Latitude and Longitude, direction, speed, wind, pressure and type of the storm. In these tables the highlighted row in each storm illustrates the exact day that storm reached Isle Madame.

Moreover, Figures G.1 to G.12 illustrate storms tracks of all sixteen Isle Madame's historical storms regarding to the year of storms happened.

Storm Name	Month	Day	Hour	Lat.	Long.	Dir.	Speed	Wind	Pressure	-------Type-------
BILL 2009										
	August	22	0 UTC	30.4N	67.6W	340 deg	35 kph	165 kph	957 mb	Hurricane - Category 2
	August	22	6 UTC	32.3N	68.4W	340 deg	37 kph	165 kph	960 mb	Hurricane - Category 2
	August	22	12 UTC	34.1N	68.8W	350 deg	33 kph	160 kph	961 mb	Hurricane - Category 2
	August	22	18 UTC	36.0N	68.9W	360 deg	35 kph	150 kph	961 mb	Hurricane - Category 1
	August	23	0 UTC	38.1N	68.4W	10 deg	38 kph	150 kph	961 mb	Hurricane - Category 1
	August	23	6 UTC	40.1N	67.3W	25 deg	38 kph	140 kph	962 mb	Hurricane - Category 1
	August	23	12 UTC	42.4N	65.4W	30 deg	50 kph	130 kph	965 mb	Hurricane - Category 1
	August	23	18 UTC	44.4N	62.5W	45 deg	53 kph	120 kph	970 mb	Hurricane - Category 1
	August	24	0 UTC	46.3N	57.9W	60 deg	68 kph	120 kph	973 mb	Hurricane - Category 1
	August	24	6 UTC	48.0N	53.0W	65 deg	68 kph	110 kph	980 mb	Tropical Storm
	August	24	12 UTC	49.2N	47.2W	75 deg	74 kph	110 kph	980 mb	Extratropical Storm
	August	24	18 UTC	50.0N	41.2W	80 deg	72 kph	110 kph	980 mb	Extratropical Storm

Table G.1: Isle Madame's historical storms

Source: NOAA (2010)

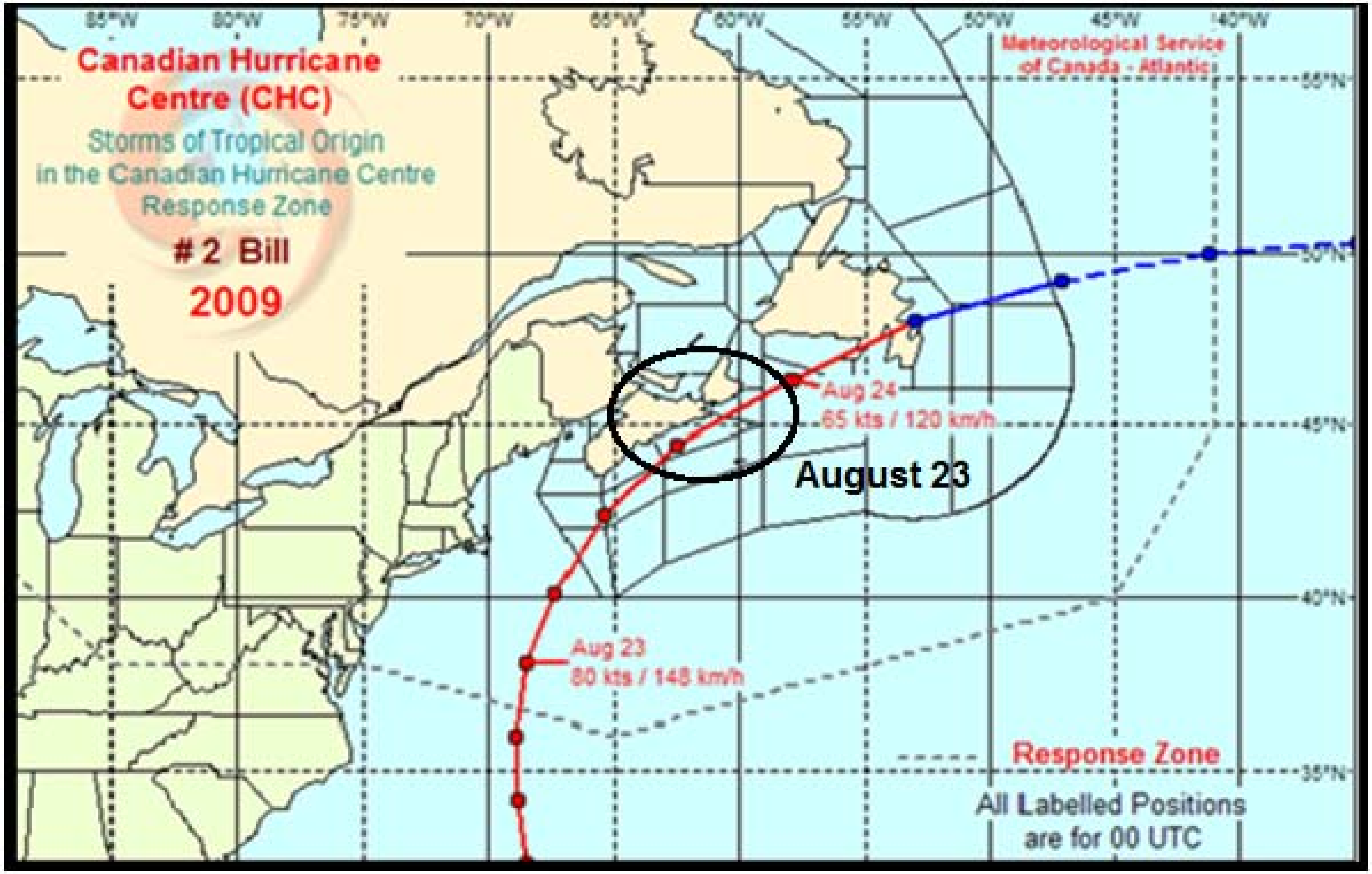

Figure G.1: 2009 Storm tracks of Isle Madame's historical storms

Source: Environment Canada (2009)

Storm Name	Month	Day	Hour	Lat.	Long.	Dir.	Speed	Wind	Pressure	-------Type-------
NO NAMED 2006										
	July	17	0 UTC	38.3N	67.6W	40 deg	12 kph	55 kph	1009 mb	Extratropical Storm
	July	17	6 UTC	39.1N	66.4W	50 deg	22 kph	55 kph	1008 mb	Tropical Depression
	July	17	12 UTC	40.0N	65.1W	50 deg	24 kph	75 kph	1003 mb	Tropical Storm
	July	17	18 UTC	41.1N	63.7W	45 deg	27 kph	85 kph	998 mb	Tropical Storm
	July	18	0 UTC	42.4N	62.1W	45 deg	31 kph	75 kph	999 mb	Tropical Storm
	July	18	6 UTC	43.7N	60.1W	50 deg	35 kph	65 kph	1004 mb	Tropical Storm
	July	18	12 UTC	45.5N	58.0W	40 deg	42 kph	55 kph	1007 mb	Tropical Storm
	July	18	18 UTC	47.1N	55.8W	45 deg	40 kph	45 kph	1009 mb	Tropical Storm
	July	19	0 UTC	48.6N	52.9W	50 deg	44 kph	45 kph	1012 mb	Tropical Storm
	July	19	6 UTC	49.2N	49.4W	75 deg	42 kph	45 kph	1012 mb	Tropical Storm
	July	19	12 UTC	49.8N	46.1W	75 deg	40 kph	45 kph	1014 mb	Tropical Storm

Table G.2: Isle Madame’s historical storms

Source: NOAA (2010)

Storm Name	Month	Day	Hour	Lat.	Long.	Dir.	Speed	Wind	Pressure	-------Type-------
ALBERTO 2006										
	June	14	0 UTC	31.3N	82.8W	30 deg	20 kph	65 kph	1001 mb	Tropical Storm
	June	14	6 UTC	32.8N	81.9W	25 deg	29 kph	55 kph	1003 mb	Tropical Depression
	June	14	12 UTC	34.3N	80.7W	35 deg	33 kph	65 kph	1003 mb	Extratropical Storm
	June	14	18 UTC	35.5N	77.5W	65 deg	51 kph	65 kph	1002 mb	Extratropical Storm
	June	15	0 UTC	37.0N	73.0W	70 deg	72 kph	85 kph	999 mb	Extratropical Storm
	June	15	6 UTC	38.8N	69.9W	55 deg	55 kph	85 kph	990 mb	Extratropical Storm
	June	15	12 UTC	40.9N	66.8W	50 deg	57 kph	95 kph	979 mb	Extratropical Storm
	June	15	18 UTC	42.6N	64.2W	50 deg	46 kph	100 kph	971 mb	Extratropical Storm
	June	16	0 UTC	44.0N	62.0W	50 deg	38 kph	100 kph	969 mb	Extratropical Storm
	June	16	6 UTC	46.0N	58.5W	50 deg	57 kph	95 kph	972 mb	Extratropical Storm
	June	16	12 UTC	47.4N	55.0W	60 deg	50 kph	85 kph	985 mb	Extratropical Storm
	June	16	18 UTC	49.3N	51.5W	50 deg	55 kph	75 kph	990 mb	Extratropical Storm
	June	17	0 UTC	50.8N	45.2W	70 deg	79 kph	75 kph	995 mb	Extratropical Storm
	June	17	6 UTC	51.5N	39.0W	80 deg	72 kph	75 kph	995 mb	Extratropical Storm
	June	17	12 UTC	53.0N	34.5W	60 deg	57 kph	75 kph	995 mb	Extratropical Storm
	June	17	18 UTC	54.0N	29.0W	75 deg	63 kph	65 kph	995 mb	Extratropical Storm

Table G.3: Isle Madame’s historical storms

Source: NOAA (2010)

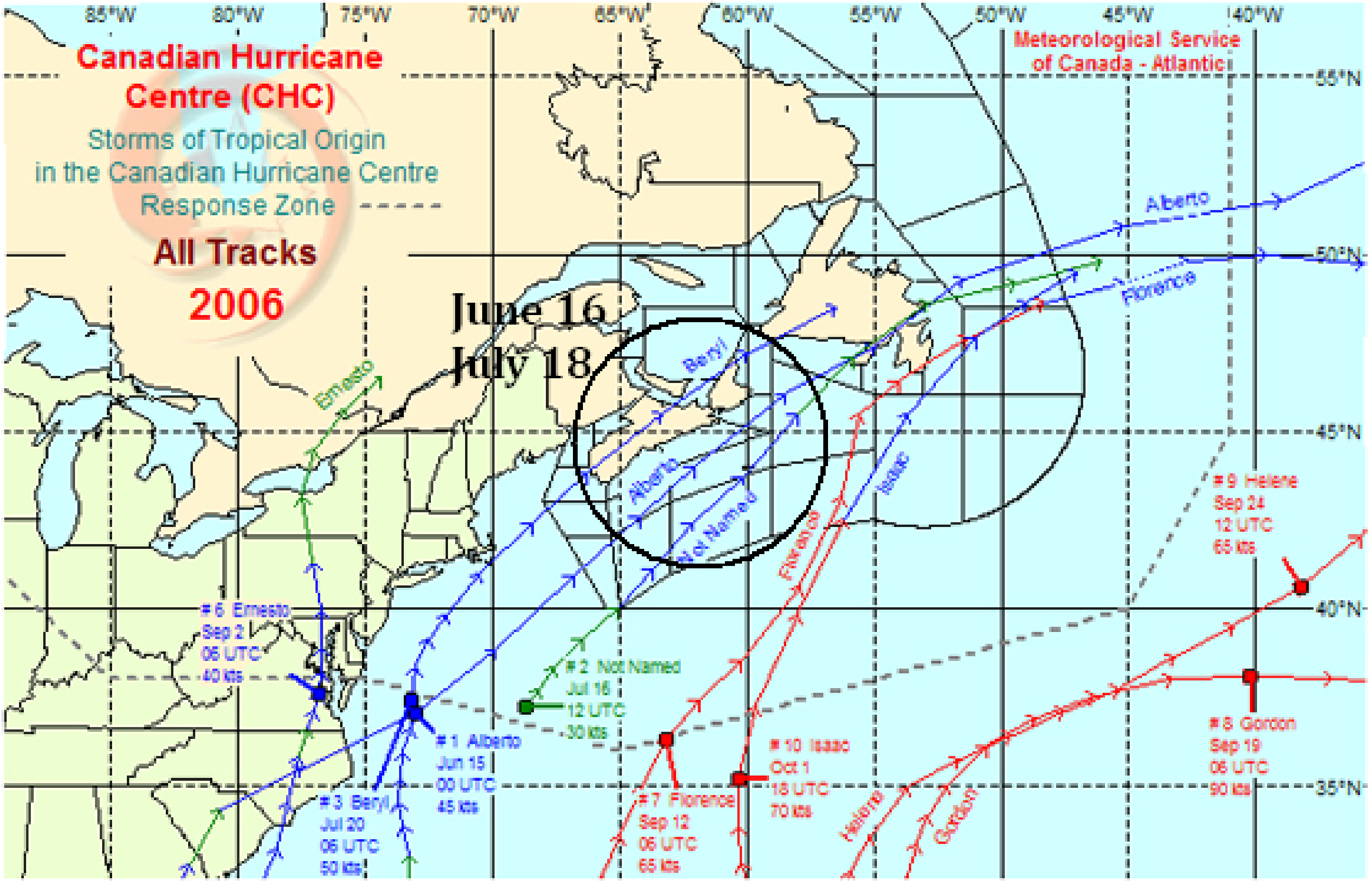

Figure G.2: 2006 Storms tracks of Isle Madame's historical storms

Source: Environment Canada (2009)

Storm Name	Month	Day	Hour	Lat.	Long.	Dir.	Speed	Wind	Pressure	-------Type-------

OPHILIA 2005										
	September	15	0 UTC	34.2N	76.9W	60 deg	9 kph	140 kph	979 mb	Hurricane - Category 1
	September	15	6 UTC	34.5N	76.3W	60 deg	9 kph	130 kph	982 mb	Hurricane - Category 1
	September	15	12 UTC	34.7N	75.8W	65 deg	7 kph	120 kph	984 mb	Hurricane - Category 1
	September	15	18 UTC	34.7N	75.6W	90 deg	1 kph	120 kph	986 mb	Hurricane - Category 1
	September	16	0 UTC	34.6N	75.1W	105 deg	7 kph	110 kph	987 mb	Tropical Storm
	September	16	6 UTC	34.7N	74.8W	70 deg	3 kph	100 kph	993 mb	Tropical Storm
	September	16	12 UTC	35.4N	74.4W	25 deg	12 kph	95 kph	995 mb	Tropical Storm
	September	16	18 UTC	36.4N	73.6W	35 deg	20 kph	100 kph	993 mb	Tropical Storm
	September	17	0 UTC	37.3N	72.7W	40 deg	20 kph	100 kph	995 mb	Tropical Storm
	September	17	6 UTC	38.7N	71.4W	35 deg	31 kph	95 kph	1000 mb	Tropical Storm
	September	17	12 UTC	40.0N	69.7W	45 deg	33 kph	95 kph	997 mb	Tropical Storm
	September	17	18 UTC	41.6N	67.3W	50 deg	44 kph	95 kph	995 mb	Tropical Storm
	September	18	0 UTC	43.2N	64.9W	50 deg	42 kph	85 kph	996 mb	Extratropical Storm
	September	18	6 UTC	44.8N	62.6W	45 deg	42 kph	85 kph	1000 mb	Extratropical Storm
	September	18	12 UTC	46.2N	59.9W	55 deg	42 kph	85 kph	1000 mb	Extratropical Storm
	September	18	18 UTC	47.4N	56.2W	65 deg	51 kph	85 kph	999 mb	Extratropical Storm
	September	19	0 UTC	48.4N	52.3W	70 deg	50 kph	85 kph	1000 mb	Extratropical Storm
	September	19	6 UTC	49.0N	48.8W	75 deg	42 kph	85 kph	1001 mb	Extratropical Storm
	September	19	12 UTC	49.5N	45.7W	75 deg	37 kph	85 kph	1000 mb	Extratropical Storm
	September	19	18 UTC	50.0N	42.1W	80 deg	42 kph	85 kph	999 mb	Extratropical Storm
	September	20	0 UTC	50.9N	38.5W	70 deg	44 kph	85 kph	998 mb	Extratropical Storm
	September	20	6 UTC	51.5N	34.7W	75 deg	44 kph	75 kph	1000 mb	Extratropical Storm
	September	20	12 UTC	52.2N	30.5W	75 deg	48 kph	75 kph	1003 mb	Extratropical Storm
	September	20	18 UTC	52.8N	26.5W	75 deg	46 kph	75 kph	1001 mb	Extratropical Storm

Table G.4: Isle Madame's historical storms

Source: NOAA (2010)

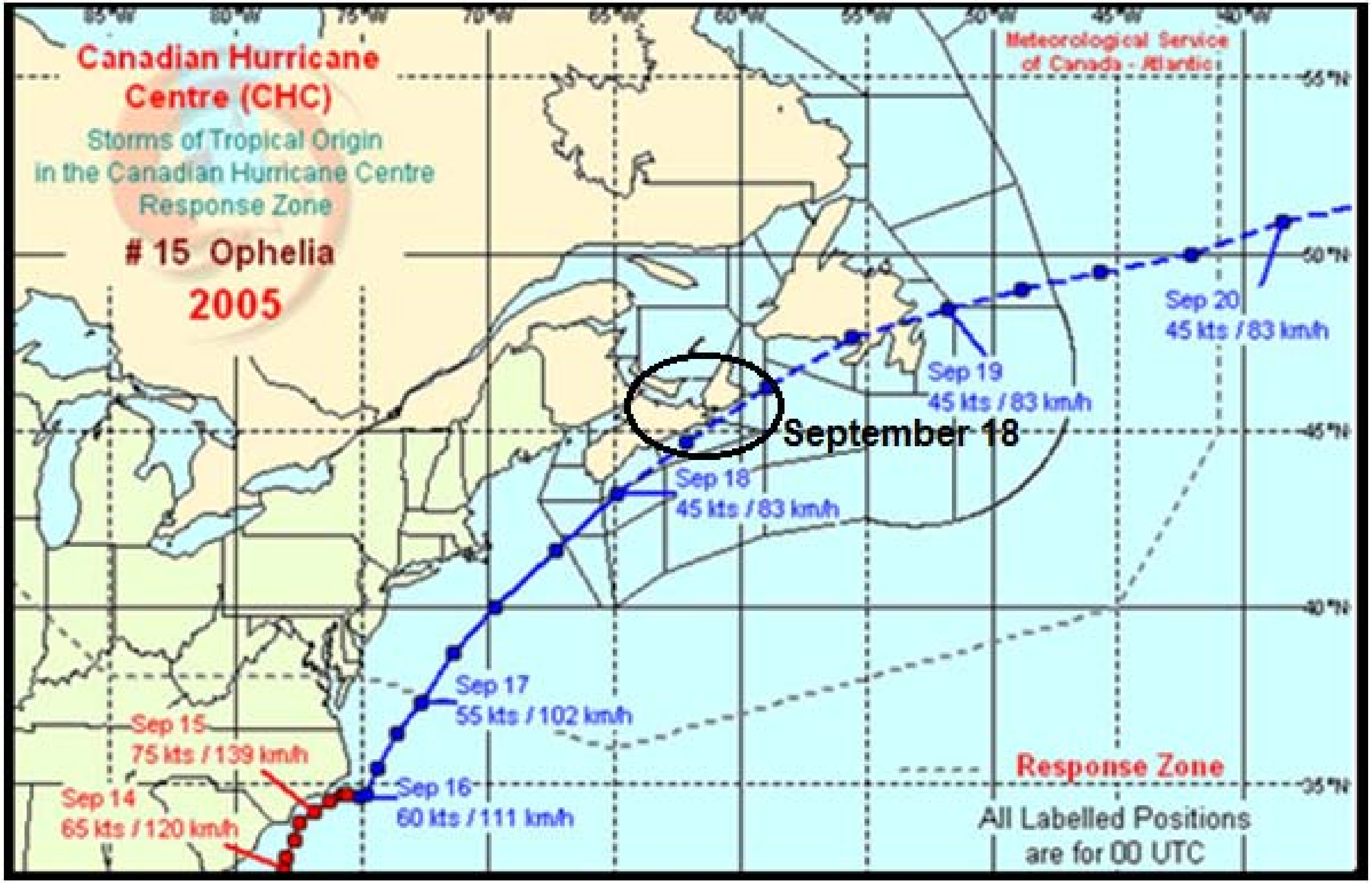

Figure G.3: 2005 Storm tracks of Isle Madame's historical storms

Source: Environment Canada (2009)

Storm Name	Month	Day	Hour	Lat.	Long.	Dir.	Speed	Wind	Pressure	-------Type-------
GUSTAV 2002										
	September	10	0 UTC	32.1N	75.5W	285 deg	14 kph	85 kph	996 mb	Subtropical Storm
	September	10	6 UTC	33.0N	75.5W	0 deg	16 kph	95 kph	990 mb	Subtropical Storm
	September	10	12 UTC	33.7N	75.4W	5 deg	12 kph	95 kph	987 mb	Tropical Storm
	September	10	18 UTC	35.0N	75.4W	0 deg	22 kph	100 kph	985 mb	Tropical Storm
	September	11	0 UTC	35.5N	74.7W	50 deg	12 kph	100 kph	983 mb	Tropical Storm
	September	11	6 UTC	36.8N	73.0W	45 deg	33 kph	110 kph	977 mb	Tropical Storm
	September	11	12 UTC	38.0N	70.8W	55 deg	38 kph	130 kph	971 mb	Hurricane - Category 1
	September	11	18 UTC	40.3N	66.8W	55 deg	70 kph	160 kph	964 mb	Hurricane - Category 2
	September	12	0 UTC	43.1N	62.8W	45 deg	74 kph	150 kph	962 mb	Hurricane - Category 1
	September	12	6 UTC	46.5N	59.6W	35 deg	74 kph	140 kph	960 mb	Hurricane - Category 1
	September	12	12 UTC	48.6N	57.7W	30 deg	44 kph	110 kph	965 mb	Extratropical Storm
	September	12	18 UTC	50.1N	55.5W	45 deg	37 kph	110 kph	967 mb	Extratropical Storm
	September	13	0 UTC	51.0N	54.0W	45 deg	24 kph	100 kph	968 mb	Extratropical Storm
	September	13	6 UTC	52.5N	52.5W	30 deg	31 kph	95 kph	968 mb	Extratropical Storm
	September	13	12 UTC	54.5N	51.4W	20 deg	38 kph	85 kph	972 mb	Extratropical Storm
	September	13	18 UTC	56.0N	49.5W	35 deg	33 kph	85 kph	976 mb	Extratropical Storm

Table G.5: Isle Madame's historical storms

Source: NOAA (2010)

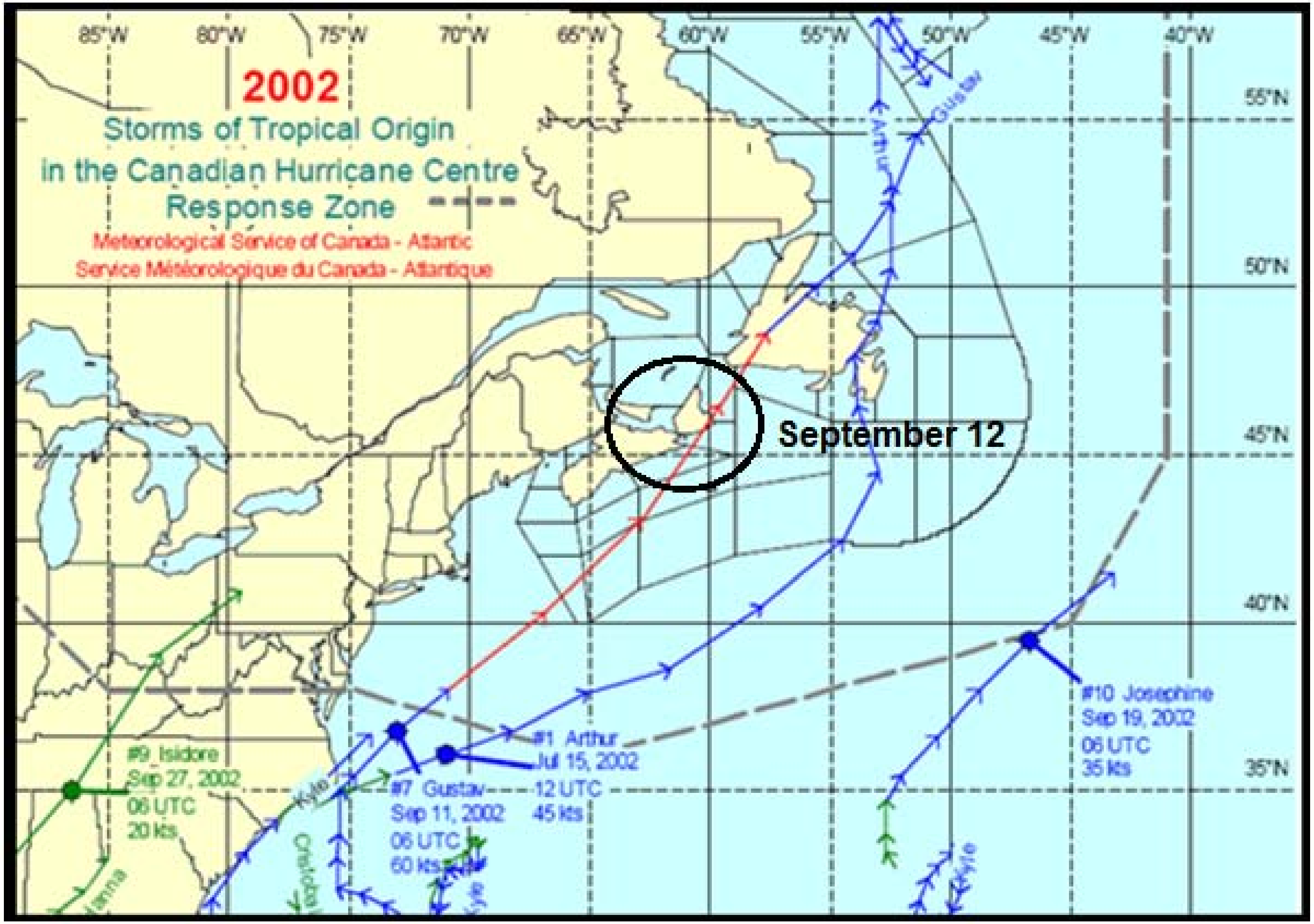

Figure G.4: 2002 Storm tracks of Isle Madame's historical storms

Source: Environment Canada (2009)

Storm Name	Month	Day	Hour	Lat.	Long.	Dir.	Speed	Wind	Pressure	-------Type-------
ALLISON 2001										
	June	17	0 UTC	37.8N	75.4W	10 deg	11 kph	45 kph	1006 mb	Subtropical Storm
	June	17	6 UTC	38.6N	74.5W	40 deg	18 kph	55 kph	1005 mb	Subtropical Storm
	June	17	12 UTC	39.3N	73.4W	50 deg	20 kph	75 kph	1004 mb	Subtropical Storm
	June	17	18 UTC	40.0N	72.1W	55 deg	22 kph	65 kph	1005 mb	Subtropical Storm
	June	18	0 UTC	40.6N	70.8W	60 deg	20 kph	55 kph	1006 mb	Extratropical Storm
	June	18	6 UTC	41.3N	69.4W	55 deg	22 kph	55 kph	1008 mb	Extratropical Storm
	June	18	12 UTC	42.0N	67.4W	65 deg	29 kph	55 kph	1009 mb	Extratropical Storm
	June	18	18 UTC	42.7N	64.6W	70 deg	38 kph	45 kph	1011 mb	Extratropical Storm
	June	19	0 UTC	43.5N	61.0W	75 deg	50 kph	35 kph	1012 mb	Extratropical Storm

Table G.6: Isle Madame's historical storms

Source: NOAA (2010)

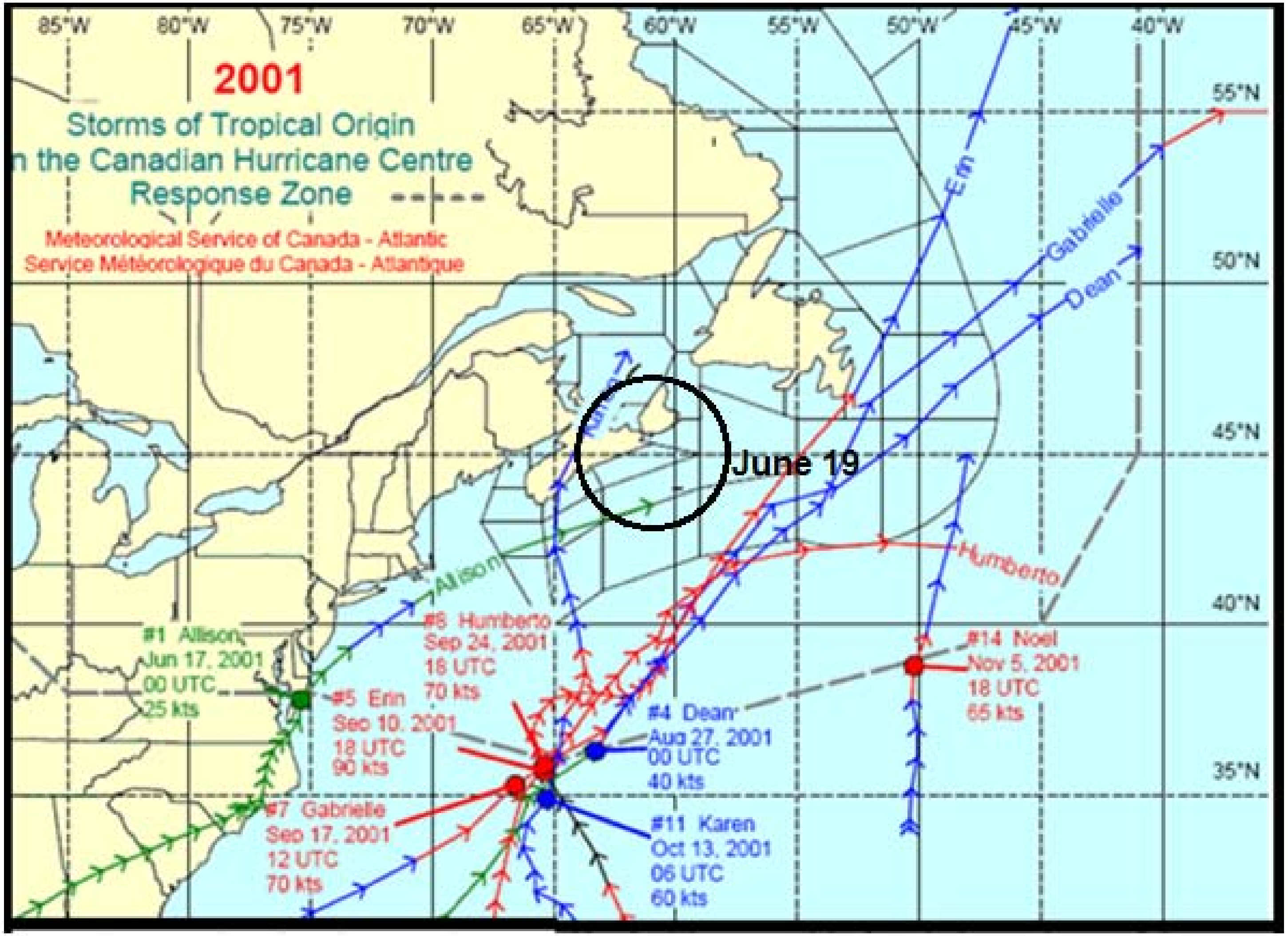

Figure G.5: 2001 Storm tracks of Isle Madame's historical storms

Source: Environment Canada (2009)

Storm Name	Month	Day	Hour	Lat.	Long.	Dir.	Speed	Wind	Pressure	-------Type-------
MICHAEL 2000										
	October	17	0 UTC	29.9N	71.1W	70 deg	3 kph	65 kph	1003 mb	Tropical Storm
	October	17	6 UTC	29.8N	71.0W	140 deg	1 kph	85 kph	1000 mb	Tropical Storm
	October	17	12 UTC	29.8N	70.9W	90 deg	0 kph	100 kph	995 mb	Tropical Storm
	October	17	18 UTC	30.1N	70.9W	0 deg	5 kph	120 kph	988 mb	Hurricane - Category 1
	October	18	0 UTC	30.4N	70.9W	0 deg	3 kph	120 kph	988 mb	Hurricane - Category 1
	October	18	6 UTC	30.8N	70.8W	10 deg	7 kph	120 kph	986 mb	Hurricane - Category 1
	October	18	12 UTC	31.5N	70.4W	25 deg	12 kph	120 kph	984 mb	Hurricane - Category 1
	October	18	18 UTC	32.6N	69.5W	35 deg	24 kph	130 kph	979 mb	Hurricane - Category 1
	October	19	0 UTC	34.2N	67.8W	40 deg	38 kph	140 kph	983 mb	Hurricane - Category 1
	October	19	6 UTC	36.3N	65.5W	40 deg	51 kph	120 kph	986 mb	Hurricane - Category 1
	October	19	12 UTC	39.8N	61.6W	40 deg	85 kph	140 kph	979 mb	Hurricane - Category 1
	October	19	18 UTC	44.0N	58.5W	30 deg	87 kph	160 kph	965 mb	Hurricane - Category 2
	October	20	0 UTC	48.0N	56.5W	20 deg	77 kph	140 kph	966 mb	Extratropical Storm
	October	20	6 UTC	50.0N	56.0W	10 deg	37 kph	130 kph	966 mb	Extratropical Storm
	October	20	12 UTC	51.0N	53.5W	60 deg	33 kph	120 kph	968 mb	Extratropical Storm
	October	20	18 UTC	52.0N	50.5W	60 deg	38 kph	110 kph	970 mb	Extratropical Storm

Table G.7: Isle Madame's historical storms

Source: NOAA (2010)

Storm Name	Month	Day	Hour	Lat.	Long.	Dir.	Speed	Wind	Pressure	-------Type-------
SUBTROP 2000										
	October	28	0 UTC	34.2N	70.7W	25 deg	31 kph	95 kph	994 mb	Subtropical Storm
	October	28	6 UTC	35.7N	69.9W	25 deg	29 kph	95 kph	992 mb	Subtropical Storm
	October	28	12 UTC	36.5N	68.1W	60 deg	29 kph	95 kph	990 mb	Subtropical Storm
	October	28	18 UTC	38.0N	65.5W	55 deg	46 kph	100 kph	984 mb	Subtropical Storm
	October	29	0 UTC	40.5N	62.6W	40 deg	61 kph	100 kph	978 mb	Subtropical Storm
	October	29	6 UTC	44.0N	60.0W	30 deg	72 kph	95 kph	980 mb	Extratropical Storm
	October	29	12 UTC	46.0N	59.5W	10 deg	37 kph	85 kph	992 mb	Extratropical Storm

Table G.8: Isle Madame's historical storms

Source: NOAA (2010)

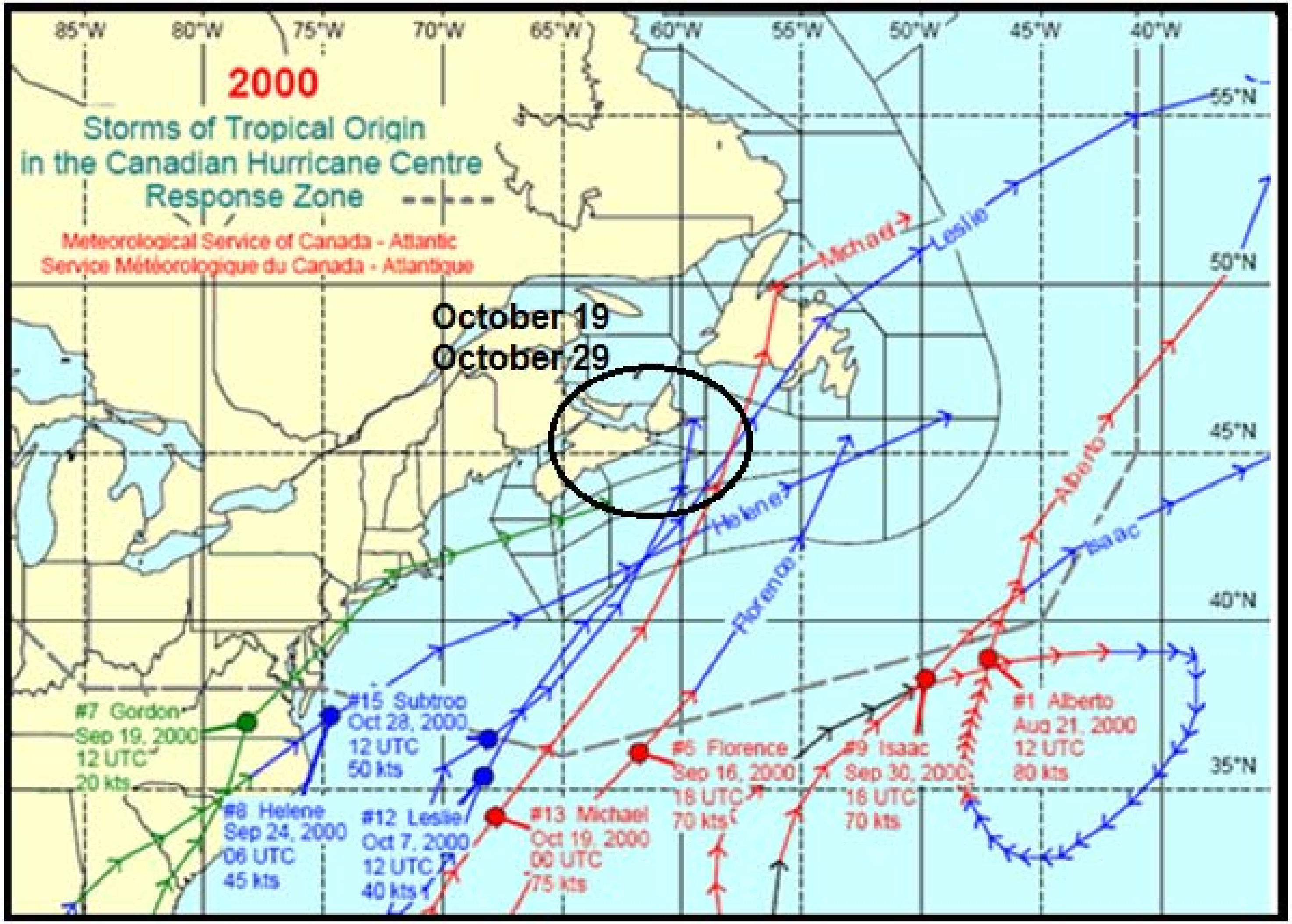

Figure G.6: 2000 Storm tracks of Isle Madame's historical storms

Source: Environment Canada (2009)

Storm Name	Month	Day	Hour	Lat.	Long.	Dir.	Speed	Wind	Pressure	-------Type-------
HORTENSE 1996										
	September	13	0 UTC	25.9N	71.5W	15 deg	22 kph	220 kph	935 mb	Major Hurricane - Category 4
	September	13	6 UTC	27.2N	71.4W	5 deg	24 kph	215 kph	942 mb	Major Hurricane - Category 4
	September	13	12 UTC	29.0N	70.9W	15 deg	33 kph	185 kph	948 mb	Major Hurricane - Category 3
	September	13	18 UTC	31.0N	70.3W	15 deg	37 kph	185 kph	948 mb	Major Hurricane - Category 3
	September	14	0 UTC	33.3N	69.5W	15 deg	42 kph	165 kph	948 mb	Hurricane - Category 2
	September	14	6 UTC	35.9N	68.4W	20 deg	50 kph	165 kph	955 mb	Hurricane - Category 2
	September	14	12 UTC	38.5N	67.1W	20 deg	50 kph	160 kph	960 mb	Hurricane - Category 2
	September	14	18 UTC	42.0N	65.2W	25 deg	68 kph	140 kph	960 mb	Hurricane - Category 1
	September	15	0 UTC	44.3N	63.3W	30 deg	48 kph	130 kph	970 mb	Hurricane - Category 1
	September	15	6 UTC	45.5N	61.5W	45 deg	31 kph	120 kph	980 mb	Hurricane - Category 1
	September	15	12 UTC	46.3N	59.1W	65 deg	33 kph	110 kph	982 mb	Tropical Storm
	September	15	18 UTC	46.0N	55.0W	95 deg	51 kph	75 kph	996 mb	Extratropical Storm
	September	16	0 UTC	46.0N	54.0W	90 deg	11 kph	75 kph	998 mb	Extratropical Storm
	September	16	6 UTC	45.0N	50.0W	110 deg	53 kph	65 kph	999 mb	Extratropical Storm

Table G.9: Isle Madame's historical storms

Source: NOAA (2010)

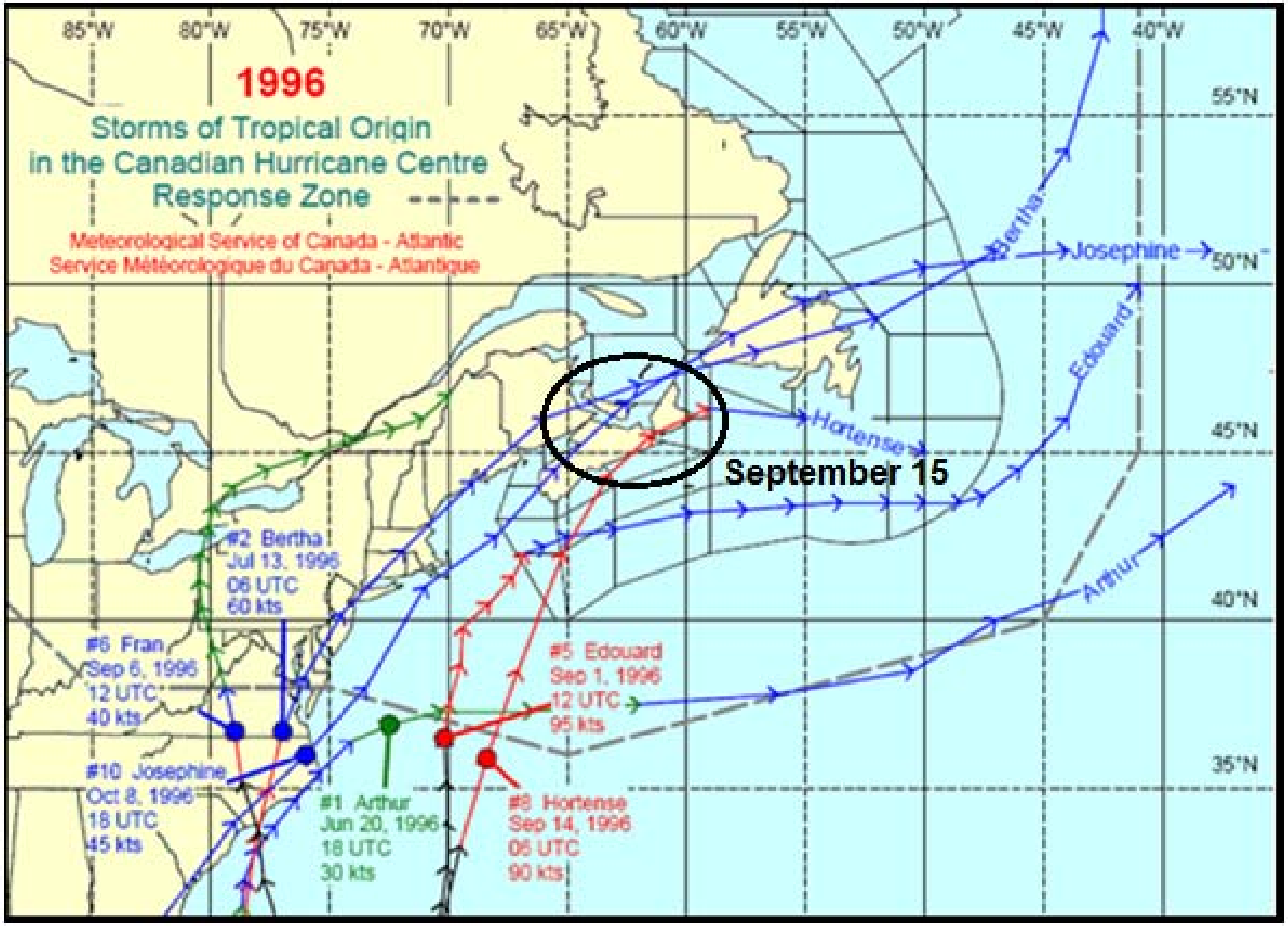

Figure G.7: 1996 Storm tracks of Isle Madame's historical storms

Source: Environment Canada (2009)

Storm Name	Month	Day	Hour	Lat.	Long.	Dir.	Speed	Wind	Pressure	-------Type-------
BARRY 1995										
	July	8	0 UTC	34.0N	69.6W	30 deg	16 kph	110 kph	997 mb	Tropical Storm
	July	8	6 UTC	34.9N	68.9W	35 deg	18 kph	100 kph	997 mb	Tropical Storm
	July	8	12 UTC	35.9N	68.2W	30 deg	20 kph	95 kph	997 mb	Tropical Storm
	July	8	18 UTC	37.2N	67.2W	30 deg	27 kph	95 kph	997 mb	Tropical Storm
	July	9	0 UTC	38.7N	66.0W	30 deg	31 kph	95 kph	996 mb	Tropical Storm
	July	9	6 UTC	40.5N	64.6W	30 deg	37 kph	95 kph	995 mb	Tropical Storm
	July	9	12 UTC	42.3N	63.1W	30 deg	38 kph	95 kph	993 mb	Tropical Storm
	July	9	18 UTC	44.3N	61.7W	25 deg	40 kph	95 kph	991 mb	Tropical Storm
	July	10	0 UTC	46.4N	60.5W	20 deg	40 kph	85 kph	990 mb	Tropical Storm
	July	10	6 UTC	48.5N	59.2W	25 deg	40 kph	75 kph	989 mb	Tropical Storm

Table G.10: Isle Madame’s historical storms

Source: NOAA (2010)

Storm Name	Month	Day	Hour	Lat.	Long.	Dir.	Speed	Wind	Pressure	-------Type-------
ALLISON 1995										
	June	6	0 UTC	31.8N	82.8W	40 deg	24 kph	55 kph	993 mb	Tropical Depression
	June	6	6 UTC	32.7N	81.5W	50 deg	25 kph	65 kph	994 mb	Extratropical Storm
	June	6	12 UTC	33.6N	80.0W	55 deg	27 kph	65 kph	995 mb	Extratropical Storm
	June	6	18 UTC	34.5N	78.1W	60 deg	33 kph	75 kph	995 mb	Extratropical Storm
	June	7	0 UTC	35.6N	75.9W	60 deg	38 kph	75 kph	992 mb	Extratropical Storm
	June	7	6 UTC	37.1N	73.6W	50 deg	42 kph	85 kph	990 mb	Extratropical Storm
	June	7	12 UTC	38.5N	71.0W	55 deg	44 kph	85 kph	988 mb	Extratropical Storm
	June	7	18 UTC	39.8N	69.2W	45 deg	35 kph	85 kph	984 mb	Extratropical Storm
	June	8	0 UTC	41.0N	67.7W	45 deg	29 kph	95 kph	982 mb	Extratropical Storm
	June	8	6 UTC	42.4N	66.0W	40 deg	33 kph	95 kph	984 mb	Extratropical Storm
	June	8	12 UTC	43.8N	63.7W	50 deg	38 kph	95 kph	989 mb	Extratropical Storm
	June	8	18 UTC	45.2N	61.2W	50 deg	40 kph	85 kph	993 mb	Extratropical Storm
	June	9	0 UTC	46.5N	58.5W	55 deg	40 kph	75 kph	995 mb	Extratropical Storm
	June	9	6 UTC	48.1N	55.9W	50 deg	42 kph	75 kph	996 mb	Extratropical Storm
	June	9	12 UTC	50.0N	53.0W	45 deg	48 kph	75 kph	997 mb	Extratropical Storm
	June	9	18 UTC	53.0N	52.0W	10 deg	55 kph	75 kph	1000 mb	Extratropical Storm
	June	10	0 UTC	57.0N	52.0W	0 deg	74 kph	75 kph	997 mb	Extratropical Storm
	June	10	6 UTC	60.0N	52.0W	0 deg	55 kph	75 kph	990 mb	Extratropical Storm
	June	10	12 UTC	62.0N	53.0W	345 deg	37 kph	75 kph	992 mb	Extratropical Storm
	June	10	18 UTC	64.0N	55.0W	335 deg	38 kph	65 kph	992 mb	Extratropical Storm
	June	11	0 UTC	65.0N	56.0W	335 deg	18 kph	65 kph	993 mb	Extratropical Storm

Table G.11: Isle Madame’s historical storms

Source: NOAA (2010)

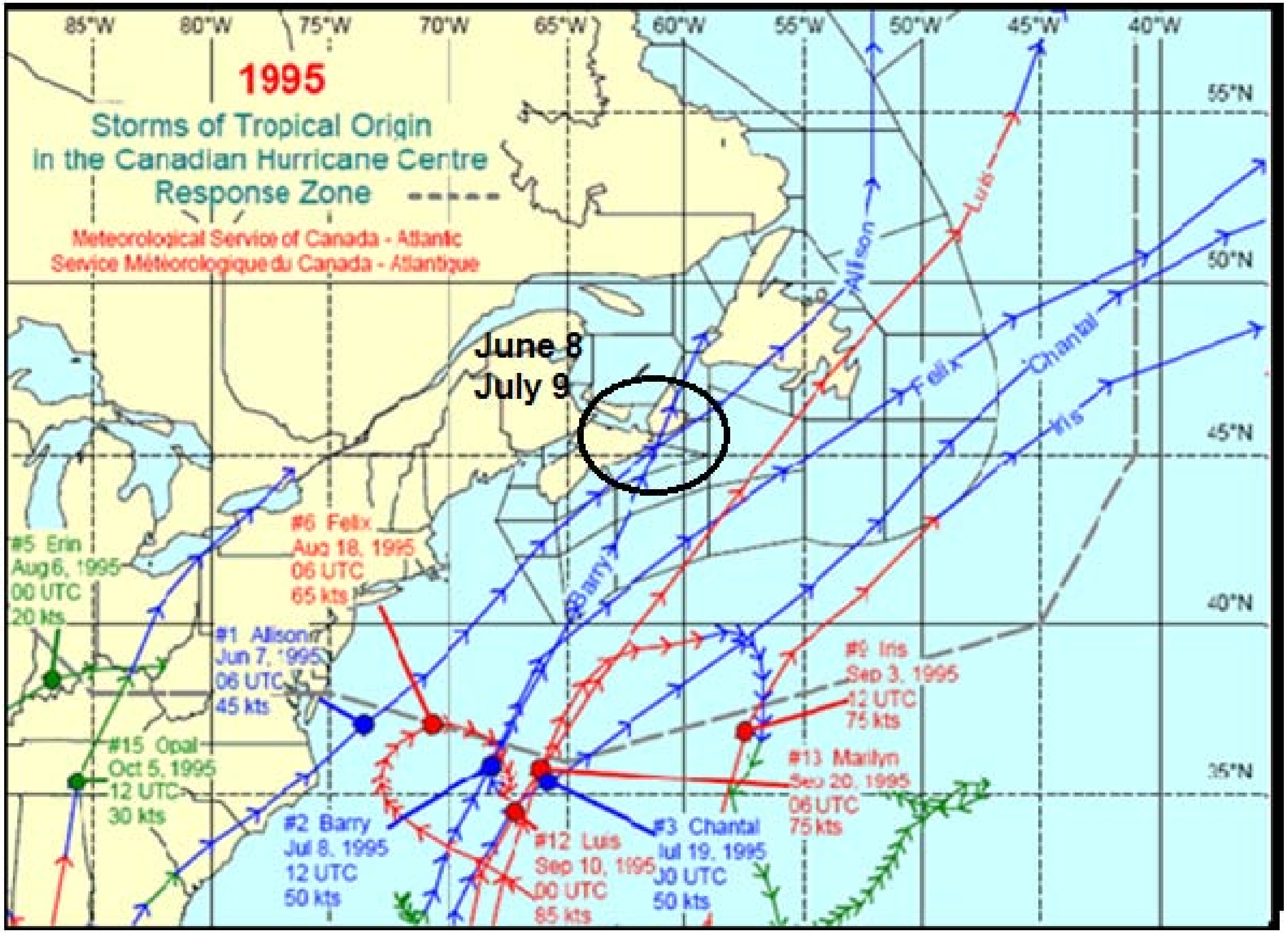

Figure G.8: 1995 Storm tracks of Isle Madame's historical storms

Source: Environment Canada (2009)

Storm Name	Month	Day	Hour	Lat.	Long.	Dir.	Speed	Wind	Pressure	-------Type-------
LILI 1990										
	October	13	0 UTC	32.1N	72.1W	335 deg	24 kph	120 kph	992 mb	Hurricane - Category 1
	October	13	6 UTC	33.2N	72.5W	345 deg	20 kph	120 kph	992 mb	Hurricane - Category 1
	October	13	12 UTC	34.3N	72.4W	5 deg	20 kph	110 kph	995 mb	Tropical Storm
	October	13	18 UTC	35.5N	72.0W	15 deg	22 kph	95 kph	997 mb	Tropical Storm
	October	14	0 UTC	36.6N	71.3W	25 deg	22 kph	95 kph	996 mb	Tropical Storm
	October	14	6 UTC	38.0N	69.7W	40 deg	33 kph	95 kph	995 mb	Tropical Storm
	October	14	12 UTC	40.0N	67.5W	40 deg	48 kph	95 kph	995 mb	Tropical Storm
	October	14	18 UTC	42.4N	65.0W	40 deg	55 kph	85 kph	995 mb	Tropical Storm
	October	15	0 UTC	44.9N	61.0W	50 deg	70 kph	75 kph	995 mb	Extratropical Storm
	October	15	6 UTC	46.6N	56.4W	60 deg	66 kph	75 kph	994 mb	Extratropical Storm
	October	15	12 UTC	47.5N	51.0W	75 deg	68 kph	75 kph	994 mb	Extratropical Storm

Table G.12: Isle Madame's historical storms

Source: NOAA (2010)

Storm Name	Month	Day	Hour	Lat.	Long.	Dir.	Speed	Wind	Pressure	-------Type-------
BERTHA 1990										
	July	29	0 UTC	30.2N	73.6W	40 deg	12 kph	120 kph	990 mb	Hurricane - Category 1
	July	29	6 UTC	30.8N	73.0W	40 deg	12 kph	120 kph	988 mb	Hurricane - Category 1
	July	29	12 UTC	31.3N	72.2W	55 deg	14 kph	120 kph	989 mb	Hurricane - Category 1
	July	29	18 UTC	31.9N	71.2W	55 deg	18 kph	110 kph	990 mb	Tropical Storm
	July	30	0 UTC	32.7N	70.2W	45 deg	20 kph	110 kph	989 mb	Tropical Storm
	July	30	6 UTC	33.7N	69.2W	40 deg	24 kph	110 kph	987 mb	Tropical Storm
	July	30	12 UTC	34.7N	68.3W	35 deg	22 kph	120 kph	985 mb	Hurricane - Category 1
	July	30	18 UTC	35.7N	67.5W	35 deg	20 kph	120 kph	979 mb	Hurricane - Category 1
	July	31	0 UTC	36.6N	67.0W	25 deg	16 kph	130 kph	974 mb	Hurricane - Category 1
	July	31	6 UTC	37.5N	66.5W	25 deg	16 kph	120 kph	975 mb	Hurricane - Category 1
	July	31	12 UTC	38.3N	65.9W	30 deg	16 kph	120 kph	976 mb	Hurricane - Category 1
	July	31	18 UTC	39.0N	65.3W	35 deg	14 kph	120 kph	977 mb	Hurricane - Category 1
	August	1	0 UTC	39.6N	64.5W	45 deg	14 kph	120 kph	977 mb	Hurricane - Category 1
	August	1	6 UTC	40.3N	63.7W	40 deg	16 kph	120 kph	977 mb	Hurricane - Category 1
	August	1	12 UTC	41.1N	62.7W	45 deg	20 kph	120 kph	977 mb	Hurricane - Category 1
	August	1	18 UTC	42.4N	61.5W	35 deg	27 kph	120 kph	975 mb	Hurricane - Category 1
	August	2	0 UTC	44.2N	60.5W	20 deg	35 kph	130 kph	973 mb	Hurricane - Category 1
	August	2	6 UTC	46.0N	60.0W	10 deg	33 kph	110 kph	978 mb	Extratropical Storm
	August	2	12 UTC	48.4N	60.0W	0 deg	44 kph	100 kph	982 mb	Extratropical Storm

Table G.13: Isle Madame's historical storms

Source: NOAA (2010)

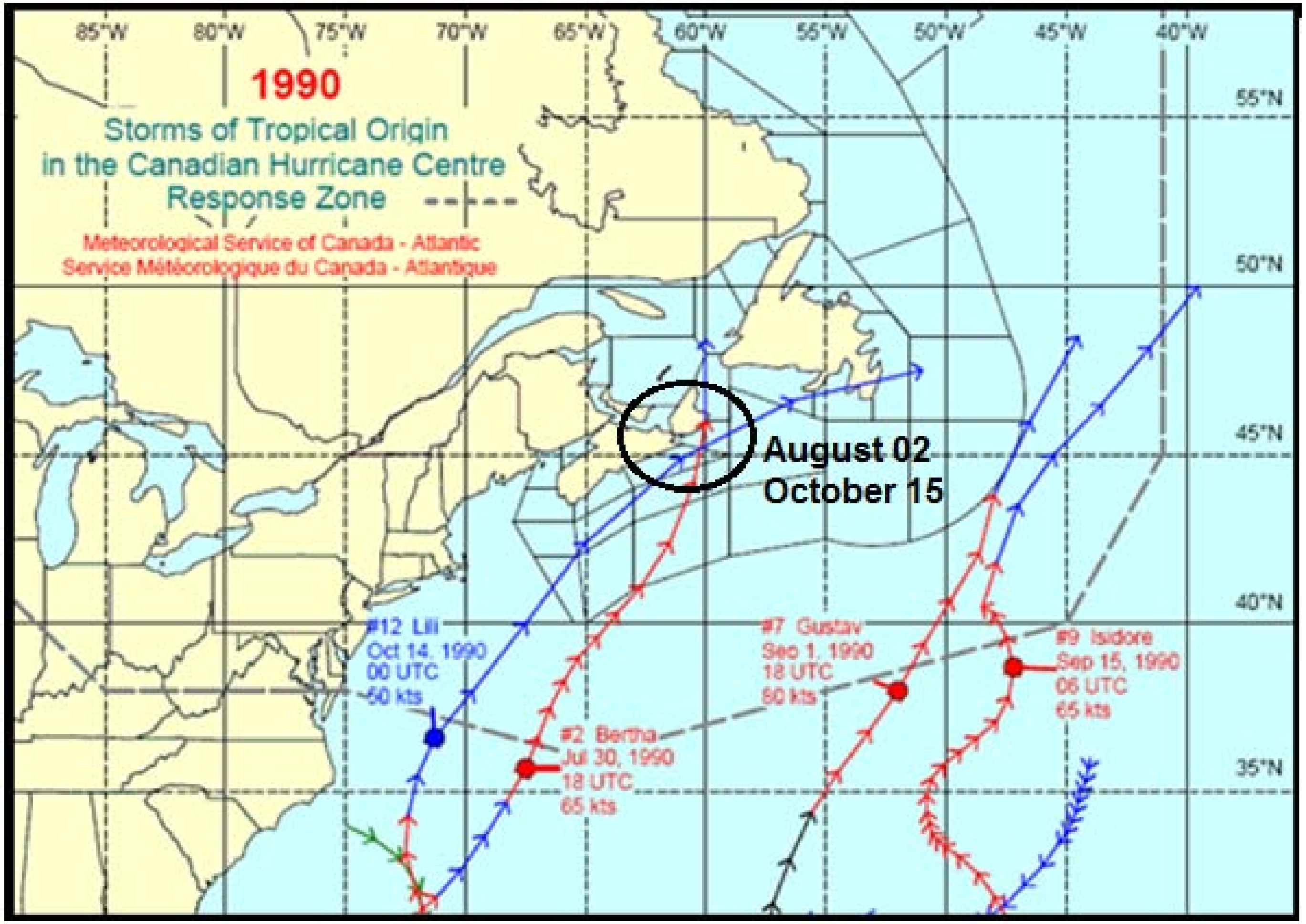

Figure G.8: 1990 Storm tracks of Isle Madame's historical storms

Source: Environment Canada (2009)

Storm Name	Month	Day	Hour	Lat.	Long.	Dir.	Speed	Wind	Pressure	-------Type-------
CHRIS 1988										
	August	29	0 UTC	34.1N	81.1W	0 deg	22 kph	45 kph	1008 mb	Tropical Depression
	August	29	6 UTC	35.8N	80.6W	15 deg	31 kph	35 kph	1009 mb	Tropical Depression
	August	29	12 UTC	37.5N	79.5W	25 deg	35 kph	35 kph	1009 mb	Tropical Depression
	August	29	18 UTC	39.2N	77.6W	40 deg	40 kph	35 kph	1010 mb	Tropical Depression
	August	30	0 UTC	41.2N	73.6W	55 deg	66 kph	35 kph	1008 mb	Tropical Depression
	August	30	6 UTC	43.5N	69.9W	50 deg	64 kph	35 kph	1008 mb	Tropical Depression
	August	30	12 UTC	45.0N	65.0W	65 deg	70 kph	45 kph	1008 mb	Tropical Depression
	August	30	18 UTC	46.5N	60.0W	65 deg	68 kph	45 kph	1008 mb	Tropical Depression

Table G.14: Isle Madame's historical storms

Source: NOAA (2010)

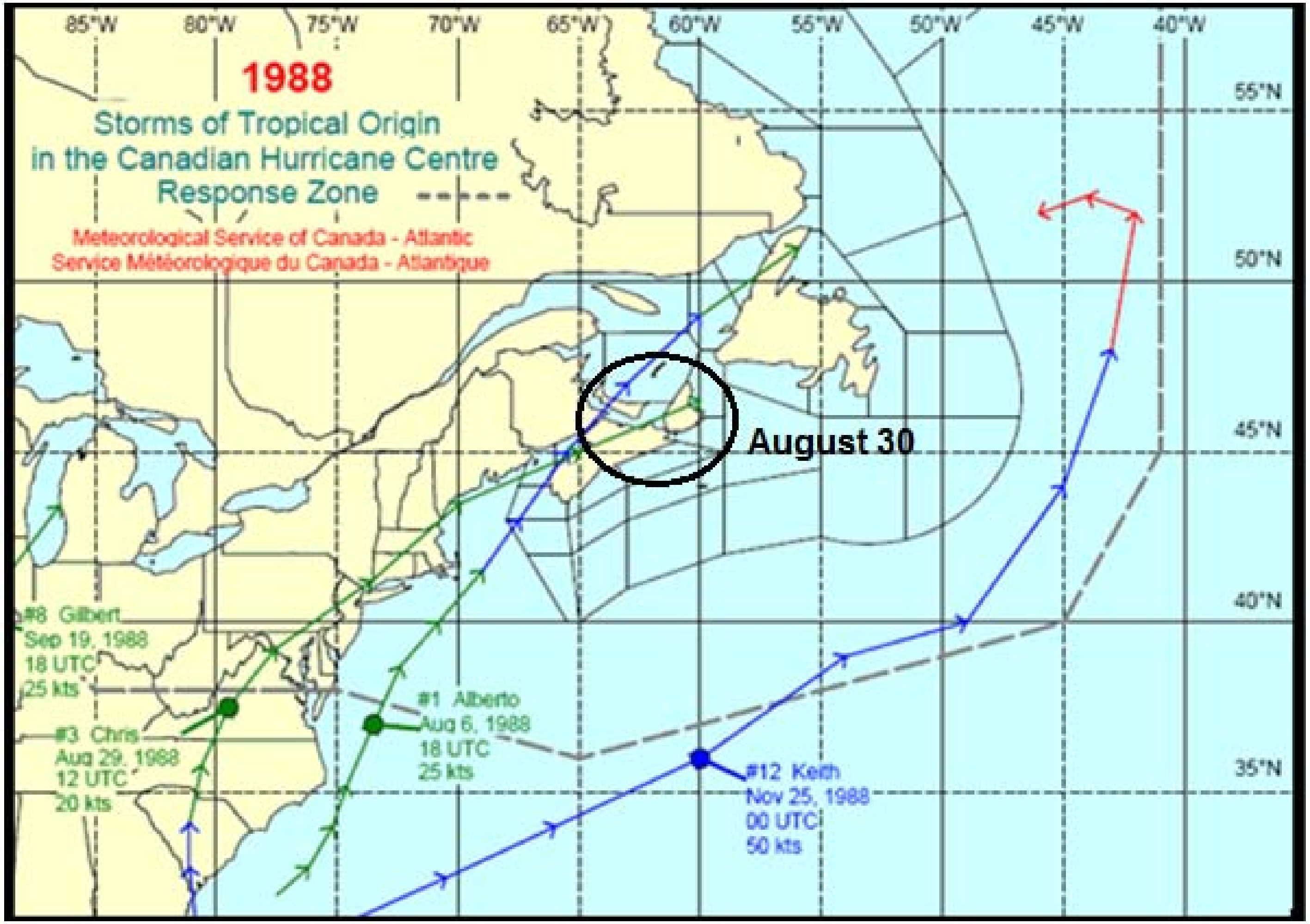

Figure G.10: 1988 Storm tracks of Isle Madame's historical storms

Source: Environment Canada (2009)

Storm Name	Month	Day	Hour	Lat.	Long.	Dir.	Speed	Wind	Pressure	-------Type-------
SUBTROP 1982										
	June	19	0 UTC	32.5N	79.2W	40 deg	25 kph	110 kph	992 mb	Subtropical Storm
	June	19	6 UTC	33.9N	77.8W	40 deg	33 kph	110 kph	992 mb	Subtropical Storm
	June	19	12 UTC	35.3N	76.0W	45 deg	37 kph	110 kph	992 mb	Subtropical Storm
	June	19	18 UTC	37.1N	73.0W	55 deg	55 kph	110 kph	992 mb	Subtropical Storm
	June	20	0 UTC	39.5N	70.0W	45 deg	61 kph	110 kph	992 mb	Subtropical Storm
	June	20	6 UTC	42.5N	65.5W	50 deg	83 kph	110 kph	988 mb	Subtropical Storm
	June	20	12 UTC	44.5N	60.0W	65 deg	81 kph	110 kph	984 mb	Subtropical Storm
	June	20	18 UTC	45.4N	56.0W	70 deg	53 kph	110 kph	990 mb	Extratropical Storm

Table G.15: Isle Madame's historical storms

Source: NOAA (2010)

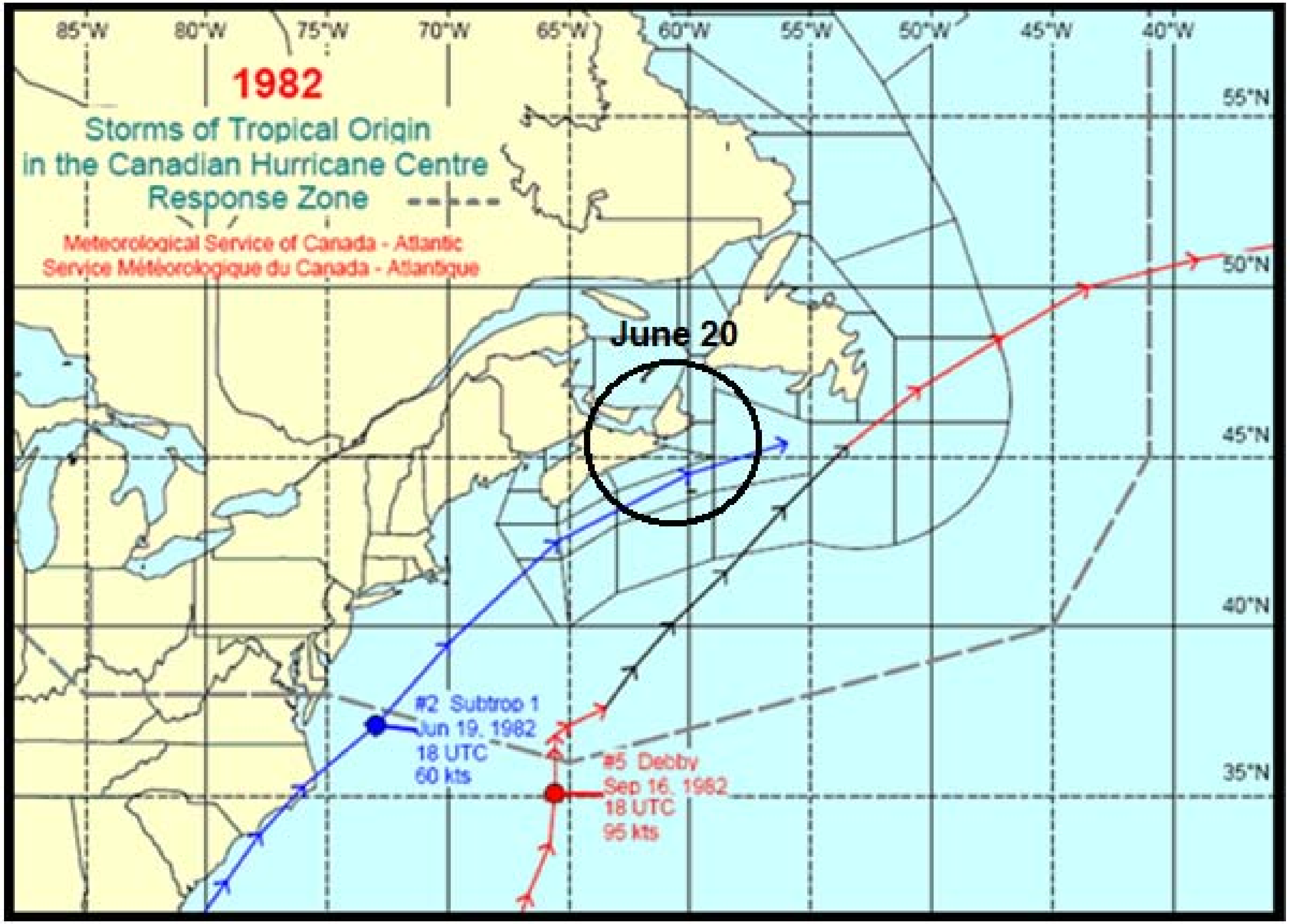

Figure G.11: 1982 Storm tracks of Isle Madame's historical storms

Source: Environment Canada (2009)

Storm Name	Month	Day	Hour	Lat.	Long.	Dir.	Speed	Wind	Pressure	-------Type-------
EVELYN 1977										
	October	14	0 UTC	29.0N	64.0W	335 deg	42 kph	55 kph	1008 mb	Tropical Depression
	October	14	6 UTC	30.9N	64.9W	340 deg	37 kph	65 kph	1005 mb	Tropical Storm
	October	14	12 UTC	33.0N	64.9W	0 deg	38 kph	75 kph	1002 mb	Tropical Storm
	October	14	18 UTC	35.9N	64.4W	10 deg	53 kph	95 kph	999 mb	Tropical Storm
	October	15	0 UTC	39.2N	63.3W	15 deg	63 kph	120 kph	994 mb	Hurricane - Category 1
	October	15	6 UTC	42.4N	61.5W	25 deg	63 kph	130 kph	996 mb	Hurricane - Category 1
	October	15	12 UTC	45.5N	60.1W	20 deg	59 kph	130 kph	998 mb	Hurricane - Category 1
	October	15	18 UTC	47.4N	59.2W	20 deg	35 kph	130 kph	999 mb	Hurricane - Category 1
	October	16	0 UTC	49.1N	58.3W	20 deg	33 kph	85 kph	1000 mb	Extratropical Storm

Table G.16: Isle Madame's historical storms

Source: NOAA (2010)

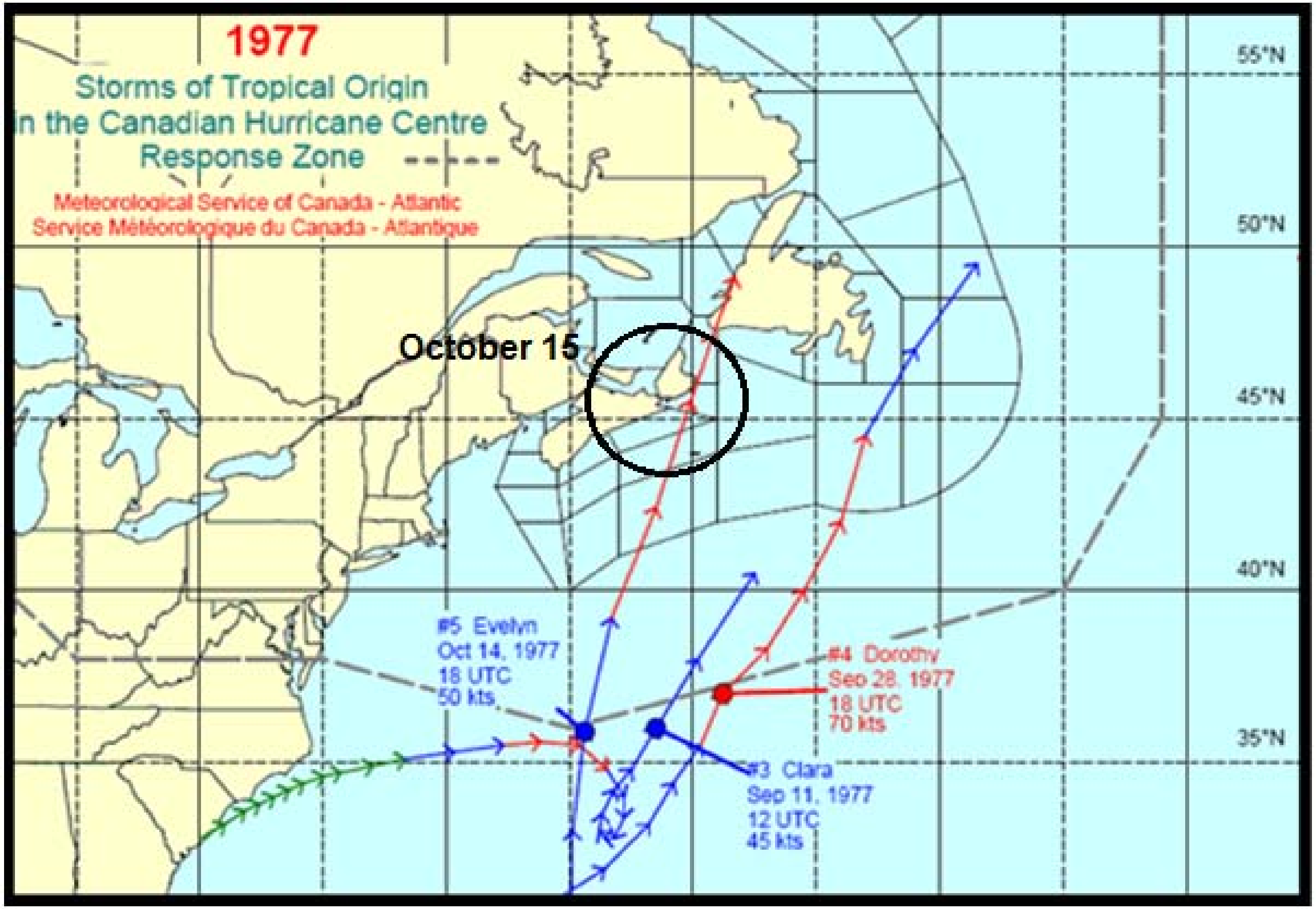

Figure G.12: 1977 Storm tracks of Isle Madame's historical storms

Source: Environment Canada (2009)

Appendix H: Results of the System Dynamics Model for each Storm Scenario

In this section results of Total Damage, Direct Damage, and Indirect Damages for four pillars of all six Storm Scenarios are shown in Tables H.1 to H.6 over the period of three weeks. Moreover, for each Storm Scenario comparison of Total Damage over the period of three weeks of four pillars is illustrated in Figure H.1 to H.6 for Storm Scenario I to Storm Scenario IV respectively. As can be seen in Figure H.1 to H.6, Economic Pillar has the highest Total Damage (over period of three weeks followed) by Environmental, Cultural, and Social Pillars.

End of week	Damage	Environment	Economic	Social	Cultural	**Total Damage of Storm Scenario I**
0	Direct	$704,395	$1,015,613	$123,656	$124,233	$1,967,897
1	Indirect	$220,196	$292,677	$54,849	$90,484	$658,205
2	Indirect	$292	$529	$130	$294	$1,245
3	Indirect	$32	$72	$18	$44	$165
	Total	**$924,916**	**$1,308,890**	**$178,652**	**$215,054**	**$2,627,513**

Table H.1: Results of SD Model for Storm Scenario I

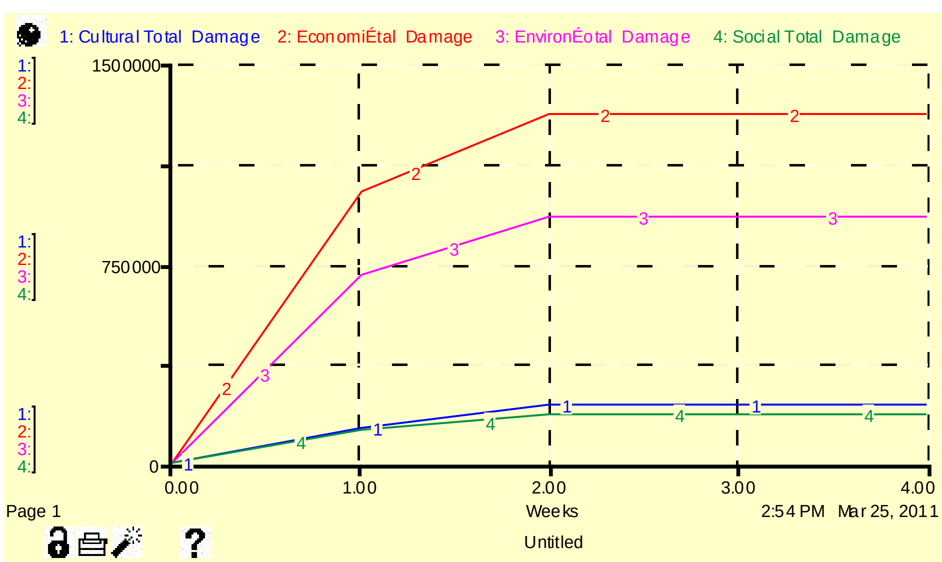

Figure H.1: Comparison of Total Damage of four pillars in Storm Scenario I

End of week	Damage	Environment	Economic	Social	Cultural	Total Damage of Storm Scenario II
0	Direct	$775,137	$1,358,688	$148,647	$177,398	$2,459,869
1	Indirect	$265,853	$379,339	$67,901	$106,952	$820,045
2	Indirect	$320	$609	$145	$321	$1,395
3	Indirect	$34	$79	$19	$46	$179
	Total	**$1,041,344**	**$1,738,715**	**$216,711**	**$284,718**	**$3,281,488**

Table H.2: Results of SD Model for Storm Scenario II

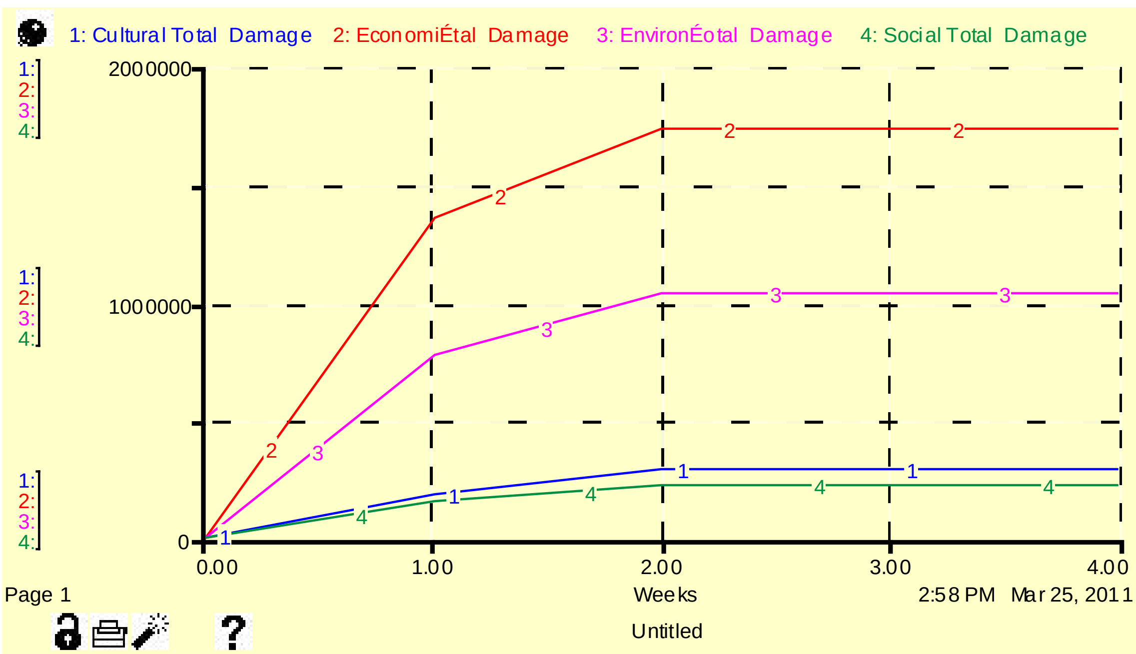

Figure H.2: Comparison of Total Damage of four pillars in Storm Scenario II

End of week	Damage	Environment	Economic	Social	Cultural	Total Damage of Storm Scenario III
0	Direct	$847,710	$1,945,130	$173,865	$249,677	$3,216,382
1	Indirect	$336,016	$514,839	$87,707	$125,654	$1,064,217
2	Indirect	$356	$703	$163	$349	$1,571
3	Indirect	$37	$87	$21	$49	$193
	Total	**$1,184,119**	**$2,460,759**	**$261,756**	**$375,729**	**$4,282,363**

Table H.3: Results of SD Model for Storm Scenario III

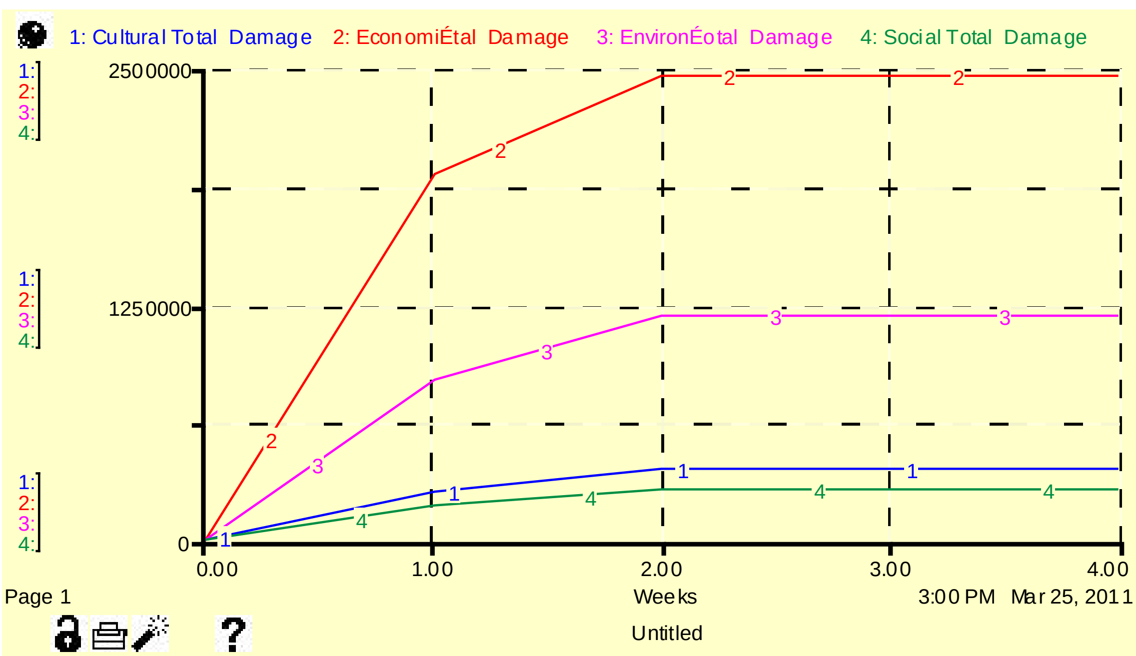

Figure H.3: Comparison of Total Damage of four pillars in Storm Scenario III

End of week	Damage	Environment	Economic	Social	Cultural	Total Damage of Storm Scenario VI
0	Direct	$950,629	$2,706,912	$200,792	$355,371	$4,213,704
1	Indirect	$429,685	$691,669	$127,089	$149,050	$1,397,493
2	Indirect	$403	$812	$194	$380	$1,788
3	Indirect	$40	$95	$23	$52	$210
	Total	**$1,380,757**	**$3,399,488**	**$328,098**	**$504,853**	**$5,613,196**

Table H.4: Results of SD Model for Storm Scenario IV

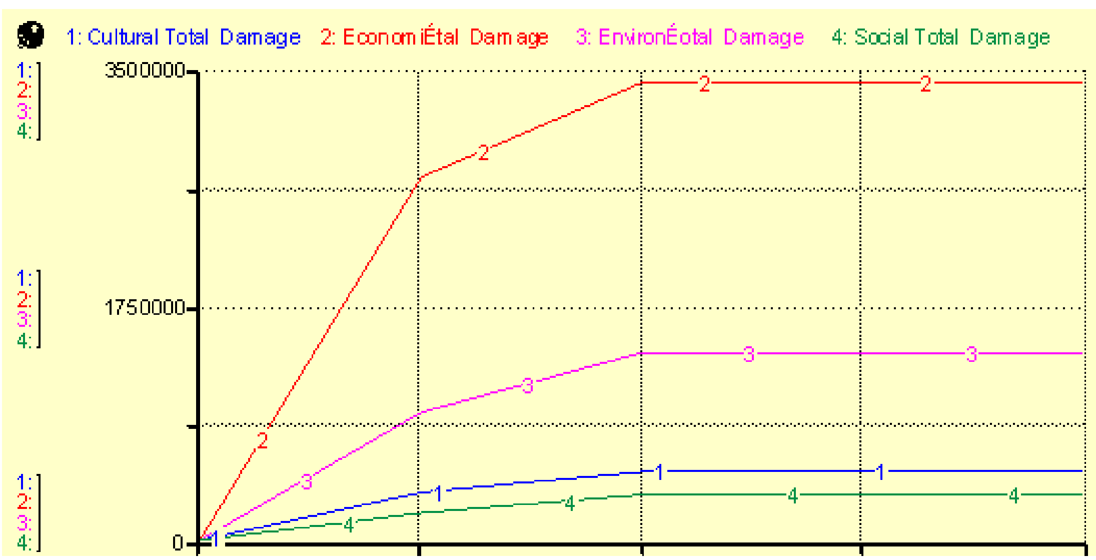

Figure H.4: Comparison of Total Damage of four pillars in Storm Scenario IV

End of week	Damage	Environment	Economic	Social	Cultural	Total Damage of Storm Scenario V
0	Direct	$1,028,221	$3,435,982	$228,457	$565,595	$5,258,256
1	Indirect	$514,674	$856,714	$154,631	$184,551	$1,710,570
2	Indirect	$436	$893	$213	$418	$1,961
3	Indirect	$42	$102	$25	$55	$223
	Total	**$1,543,373**	**$4,293,691**	**$383,326**	**$750,620**	**$6,971,010**

Table H.5: Results of SD Model for Storm Scenario V

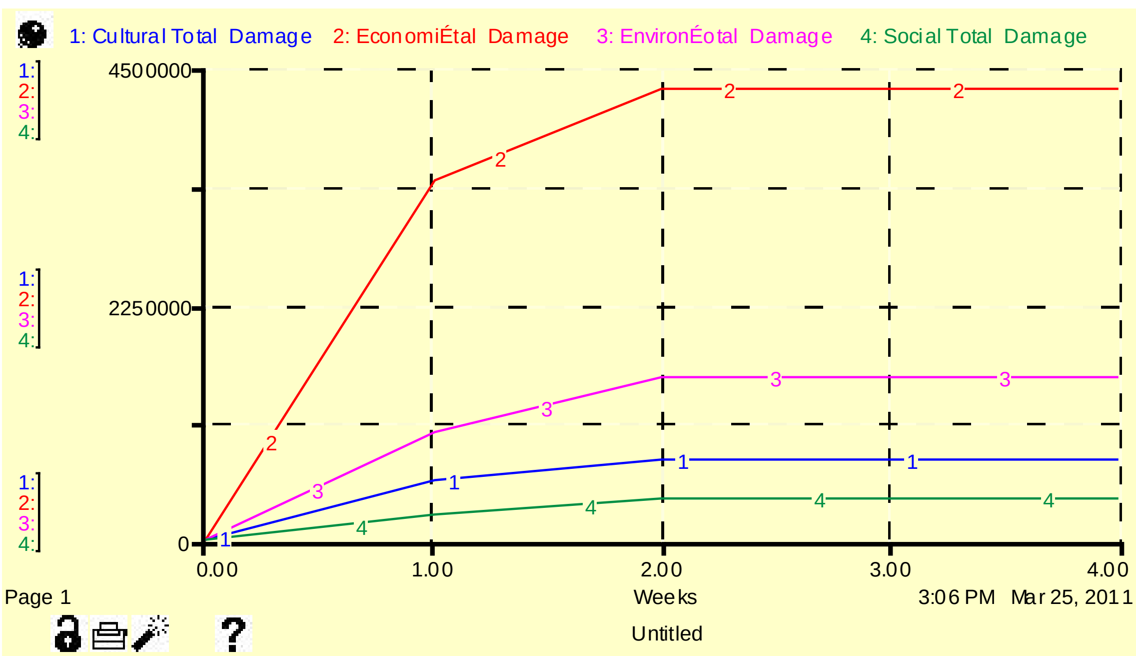

Figure H.5: Comparison of Total Damage of four pillars in Storm Scenario V

End of week	Damage	Environment	Economic	Social	Cultural	Total Damage of Storm Scenario IV
0	Direct	$1,109,980	$4,165,576	$255,321	$969,618	$6,500,496
1	Indirect	$600,263	$1,022,495	$190,028	$240,560	$2,053,346
2	Indirect	$466	$968	$235	$463	$2,133
3	Indirect	$44	$107	$26	$59	$236
	Total	**$1,710,753**	**$5,189,146**	**$445,611**	**$1,210,700**	**$8,556,211**

Table H.6: Results of SD Model for Storm Scenario VI

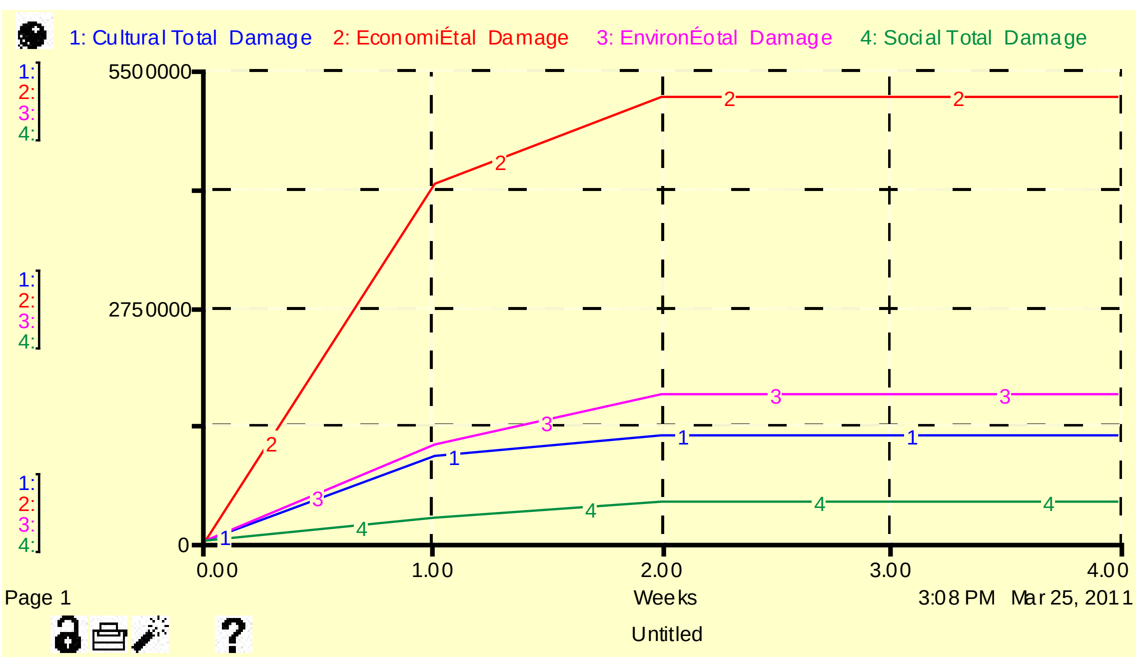

Figure H.6: Comparison of Total Damage of four pillars in Storm Scenario VI