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Thesis:

System Dynamics and Statistical Modeling of Severe Storms: The Case of Charlottetown, P.E.I., Canada

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Abstract

Scientific evidence points to a changing global climate. The most vital and visible impacts of this phenomenon for sea-level communities are sea-level rise, coastal erosion, and more frequent severe coastal storms. However, limited research has been conducted to date to project the damage from rising maximum water levels and corresponding storm surges, and their impacts on the sustainability of coastal communities. This research focuses on the urban coastal community of Charlottetown, Prince Edward Island (P.E.I.), Canada as part of the C-Change International Community University research Alliance (ICURA), "Managing Adaptation to Environmental Change in Coastal Communities: Canada and the Caribbean." The stochastic process that underlies, maximum observed water levels in Charlottetown, is modeled using historical data. Maximum observed water levels and storm surges are represented by fitted conditional and marginal univariate probability density functions. The statistical package "Easy-Fit" is used as a tool for analyzing goodness of fit to the historical data for maximum observed water levels in Charlottetown. A System Dynamics (SD) model, using STELLA, is developed to simulate the projected impacts of maximum observed water levels on the City of Charlottetown. The SD model captures the dynamics of the four pillars of community sustainability, namely Environmental, Economic, Social-Cultural and Human sectors identified for the City of Charlottetown. The model defines and evaluates the robustness of alternative adaptation strategies for various model scenarios to projected storms over a long-term planning period. The results quantify the vulnerability of Charlottetown. The analysis of the results from implementing 3 main adaptation strategies for protection, accommodation, and retreat scenarios as well as the ones from the most common current response of "doing nothing", provide information on the dynamic and pillar-related impacts of storms on Charlottetown. Analysis of these strategy options clearly indicates that doing nothing in the face of more frequent severe storms is an inefficient strategy. Model results show that the protect strategy is unlikely to deliver complete protection, and the retreat option is costly and not well received. The accommodation strategy including a combination of protection options and controlled retreat will provide the most robust option for the coastal City of Charlottetown. The SD model and analysis provides a framework for the evaluation of adaptation strategies for alternative coastal communities.

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1. Introduction

This document presents ongoing research in the form of a thesis in partial fulfillment of the M.Sc. degree in Systems Science at the University of Ottawa. This research is undertaken as part of the C-Change International Community-University Research Alliance (ICURA) program with particular focus on the C-Change coastal community of Charlottetown, Prince Edward Island.

This introductory chapter is divided into three main subsections: (1.1) Motivation and problem statement; (1.2) Research questions and objectives; and (1.3) Outline of the research proposal.

1.1. Motivation and Problem Statement

Global climate is changing and its change has significant impacts on environmental and socio-economic aspects of human life (IPCC AR5-WGII, 2014). One of the significant impacts of climate change is sea-level rise, which affects coastal communities and island states all around the world. This issue is important because even small rises in sea-level may have large impacts on coastal communities.

Sea-level rise causes flooding, erosion, and other coastal hazards that have severe effects on man-made infrastructure and coastal ecosystems (EPA, 2012). It is important to secure these structures from coastal hazards since their failure could have significant impacts on standards of living and even human life (IPCC AR5-WGII, 2014). Recent cases have provided examples of how vulnerable coastal areas can be. On October 29, 2012, Hurricane Sandy was the 18th named storm of the 2012 Atlantic hurricane season. It sustained winds of 185 kilometers an hour (115 mph), resulting in damages estimated at nearly $75 billion (2012 USD). Thirty-eight people died as a consequence of Sandy (International News, 2013).

Between September 1st and September 14th, 2008, Hurricane Ike brought damages of

$29.6 billion to the United States, $7.3 billion to Cuba, $500 million to the Turks and Caicos, $200 million to the Bahamas, totaling approximately $37.6 billion (2008 USD). Hurricane Ike was responsible for 195 lives being lost (Berg, 2010).

On August 29, 2005, Hurricane Katrina hit the Gulf coast of the United States. It was recorded as the costliest hurricane in the history of the United States, with 1,836 deaths and an estimated $81 billion in damages (Knabb, Rhome, & Brown, 2006).

On September 29th, 2003, Hurricane Juan hit Halifax, Nova Scotia as a Category 1 hurricane with peak continued winds of 154 kilometers an hour, resulting in 8 deaths and over $200 million in damages to Nova Scotia and Prince Edward Island (Vasseur, 2008). Not only have the number of severe storms increased in frequency, but also, their duration and intensity have also increased (Environment Canada, 2006).

For the purpose of this research, a storm is defined as sustained winds above 40 km/h for at least six hours (Environment Canada, 2006).

Storm surges associated with severe storms are becoming a more common occurrence. Due to the increased frequency, intensity and duration of severe storms leading to storm surges, vulnerable regions must be identified and monitored in order to limit future storm damage impacts.

"Storm surges are defined as the difference between the observed coastal water level and the predicted astronomical tide. Large positive storm surges at high tide are events that lead to coastal inundation while maximum water levels determine coastal flooding severity." (Environment Canada, 2006).

Storms depend on winds and on barometric pressure and generate storm surges which in turn are responsible jointly with astronomical tides for maximum water levels. Climate change affects winds directly because ocean warming increases evaporation. Climate change affects mean water levels directly because of thermal expansion of the ocean and glacier melting, especially in Groenland and the Western Antartic. Subsidence, the slow sinking of North America eastern coast increases water level on top of climate change (Environment Canada, 2006).

Projections are that Canada, which has the longest coastline of all countries in the world, will experience significant shifts in climate and weather patterns. Evidence of the changing Canadian climate is already being recognized in coastal communities, especially in Canada's Arctic (Pilkey & Young, 2009). It is predicted that these changes will continue, regardless of efforts to reduce greenhouse gas emissions because atmospheric has effects (Santiago, 2001). To respond to the changing climate, all Canadian coastal communities need, in different ways, to adapt to climate change and encompass new policies and tools into their every-day adaptive decision-making. Adaptation planning, and vulnerabilities assessment are methods by which a community can consider the probable current and future impacts of climate change, in order to decrease the resulting risks.

This research, as part of the C-Change ICURA project, "Managing Adaptation to Environmental Change in Coastal Communities: Canada and the Caribbean" represents a collaboration of coastal community members and university researchers, in Canada and the Caribbean region, who research coastal adaptation to the impacts of storm surge and sea-level rise (C-Change, 2010). Among the C-Change coastal community sites, Charlottetown, the capital of the Province of Prince Edward Island, is chosen for this research because of its unique position located on the junction of three rivers, which forms Charlottetown harbor that opens into the Northumberland Strait in Atlantic Canada. Charlottetown is the focus of this research and is the application area for the community damage impacts system model and for maximum observed water level (MOWL) statistical analyses. In Charlottetown, it is anticipated that higher water levels will occur leading to more flooding at higher ground levels in the future and resulting in increased damages (Environment Canada, 2006).

The purpose of this research is to develop a system dynamics model of the coastal community of Charlottetown and of the impacts of maximum observed water levels on its natural, human, manufacture, and social sectors. To this effect, a statistical analysis of the historical data of maximum observed water levels from storms affecting Charlottetown is conducted. This information is indispensable for Charlottetown's ability to prepare and adapt to the pending risks resulting from the changing climate.

1.2. Research Questions and Objectives

The focus of this research is on system modeling of the impacts of storm surge and sea-level rise on the coastal community of Charlottetown. The relevant research questions of this thesis research are as follows:

1. How can the coastal community be profiled in order to capture its multidimensional characteristics?
2. How can the threats to and vulnerabilities of the coastal community be characterized with regard to maximum observed water level (MOWL) aspects based on existing historical storm data?
3. How can the impacts of historical Maximum Observed Water Level (MOWL) events be modeled in order to analyze and evaluate the robustness of alternative adaptation strategies?

In response to the research question the associated objectives of this research are as follows:

1. To model the coastal community with respect to its environmental, economic, social and cultural sustainability pillars.
2. To define a stochastic process for maximum observed water levels events and storm surges for Charlottetown based on a statistical analysis of historic data.
3. To develop a System Dynamics model to estimate, under different scenarios and alternative adaptation strategies, the temporal impact of maximum observed water level damage on the interacting four pillars of community capital, namely, the environmental, cultural and social, economic and human dimensions.

1.3. Outline of the Research

There are eight main chapters in this thesis. The current chapter provides the motivation and problem statement for the research. The second chapter presents the literature review on the different features of the system under investigation. The research methodology, including data, tools, design, and the research process, constitutes the third chapter of the research. The fourth chapter presents the analysis and results of goodness of fit testing of the storm events characterized by maximum observed water levels history in Charlottetown. The fifth chapter presents the STELLA System Dynamics model for Charlottetown including the storm and the storm impacts simulation. Chapter 6 presents the research design of scenarios and strategies in the SD model. Chapter 7 presents the analysis and results of the SD model including the evaluation of the alternative adaptation strategies for Charlottetown. And finally, Chapter 8 presents the summary conclusions and recommendations for future research. The thesis document includes an extensive bibliography of the relevant literature. Finally, the thesis also provides a number of appendices in support of the system modeling and statistical analysis including detailed data, coding, and the complete set of analyses.

2. Literature Review

The literature review pertains to the methodology adopted in this thesis and is divided into five sections namely: (2.1) coastal vulnerability; (2.2) systems thinking and system dynamics; (2.3) statistical analysis; (2.4) the application to Charlottetown; and (2.5) the summary section.

2.1. Coastal Vulnerability

Prince Edward Island (P.E.I.) is a province of Canada whose provincial capital is Charlottetown. The former counts about 146,000 inhabitants while the population of Charlottetown is about one fourth of the island population. The total area of the province is about 57,000 km^2 while Charlottetown's area is less than 1/1000 the island area. Therefore, neither P.E.I. nor Charlottetown, the focus of this research, qualifies as a small island with respect to climate change (IPCC AR5-WGII, 2014). However they both share in small islands climate change features such as sea-level rise, tropical and extra-tropical cyclones, increasing air and sea surface temperatures, and changing rainfall patterns (*high confidence, robust evidence, high agreement*).

The IPCC Fifth Assessment Report (WGII AR5) shows how patterns of risks and potential benefits are shifting due to climate change through the assessment of impacts, adaptation, and vulnerability. "It considers how impacts and risks related to climate change can be reduced and managed through adaptation and mitigation. The report assesses needs, options, opportunities, constraints, resilience, limits, and other aspects associated with adaptation" (IPCC AR5-WGII, 2014). IPCC AR5 defines vulnerability as: "The propensity or predisposition to be adversely affected. Vulnerability encompasses a variety of concepts including sensitivity or susceptibility to harm and lack of capacity to cope and adapt" (IPCC AR5-WGII, 2014). Contextual vulnerability (Starting-Point vulnerability), which is the vulnerability definition adopted in this thesis is "A present inability to cope with external pressures or changes, such as changing climate conditions. Contextual vulnerability is a characteristic of social and ecological systems generated by multiple factors and processes." (O'Brien, et al., 2008), and (IPCC AR5-WGII, 2014).

The definition of Adaptation capacity by the IPCC is "the ability of systems, institutions, humans, and other organisms to adjust to potential damage, to take advantage of opportunities, or to respond to consequences" (IPCC AR5-WGII, 2014). Resilience is defined by IPCC as "The capacity of a social-ecological system to cope with a hazardous event or disturbance, responding or reorganizing in ways that maintain its essential function, identity, and structure, while also maintaining the capacity for adaptation, learning, and transformation." (Arctic Council, 2013), and (IPCC AR5-WGII, 2014).

Another characteristic of small islands is that most important infrastructures are located in a coastal area, which are at highest risk to storm surges (Hartt, Master's Thesis, 2011), (IPCC AR5-WGII, 2014). Facilities such as hospitals, emergency resources, international airports, and governmental centers are usually found in coastal zones. The effect of having the coast as a center makes it dependent on coastal resources, which in turn, adds to the vulnerability of the islands and coastal communities. High concentrations of people in urban areas generate different social, economic and political stresses, and make people more vulnerable to temporary physical and biological hazards (Mimura, et al., 2007). As stated in the IPCC report on small islands,

> "External pressures that contribute to the vulnerability of small islands to climate change include energy costs, population movements, financial and currency crises, international conflicts, and increasing debt. Internal processes that create vulnerability include rapid population growth, attempts to increase economic growth through exploitation of natural resources such as forests, fisheries and beaches, weak infrastructure, increasing income inequality, unemployment, rapid urbanization, political instability, a growing gap between demand for and provision of health care and education services, weakening social capital, and economic stagnation. These external and internal processes are associated with, and interact in complicated ways to intensify the vulnerability of islands' and coastal states' social and ecological systems to climate change." (Mimura, et al., 2007), and (IPCC AR5-WGII, 2014).

Although the above-mentioned stressors are vulnerability factors, the main factor is the natural hazard of storm surges, their height and frequency, which cause large negative impacts on small islands and coastal communities (Bettencourt, 2006). Other perspectives on the vulnerability of coastal communities are the socioeconomic impacts, losses of economic, ecological, built infrastructure and coastal land, increased flood risk to people, and other impacts related to salinity and other land and water issues such as management and ecological issues (Klein & Nicholls, 1999).

Frequently, the biggest challenge is related to the time needed to recover, and because of the regular occurrence of these hazards, communities have less time to rebuild, economically and physically. For example, agriculture can suffer from soil salinization, building infrastructure can be irreversibly damaged, and urban water systems can be polluted (Mimura, et al., 2007), and (IPCC AR5-WGII, 2014).

With rising sea levels and storm surge activity, island states such as Tuvalu and Kiribati in the Pacific Ocean are shrinking very fast. These islands face the loss of the very physical basis of their national sovereignty and the loss of their culture (Pilkey & Young, 2009). This issue has long been the concern of the media and of the UNFCCC Conferences of the parties (COP15, 2009). For example, the Maldives as one of the small islands developing states (SIDS) has been the center of the United Nation's attention. About 50% to 80% of the land area of the Maldives archipelago is less than 1 meter above sea level. In order to protect the Maldives from overtopping, flooding, and the impact of large waves, a system of protective barriers was built at a cost of $4,000(US) per meter financed by Japan. In COP 17, Japan pledged $16 billion (US) over three years to developing countries to combat climate change, and to assure that SIDS would be the priority in mobilizing their aid (COP 17, 2011). Another island whose existence is threatened by sea level rise is Tuvalu in the South Pacific. At merely 0.75 meter above sea level, Tuvalu will soon be overtopped and is in danger of becoming extinct. As such, climate change is not only more than a health and economic concern, but also a major survivability and security issue (COP 18, 2012).

Outcome vulnerability (End-point vulnerability) is defined by IPCC (AR5) as:

"Vulnerability as the end point of a sequence of analyses beginning with projections of future emission trends, moving on to the development of climate scenarios, and concluding with biophysical impact studies and the identification of adaptive options. Any residual consequences that remain after adaptation has taken place define the levels of vulnerability." (Adger, 2006) , and (O'Brien, et al., 2008).

Kelly & Adger (2000) suggest that the level of vulnerability is defined by the potential negative consequences that remain after the process of adaptation has happened (Kelly & Adger, 2000).

2.2. Systems Thinking and System Dynamics

This section presents a perspective on systems thinking and system dynamics modeling and the relevant applied literature.

2.2.1 Systems Thinking

According to Ackoff (1994), a system is a whole package consisting of two or more parts. Each part can effect the performance of the other parts of the system, none of the parts can effect independently the whole system, and no subset of which can have an independent effect on the whole system (Ackoff, 1994). Systems thinking, used in this context, asserts that the complexity of the real world can be best understood by seeing how its components operate as a whole. The connectivity of these components of the system and how they interact over time as a whole is of paramount importance. This idea is somewhat counter-intuitive since it is more natural to understand a system by breaking it down into component parts and to understand the behavior of each component and then use the knowledge of the components to understand the system as a whole. According to Sherwood (2002), there are two tools that are used in applying systems thinking, causal loop diagrams and system dynamics models (Sherwood, 2002).

Causal loop diagrams describe the cause and effect relationship between objects. A simple cause-and-effect relationship can be illustrated as a description of population dynamics. The cause and effect is represented by an arrow, which links the cause with the effect. The cause is population level and the effect is either births (an increase in the effect) or deaths (a decrease in the effect). There are only two link types, either positive (reinforcing) or negative (balancing). These concepts are shown in the causal loop of Table 2.1 below.

Table 2. 1: Causal loop

Cause →	**Effect (+ve or –ve)**
(increase)	(increase or decrease)
(decrease)	(decrease or increase)

The growth in population can be represented by a pair of interconnected feedback loops (links) as explained by Sherwood (2002, p 241) and as shown in Figure 2.1.

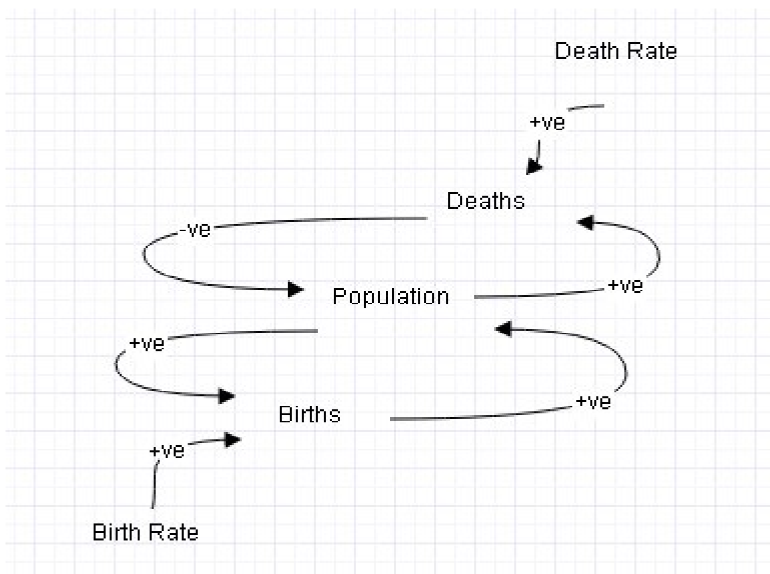

Figure 2. 1: Causal loop diagram of population **(Sherwood, 2002)**

In Figure 2.1, one loop is a reinforcing loop (positive feedback) involving population driven by the Birth Rate, and the other loop is a balancing loop (negative feedback) involving population driven by the Death Rate. The reinforcing loop grows exponentially but is slowed down by the balancing loop. Since Birth Rate and Death Rate are exogenous drivers this system either grows, declines or reaches equilibrium.

2.2.2 System Dynamics

System Dynamics, as developed by Forrester (1971), is the use of computer models to support systems thinking when the system behavior can be represented by difference equations which generally have no closed-form solutions (Forrester, 1971). System Dynamics is a computer-assisted method for policy analysis and design. It applies to dynamic modeling problems happening in complex social, managerial, economic, or ecological systems (Hannon & Ruth, 2001).

Taylor (2008) defined System Dynamics simply as:

> "An approach to understanding the behavior of complex systems over time. It deals with internal feedback loops and time delays that affect the behavior of the entire system and it is a computer simulation modeling technique for framing, understanding, and discussing complex issues and problems" (Taylor, 2008).

System dynamics computer models provide the system variable's time-dependent equilibrium behavior. All SD models consist of only two variable types, stocks and flows, time dependent integrals and time derivatives. In the description of "The Field of System Dynamics", it is stated:

> "A constant inflow generates a linearly rising stock; a linearly rising inflow yields a stock rising along a parabolic path, and so on" (System Dynamics Society, 2013).

Stocks or state variables are the memory of a dynamic system and flows are the source of its dynamic behavior. It is also stated that:

> "Forrester (1961) sited the operating policies of a system among its rates (flows), many of which assume the classic structure of a balancing feedback loop striving to take action to reduce the discrepancy between the observed condition of the system and a goal. The simplest such rate structure results in an equation of the form NETFLOW = (GOAL – STOCK)/(ADJTIM), where ADJTIM is the time over which the level adjusts to reach the goal" (Richardson, Alexander, & Pugh, 1981) and (System Dynamics Society, 2013).

Stocks accumulate net flows over time and are measured at an instant of time. They are represented in the STELLA iconic language, which implements SD models as a rectangle with inputs and outputs, which are flows.

Flows increase or decrease stocks and are measured over a period of time. Flows that increase a stock are inputs to the rectangle and are drawn as a pipe-and-tap where the pipe head points to a rectangle, or inflow rate per unit of time. Conversely, a flow that reduces a stock is drawn as a pipe-and-tap where the tail of a pipe is attached to the stock, outflow rate per unit of time. The pipe-and-tap dynamics are shown in the stock-and-flow diagram of Figure 2.2 (STELLA®, 2012).

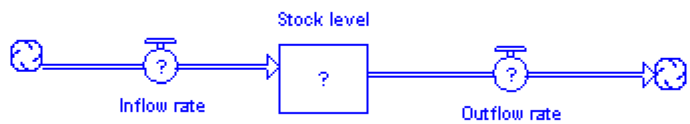

Figure 2. 2: A stock variable with two flows: Input and output flows **(STELLA®, 2012)**

The sources and sinks of these flows in Figure 2.2 are represented by clouds, which means they can originate from or are destined to points outside of the system boundary of interest. They come from, or go to "somewhere". The question mark indicates that no data have been applied to the model at this point.

The easiest analogy to use is water flowing into or draining out of a bath. It is important to recognize that flows are only measurable over a period of time and that stocks are measured at an instant in time, i.e., when time stops. If time stops, the level of water in the bath is measurable but flows are not continued because time has stopped. The diagram of Figure 2.2 is called a stock flow diagram. The term stock-and-flow diagram is being used because it relates to the causal loop diagram of Figure 2.1 (Sherwood, 2002).

There is one stock, two flows, and two converters (auxiliaries) in Figure 2.3. The stock is population. The auxiliaries are annual birth rate and the annual death rate. The flows are the births per year and deaths per year, such that

$$Births\ per\ year\ (in\ 1000s) = Population\ (in\ 1000s) \times annual\ birth\ rate \qquad 2.1$$

One way of representing the causal loop diagram of Figure 2.1 is in the following stock-and-flow diagram of Figure 2.3:

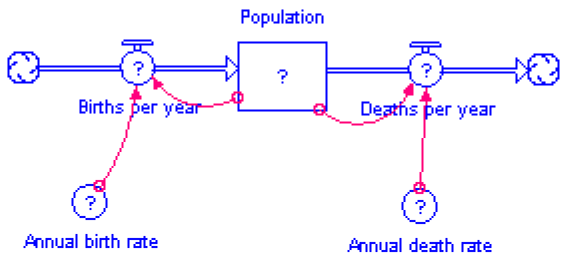

Figure 2. 3: Stocks for annual birth rate and annual death rate **(STELLA®, 2012)**

The flows are calculated from the following equations:

$$Births_{per_{year}}(in\ 1000s) = Population\ (in\ 1000s) \times Annual\_birth\_rate \qquad 2.2$$

$$Deaths_{per_{year}}(in\ 1000s) = Population\ (in\ 1000s) \times Annual\_death\_rate \qquad 2.3$$

The arrows in Figure 2.3 signify that the tail of the arrow corresponds to the argument that is used in the function at the head of the arrow. Thus, Births_per_year have two arrows pointing to it from the two variables Population and Annual_birth_rate.

The two feedback loops in the causal diagram can be seen in the stock-and-flow diagram as a combination of flows and arrows. For example, from Births_per_year by a flow, and backed by an arrow (positive feedback) and similarly for Population and Deaths_per_year by a flow and an arrow (negative feedback) since as the number of Deaths_per_year increases, the Population decreases, and is shown as an outflow from Population.

In summary, stock-and-flow diagrams (e.g., Figure 2.3) are structurally equivalent to the corresponding causal loop diagram (Figure 2.1) and show the same feedback loops and variables. Their visual representation is different and usually contains more variables than the corresponding causal loop diagram. This is because the causal loop concentrates on the cause and effect relationship between the main variables and the stock-and-flow diagram requires to know how each link works and needs additional variables to explain them.

The system dynamics approach starts with defining problems dynamically and continues through the stocks and flows mapping and modeling stages, to steps for validating and verifying the model, and the understanding of its strategy implications (System Dynamics Society, 2013). The system dynamics approach involves:

- "Describing problems dynamically
- Incorporating an internal, behavioral view of the important dynamics of a system, a concentration on the characteristics of a system that generate the apparent problem.
- Thinking of all concepts in the real system as continuous quantities connected in loops of information feedback and circular connection.
- Identifying independent stocks (levels) in the system and their inflows and outflows (rates).
- Formulating a behavioral model capable of reproducing, by itself, the dynamic problem of concern. The model is usually a computer simulation model.
- Originating understandings and applicable policy insights from the resulting model.
- Applying changes resulting from model-based understandings and insights" (System Dynamics Society, 2013).

The basic structure of a formal system dynamic computer simulation model consists of a system of differential equations, e.g.

$$\frac{dx(t)}{dt} = f(x,p) \qquad 2.4$$

where x is a vector of levels (stocks or state variables), p is a set of parameters, and f here is a nonlinear, vector-valued function.

The simulation of such a system is achieved by partitioning simulated time into discrete intervals of length Δt and walking through time one Δt at a time. Each state variable is calculated from its previous value and its net rate of change $x'(t)$:

$$x'(t){:}\;\; x(t) = x(t-\Delta t) + \Delta t \;*\; x'(t-\Delta t) \qquad 2.5$$

The feedback concept is the heart of the system dynamics approach (Sterman, 2000). As

Simonovic and Ahmad (2005) note: “A feedback system is influenced by its own past behavior” (Simonovic & Ahmad, 2005). Diagrams of loops of feedback and circular connection are tools for conceptualizing the structure of a complicated system and for collaborating model-based insights (System Dynamics Society, 2013). A feedback loop happens when information rising from some action travels through a system and ultimately returns as a state to its policy control, potentially affecting future action. There are two different types of feedback: positive and negative. If the tendency in the feedback loop is to support the initial action, the loop is called a positive or reinforcing feedback loop, and if the tendency is to resist the initial action, the loop is called a negative or balancing feedback loop (System Dynamics Society, 2013). Joined together positive and negative feedback processes can create all kinds of dynamic patterns (Morecraft, 2007) and (Richardson G. , 1992).

2.2.3 System Dynamics Applications

Applications of SD in socio and ecological-economic modeling have been used to analyze the impact of population growth and land use changes both in local and global analyses. Examples of these models in the literature that are of particular relevance to the thesis research are presented below.

In the paper by Pena and Fuentes (2007), a system dynamics model is developed to simulate land use changes based on the accelerating population growth of a city in Mexico. This land use change is mainly driven by demographics and urban growth. The land demand is categorized by Industrial, Residential and Commercial land use. Farm and desert land are the main suppliers of land to accommodate the urban growth. The demand for residential land expands due to increases in household formation. Income-scenarios are generated to assist urban planning using STELLA as the simulation tool. The model simulated the demand for land among different land uses for the next 10 or 20 year (Pena & Fuentes, 2007).

The paper by Boumans et al., (2002), describes GUMBO, the first global unified system dynamics model of the biosphere, developed to simulate the dynamic interactions between human technology, economic production and welfare and ecosystem services within the integrated earth system. GUMBO consists of 5 distinct modules, which include the simulation of carbon, water, and nutrient fluxes through the Atmosphere, Lithosphere, Hydrosphere, and

Biosphere. The Human components of social and economic systems are simulated in the Anthroposphere component. The objective of GUMBO is to model the complex, dynamic inter-linkages between social, economic and biophysical systems on a global scale, focusing on the contribution of ecosystem goods and services to sustaining human welfare. Economic production and human welfare are modeled as Cobb-Douglas production functions for economic goods and services (Gross World Product, GWP) and sustainable social welfare (SSW) (Boumans, et al., 2002). The GUMBO framework allows for the aggregation of "factors of production" which contribute to both GWP and SSW into four separate types of capital stocks: (1) natural capital, (2) human capital, (3) social capital, and (4) built capital (Costanza, 1997) (Serageldin, 1996). Ranges of future scenarios showing different assumptions about future technological change, investment strategies, and other factors have been simulated.

Tasuku Kato (2005) developed a system dynamics model to simulate water quality as a result of population, runoff, and land-use changes. Water quality is degraded due to urbanization, which causes population growth, and to land use changes in a watershed. The model consists of three sectors: (1) the Agriculture sector, (2) the Nature sector, and (3) the Urban sector. The stock, flow, and converters (auxiliaries) variables of the water system dynamics model were selected according to interviews with local government agencies. In the Agriculture sector, the areas (stocks) of paddy fields and upland fields were simulated. For example, a causal loop for paddy fields consists of the paddy fields area, planting area, income, technical level, working hours and retirement rate. Since this loop showed a decreasing tendency, it was constructed as a negative feedback loop. For the Urban sector, household area (HA) and population (POP) were simulated. HA includes residential area, commercial area, and industrial area. HA was affected by agriculture area, the development coefficient, and population. Finally, a sensitivity analysis is used to determine the degree to which a model output is sensitive to change in the value of the parameters. For example, the sensitivity analysis notes that applying increased rainfalls to the model provokes some small changes in the values of nitrogen and phosphors in the land productivity, which deems the model to be reasonable (Kato, 2005).

Simonovic (2009) describes the system approach and its application to ongoing water resource management. The focus is one of three main groups of tools including simulation, optimization, and multi-objective analysis. "This approach is presented in the context of sustainable planning and development under condition of uncertainty. There are two particular features of Managing Water Resources: its introduction of system dynamic simulation as a tool for integrated modeling and its coverage of the use of fuzzy sets for incorporating objective and subjective uncertainties" (Simonovic S. , 2009). McCartnet and Arranz (2007) modeled the application of Water Evaluation And Planning (WEAP) to evaluate future water demands and resources in the Olifants Catchment, South Africa (Arranz & McCartney, 2007).

2.2.4 System Dynamics Software

A comparison of different software environments for system dynamics is given below. This includes Vensim (Ventana Systems) (Ventana Systems, Inc., 2012), PowerSim (Powersim Software AS, 2013), AnyLogic (xj technologies) (AnyLogic. Inc, 1992-2012), and STELLA (STELLA®, 2012). A brief description and comparison of each of these simulation environments is provided below.

Vensim is industrial strength systems simulation software for improving the performance of real systems. Vensim fully supports the system dynamics method and it allows flexible graphical representations without clutter. It contains a panoply of tools for model analysis and testing. Vensim is an open source product and currently is freely available for academic users and student researchers (Ventana Systems, Inc., 2012).

PowerSim Studio 8 uses a graphical interface for building systems simulation models on a Windows platform. The tool supports large and complex models with up to 6-dimensional arrays plus the time dimension. Simulation can be discrete or continuous. Live connectivity is possible with MS Excel, and relational databases like Structured Query Language (SQL), Access and Oracle. Such models can be shared through the PowerSim Studio end-user tools. However, to build a tailored or integrated application or web-based solution, Studio Developer Suite using a platform such as Visual basic, and .NET need to be installed. Also, PowerSim is not an open source software application (Powersim Software AS, 2013).

AnyLogic simulation engine is a proprietary software. The unique flexibility of the modeling language enables the user to capture the complexity and heterogeneity of business, economic and social systems to any desired level of detail. AnyLogic's graphical interface, tools, and library objects allow you to quickly model diverse topics such as manufacturing and logistics, business processes, human resources, consumer and patient behavior. AnyLogic includes numerical solver for differential, algebraic, and mixed equations. In addition to its traditional toolset such as sensitivity analysis, calibration and optimization, compare runs, AnyLogic offers several important extensions as below:

- “System dynamics can be combined with discrete events and agent based modeling.
- AnyLogic simulation engine is a hybrid engine designed for efficient and accurate simulation of continuous dynamics being interrupted by a large number of discrete events.
- Animation capabilities are rich in this simulation package and include 2D and 3D animation and business graphics.
- AnyLogic models are standalone, 100 % Java applications and therefore run on any platform. It means models can be shared and delivered easily with end users.
- AnyLogic works on Windows, Mac and Linux” (AnyLogic. Inc, 1992-2012).

STELLA is an easy-to-use system dynamic modeling software that thousands of educators and researchers consider as the gold standard. STELLA is used to study everything from economics to physics, literature to calculus, chemistry to public policy. It has a graphical interface for building models and learning environments, e.g., management flight simulators. STELLA has an extensive communication feature for sharing models, scenario planning, and decision support. The modules provide an easy way to create a high-level map for a model, and break down components into hierarchical model structures or reusable “building blocks”. Storytelling supports step-by-step model unveiling with the ability to both explain and simulate the behavioral story of a model as it unfolds.

STELLA has the processes that allow users to:

1) Draw stock-and-flow diagrams
2) Specify input values
3) Specify the relationship between variables
4) Derive outputs in terms of graphs and data tables.

There are four screen levels to interact with an SD model: Interface, Map, Model, and Equation. The Interface screen summarises the basic structure of the model. The Map level shows the stock-and-flow diagram. The Model level has the stock-and-flow diagram and allows for the setting of intial conditions, parametrization, and functional relations among variables. Finally, the Equation level delineates the algebraic expressions of the model.

STELLA is widely used and is popular systems dynamics software with applications in academia, and private and public institutions. The STELLA software is proprietary, however it is available for both Windows and Macintosh operation systems with academic and commercial versions available. (Rizzo, et al., 2006).

2.3. Statistical Analysis

This section presents the statistical literature on goodness of fit data analysis as well as its application to extreme values. It is particularly relevant for the analysis and modeling of the Charlottetown MOWL data.

2.3.1 Goodness of Fit Tests

A time series is a chronological sequence of observations on a particular variable. Normally, the observations are taken at regular intervals (days, months, years), but the sampling could be irregular. Reasons for fitting a probability distribution to a set of data have been summarized by Hahn and Shapiro (1967) as the desire for generality, the need for automating the data analysis, and interest in the value of the distribution parameters (Romberg et al. 1979, Hahn & Shapiro 1967). The aim of a goodness of fit statistical procedure is to minimize the error between the theoretical target variable and its empirical value (Charlton & Caimo, 2012). The goal of time series analysis in this research is to look at patterns for historical storm surges and maximum observed water level frequencies and to identify the domain for these events. Fitting a theoretical stochastic process to data is determined by statistical analysis of the historical data using goodness of fit tests in an effort to characterize the theoretical distribution of MOWL events for Charlottetown.

Goodness-of-fit tests are a form of hypothesis testing used to indicate whether a sample of data may be declared as having come statistically from a specific distribution (Fliess & Levin, 2003). The goodness of fit (GOF) tests measure the fitness of a random sample with a theoretical probability distribution function. In other words, the goodness of fit tests can be used to compare the fitted distributions, select one of the theoretical distributions, and determine how well it fits to the data. In this research, the statistical package "Easy-Fit" is used as a tool for analyzing goodness of fit (MathWave Technologies, 2004-2013). Three goodness-of-fit tests are examined in detail:

1) Kolmogorov-Smirnov Test

The Kolmogorov-Smirnov (K-S) test is used to decide whether a sample comes from a population with a specific distribution. Its base is the Empirical Cumulative Distribution Function (ECDF). For instance, a random sample $x_1 \dots x_n$ of continuous random variables is assumed to belong to a distribution to be tested. The empirical CDF of the data is denoted by

$$E_N = n(i)/N \qquad 2.10$$

where N is the number of independent identical distributed (iid) observations, and $n(i)$ is the number of values less than x_i, and the x_i are ordered from smallest to largest value (NIST Sematech, 2012).

The K-S statistic (D) is:

$$D = \underbrace{max}_{1 \le i \le N} \left(F(x_i) - \frac{i-1}{N}, \frac{i}{N} - F\ (x_i) \right) \qquad 2.11$$

where F is the theoretical continuous distribution being tested.

Hypothesis testing;

The null H_0 and alternative H_A hypotheses are respectively:

- H_0: the data follow the specified distribution.
- H_A: the data do not follow the specified distribution.

The hypothesis H_0 relating to the distributional form is rejected at the chosen significance level (α), if the test statistic (D), is greater than the critical value obtained from a table. As a rule of thumb, a value of α=0.05 is used for most applications, although lower α value may also be applied.

P-Value

The p-value is calculated based on the test statistic (in contrast to a chosen α value). It is the threshold value of significance level at which the null hypothesis (H_0) is accepted for all values of α less than the p-value. As an example, if $p = 0.025$, then (H_0) will be accepted at all significance levels less than p $(i.e. 0.01\ and\ 0.02)$ and rejected at higher levels, including 0.05 and 0.1.

In short, the p-value is useful when H_0 is rejected at all predefined significance levels, and it is required to know at which level it could be accepted.

2) Anderson-Darling Test

The Anderson-Darling test is used to compare the fit of an observed cumulative frequency to an expected distribution function. This test is a modification of the K-S test and gives more weight to the tails than does the K-S test. Weights are essentially the number of observations. The right tail is treated the same as the left tail in terms of weights in Anderson-Darling test.

The Anderson-Darling statistic (A^2) is defined as

$$A^2 = -n - S \qquad 2.12$$

$$S = \sum_{i=1}^{n} (2i-1).[\ln F(x_i) + \ln(1 - F(X_{n-i+1}))] \qquad 2.13$$

Where

$$A^2 = -n - \sum_{i=1}^{n} \frac{(2i-1)}{n}.[\ln F(x_i) + \ln(1 - F(X_{n-i+1}))] \qquad 2.14$$

where *F(X)* is the cumulative distribution function of the specified theoretical distribution. Note that x_i are the data ranked by size. The null and alternative hypotheses are as before.

The hypothesis relating to the distributional form is rejected at the chosen significance level (α) if the test statistic (A^2), is greater than the critical value obtained from a table. A fixed value of α is used to evaluate the null hypothesis (H_0). The Anderson-Darling test implemented in Easy-Fit uses the same critical values for all distributions (NIST Sematech, 2012). These values are calculated using an approximation formula, and depend on the sample size only (MathWave Technologies, 2004-2013). This test is restricted to continuous distributions as well.

3) Chi-Squared Test

The Chi-Squared test is used to determine if a sample comes from a specific distribution. Normally this test is used for binned or grouped data, therefore the value of the test depends on and in what way the data are binned. Each bin must include at least 5 or more data points, so certain adjacent bins might need to be joined together in order to satisfy this condition (Weisstein, 1999-2013). This test can apply to both discrete and continuous data.

The Chi-Squared statistic is defined as:

$$\chi^2 = \sum_{i=1}^{k} \frac{(O_i - E_i)^2}{E_i} \qquad 2.15$$

where O_i is the observed frequency for bin i, and E_i is the expected frequency for bin i calculated by

$$E_i = F(x_2) - F(x_1) \qquad 2.16$$

where *F(x)* is the probability distribution being tested, and x_1 and x_2 are the limits for bin i. The null and alternative hypotheses are as before.

The hypothesis relating to the distributional form is rejected at the chosen significance level (α) if the test statistic (χ^2), is greater than the critical value, ${\chi^2}_{1-\alpha,k-1}$ obtained from a table.

P-Value

The concept of p-value is same as the definition for Kolmogorov-Smirnov Test. Easy-Fit produces the p-values based on the Chi-Squared test statistics (χ^2) computed for each fitted distribution (MathWave Technologies, 2004-2013).

2.3.2 Extreme Value Distributions

The problem of modeling rare events, including severe storms, arises in many areas where such events can have very negative consequences. Some examples of rare events include extreme floods and snowfalls, high wind speeds, extreme temperatures, large fluctuations in exchange rates, and market crashes. To develop appropriate probabilistic models and assess the risks caused by these events, business analysts and engineers frequently use the Extreme Value Distributions (EVD). Extreme value theory is a branch of statistics that deals with extreme events such as Gumbel, Frechet, Weibull, and Generalized Extreme Value distribution (MathWave Technologies, 2004-2013). These distributions are widely used in applications for risk management, finance, insurance, economics, hydrology (e.g. floods), material sciences, telecommunications (Davison & Anthony, 2001).

As this research is related to distributions of extreme events, such as storm surges and maximum observed sea water levels, several families of distributions, which are commonly used in hydrology, are considered and discussed (Maidment, 1993). Simonovic et al (2011) used the historical climate data from the London (Ontario) International Airport station in 11 different Atmosphere Ocean Global Climate Models, to project future climate change (Simonovic, Millington, & Das, 2011). He compared the fitness of three different distributions such as the Generalized Extreme Value (GEV), Log-Pearson, and Gumbel on the upper Thames River Watershed data in global climate models. Cunnane (1990) was concerned with fitting statistical distributions to annual maxima such as flood frequency, but also with partial precipitation duration series (Cunnane, 1990). Chen et al (2012) evaluate six precipitation probability distributions such as exponential, Gamma, Weibull, skewed normal, mixed exponential and hybrid exponential/Pareto distribution, on their ability to reproduce the statistics of the original observed time series. Data from 24 weather stations and two watersheds, which are Chute-du-Diable and Yamaska watersheds in the province of Quebec (Canada), were used for this evaluation (Chen, Brissette, & Li, 2012).

Further detail on related distributions' applications in different areas for this research is discussed below. Table 2.2 summarizes various probability density functions (PDF) with their contextual application that have been evaluated for this research including extreme value distributions. Table A.1 in Appendix A presents their functional forms and their parameters.

Table 2. 2: Probability Density functions with their explanations

PDF Name	**Description**
Gumbel	In hydrology, the Gumbel distribution is used to analyze such variables as monthly and annual maximum values of daily rainfall and river discharge volumes, (Ritzema, 1994) and also to describe droughts (Burke & Richard H.J. Perry, 2010). It can be used to represent the distribution of the maximum level of a river in a particular year if a time series of maximum levels is available. It is also useful for predicting the occurrence of extreme earthquakes, floods or other natural disasters (Mujere, 2011). The Gumbel Type I distribution is a two-parameter distribution and is a particular case of the generalized extreme value distribution (also known as the Fisher-Tippett distribution). It is also known as the log-Weibull distribution. It is likely to be useful if the distribution of the underlying sample data is of the normal or exponential type.
Weibull	The Weibull distribution (type III of Extreme Value Distributions) is used to model length of life data. It is extensively used in reliability applications to model failure times (NIST, 2012). In hydrology, it is applied to extreme events such as annual maximum one-day rainfalls and river discharges ((Reiss & Thomas, 2001), and (Singh, 1987). This distribution can be used to model survival analysis as well (Lee & Wang, 2003). It can be used in weather forecasting (Sharif & Islam, 1980). It can be used to describe wind speed distributions, as the empirical distribution often matches the Weibull shape (Carta, Ramírezb, & Velázquez, 2009)
Generalized logistic	There are four types of generalized logistic distributions. A number of authors discussed important applications of the logistic distribution in many fields including survival analysis, growth models, public health and economic demography (Nassar & Elmasry, 2012). The generalized logistic distribution has been used to model the data with a unimodal density function (Alkasasbeh &

	Raqab, 2009).
Dagum	The Dagum distribution is also called inverse Burr distribution, and has been used to model the distribution of physical sizes, of waiting times, and per capita income for which it has been mainly used (Kleiber, 2008) (Wolfrom, 2013). There are two types of Dagum distributions: a Type I with three-parameter which is mentioned above, and a Type II with 4 parameters which adds a mass to the distribution function at the origin and then follows the Type I specification. Dagum and Burr distributions belong to the family of log-logistic distributions, which have been used in hydrology (to model stream flow and precipitation), in survival analysis (events whose rate increases initially and decreases later) and in economics (for wealth or income distribution). The log-logistic distribution is the probability distribution of a random variable whose logarithm has a logistic distribution. It is similar in shape to the lognormal distribution but has heavier tails. Extreme values like maximum one-day rainfall and river discharge per month or per year often follow a lognormal distribution. Monroy et al 2013 used Dagum distribution in Modeling Tropospheric Ozone Levels (Monroy, Huerta, & Arnold, 2013).

2.4. Systems Application: Charlottetown

Charlottetown is the capital city of the Province of Prince Edward Island situated on Canada's Atlantic coast. Charlottetown is a flourishing community of over 34, 562 people based on 2011 Census Canada (Statistics Canada, 2012). The major industries in Charlottetown are public administration (local and provincial governments), and retail trade. Charlottetown is well known for its short-term boost in population during the tourism season in the summer months. A map of Charlottetown is shown in Figure 2.4 below.

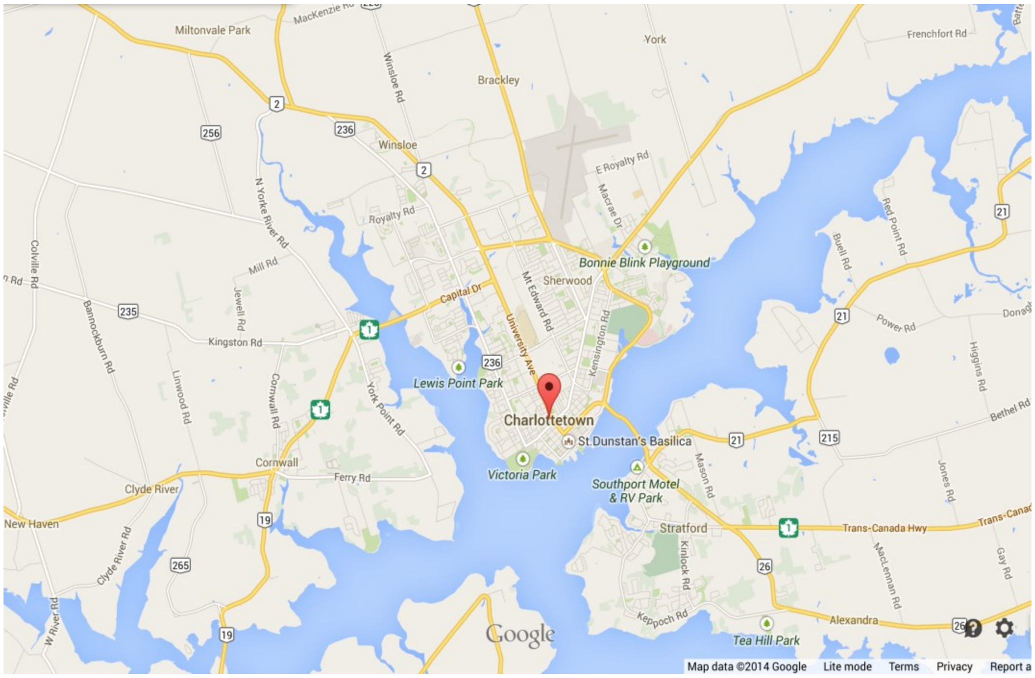

Figure 2. 4: Map of Charlottetown, Source: **(GoogleMaps, 2014)**

Recently, Charlottetown has been seriously affected by severe storms and flooding from storm surges. Storms are created when a center of low pressure develops within a system of high pressure surrounding it. Ocean storms out at sea are defined as having sustained winds of 48 knots (90 km/h) or greater but, for this study, we adopt the Environment Canada definition of winds in excess of 40 km/h for at least 6 hours. (Environment Canada, 2006). As an example, in January 2000, a storm with speeds of more than 70 km/h from the northeast moved through the east coast of the island marking Charlottetown with a record maximum observed water level of 4.23 meters. The storm caused severe damage to public and private property, to the wharves in Charlottetown harbor, to a lighthouse, and to a power-generation station. The total damage was estimated at about (CAN) $20 million (Bowyer, 2009).

Hurricane Juan occurred in October 2003, which also severely damaged parts of Prince Edward Island and Nova Scotia. Its path is shown in Figure 2.5. The complex storm that caused chaos through the Canadian Maritime provinces did most of its damage in Halifax but also hit Charlottetown with tropical depression storm force. Juan was responsible for eight deaths, and, with an alleged damage of (CAN) $200 million, was considered the worst hurricane to hit Halifax in 110 years.

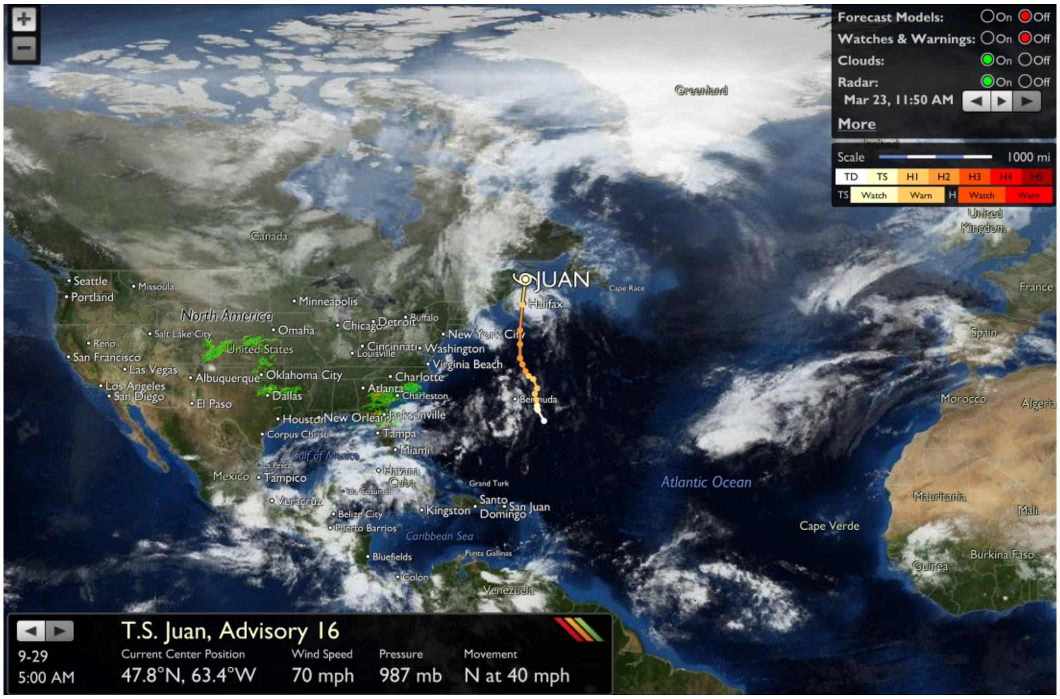

Figure 2.5: Path of hurricane Juan 2003, Source: **(Pulse, 2013)**

Since Hurricane Juan, more effort has been devoted to the understanding and forecasting of high-latitude land falling hurricanes. However, as just about 5% of total hurricane activity occurs in the coastal regions of New England and of the Canadian Maritime provinces, research on these topics is not a priority.

Waters in the southern Gulf of St. Lawrence are relatively shallow and large storm surges develop along all coastlines in response to strong northeast to northwest winds (Figure 2.6). The higher storm surge events were occurring closer to the Charlottetown tide gauge. The highest storm surges occur mostly with storm systems passing to the east of the tide gauge site. Systems passing to the west give a strong response only when the storms come close to the site (Environment Canada, 2010).

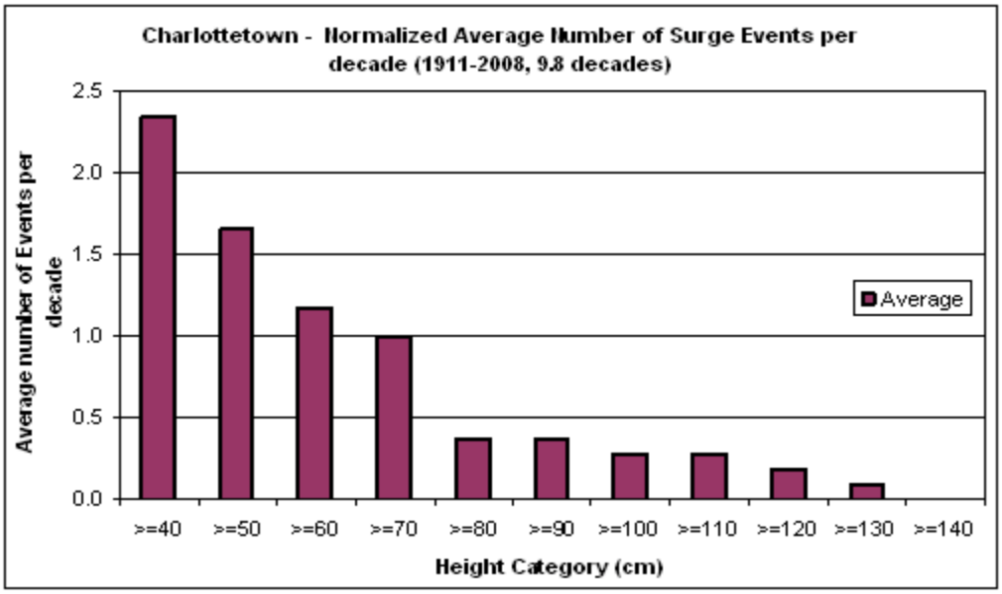

Figure 2. 6: Normalized average number of surge events for Charlottetown per decade 1911-2008 **(Environment Canada, 2013)**

Figure 2.6 shows the normalized average number per decade (1911-2005) of storm surge events. For instance, the average number of surge events above threshold (40cm) for Charlottetown is 2.34 events and above 50 cm is 1.66 events per decade. However, as it can be observed from the graph, the number of storm surge events above 80 cm, up to and above 130 cm occurred with an average of less than 0.5 events per decade (Environment Canada, 2010).

2.5. Summary

In this literature review, definitions of vulnerability, adaptive capacity, and resilience were presented (IPCC AR5-WGII, 2014). For this dissertation, the term vulnerability is defined as contextual vulnerability.

The simulation environment for modeling system dynamics is adopted in this research through the use of the STELLA system dynamics operating software. STELLA's user-friendly application and compatibility with different operation systems are enabling features of the package. This research investigates system dynamics and simulated exogenous events. STELLA provides the unique opportunity to incorporate dynamical systems analysis of community dynamics subject to severe storms with structured exploration of simulated exogenous storms, alternative decision strategies, and sensitivity of parameters.

Finally, the different methods of goodness-of fit for fitting extreme value data lead to this research to adopt the three tests of (i) chi-squared, (ii) Kolmogorov-Smirnov and (iii) Anderson-Darling as the key measures for evaluating and choosing the best fitted distribution to Charlottetown maximum observed water level and storm surges data. The extreme value distribution is evaluated as an appropriate probabilistic model to assess the risks of flooding, as it is the right tail of the distribution, which is responsible for the extreme potential damages.

These concepts, software, and tests will together with the profile of the Charlottetown community to be described in the next chapter constitute the core of the methodology in the balance of the thesis.

3. Methodology

This chapter presents the research methods and research processes applied in this study of the City of Charlottetown's coastal vulnerability. This chapter focuses on the system dynamics methodology for modeling the feedbacks and interconnections of the storm system with its impacts on the coastal community. The system dynamics model is subject to the stochastic processes developed from the statistical analysis of storm surges and maximum observed water levels of Charlottetown. An introductory statement of different methods used in this research is presented in the paragraph below. This chapter presents a mixed methodology for developing community based participatory research in the form of design-oriented systems analysis research. As such, the mixed methodologies employ: (1) statistical analysis (of critical storm events); (2) systems dynamic modeling (to describe critical feedback loops related to community impacts from severe storms); and (3) simulation modeling and analysis (to explore and evaluate alternative adaptation strategies).

Accordingly, this chapter is divided into four main sections namely: (3.1) community profile; (3.2) Charlottetown maximum observed water level (MOWL) data and goodness of fit; (3.3) system dynamic modeling; and (3.4) the phases of the research process.

The first section, (3.1) community profile, identifies the assets and threats faced by the City of Charlottetown. Four different pillars are defined for this model as environmental (land use) pillar, economic (good and services) pillar, Cultural and Social pillar. In section (3.2), Charlottetown MOWL data are analyzed using statistical goodness-of-fit tests to find the best-fit characterized distribution of historical MOWL Charlottetown data. In this section, Easy-Fit software is used as a tool to evaluate different distributions and find the best fit among candidate functional forms for maximum observed water level data. In the third section, (3.3) system dynamic modeling, a robust system dynamic model is articulated by considering the four pillars using the STELLA software as a tool. The system is simulated by applying the MOWL distribution as an exogenous factor in the system dynamics model.

3.1. Community Profile

It is necessary to establish the components used to describe the profile of the City of Charlottetown. The major dimensions of the Community Profile are defined as the "sustainability pillars" of the community as defined in the Integrated Community Sustainability Plan (ICSP) developed by STANTEC (City of Charlottetown, 2010), as follows: Environmental, Economic, Social, and Cultural pillars (Hartt, Master's Thesis, 2011); (Pakdel, 2011); (Mostofi Camare, 2011). The ICSP defined the "sustainability pillars" as the means by which communities were expected to describe themselves. In the same way, and in order to avoid alternative descriptors, this research adopted these pillars in order to comply with the communities' previously defined dimensions. A brief description of each dimension is explained below followed by some challenges related to each dimension.

3.1.1. Environmental pillar

The environment is one of the significant issues when considering community sustainability. Environmental sustainability means living within environmental limits. The environment can and often does mean many things, but to this discussion, very generally, the environment provides the food that we eat, absorbs the wastes that we generate, provides resources that we use to improve our quality of life, and enables life-sustaining processes, and etc. Municipalities have much control over environmental sustainability issues through control of local land use, infrastructure and development, transportation, and taxation" (City of Charlottetown, 2010). "From Rachel Carson's Silent Spring (Carson, 1962) to David Suzuki's The Nature of Things (Suzuki, 2013), public environmental awareness, education, and stewardship action has increasingly captivated Canadians" (City of Charlottetown, 2010). Environment refers to the ecosystem including the natural elements of parks, forested lands, lakes, and waterways (Hartt, Master's Thesis, 2011) and (City of Charlottetown, 2010).

3.1.2. Economic pillar

The economy provides incomes and wages, and a return on investments. Economic sustainability, the maintenance of the value of various capital assets, is not a new concept. However, with the rapid increase in the world's population, threats to long-term economic sustainability have amplified given resource limitations. Economics is the efficient organization of the production and consumption of goods and services toward growing the welfare of a population. The economic pillar is the description and analysis of the production and consumption of goods and services and investment therein. The production of goods and services is rooted in the resources of the land, air, and sea, and the creativity, labor, work skills, education, and health, of individuals that make up the community (City of Charlottetown, 2010).

3.1.3. Social pillar

Social sustainability is “quality of life including the skill of individuals to meet their basic human needs, the capability of individuals to meet their personal goals, and the degree to which communities evolve relationships, networks, and social norms to improve society’s collective quality of life" (City of Charlottetown, 2010). Social sustainability, as defined by the ICSP, involves: social equity, social inclusion, security, social networking, collaboration, and individual and community resiliency and adaptive capacity in the event of emergencies.

3.1.4. Cultural pillar

The concept of cultural sustainability is hard to define since it is intangible, in spite of the fact that its importance is easily recognized. Culture spreads over all features of society at many levels, from households, to organizations, to communities and well beyond (City of Charlottetown, 2010). Culture delivers a shared framework of meaning through which the world and societal roles are interpreted. It includes shared attitudes, beliefs and values, basic underlying assumptions, symbols, myths, and social norms.

Based on the ISCP (City of Charlottetown, 2010) for the City of Charlottetown, the SD model is built around these four sustainability pillars of environmental, economic, social and cultural. A conceptual framework is shown in Figure 3.1.

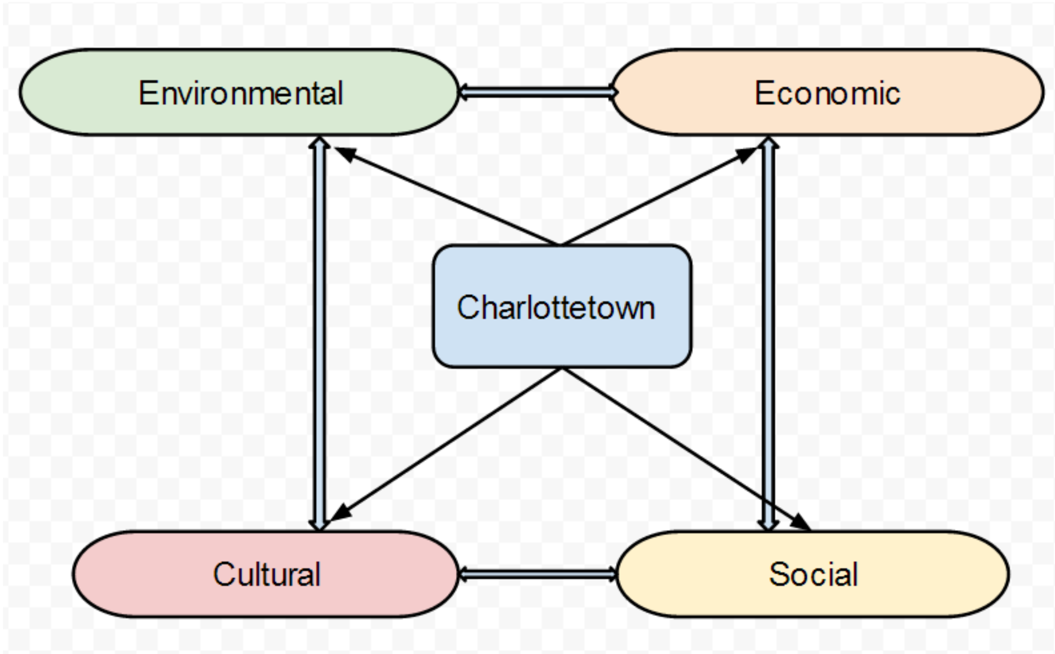

Figure 3. 1: Conceptual framework for defining the profile of the City of Charlottetown according to the 4 sustainability pillars of the Integrated Community Sustainability Plan (ICSP)

3.2. Charlottetown Data Sources

This section presents the data sources to be used in the Charlottetown community profile description and the historical storm data. With respect to the storm data, this research models the stochastic processes that underlie coastal maximum observed water levels and storm surges in Charlottetown in subsection 3.2.1 below. Maximum observed water levels are responsible for flooding and result from high tides combined with storm surges. In this research, maximum observed water level is represented by fitted marginal univariate probability density functions. The historical series of maximum observed water level data for Charlottetown are presented below. Subsection 3.2.2 describes the data used in describing the community sustainability pillars discussed in section 3.1 above.

3.2.1. Storm surges and Maximum Observed Water Level data

One of the most obvious effects of climate change has been the loss of polar ice mass or glaciers melting due to the significant rise in Arctic temperatures that in turn causes rising sea levels. In addition, global warming produces more severe and more frequent storms with more powerful storm surges.

Storm surge and maximum observed water level data for Charlottetown are sourced from the national dataset of Environment Canada (2006). These data “Storm-surge, wind, wave and ice climatology” (Parkes, 2006) are the maximum observed water levels de-trended for the secular increase of the sea-level. Maximum observed water levels are measured with respect to local Chart Datum (CD), i.e., the plane of lowest normal tides (Environment Canada, 2006). The maximum observed water level reached during the storm event is not the actual observed water level, but may be thought of as the level that the event would have reached if it had occurred in 1977, since all data have been de-trended for secular sea level increase and the trend line passes through actual data for 1977 (Environment Canada, 2006). According to these data, the sea-level water (relative to CD), as a linear trend, is rising at approximately 30 cm/century in Charlottetown, P.E.I. (Environment Canada, 2006). (See also Appendix B “Charlottetown Storm surges and Water Level Data” Storm surge Tables B.4 and Figure B.1).

Water levels are a function of two physical processes. The first process is the astronomical tide process, which is periodic on a daily and seasonal basis, and is relatively deterministic. The second process, the storm surge, is stochastic and itself a function of storm severity. Storm surges are defined as the difference between the coastal maximum observed water level (de-trended) and the predicted astronomical tide. Large positive storm surges at high tide are those events that lead to coastal flooding, while maximum observed water levels define coastal flooding severity.

Charlottetown storm surge data from November 1961 to December 2005 are quality-controlled data. However, the data from January 1911 to October 1961 are found to be fairly incomplete prior to 1938. For this reason, two sets of calculations have been performed on the two datasets: (1) using the quality-controlled, reliable data from 1961 to 2005; and (2) using the less reliable but longer time series from 1911 to 2005. In other words, the storm surge data are analyzed based on two time series; the first from 1911 to 2005, which is less accurate and had missing data before 1960, and the second series from 1961-2005, which is more accurate and has fewer missing data.

According to Environment Canada, "On the whole, the water level data are of very good quality" for the entire period 1911-2005 (Environment Canada, 2006). Since 1961, storm surges above 60 cm are more frequent events in Charlottetown, occurring about 8 times a year on average (compared with, for instance, twice a year along the Atlantic coast, as measured at Halifax). Thirty storm surge events at 100 cm or more occurred since 1961, representing almost one such event on average every year. Storm surge events above 120 cm are uncommon (13 such events identified since 1961) and occur on average about three times a decade. Storm surges above 120 cm do appear to have become a little more frequent. Two events were found at 150 cm (Environment Canada, 2006). The statistical analysis of storm surges is found in Appendix B- Charlottetown Storm surge and water level data Table B.4 and Figure B.1.For the purpose of this thesis research, the focus is exclusively on maximum observed water levels.

Maximum observed water levels are modeled as a stochastic process whose parameters can be estimated. Several univariate probability distributions have been fitted to the maximum observed water levels datasets. Table 3.1 shows the raw data record format with two examples for 1911 and 1959. The Start and End columns shows the start and end time of a storm that occurred during the specified day(s) and times. Data entries show that multiple storm events occur yearly, i.e., up to 15 storm events of greater than 60 cm may be recorded in a given year. The Duration column is the length of the storm (in hours) as the difference between the start and end times of the storm event. The Surge Height column is the height of water level, measured in meters, with respect to the local Chart Datum (CD). The Water Level at Maximum Surge provides the water level (relative to CD) at the time of the storm surge component of the dataset (in meters). Finally, the Maximum Water Level is the highest observed level the water attained over the course of the storm (also in meters measured from CD). Note that the maximum storm surge (Surge Height) does not necessarily coincide with the occurrence of the maximum observed water level. The complete set of the raw data of Charlottetown storm surge and maximum observed water level can be found in Appendix B - Charlottetown Storm (Water Level) Data, Tables B1 and B2.

Table 3. 1: An example of raw data for storm surge **(Environment Canada, 2006)**

Start	End	Duration (Hours)	Surge Height (m)	Water Lvl at Max Surge (m)	Maximum Water Level (m CD)
Oct 13, 1911 19:00	Oct 13, 1911 22:00	3	0.73	2.06	2.58
Jun 20, 1959 04:00	Jun 20, 1959 06:00	2	0.63	1.98	2.28

In Figure 3.2, the time series of raw data for maximum observed water level from 1911-2005 is shown. The raw data for maximum water level and storm surges are also provided in Appendix B, Table B3. The time series for maximum water level in Figure 3.2 records all Charlottetown storm events in the database in a given year, including years that may be showing more than one storm and up to five storms in that year. Over the 95 years history from 1911 to 2005 there are 589 storm entries in the database representing, on average, 6.2 recorded maximum water level entries for Charlottetown per year.

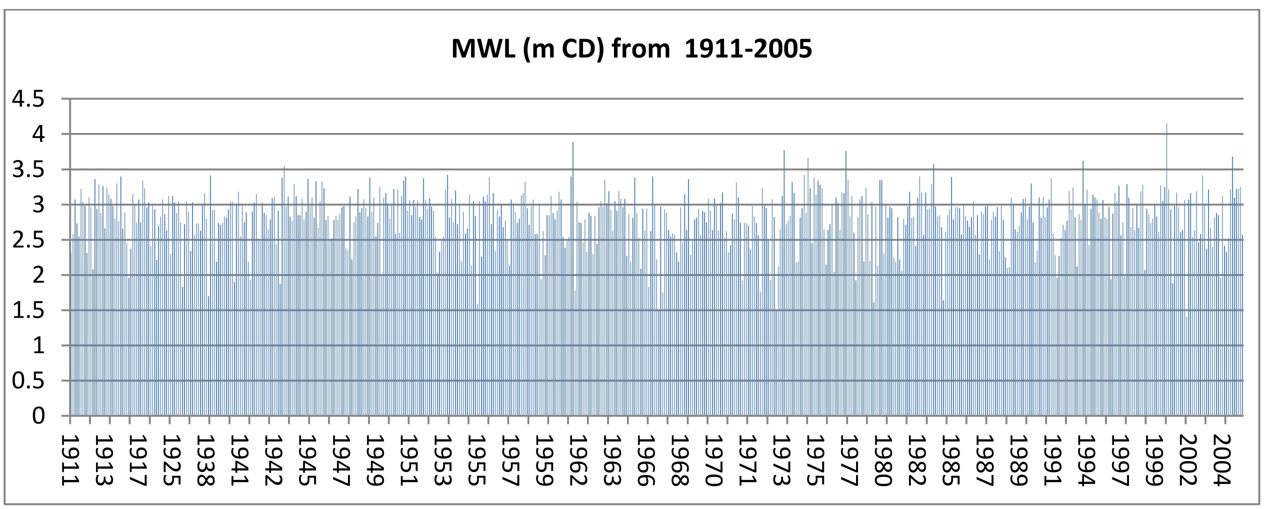

Figure 3. 2: Maximum observed water level from 1911-2005 Source: **(Environment Canada, 2006)**

An exploratory data analysis of the Charlottetown water levels data was undertaken using Excel (Microsoft 2011). In Table 3.2, the descriptive statistics for the time series data for 1911 to 2005 are presented.

Table 3. 2: Parameters of the frequency density function for Maximum observed water levels (Microsoft 2011)

Mean	**2.817104**
Standard Error	0.016048
Median	2.88
Mode	3.1
Standard Deviation	0.389482
Sample Variance	0.151696
Kurtosis	0.992205
Skewness	-0.70937
Range	2.74
Minimum	1.41
Maximum	4.15
Sum	1659.274
Count	589

The density function for water levels has its mode at 3.1m. Its mean is 2.82m and its standard deviation is 0.39m.

To show a summary of the raw data (Parkes, 2006) of maximum observed water level from the lowest to the highest point from 1911 to 2005, a grouped data frequency histogram was constructed based on classes of 10 cm of MOWL. The resulting class definitions and corresponding frequencies are presented in Table 3.3 and Figure 3.3 below.

Table 3. 3: Charlottetown Maximum observed water level data frequency from 1911-2005 **(Environment Canada, 2006)**

Group 10cm	Frequency	Group 10 cm	Frequency	Group 10 cm	Frequency
1.3-1.39	0	2.3-2.39	20	3.3-3.39	25
1.4-1.49	1	2.4-2.49	20	3.4-3.49	9
1.5-1.59	3	2.5-2.59	32	3.5-3.59	2
1.6-1.69	2	2.6-2.69	37	3.6-3.69	3
1.7-1.79	4	2.7-2.79	56	3.7-3.79	2
1.8-1.89	4	2.8-2.89	81	3.8-3.89	1
1.9-1.99	11	2.9-2.99	75	3.9-3.99	0
2-2.09	7	3-3.09	71	4-4.01	0
2.1-2.19	17	3.1-3.19	57	4.1-4.19	1
2.2-2.29	16	3.2-3.29	32	4.2-4.29	0

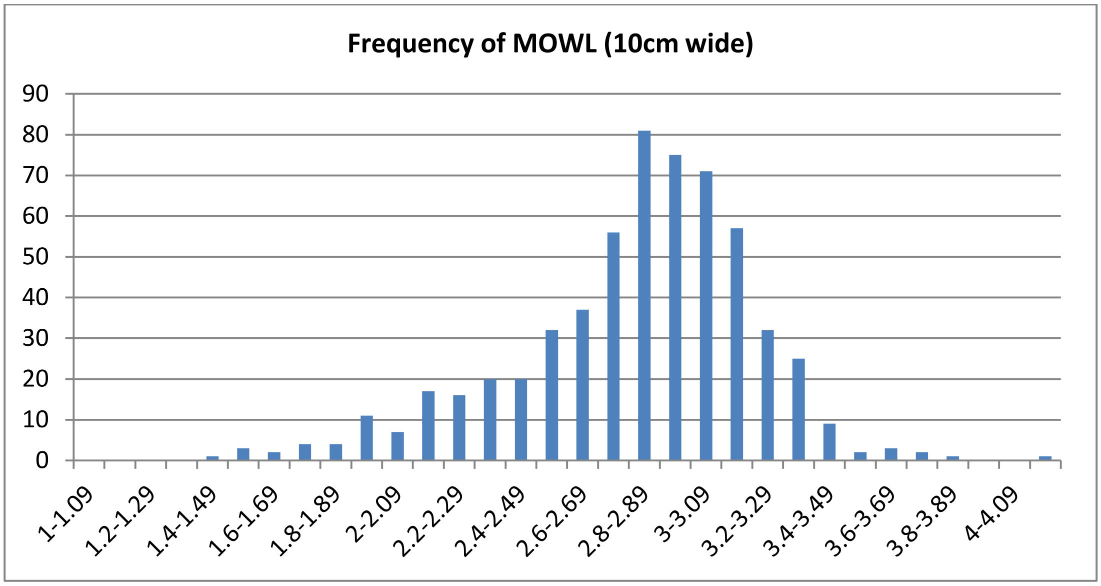

Figure 3. 3: Frequency of Maximum Observed Water Level with 10 cm wide classes 1911-2005 **(Environment Canada, 2006)**

In this research, three tests of goodness-of-fit (Kolmogorov-Smirnov, Anderson-Darling, Chi-Squared) are examined with Easy-Fit application to the case of Charlottetown's historical data on MOWL from Environment Canada (2006). For the test, 5 distributions out of 58 distributions are evaluated based on their goodness of fit. The result of each fit is compared with the others, and the best-fitted distribution is selected. Generally, the candidate distributions are chosen depending on a priory consideration such as their extensive use in hydrology.

3.2.2. Data required by the Charlottetown pillars

As mentioned in section 3.1, there are four community sustainability pillars or dimensions. For the purpose of this research, these are described as: (1) environmental (land use), (2) goods and services (economic), (3) human (population), and (4) social and cultural pillars to correspond to Figure 3.1 above. Thus the demographic features, including education, health, and employment status, are separated from the social pillar to form a new one, the human pillar, and the balance of the social pillar is merged with the cultural pillar as they both are largely intangible. The environmental pillar is reduced to land use. The data collection for the pillars are collected from provincial gross domestic product by industry for Prince Edward Island (P.E.I) for the time frame of the years 2007-2012 (P.E.I. Statistics Bureau, 2013) and Statistics Canada-CANSIM, gross domestic product at basic prices, according to the North American Industry Classification System (NAICS) for the province of Prince Edward Island (P.E.I) which is calculated annually (Canada, 2012).

Table 3.4 shows the component data for PEI Gross Domestic Product (GDP) for the period 2007 to 2012 (Canada, 2012) that is used to categorize annual measures for the sustainability pillars. The value is chained to 2007 dollars and the North American Industry Classification System (NAICS) is applied for all industries. Based on the sustainability pillars model of Figure 3.1, the “Goods and Services” (Economic Pillar) consists of aggregating Industrial Production, Commercial Services and Public Services in Table 3.4, and “Cultural and Social” capital includes Cultural & Social Services and Ecosystem Services from Table 3.4. The yellow highlighted in Table 3.4 shows the categorization of different service components belonging to “Economic pillar” and “Cultural and Social pillar”. Each service or production components’ value is the sum of its subcategories. For example public services value is the sum of waste management, education, other services, and public administration.

Table 3. 4: GDP at basic prices in 2007 Canadian dollars (in millions), by North American Industry Classification System (NAICS) for the province of P.E.I. **(Canada, 2012)**

Industry	2007	2008	2009	2010	2011	2012
Industrial Production	726.6	721.4	715.8	723.8	736.7	725.5
Mining Oil Gas	1.2	2.7	1.4	1.3	1.4	2.4
Utilities	35.8	40.4	43.6	51.7	57.5	57.6
Construction	276.7	267.8	278.6	291.1	300.7	269.5
Manufacturing	412.9	410.5	392.2	379.7	377.1	396
Commercial Services	1414	1438.7	1444.8	1499	1535	1568.8
Wholesale trade	87.9	90	84.9	86.5	89.7	90.4
Retail	284.3	290.1	294.3	308.4	313.9	321
Transport and warehouse	112.7	109.6	109.1	112.7	116.1	119.8
Finance and insurance	238.3	237.5	233.3	238.1	240.2	241.4
Real estate	541.8	555.4	574.7	600.2	619.9	640.1
Prof science and tech	120.3	123.3	114.5	118.9	120.9	122.5
Management of enterprises	28.7	32.8	34	34.2	34.3	33.6
Public Services	1083.2	1115.5	1124.3	1154	1170.8	1177.3

Waste management	116.5	117	109.3	111.4	108.1	106.6
Education	295	306.4	318.6	333.4	342.5	350.1
Other services	106.1	109.6	109.5	111.9	115	113.2
Public Administration	565.6	582.5	586.9	597.3	605.2	607.4
Cultural & Social Services	717.5	725	736.7	752.5	767.2	776.5
Health Care and Social Assist	401.3	408.9	421.4	433.7	444.9	453.5
Arts Entertainment and Recreation	49	49.7	51.1	51.6	52.3	52.5
Accommodation and Food Services	133.1	133.2	132	133.7	133.6	133.2
Information and Cultural Industries	134.1	133.2	132.2	133.5	136.4	137.3
Ecosystem Services	276.5	256	256.2	265.4	254.6	276.5
Agriculture	196.6	183	181.5	194.2	188	189.1
Forestry	6.8	4.5	3.7	3.6	4	4
Fishing trapping and hunting	73.1	68.5	71	67.6	62.6	83.4

Given the total area of the City of Charlottetown, which is known, the data for the environmental pillar (land use) is estimated from the percentages allocation of the components of the GDP category (identified in yellow in the above Table 3.4). It is used to estimate the initial land area allocation among the categories, which is known. The human pillar, which corresponds to part of the Social pillar of Figure 3.1 includes demographic characteristics of Charlottetown such as education, health, and employment status of the population, and is collected from the National Household Survey (NHS) - Census data, Statistics Canada for Charlottetown City (Statistics Canada, 2013). More explanation of how the data are calculated for the land use area can be found in Chapter 5, section 5.2.

3.3. System Dynamics Modeling

The C-Change research, (Community Profile metadata analyses (Hartt 2010) provides the basic data for the project system dynamic modeling and hierarchical decision-making problem. This can be seen in Appendix C - Community Profile Data. The main dimensions of the community profile are divided into main dimension and its Categories that shows the different items that contribute to the analysis of the community, for example for one dimension called the

Economic Pillar, there are items which include industrial production, public services, and commercial services.

The System Dynamics (SD) model developed for the City of Charlottetown assesses the interconnections between the key components of the community profile and the sustainability pillars. The dynamics are designed to capture the feedbacks across the pillars through the measured indicators, (as noted above). Further, the model is designed to examine the impacts on the pillars resulting from alternative scenarios for storms and for applied adaptation strategies. Sensitivity results are presented to convey understanding of the interconnecting relationships. When the sensitivity results have been sufficiently established, the validated model is used to simulate future storm and sea-level rise events. The model is based on the conceptual model of ICSP from Figure 3.1 and modified for Charlottetown as presented in Figure 3.4. The SD software STELLA is used to develop the model (iSeeSystem, 2012).

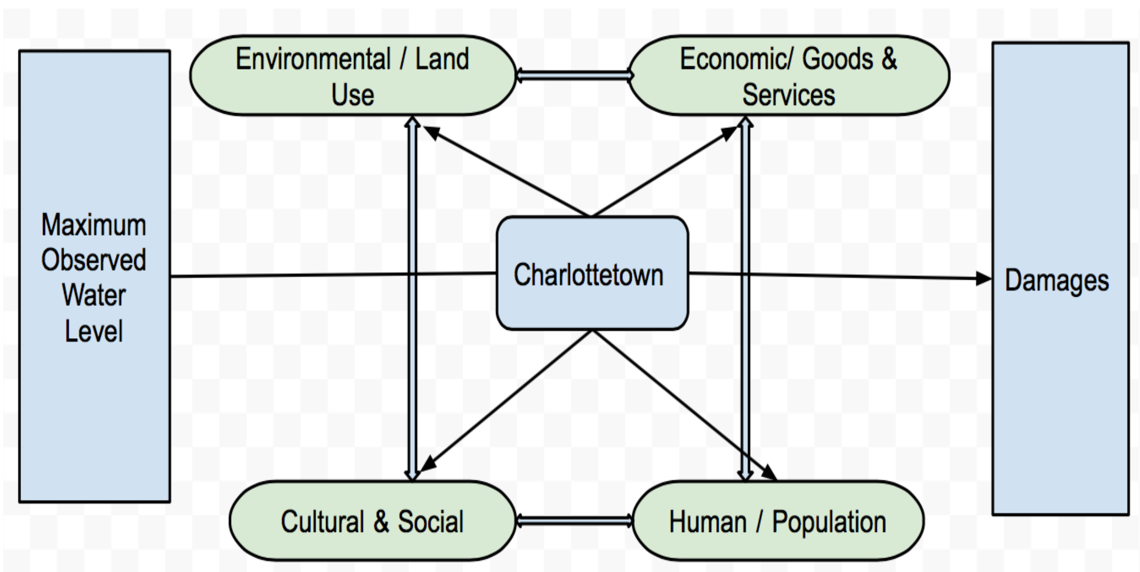

Figure 3. 4: Revised conceptual framework

For operational and communication purposes, the SD model is built around the four sustainability pillars of the ICSP. Figure 3.4 shows the revised conceptual model for this research. The cultural pillar is merged with the social pillar. The social and cultural pillar is broken down into three subcategories: (i) cultural and social services including arts, entertainment, food services, cultural information; (ii) ecosystem services including agriculture, forestry, and fishing and hunting; and (iii) social mapping including social networks, wellbeing, and collaboration.

The economic pillar (Goods and Services) is broken down into three smaller components: (i) commercial services including wholesale trade, retail trade, transportation, real estate, finance and insurance, and enterprises; (ii) public services dealing with waste management and remediation, education, and public administration services; (iii) industrial production dealing with mining, oil and gas, utilities, construction, and manufacturing.

A Population pillar (human) is broken down into four characteristics: (i) education status dealing with high school, degree, and diploma; (ii) age dealing with young, middle, and old; (iii) health status dealing with healthy and unhealthy people; and (iv) work skill status dealing with service, trade, and professional.

The environmental pillar (Land Use), often called natural capital by economists, deals with land cover and land use including green space, public work land, cultural and social land, industrial land, residential housing, and commercial area. Table C.1 in Appendix C (Community Profile Data) shows the summary of categorized pillars with their components.

3.4. Research Process

The steps defining the process of this research are divided into seven phases. The research phases are described below:

Step 1) **Statistical Analysis** of maximum observed water level data for Charlottetown, which involves finding the best-fit probability distribution for the historical data (subsection 3.2, and Chapter 4).

Step 2) **Design and Calibration of System Dynamics (SD) model** the integrated four-pillar (Environment, Human, Social and Cultural and Economic) model to simulate changes in the dynamic profile of the City of Charlottetown, Prince Edward Island, in response to coastal storms. The model robustly articulates the dynamics of four sectors: Human, Land use, Cultural and Social and the Goods and Services for the Base Case with no storm (subsection 3.3, and Chapter 5).

Step 3) **Storm Simulation** storms are simulated and applied to the four-pillar SD framework using a stochastic model of historical MOWL. Simulations are generated of the impact of MOWL on the productivity of assets by sector type using a Cobb-Douglas function for each sector (Chapter 6).

Step 4) **Validation of the SD model** including sensitivity analysis is performed for different scenarios of storms and adaptation scenarios (Chapter 6).

Step 5) **Analysis and development of alternative adaptation strategies** to quantify measures of community resilience in adapting to these strategies (Chapters 6 and 7) to adaptation policies.

Step 6) **Determination of robust strategic long-term adaptation strategies** (Chapters 6 and 7), and

Step 7) **Policy recommendations** for Charlottetown and future research work (Chapter 8).

The following 5 chapters (Chapters 4 through 8) present the results of the research process described above. Chapter 4 details the statistical analysis of MOWL for Charlottetown. Chapter 5 describes and validates the SD model. Chapter 6 describes the detailed input and output components of the model for the Base Case. Chapter 7 presents the results of the SD model under storm scenarios and alternative adaptation strategies. Chapter 8 summarizes the conclusions and recommendations of the thesis and discusses areas for future research.

4. Statistical Analysis of MOWL in Charlottetown

This chapter presents the results of the statistical analysis of the goodness of fit testing of the Charlottetown storm data discussed in the research process of section 3.2.1 above. The objective of this chapter is to develop a probability distribution function of the maximum observed water levels corresponding to Charlottetown storms as a stationary stochastic process for simulating storm events. The ability to simulate historical storms and project them into the future is required for the development the SD model.

Chapter four is divided into four sections. Section 4.1 presents the yearly maximum observed water levels data from 1911- 2005. Section 4.2 provides the summary of the results for the most suitable distribution for maximum observed water level data, section 4.3 provides annual storm statistics, and section 4.4 discusses the storm damage impacts.

4.1. Yearly Maximum Observed Water levels (1911-2005)

Three probability distributions are good candidates to fit the Maximum Observed Water Levels (MOWL) data from 1911 to 2005 for Charlottetown, P.E.I. based on their common usage in hydrology and their high ranking in the Easy-Fit software. The following distributions are discussed further below: (1) Gumbel Min; (2) Generalized Logistic; and (3) Dagum distribution. Each distribution is discussed in more detail below. All three distributions are continuous and defined over non-negative, real-valued numbers. There are 589 data points from 1911-2005 for maximum observed water level corresponding to storm events. Therefore, the date of occurrence of the storm event is random. A MOWL occurs conditionally to a storm. Accordingly, the probability distributions fitted are conditional upon the occurrence of a storm. The following discusses the fitness of the probability distribution functions (PDFs).

(1) Gumbel Min

The Gumbel Min distribution (Type I of Extreme Value Distributions) is used to model the distribution of the maximum (or the minimum) of a number of samples of various distributions. It can be used to represent the distribution of the maximum water level of a river of a particular year, or to predict the occurrence of extreme floods (Ritzema, 1994). The probability density function of the Gumbel Min is asymmetric and skewed to the right tail (compared to the Gumbel Max that is skewed to the left tail). For the Charlottetown MOWL dataset, the Gumbel Min has location parameter $\alpha = 2.99$ meters, the mode of the Probability Density Function; $\beta = 0.3$ is its scale parameter. For large values of the random variable, x, the PDF is asymptotically equivalent to an exponential distribution with the same parameters. Gumbel Min yields the best fit among extreme value distributions. It is also widely used in hydrology. The graph for Gumbel Min PDF for the histogram of the Charlottetown MOWL dataset is shown in Figure 4.1.

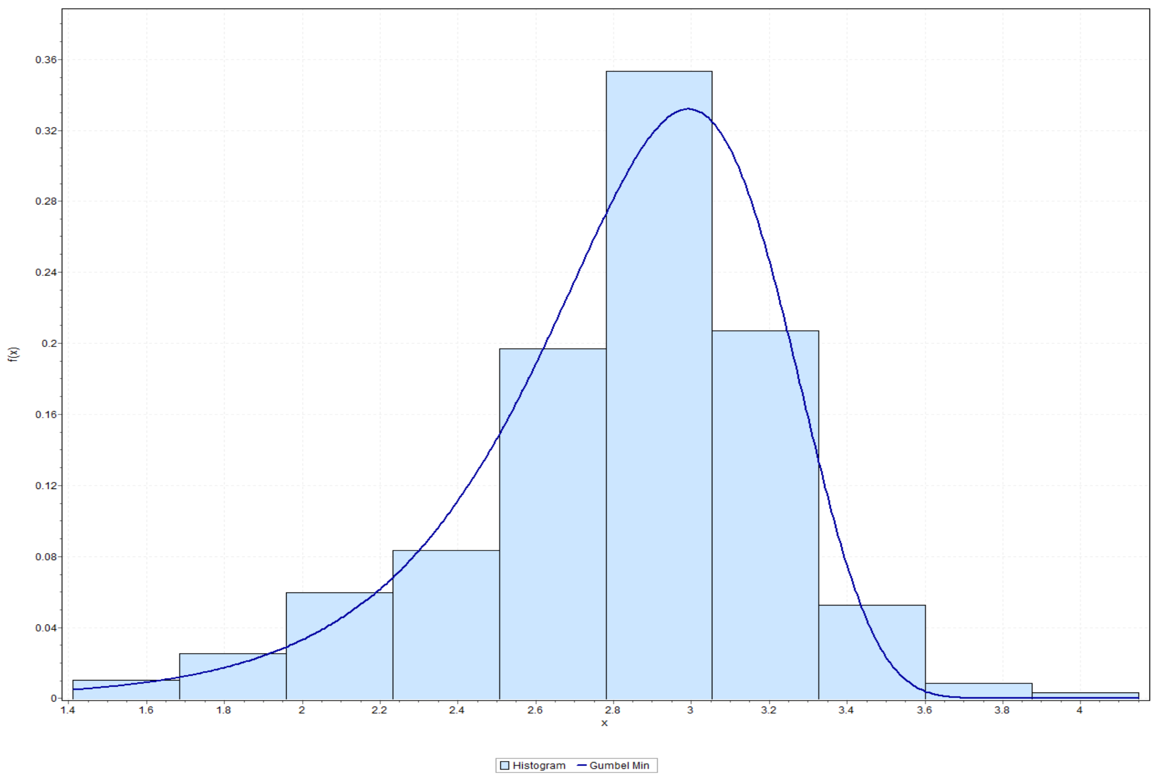

Figure 4. 1: Gumbel Min distribution fit to the Charlottetown MOWL Dataset **(MathWave Technologies, 2004-2013)**

The detail of the various tests of goodness of fit of the Gumbel Min is shown in Table 4.1. The distribution is not rejected based on Kolmogorov-Smirnov test for any of the values of α. For the Chi-Squared test, the Gumbel Min is not rejected for any value of α except for α= 0.2.

For the Anderson-Darling test, the Gumbel Min is rejected for all values of α except for the smallest value of α= 0.01.

Table 4. 1: Gumbel Min goodness of fit results for the Charlottetown MOWL dataset **(MathWave Technologies, 2004-2013)**

Gumbel Min					
Kolmogorov-Smirnov					
Sample Size	589	Statistic	0.039	Rank	3
P-Value	0.296				
α	0.2	0.1	0.05	0.02	0.01
Critical Value	0.044	0.050	0.055	0.062	0.067
Reject?	No	No	No	No	No
Anderson-Darling					
Sample Size	589	Statistic	3.346	Rank	2
α	0.2	0.1	0.05	0.02	0.01
Critical Value	1.374	1.928	2.501	3.289	3.90
Reject?	Yes	Yes	Yes	Yes	No
Chi-Squared					
Deg. of freedom	9	Statistic	12.338	Rank	2
P-Value	0.194				
α	0.2	0.1	0.05	0.02	0.01
Critical Value	12.242	14.684	16.919	19.679	21.666
Reject?	Yes	No	No	No	No

(2) Generalized Logistic Distribution

Easy-Fit uses the 3 parameters version. The estimated parameters for the Charlottetown MOWL dataset are: κ =-0.143, σ =0.205, μ =2.866, where κ is the shape parameter, σ is the scale parameter and μ is the location parameter of the PDF. The Generalized Logistic Distribution yields a good fit among the selected PDFs to the Charlottetown MOWL dataset. The graph for the Generalized Logistic Distribution to the Charlottetown MOWL histogram is shown in Figure 4.2. The detail of goodness of fit statistics is shown in Table 4.2.

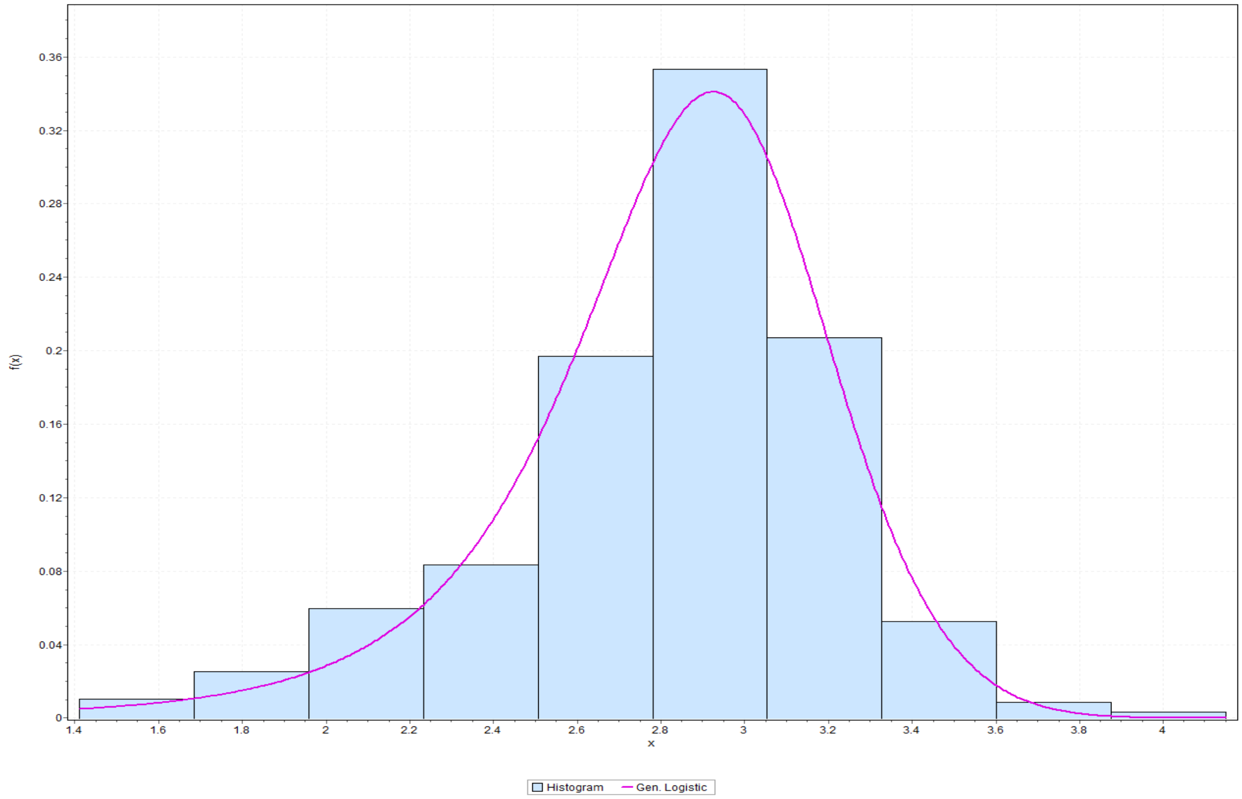

Figure 4. 2: Generalized Logistic Distribution for the Charlottetown MOWL dataset **(MathWave Technologies, 2004-2013)**

The detail of goodness of fit tests is shown in Table 4.2.

Table 4. 2: Goodness of fit result for Generalized Logistic Distribution for the Charlottetown MOWL dataset **(MathWave Technologies, 2004-2013)**

Generalized Logistic					
Kolmogorov- Smirnov					
Sample Size	589	Statistic	0.035	Rank	1
P-Value	0.468				
α	0.2	0.1	0.05	0.02	0.01
Critical Value	0.044	0.050	0.055	0.062	0.067
Reject?	No	No	No	No	No
Anderson-Darling					
Sample Size	589	Statistic	0.885	Rank	3
α	0.2	0.1	0.05	0.02	0.01
Critical Value	1.374	1.928	2.501	3.289	3.907
Reject?	No	No	No	No	No
Chi-Squared					
Deg. of freedom	9	Statistic	21.469	Rank	3
P-Value	0.010				
α	0.2	0.1	0.05	0.02	0.01
Critical Value	12.242	14.684	16.919	19.679	21.666
Reject?	Yes	Yes	Yes	Yes	No

The detail of the goodness of fit tests of Generalized Logistic is shown in Table 4.2. The distribution fit is not rejected based on Kolmogorov-Smirnov test and Anderson-Darling test for none the values of α. For the Chi-Squared test, the Generalized Logistic is rejected for all α values except α =0.01.

(3) Dagum Distribution (Type I)

There are two types of Dagum distributions: a Type I with three-parameters and a Type II with 4 parameters. The Type Dagum is used to describe water level data and is used here to describe the Charlottetown MOWL dataset. Its 3 parameters are respectively: κ=0.285, α=26.101, β=3.139 where α and κ are shape parameters, and β is a scale parameter. The Dagum distribution (both types) yielded a good fit among the six selected distributions based on Easy-Fit. The graph for Dagum Distribution is shown in Figure 4.3.

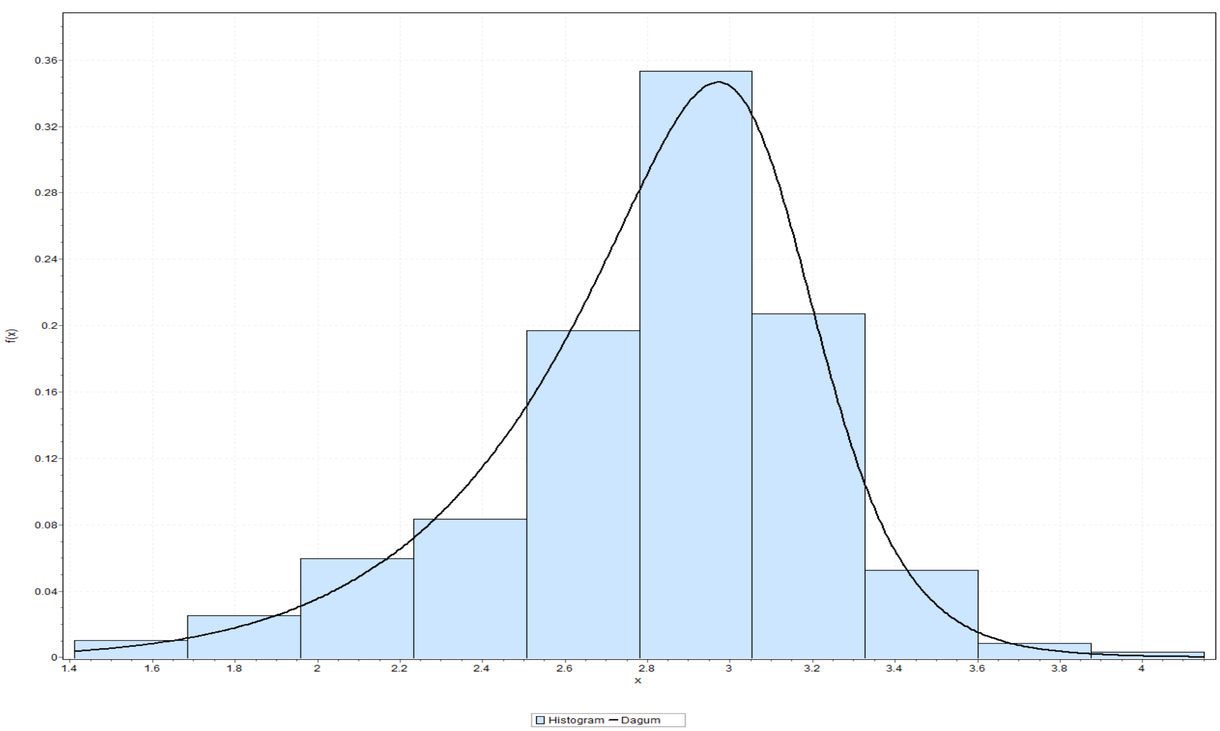

Figure 4. 3: Dagum Distribution for the Charlottetown MOWL dataset **(MathWave Technologies, 2004-2013)**

The detail of goodness of fit test is shown in Table 4.3.

Table 4. 3: Goodness of fit for Dagum distribution for the Charlottetown MOWL dataset **(MathWave Technologies, 2004-2013)**

Dagum					
Kolmogorov-Smirnov					
Sample Size	589	Statistic	0.037	Rank	2
P-Value	0.380				
α	0.2	0.1	0.05	0.02	0.01
Critical Value	0.044	0.050	0.055	0.062	0.067
Reject?	No	No	No	No	No
Anderson-Darling					
Sample Size	589	Statistic	0.550	Rank	1
α	0.2	0.1	0.05	0.02	0.01
Critical Value	1.374	1.928	2.501	3.289	3.907
Reject?	No	No	No	No	No
Chi-Squared					
Deg. of freedom	9	Statistic	12.006	Rank	1
P-Value	0.213				
α	0.2	0.1	0.05	0.02	0.01
Critical Value	12.242	14.684	16.919	19.679	21.666
Reject?	No	No	No	No	No

The detail of the various tests of goodness of fit of the Dagum is shown in Table 4.3. The distribution fit is not rejected based on Kolmogorov-Smirnov test, Anderson-Darling test, and Chi-squared test for any of the values of α.

4.2. Summary of the results

Different distributions are examined and evaluated for the historical data for Charlottetown maximum observed water level (MOWL). Table 4.4 summarizes the result of the Easy-Fit goodness of fit to the Charlottetown data for the five mentioned distributions.

Table 4. 4: Goodness of fit for the distributions for Charlottetown MOWL 1911-2005 **(MathWave Technologies, 2004-2013)**

#	Distribution	Kolmogorov Smirnov		Anderson Darling		Chi-Squared	
		Statistic	Rank	Statistic	Rank	Statistic	Rank
1	**Gumbel Min**	0.039	3	3.346	2	12.338	2
2	**Gen. Logistic**	0.034	1	0.885	3	21.469	3
3	**Dagum**	0.037	2	0.550	1	12.006	1

For maximum observed water level data, as seen from the graphs shown in section 4.1, most examined distributions assume the same shape specifically in the right tail (we are interested in the right tail due to corresponding severe damages). Based on the results from Table 4.4, the Dagum (Type I) distribution is ranked highest among the three selected distributions based on the Chi-Squared test and the Anderson Darling test, and ranked number two based on the Kolmogorov Smirnov test. However, due to the interest of this research, which is the application of a distribution in hydrology, the Gumbel Min distribution is chosen as the preferred characteristic distribution for the Charlottetown dataset of 589 data points of maximum observed water level from 1911 to 2005. The Gumbel Min distribution is widely used in hydrology, e.g. for floods, and maximum values of daily rainfall (Mujere, 2011). Furthermore, its second rank in Table 4.4, based on chi-squared and Anderson Darling tests and third for Kolmogorov Smirnov test which reinforces its selection.

4.3. Single Annual MOWL Statistics

While the Gumbel Min is a good fit for the multiple annual severe storm incidences of the Charlottetown dataset, it seems to underestimate the extreme right tail of the distribution. Therefore, it is of interest in this research to model the single yearly maximum observed water level, which can be thought out as the marginal distribution of a joint probability distribution on storm events and MOWL under the assumption that a storm event occurs every year. This assumption is empirically verified in the data for most years (missing data for 11 years before 1960) and for MOWL larger than 1.4 m and less than 4 m (Figure 3.3) (which is annually the most severe storm) per year from 1911-2005. Figure 4.4 shows the graphic of the single most severe storm, i.e., largest annual MOWL for Charlottetown that occurred per year from 1911 to 2005 in the historical data series.

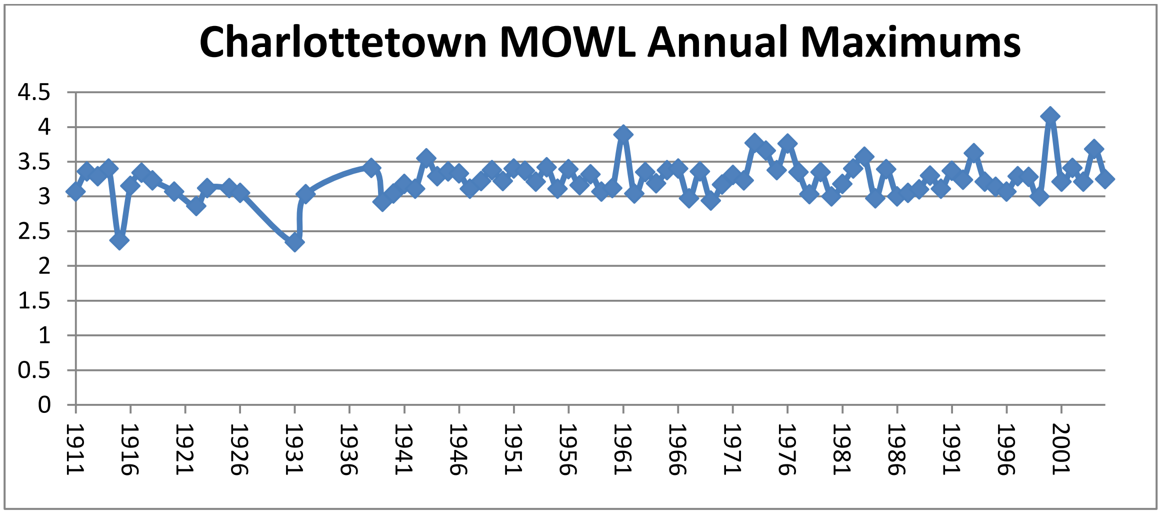

Figure 4. 4: Maximum annual storm events from 1911-2005

Four probability distributions are good candidates to fit the single Maximum Observed Water Levels (MOWL) data from 1911 to 2005 for Charlottetown, P.E.I. based on their common usage in hydrology and their good ranking in the Easy-Fit software. The following distributions are discussed further below: (1) Dagum; (2) Gen Logistic; (3) Gumbel Min; and (4) Gumbel Max distribution. Each characteristic distribution is discussed in more detail below. All four distributions are continuous and defined over non-negative, real-valued numbers. There are 83 data points from 1911-2005 for capturing the most severe storm (single maximum observed water level). The following discusses the probability distribution functions (PDFs) 1 through 4 above.

(1) Dagum Distribution

Dagum has 3 parameters are respectively: κ=0.809, α=26.157, β =3.276 where α and κ are shape parameters, and β is a scale parameter. The Dagum distribution yielded a good fit among the four selected distributions based on Easy-Fit. The graph for Dagum Distribution is shown in Figure 4.5.

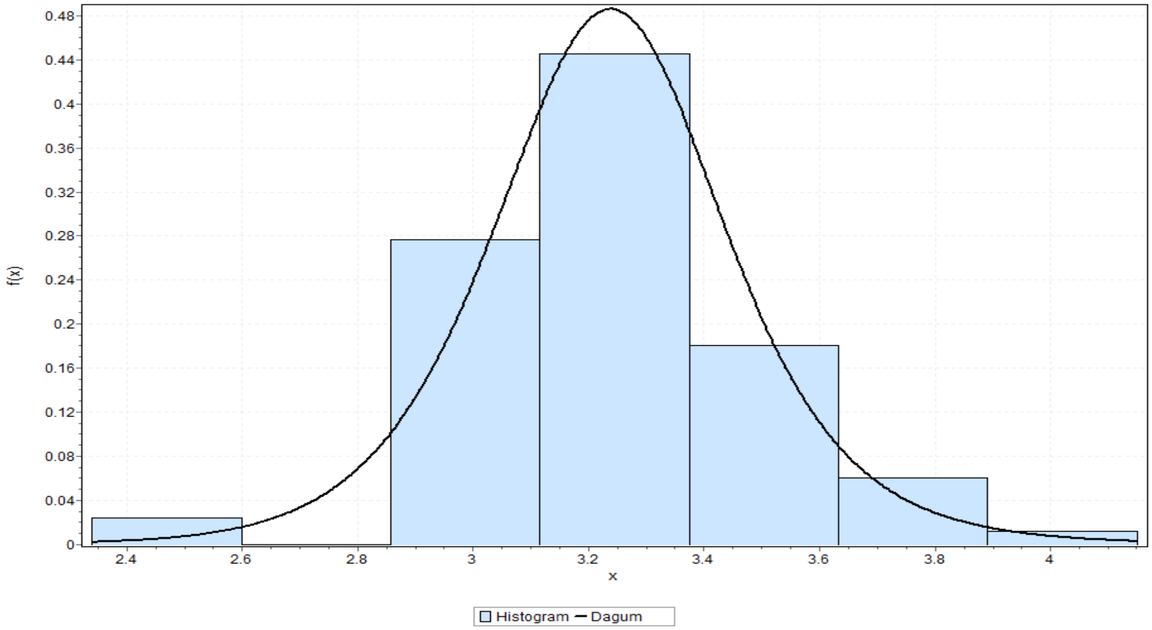

Figure 4. 5: Dagum Distribution for the single annual Charlottetown MOWL dataset **(MathWave Technologies, 2004-2013)**

The detail of goodness of fit test is shown in Table 4.5.

Table 4. 5: Goodness of fit for Dagum distribution for the single annual Charlottetown MOWL dataset **(MathWave Technologies, 2004-2013)**

Dagum					
Kolmogorov-Smirnov					
Sample Size	83		Statistic	0.094	
P-Value	0.421		Rank	1	
α	0.2	0.1	0.05	0.02	0.01
Critical Value	0.115	0.132	0.146	0.164	0.176
Reject?	No	No	No	No	No
Anderson-Darling					
Sample Size	83		Statistic	0.719	
Statistic	0.719		Rank	1	
α	0.2	0.1	0.05	0.02	0.01
Critical Value	1.374	1.928	2.501	3.289	3.907
Reject?	No	No	No	No	No
Chi-Squared					
Deg. of freedom	6		Statistic	8.799	
P-Value	0.185		Rank	2	
α	0.2	0.1	0.05	0.02	0.01
Critical Value	8.55	10.645	12.592	15.033	16.812
Reject?	Yes	No	No	No	No

The detail of the various tests of goodness of fit of the Dagum is shown in Table 4.5. The distribution fit is not rejected based on Kolmogorov-Smirnov test, Anderson-Darling test, and it is rejected for Chi-squared test for the values of α=0.2.

(2) Generalized Logistic Distribution

Easy-Fit uses the 3 parameters version. The estimated parameters for the Charlottetown MOWL dataset are: κ =0.032, σ =0.137, μ =3.236, where κ is the shape parameter, σ is the scale parameter and μ is the location parameter of the PDF. The Generalized Logistic Distribution also yields a good fit among the selected PDFs to the Charlottetown MOWL dataset. The graph for the Generalized Logistic Distribution to the Charlottetown MOWL histogram is shown in Figure 4.6. The detail of goodness of fit statistics is shown in Table 4.6.

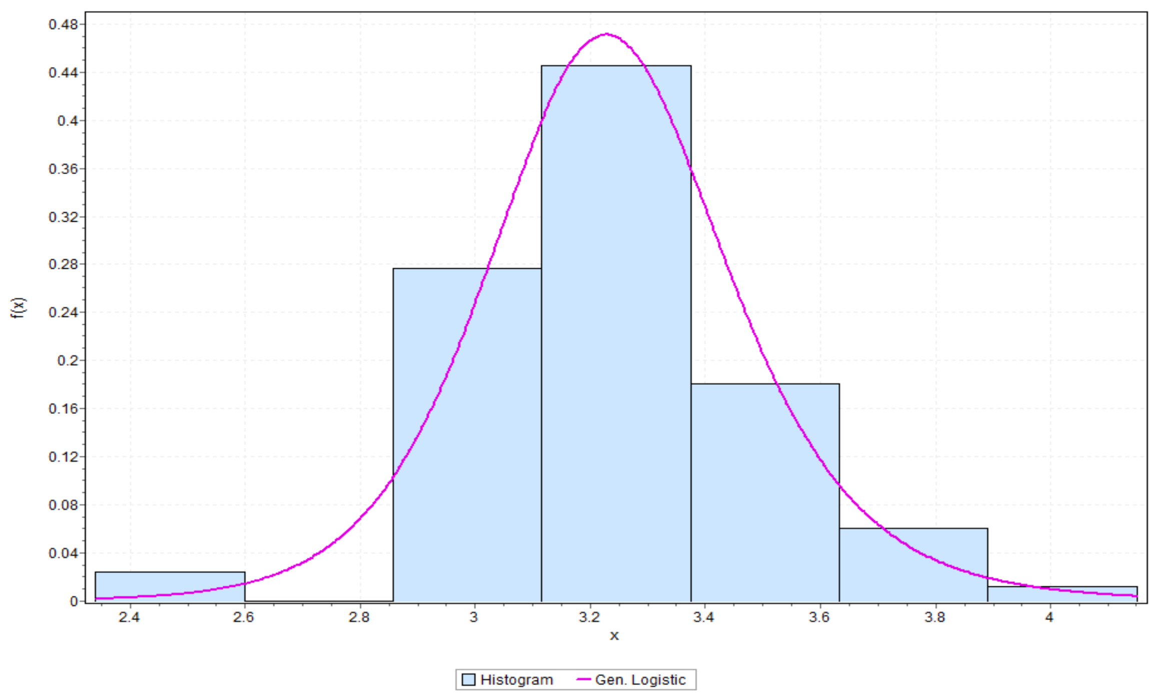

Figure 4. 6: Generalized Logistic Distribution for the single annual Charlottetown MOWL dataset **(MathWave Technologies, 2004-2013)**

The detail of goodness of fit test is shown in Table 4.6.

Table 4. 6: Goodness of fit for Generalized Logistic Distribution for the single annual Charlottetown MOWL dataset **(MathWave Technologies, 2004-2013)**

Gen. Logistic					
Kolmogorov-Smirnov					
Sample Size	83		Statistic	0.104	
P-Value	0.308		Rank	3	
α	0.2	0.1	0.05	0.02	0.01
Critical Value	0.115	0.132	0.146	0.164	0.176
Reject?	No	No	No	No	No
Anderson-Darling					
Sample Size	83		Statistic	0.747	
			Rank	2	
α	0.2	0.1	0.05	0.02	0.01
Critical Value	1.374	1.928	2.501	3.289	3.907
Reject?	No	No	No	No	No
Chi-Squared					
Deg. of freedom	6		Statistic	7.808	
P-Value	0.252		Rank	1	
α	0.2	0.1	0.05	0.02	0.01
Critical Value	8.558	10.645	12.592	15.033	16.812
Reject?	No	No	No	No	No

The detail of the various tests of goodness of fit of the Gen.Logistic is shown in Table 4.6. The distribution fit is not rejected based on Kolmogorov-Smirnov test, Anderson-Darling test, and Chi-squared test for none the values of α.

(3) Gumbel Min

The parameters of Gumbel Min are $\alpha = 3.3$ meters as location parameter, the mode of the PDF, and $\beta = 0.205$ as its scale parameter. The graph for the Gumbel Min Distribution to the Charlottetown MOWL histogram is shown in Figure 4.7. The detail of goodness of fit statistics is shown in Table 4.7.

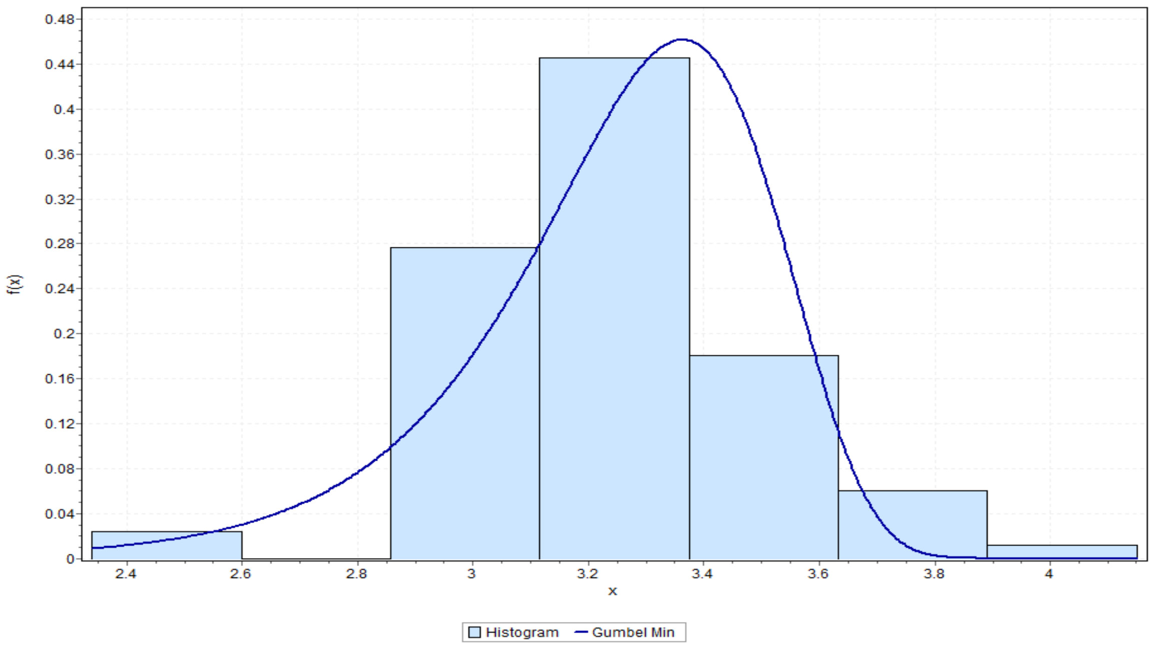

Figure 4. 7: Gumbel Min Distribution for the single annual Charlottetown MOWL dataset **(MathWave Technologies, 2004-2013)**

The detail of goodness of fit tests is shown in Table 4.7.

Table 4. 7: Goodness of fit for Gumbel Min Distribution for the single annual Charlottetown MOWL dataset **(MathWave Technologies, 2004-2013)**

Gumbel Min					
Kolmogorov-Smirnov					
Sample Size	83		Statistic	0.163	
P-Value	0.02		Rank	4	
α	0.2	0.1	0.05	0.02	0.01
Critical Value	0.115	0.132	0.146	0.164	0.176
Reject?	Yes	Yes	Yes	No	No
Anderson-Darling					
Sample Size	83		Statistic	5.163	
			Rank	4	
α	0.2	0.1	0.05	0.02	0.01
Critical Value	1.374	1.928	2.501	3.289	3.907
Reject?	Yes	Yes	Yes	Yes	Yes
Chi-Squared					
Deg. of freedom	5		Statistic	26.278	
P-Value	7.88E-05		Rank	4	
α	0.2	0.1	0.05	0.02	0.01
Critical Value	7.289	9.236	11.07	13.388	15.086
Reject?	Yes	Yes	Yes	Yes	Yes

The detail of the various tests of goodness of fit of the Gumbel Min is shown in Table 4.7. The distribution is not rejected based on Kolmogorov-Smirnov test for the values of $\alpha = 0.02$ and 0.01. For the Chi-Squared test, and Anderson-Darling test, the Gumbel Min is rejected for all the values of α.

(4) Gumbel Max

The parameters of Gumbel Max are $\alpha = 3.124$ meters as location parameter, the mode of the PDF, and $\beta = 0.205$ as its scale parameter. The graph for the Gumbel Max Distribution is shown in Figure 4.8. The detail of goodness of fit statistics is shown in Table 4.8.

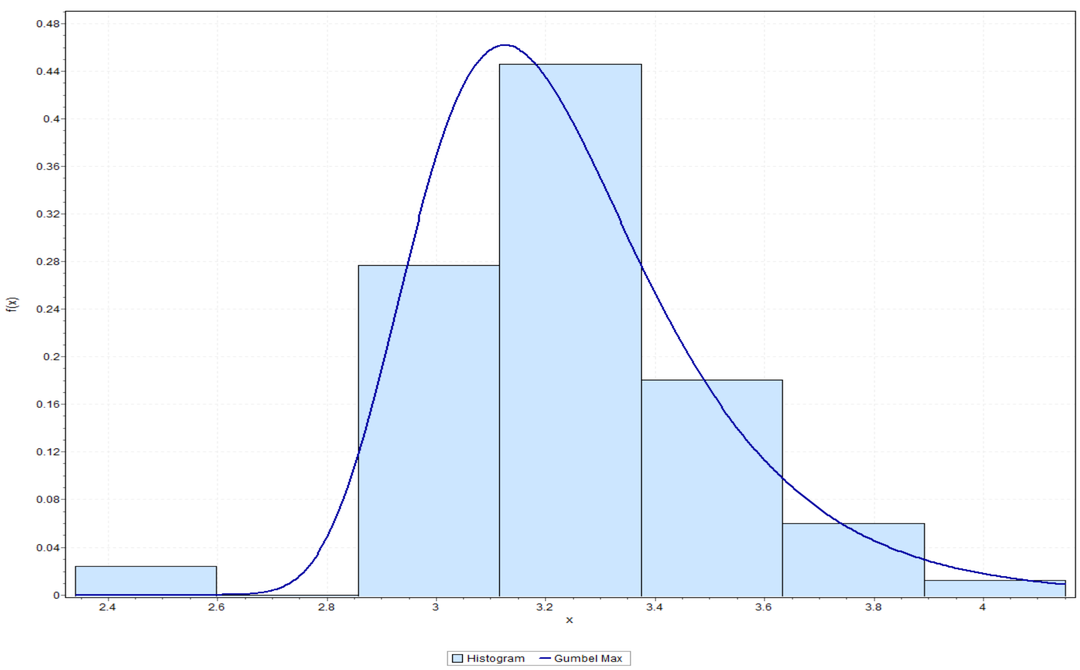

Figure 4.8: Gumbel Max Distribution for the single annual Charlottetown MOWL dataset **(MathWave Technologies, 2004-2013)**

The result of goodness of fit tests for Gumbel max is shown in Table 4.8.

Table 4. 8: Goodness of fit for Gumbel Max distribution for the Charlottetown MOWL dataset **(MathWave Technologies, 2004-2013)**

Gumbel Max					
Kolmogorov-Smirnov					
Sample Size	83		Statistic	0.103	
P-Value	0.311		Rank	2	
α	0.2	0.1	0.05	0.02	0.01
Critical Value	0.115	0.132	0.146	0.164	0.176
Reject?	No	No	No	No	No
Anderson-Darling					
Sample Size	83		Statistic	2.998	
			Rank	3	
α	0.2	0.1	0.05	0.02	0.01
Critical Value	1.374	1.928	2.501	3.289	3.907
Reject?	Yes	Yes	Yes	No	No
Chi-Squared					
Deg. of freedom	6		Statistic	9.67	
P-Value	0.139		Rank	3	
α	0.2	0.1	0.05	0.02	0.01
Critical Value	8.558	10.645	12.592	15.033	16.812
Reject?	Yes	No	No	No	No

The detail of the various tests of goodness of fit of the Gumbel Max is shown in Table 4.8. The distribution is not rejected based on Kolmogorov-Smirnov test for none of the α. For the Chi-Squared test is not rejected for none of the α value except $\alpha = 0.2$, and for Anderson-Darling test, the Gumbel Min is accepted for the values of $\alpha = 0.02$ and 0.01.

Summary of the result for single annual MOWL

Different distributions are examined and evaluated for the historical data for Charlottetown single maximum observed water level (MOWL). Table 4.9 summarizes the result of the Easy-Fit goodness of fit to the Charlottetown data for the four mentioned distributions.

Table 4. 9: Goodness of fit for the distributions for Charlottetown single annual MOWL 1911-2005 **(MathWave Technologies, 2004-2013)**

#	Distribution	Kolmogorov Smirnov		Anderson Darling		Chi-Squared	
		Statistic	Rank	Statistic	Rank	Statistic	Rank
1	**Dagum**	0.094	1	0.719	1	8.799	2
2	**Gumbel Max**	0.103	2	2.996	3	9.67	3
3	**Gen. Logistic**	0.104	3	0.747	2	7.808	1
	Gumbel Min	0.163	4	5.163	4	26.27	4

As it can be seen in Figure 4.8, the Gumbel Max distribution becomes the preferred fit to capture the single annual MOWL corresponding to the most severe storm of that year. Its extreme right tail fits better the annual maxima than did the Gumbel min for multiple storms in a given year. The decision is not only made based on high ranking in Easy-Fit but also based on its widely used applicability in hydrology. Hence, the Gumbel Max distribution is used in the SD simulation model.

4.4. Storm damage impacts

Storm damage impacts occur to the 4 pillars of the community: environmental, economic, social and cultural, and human. Hartt (2011) provided an historical analysis of estimated storm damages by major storm events for Charlottetown (Hartt, Master Thesis, 2011). Mohammadi (2014) related Hartt's storm damages to the maximum observed water levels (MOWL). The functional relationships for Charlottetown are exponential damage functions (Table 4.10).

Table 4. 10: estimated storm damage impacts by pillar. Source: **(Mohammadi, 2014)**

SD damage sectors	Impacted service sector	Related community pillars	Storm damage functions
Goods & Services (** SD)	Industrial (* STC)	Economic	$0.5 \times (0.1292e^{0.939MOWL})$
	Commercial (* STC)	Economic	$0.5 \times (0.1292e^{0.939MOWL})$
Cultural & Social (** SD)	Cultural & Social (* STC)	Cultural Social	$0.015e^{0.929MOWL}$ $0.0089e^{0.941MOWL}$
	Ecosystem (* STC)	Environmental	$0.1649e^{0.926MOWL}$

(* STC): Statistics Canada definition of sector

(** SD): System Dynamics definition of sector

The SD model presented in this research distributes the storm damages calculated in Table 4.10 among the corresponding service sectors (Chapter 5 below). For example, half of the total damage to the economic pillar is assigned to Industrial services, and half are assigned to commercial services, both included in the Goods and Services pillar of the SD model. For the Cultural and Social sector in the SD model, total damage attributed to each of the cultural pillar and total damage of the social pillar are summed for the Cultural and Social sector damages. Finally, the total damage estimated by Mohammadi (2014) for the environmental pillar is assigned to the SD model ecosystem services (Mohammadi, 2014).

The following chapter describes the components of the SD model and presents the input and output results for the SD model Base Case.

5. System Dynamics Model

This chapter describes the details of the System Dynamics (SD) model, initially defined in Chapter 3, section 3.3 to simulate changes in the sector (pillar) profile of Charlottetown, Prince Edward Island, in response to maximum observed water levels. The model articulates the dynamics of four sectors: (1) Human (part of Social pillar), (2) Land use (Environmental pillar), (3) Goods and Services (Economic pillar), and (4) Cultural and Social (Cultural and Social pillar). This chapter implements Figure 3.4 representing the conceptual model with the four pillars presented in Chapter 3. The SD model traces the annual dynamics of Charlottetown, as it is likely impacted by high water levels resulting from severe coastal storms. The System Dynamics model is explained in four sections of this chapter as: (5.1) Human sector, (5.2) Land use sector, (5.3) Cultural and Social sector, and (5.4) Goods and Services sector. An introductory statement of how the system works is also presented in the paragraph below.

Human sector is represented by a simple age-structured population model of Young (ages 0-14), Middle (ages 15-65) and Old (ages 65+) members. This sector of the model attributes health, education and work skills characteristics of the population. The movement of people between these age classes drives the component of the land use sector, which describes the dynamics of residential housing and commercial space activity. The changes in residential and commercial land use adjust the community's other land use, including land for Green space, Industrial, Public Works, and Cultural and Social land use together with related Human capital inputs of Work Skills as labor. These land area stocks are capital inputs to the Cultural and Social sector, and the Goods and Services sector. In the Cultural and Social sector, Green space, and cohort specific population stocks generate Ecosystem Services using a Cobb-Douglas production function. A Cobb-Douglas production function is used as well with the Cultural and Social land to create Cultural and Social production services. This approach of using a Cobb-Douglas production function is modeled after (Boumans, et al., 2002). Finally, the Goods and Services components of Charlottetown's annual Gross Domestic Product (GDP) are generated using Cobb-Douglas functions with capital inputs of Commercial, Industrial and Public Works land together with related Human capital inputs of Work Skills as labor. The Cobb-Douglas production function uses capital (land) measured in acres and labor (human skills) measured in number of people as inputs and dollar-valued outputs, components of the related Charlottetown GDP. Elasticities the parameters of the production function, assumed to 1 for all Cobb-Douglas functions. The scaling parameter of the Cobb-Douglas converts people and acres into dollar values by using the ratio of $\frac{\$}{acre \times people}$.

The following sections detail the sector-by-sector components of the SD model as introduced above.

5.1. Human Sector

Human capital dynamics is represented by a three age-class structured population model as illustrated in the STELLA SD model graphic of Figure 5.1. The age-class widths in years are defined by the parameters $D1$ and $D2$. The Young age-class is from 0 to 14 i.e., $D1 = 15$ years and the Middle age-class is from 15 to 65, i.e., $D2 = 51$ years. The Old age class includes all ages greater than 65, i.e., 65+. Given the annual step, $dt = 1$ year, the annual flow of people from Young to Middle is represented by $YtoM = Young/D1$ and from Middle to Old by $MtoOld = Middle/D2$. The age class width determines how many years members stay in each class. For example, in the young age class (0-14 years) there is an input flow of births per year, and an outflow from the Young age population class of 1/14 (one-fourteenth) members (persons) per year. Thus, it is assumed that the age distribution within the Young population group is uniform. The auxiliary variables $YtoM$ and $MtoOld$ are defined as inputs to configure the Land Use Sector components of Commercial and Residential land use formation based on the population numbers in the Middle and Old age-classes.

Important characteristics of human capital are: (i) health (Unhealthy, Healthy), (ii) education (High School, Diploma, Degree), and (iii) work skills status (Services, Trades, Professional), which stratify the age groups (Young, Middle, and Old).

Age-class population segments of Young, Middle, and Old are first split according to their highest level of education: (i) High School, (ii) Diploma, or (iii) University degree. Persons with a given education level are further stratified into work skills status. The education and work-skills status are used as human capital inputs for the Social and Cultural and Goods and Services production functions. In addition, the age specific health status of the population can be calculated by multiplying the number of persons in each age group by age and health specific probabilities as indicated in the historical data for Charlottetown.

One of the main linkages of the SD model is from the human sector to the land use sector. The flows of people from Young to Middle to Old determine the requirements for Residential Housing and Commercial space. A basic assumption of the SD model is that age decreases the need for residential and commercial space. For example, the aging of the population changes the status of households and the demand for residential housing and commercial activity, i.e., residential housing and commercial space are reduced by Charlottetown population members who move from the Middle to Old age group (See also section 5.2.1 below).

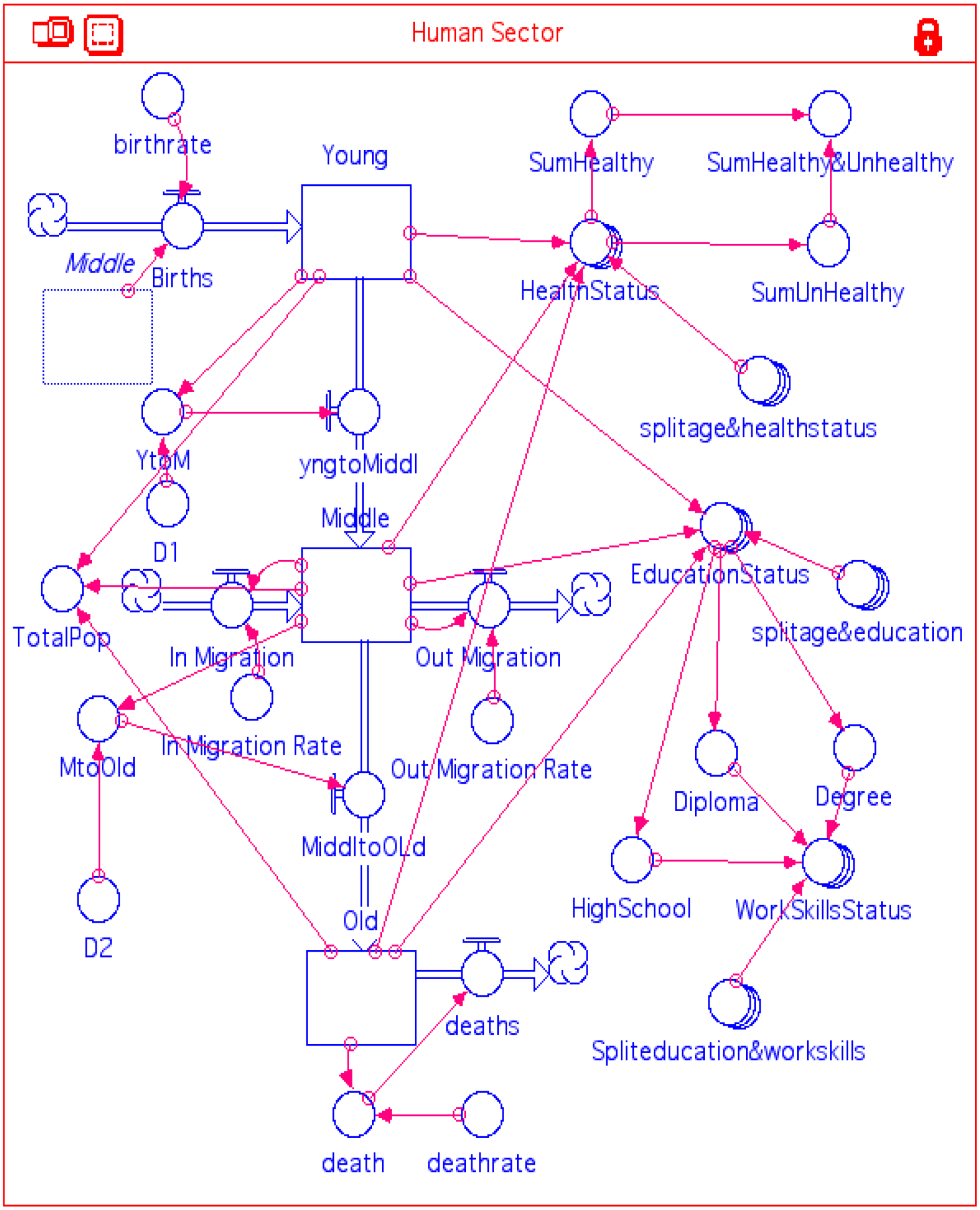

Figure 5. 1: Human Sector of the Charlottetown SD model **(STELLA®, 2012)**

The flow of *Middle age* group in the human sector is illustrate by equation 5.1 below:

$$Middle(t) = Middle(t - dt) + (yngtoMiddl - MiddltoOLd) * dt \quad 5.1$$

$$INIT\ Middle = 20175$$

INFLOWS: $yngtoMiddl = YtoM$

OUTFLOWS: $MiddltoOLd = Middle/D2$

5.2. Land-Use Sector

This sector is divided to four sections: (1) residential housing and commercial area; (2) alternate land use categories; (3) unaffected and affected land, and (4) initial land use areas. These sections are explained in further detail below:

5.2.1 Residential Housing and Commercial Area

The stock-flow dynamics for Commercial Space and Residential Housing stocks (Figure 5.2a) are driven by the population flows between age-classes. The model articulates the demand for Commercial space and Residential Housing units as a function of the subpopulation sizes of the *Middle* and *Old* age-classes. The current (2012) rate conversion of people into Residential Housing units to support the *Middle* population segment is 500 units per 1000 *Middle* residents in Charlottetown; the current (2012) rate of conversion of people into Commercial area to support the *Middle* population segment is 1700 acres per 1000 *Middle* residents in Charlottetown. Similarly, based on the current Charlottetown population, the rate of Residential Housing units to support the *Old* population segment is 500 units per 1000 *Old* residents; the rate of Commercial area to support the *Old* population segment is 100 acres per 1000 *Old* residents.

Figure 5.2a shows that in the commercial and residential sectors, the household demand for stocks of Residential Housing and Commercial Area are separated into two components: one component that results from the flow of *Middle* aged people into the *Old* age group, and the other component that results from the flow of people from the $Young$ to $Middle$ aged group. These two components represent gains in flow for Residential Housing (initial stocks: 15000 housing units) and Commercial Area (in acres) each year. Similarly, reductions in the demand for Residential Housing and Commercial Area occur as a result of deaths from the *Old* age group, and the movement of people out of the *Middle* age group. Overall, if the population segments of both the Middle and Old groups decline, then the required Residential Housing units and the Commercial Area are reduced. If these subpopulations both increase, then the number of Residential Housing units and the Commercial Area supporting this population increases accordingly. Further, Residential Housing and Commercial Area are assumed to be unaffected by Charlottetown storms.

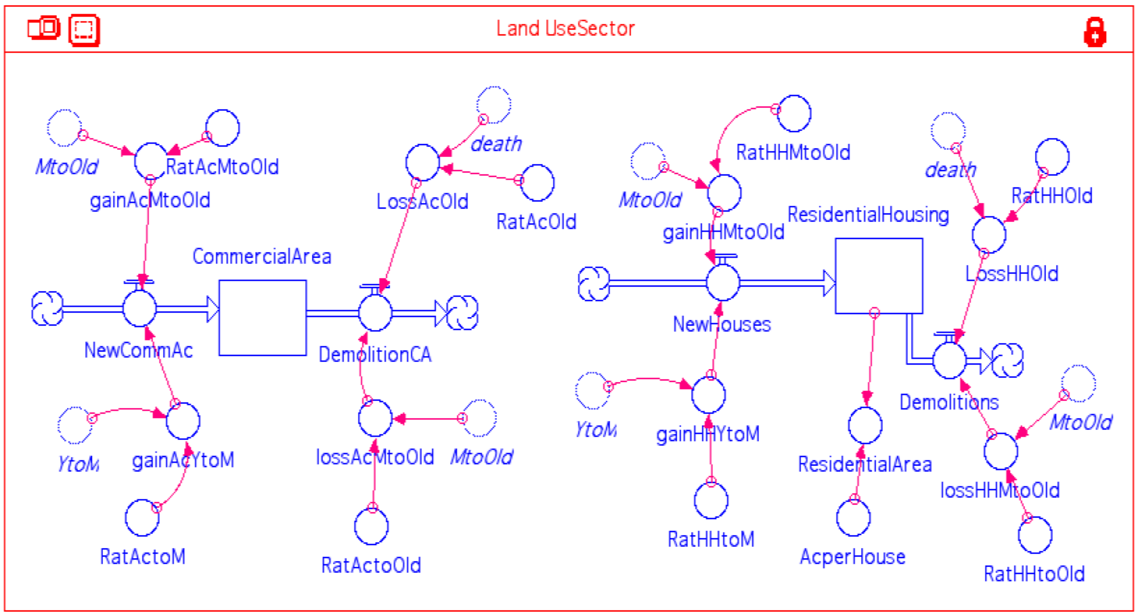

Figure 5.2a: Land Use sector: Commercial Area (acres) and Residential Housing (units) **(STELLA®, 2012)**

5.2.2 Alternate Land Use Categories

Adjustment of land use associated with stock categories of Green Space, Public Works land, Industrial land, and Cultural and Social land is, in turn, determined by the population-driven requirements for Commercial and Residential land. Since the total area of land for Charlottetown is assumed to be constant and unchanging over the planning period, then population changes will directly affect residential housing and commercial area lands, i.e., if the population goes up or down, adjustments to all land categories must be made. This dynamics is seen in the stock flow section in Figure 5.2b.

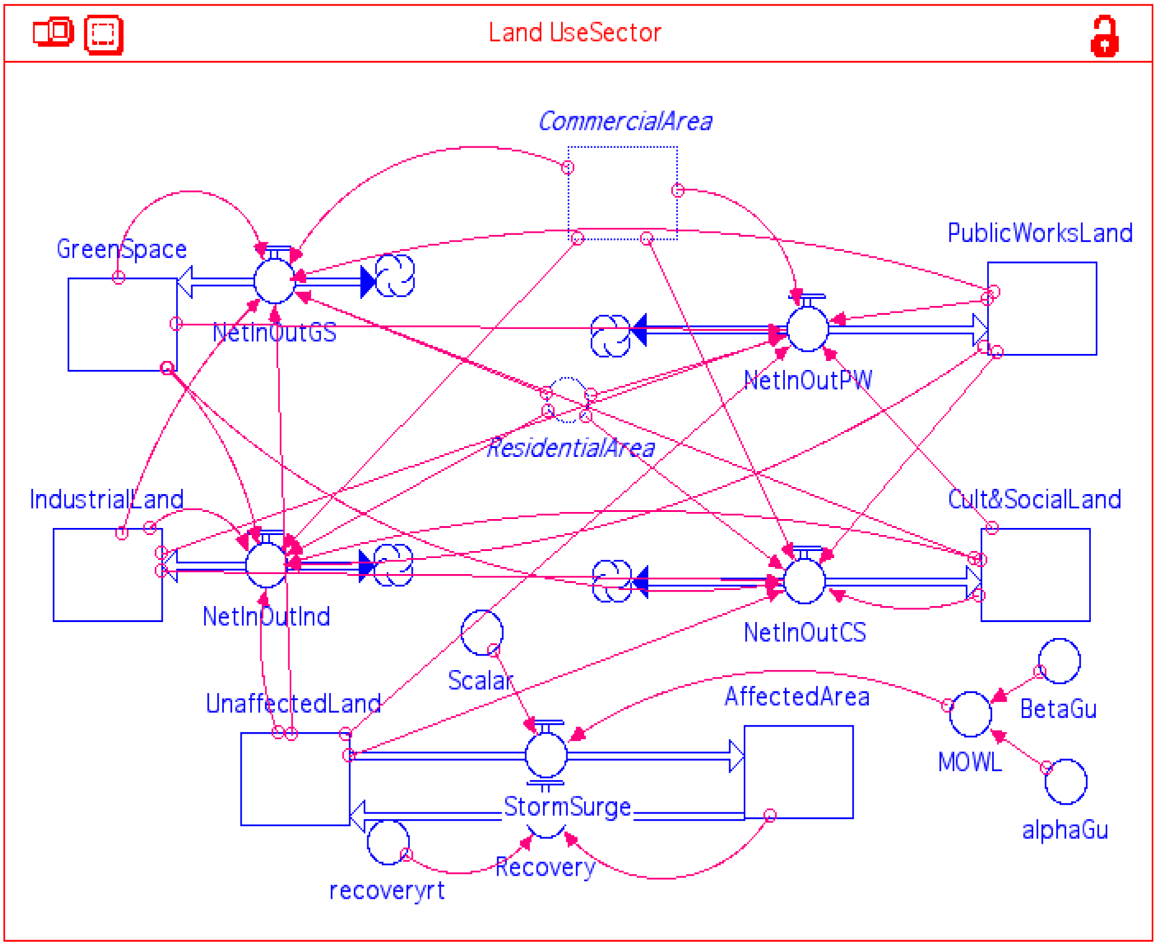

Figure 5.2b. Alternate land use categories (STELLA®, 2012)

The biflow (inflow minus outflow) associated with each stock of land has the same adjustment mechanism. An example for the case of Green Space is provided below to illustrate the impact on land use categories.

The biflow $NetInOutGS$ is defined as:

$$NetInOutGS \ = GreenSpace(t+1) - GreenSpace(t) \quad 5.2$$

Or, equivalently

$$NetInOutGS = GreenSpace(t) \times \left(\frac{UnaffectedLand - ResidentialArea - CommercialArea}{GreenSpace + IndustrialLand + PublicWorkLand + Cult\&SocialLand} - 1\right) \quad 5.3$$

GreenSpace (t+1) is calculated by multiplying the *GreenSpace* (t) by the ratio of the Unaffected land (land not affected by storms) minus the sum of residential and commercial land to the residual land which is:

$$GreenSpace + IndustrialLand + PublicWorkLand + Cult\&SocialLand \qquad 5.4$$

The ratio 5.3 similarly maintains the relative proportion of the 4 alternative land uses after the affect of population change has altered the Residential Housing (and the corresponding Residential area) and Commercial Area stocks. Thus, if total area were 100 acres of which total residential and commercial areas were 30 acres, then if population drives residential and commercial areas to a new level of 40 acres on 100 total acres, then applying 5.3 results in the reduced acreage of 60 acres (from 70) to the 4 alternative land uses but with identical proportions among the 4 alternative land uses as that prior to the population and land use shift. The calculations for the biflows for the other alternatives uses for Industrial, Social & Cultural, and Public Works land, i.e., $NetInOutIn, NetInOutSC, and\ NetInOutPW$ are similar to equation 5.3 for these stocks.

5.2.3 Unaffected and Affected Land

Finally, in the Land-Use Sector (Figure 5.2b), the impacts of severe coastal storms are considered. Two stock variables: (1) $UnaffectedLand$, and (2) $Affected\ Land$ are introduced. These interact with each other by taking account of the severity of the storm as characterized by the randomly generated Maximum Observed Water Level (MOWL). Lands affected by storms are determined by simulating MOWL (in meters) stochastically each period sampled from the Gumbel Max cumulative probability distribution function over the planning period. MOWL is simulated each period (year) using the inverse transformation function for the Gumbel Max (NtRand, 2014) as follows:

$$MOWL = \alpha lfaGu - \beta etaGu \times ln\left(ln\left(\frac{1}{Random(0,1)}\right)\right) \qquad 5.5$$

where $\alpha lfaGu$ is the value of the Gumbel Max location parameter α, and $\beta etaGu$ is the value of Gumbel scale parameter β.

The outflow from $UnaffectedLand$ to $AffectedArea$ is defined as a *Scalar* multiplied by the storm severity given by the value of MOWL, therefore

$$Affected\ Area = Scalar \times MOWL \tag{5.6}$$

Recovery from storm damage is reflected in the model by calculating a flow back from *Affected Area* to *UnaffectedLand* via the flow *Recovery* using an annual recovery rate parameter, $recoveryrt$ where $recoveryrt = 0.10$, i.e., it is assumed that Charlottetown recovers 10% of its affected land each year after the severe storm event, i.e.,

$$Recovery = AffectedArea \times recoveryrt \tag{5.7}$$

5.2.4 Initial Land Use Areas

The total land in the City of Charlottetown is registered as around 8,000 acres, not including residential area (Charlotettown, 2013). Since data for land use division for the City of Charlottetown are not readily available according to the model categories, the percentages allocation of the GDP breakdown by sector (Table 3.4) is used to estimate initial land allocation among these sectors knowing the total land area. Figure 5.3 shows the percentages of different sectors applied to relative land use (StatisticCanada, 2012).

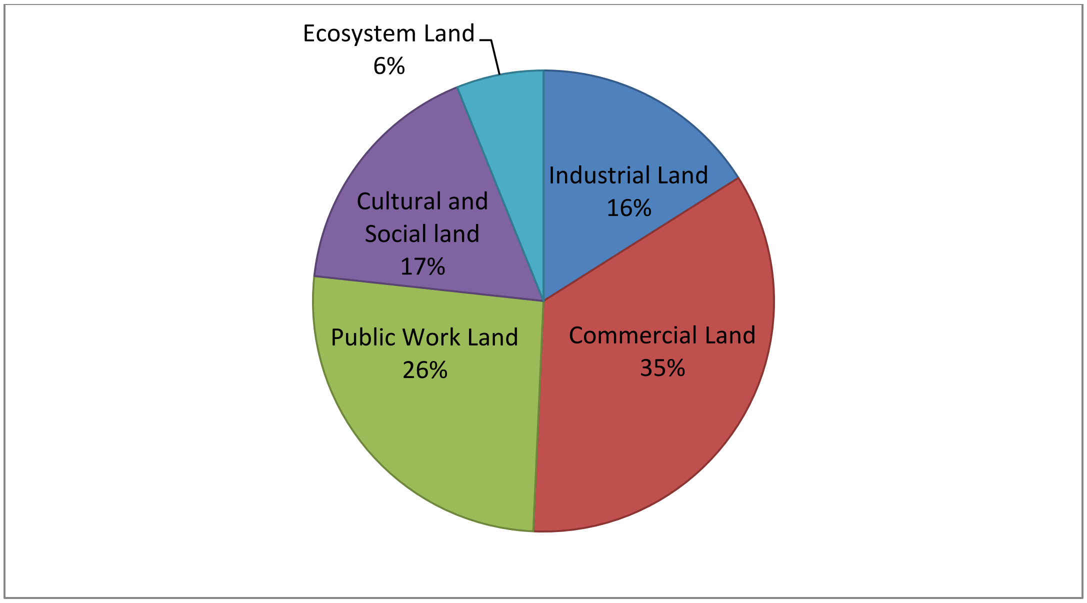

Figure 5. 3: GDP portions of Prince Edward Island, Charlottetown **(Canada, 2012)**

After adjustment, the amount of each land sector is calculated as the percentages of the total land of Charlottetown. The initial land use breakdown for all components for Charlottetown is summarized in Table 5.1. The first and second columns of Table 5.1 are production data units and their GDP based on latest available (2012) statistics (Canada, 2012). The third column of Table 5.1 is the percentage of each production unit. And finally, the last column is the proportion of land devoted to each sector of total Charlottetown land (not including residential area) reported as approximately 7729 Acres (Charlotettown, 2013).

Table 5. 1: Land area calculation

Industry 2012	**GDP components for P.E.I. ($million)**	**GDP proportions in %**	**Land-Use Portion (Acres)**
Industrial Production	725.5	16.034	1239
Commercial Services	1568.8	34.67	2680
Public Services	1177.3	26.02	2011
Cultural and social Services	776.5	17.16	1326
Ecosystem Services	276.5	6.11	472
Total	4524.6	1	7729

- **Residential Area**

The residential area is allocated according to the residential zone by law (Charlottetown zoning by-law, 2013). The method is an approximation of the Sum Product of the population and different residential zone. The result of the calculation is about 3,225 acres (Charlottetown zoning by-law, 2013) (Statistics Canada, 2013). Table 5.2 shows the result of the calculation.

Table 5. 2: Residential area calculation

Subpopulations		Low Residential Zone by Law (Sq.ft)		SumProduct (Population* Residential zone) (Millions Sq.ft)
Total Families	9120	Duplex dwelling	~8000	72.96
Married Couples	6085	Semi detach dwelling	~5980	36.38
Common-law Couples	1155	Apartment dwelling	~4995	5.77
Lone parents	1885	Single detach dwelling	~7900	14.89
Total	**18245**		**26875**	**130**

5.3. Goods and Services Sector

The Goods and Services Sector of the SD model articulates components of the economy, as (1) Commercial Services, (2) Industrial Production and (3) Public Services. The definition of these services have been created by aggregating Statistics Canada Provincial GDP by NAICS (Statistics Canada, 2012) components into the aggregates that are defined above. The aggregates include:

1) Commercial Services - Wholesale trade, Retail trade, Transportation and Warehousing, Finance and Insurance, Real Estate and Rental and Leasing, Professional and, Scientific and Technical services, and Management of Companies and Enterprises.
2) Industrial Services - Mining, Oil and Gas Extraction, Utilities, Construction, Manufacturing.
3) Public Services - Waste Management and Remediation Services, Public Administration, Education Services, and Other Services.

Figure 5.4 shows the STELLA SD model for the Goods and Services sector.

The service components identified above are represented in the System Dynamics model as Cobb-Douglas production functions. The same process is applied to the Cultural and Social sector for Cultural & Social service and Ecosystem services.

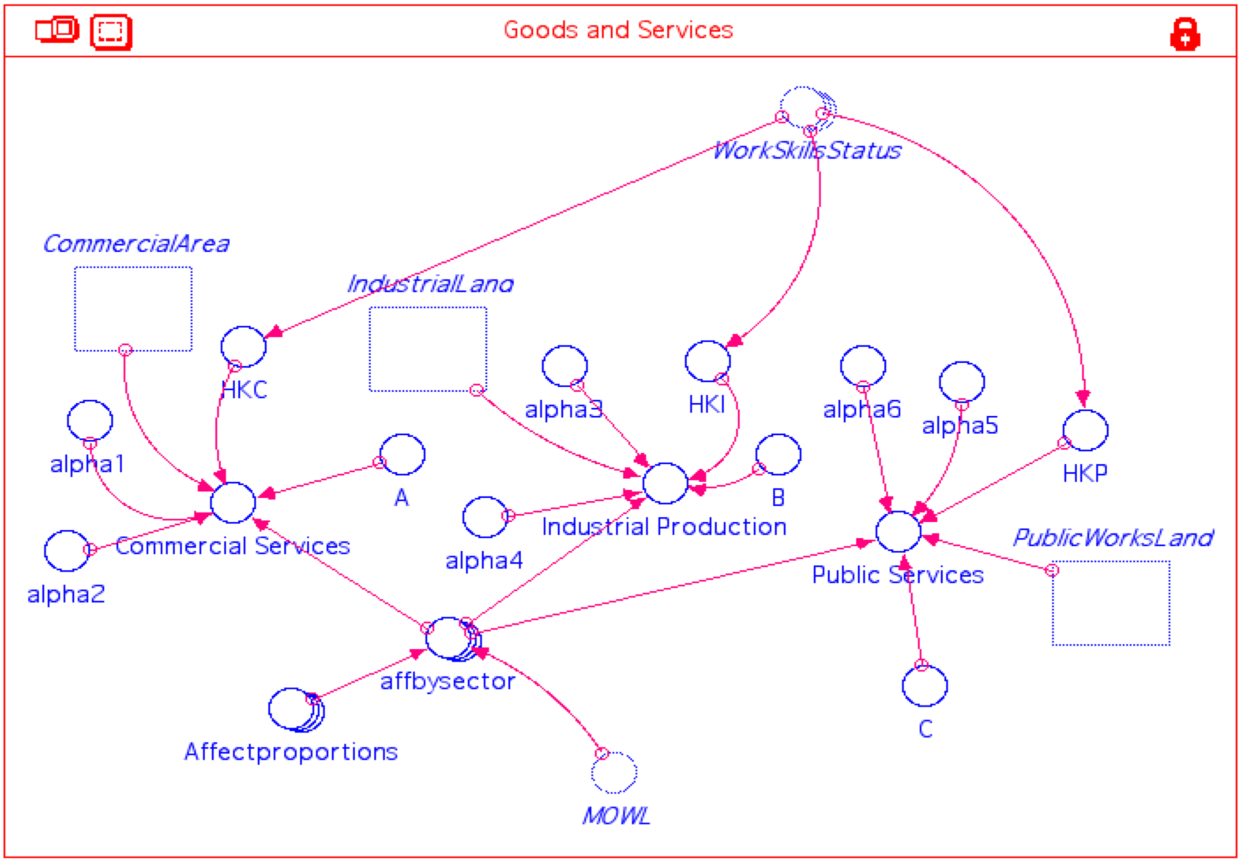

Figure 5. 4: Goods and Services Capital

As an example, the determination of annual Industrial Production is given by:

$$Industrial\_Production \ = \quad 5.8$$

$$B \times \left(Industrial\_land \times (1 - affbysector[Industrial]/\exp(5))\right)^{\alpha 3} \times HKI^{\alpha 4} \quad 5.9$$

$$affbysector[Industrial] \ = \ exp(MOWL) \times Affectproportions[Industrial] \quad 5.10$$

$$affectproportions[Industrial] \ = \ 0.1 \quad 5.11$$

where

$$alpha3 + alpha4 \ = 1 \quad 5.12$$

Where HKI is the trade's labor force for industrial production and exp (5) is exponential function of the maximum possible water level (5meters) that can occur.

5.4. Cultural and Social Sector

The next component of the four-pillar SD model consists of the Cultural and Social sector. This section describes (1) Cultural and Social services, (2) Ecosystem services, and (3) Social Mapping annual production (SocMapProd). The definition of these services has been created by aggregating Statistics Canada Provincial GDP by NAICS (North American Industry Classification System) components into the aggregates as defined below (StatisticCanada, 2012).

The composition of the component aggregates are given as:

1) Cultural and Social Services: Health Care and Social Assistance, Arts & Entertainment, Recreation and Information, Cultural Industries, Accommodation and Food Services.
2) Ecosystem Services: Agriculture, Forestry, Fishing, Trapping and Hunting
3) Social Mapping: Social Networking, Wellbeing, and Collaboration indicators as a function of the population and its age distribution, the numbers of healthy members, and the event of severe storms that trigger community action.

The service components identified above are represented in the System Dynamics model as Cobb-Douglas production functions. The Cobb–Douglas production function is a particular functional form of a production function, widely used to represent the technological relationship between the amounts of two or more inputs, particularly physical capital and labor, and the amount of output that can be produced by those inputs (Boumans, et al., 2002). Its most standard form, the production of a single good with two input factors of production, capital and labor, is given as:

$$Y = AL^{\beta}K^{\alpha} \qquad 5.13$$

where:

- Y = total production (the real dollar value of all goods produced in a year);
- L = Labor input (the total number of person-hours worked in a year);

- K = Capital input (the real value of all machinery, equipment, and buildings in the sector);
- A = Total Productivity scale factor;
- α and β are the elasticity of capital and labor, respectively. These values are constants determined by available technology; and,
- Further, for α + β = 1, (α and β>0) the production function has constant returns to scale, meaning that doubling the usage of capital K and labor L will also double output Y.

This sector is modeled in the system dynamics model as shown in Figure 5.5.

The land capital input is the stock of $Cult\&Social\_Land$ calculated in the $Land\_UseSector$. This land is reduced by a ratio of the observed storm level by sector ($affbysector$ [$SocialCult$]) to maximum total storm level. The exponential function of the maximum storm level is used to reflect a nonlinear relationship of the storm impact with higher water levels.

$$\text{Cult\&Soc\_Services} = \quad 5.14$$

$$D \times Young^{\alpha 11} \times Middle^{\alpha 12} \times Old^{\alpha 13} \times \left(Cult\&Social\_land \times (1 - affbysector[SocialCult]/\exp(5))\right)^{\alpha 14} \quad 5.15$$

$$affbysector[SocialCult] = exp(MOWL) \times Affectproportions[SocialCult] \quad 5.16$$

$$affectproportions[SocialCult] = 0.1 \quad 5.17$$

where

$$alpha11 + alpha12 + alpha13 = 1 \quad 5.18$$

reflecting constant returns to scale of each capital input (D is scalar).

It should be noted that the capital input stocks of *Young*, *Middle*, *Old* and *Cult&Social_Land* are dynamically linked to their *Human* and *Land_Use sectors*.

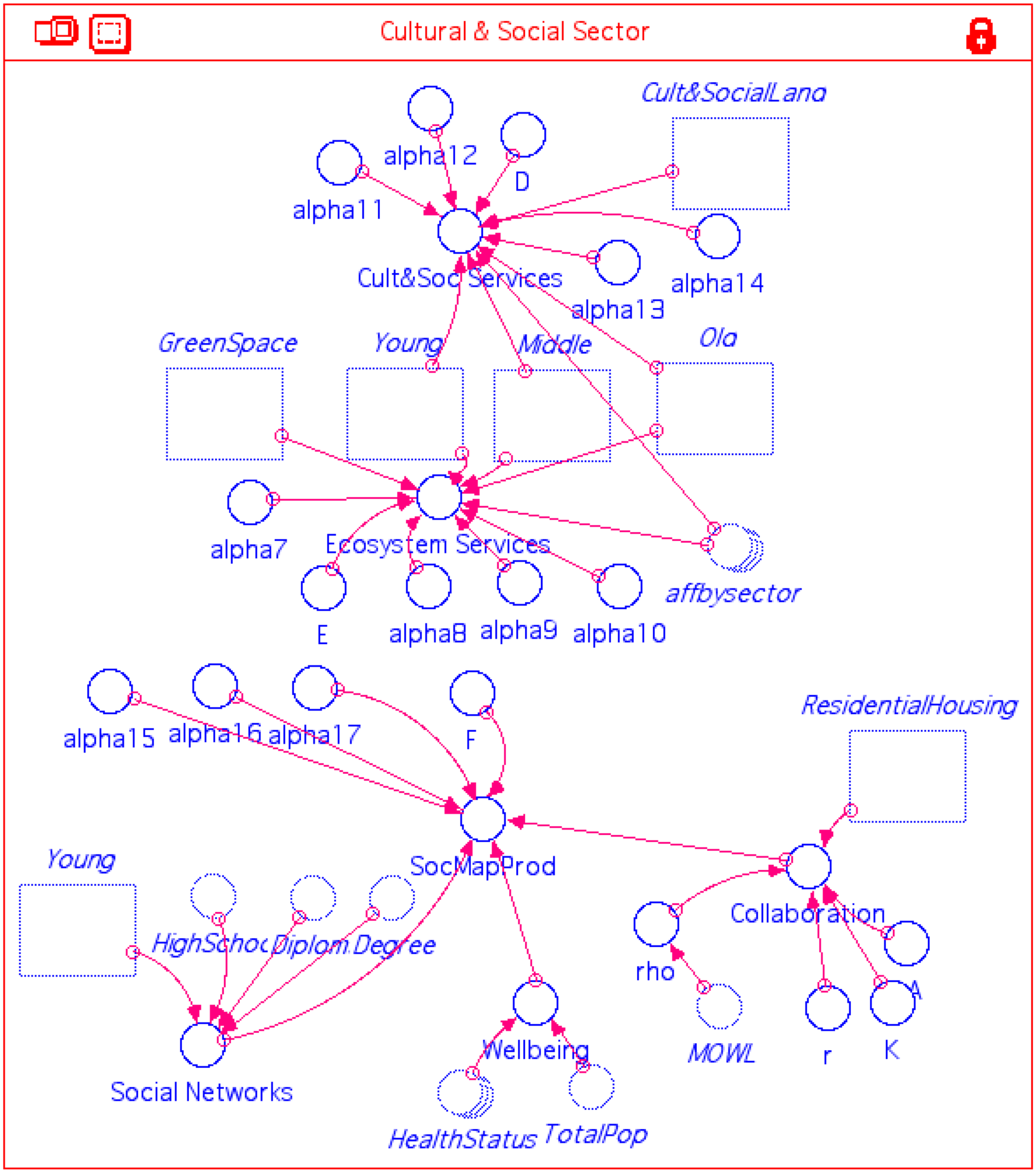

Figure 5. 5: Cultural and Social capital

The generic storm impact process on the calculation of services is also reflected in Ecosystem Services. However, the component of Cultural and Social Sector, which we call

Social Mapping Production, is treated differently. Social Mapping consists of three components called Social Networks, Wellbeing and Collaboration. For these components more difficult to quantify, indices are determined as a function of weighted human capital attributes. For example, Wellbeing is considered a function of the health of the population weighted by the different age groups. The weighting of the index is inspired by the estimation of the mean of a beta distribution. This weighting is of the form:

$$\text{Mean} = (a+4m+b)/6 \quad 5.19$$

where

a = minimum value

b = maximum value and

m = mode of the continuous variable distribution.

Hence,

$$Wellbeing = .08 \times (HealthStatus[Young, Healthy] + 4 \times HealthStatus[Middle, Healthy] + HealthStatusStatu[Old, Healthy])/(TotalPop \times 6) \quad 5.20$$

Similarly the index for *Social_Networks* is a weighted function of different education levels in the population. The index is,

$$Social\_Networks = 3(Young + 3HighSchool + 3Diploma + 4Degree)/(11(Young + HighSchool + Diploma + Degree)) \quad 5.21$$

Higher weights for social networking are given to those with more education. The scaling factors 0.08 in wellbeing and 3 in social network equations reflect their relative contributions.

Finally, the index of *Collaboration* is inspired by the logistic growth function,

$$dx/dt = F(x) = rx(1 - x/K) \quad 5.22$$

which was first used as a population growth model by (Verhulst, 1838). Using *Residential Housing* as the state variable x, then the equation for *Collaboration* is estimated as:

$$Collaboration = rho \times AA \times r \times ResidentialHousing \times (1 - ResidentialHousing/K) \qquad 5.23$$

where *K* is the carrying capacity (maximum limit) with respect to collaborative activity, i.e., *Collaboration = 0* when *Residential Housing= 0*, and reaches a maximum value of *K*. Collaboration rises to a maximum level and at this tipping point declines to 0 as *Residential Housing* increases to its carrying capacity.

The factor *rho* is set as a step function to reflect the fact that as the storm level severity increases there will be a factor increase in *Collaboration*. We implement this idea by setting *rho* accordingly:

$$rho = if(MOWL < 2)\, THEN\, (1)\, else\, (if((MOWL) < 4\, AND\, (MOWL) >= 2)\, THEN(2)\, else(3)) \qquad 5.24$$

In summary, this chapter has shown the building model of four pillars of Land-Use, Human Capital, Social-Cultural Capital and Goods-Services Capital for the City of Charlottetown.

The next chapter presents the Base Case scenario and the inputs and outputs for the SD model with respect to the established Base Case scenario as defined below.

6. System Dynamics Model Base Case

This chapter describes the details of inputs and outputs for the defined benchmark "Base Case" scenario for the system dynamics model presented in Chapter 5. The Base Case scenario presents the key inputs and outputs for the four sectors of the system dynamics model (sections 6.1 to 6.4 below) for Charlottetown. Determining these key components of the Base Case prepares for the inclusion of the exogenous storm effects as uncontrollable variables in the model and described in section 6.6 of this chapter. The key Base Case inputs also lead to the development of the adaptation strategies, while the key Base Case outputs are used to summarize and compare the results of alternative model scenarios for the alternative adaptation strategies and storms. The presentation and analysis of SD model scenarios (including adaptation strategies and simulated storms events) are found in Chapter 7.

The Base Case scenario assumes that there are no severe storms of consequence that occur in Charlottetown over the planning horizon fixed at 50 years and assumed to begin in 2011. Therefore, the Base Case scenario, also called the Status Quo scenario, describes the case for Charlottetown evolving independent of severe storms effects and without any community adaptation over the 50 years of the planning period. The purpose of this chapter is to: (i) validate and verify model assumptions; (ii) identify and explain model sensitivities and key model parameters; and (iii) prepare for the analysis of storms and adaptation strategy scenarios towards determining an effective climate action plans for Charlottetown (as presented in Chapter 7).

Chapter 6 is divided into six sections. The first four sections presents the key model inputs and outputs for the Base Case scenario for each of the SD model sectors: (6.1) Human sector; (6.2) Land use sector; (6.3) Cultural and social Services sector; and (6.4) Goods and Services Sector. Section 6.5 presents the summary of the Base Case scenario key inputs and outputs. Finally, Section 6.6 presents the identified controllable and uncontrollable (storm model) variables.

6.1. Human Sector Base Case Inputs and Outputs

The purpose of the human sector is to describe the Charlottetown community demographics including the characteristics and attributes of the population. There are three age classes: Young (ages 0-14), Middle (ages 15-65), and Old (ages 65+). The population models: (i) births (via a annual fixed birth rate applied to the Middle subpopulation group) as annual inputs to the Young age group, (ii) an annual death rate applied to the Old age group, and (iii) annual immigration and emigration rates applicable to the Middle subpopulation age group. Transitions from Young to Middle and Middle to Old age groups are made annually assuming an approximately equal representation by age within each group, e.g., one-fifteenth of the Young population shifts into the Middle population annually. The key population input parameters are determined from recent Charlottetown population data (Statistics Canada, 2013). Base Case scenario population input parameter rates are provided below in Table 6.1 and are also presented in Appendix D - STELLA Model Equations.

Table 6. 1: Base Case Scenario Charlottetown Population Demographic Input Parameters

Population Input Parameter	Annual Birth	Annual Immigration	Annual Emigration	Annual Death
Rate	2%	2%	1.8%	3%

Each age group is classified by its attributes for: (i) health condition, (ii) education status, and (iii) work skill status represented by simple percentages (based on the most recent (2012) national household survey profile with data pertaining to 2011) assigned to each attribute category. The Human or population sector is the main driver of all other sectors of the model.

6.1.1 Base Case Population Attribute Inputs for the Human Sector

The values of Tables 6.2 (Age groups, Health, and Education) and 6.3 (Work Skills) provide the best estimate of population attribute categories based on Cansim data for Charlottetown from Statistics Canada (2013). The initial value of the City of Charlottetown urban population is 34,565 residents (Statistics Canada, 2013).

Table 6. 2: base Case Initial population, Health, and Education Status Input parameters

Age	Population	Health Status (ratio)		Education Status (ratio)		
	Initial Value	Healthy	Unhealthy	High School	Diploma	Degree
Young	4830	.9	.1	.0	.0	.0
Middle	23720	.8	.2	.32	.36	.32
Old	6015	.7	.3	.21	.33	.46
Total	34565 (2012)					

The population is aggregated according to alternative educational status, i.e., High School, College Diploma and University Degree among Charlottetown residents (Table 6.3), and then split by propensity for works skills, i.e., Service, Trade, and Professional work skills, using the data presented in Table 6.3 obtained from an estimation of the Charlottetown population Canada (Statistics Canada, 2013).

Table 6. 3: Base Case Scenario Work Skill Parameters

	Work Skill Categories (ratio)		
Education Status	**Service**	**Trade**	**Professional**
High School	0	1	0
Diploma	.25	.75	0
Degree	.2	.2	.6

6.1.2 Base Case Population Attribute Outputs for the Human Sector

Table 6.4 presents the key output results for the Human Sector of the SD model for the initial population values beginning at the start time of zero (based on year 2011) and ending time of the planning period after 50 years or to 2061. All the value-based units of Table 6.4 are in numbers of City of Charlottetown residents.

Table 6. 4: Base Case Population Attribute Outputs (in numbers of Charlottetown residents) for the Human Sector

	Population				Health Status		Education Status			Work Skill Status (sum)		
	Young	Middle	Old	Total Pop	Healthy	Un-Healthy	High School	Diploma	Degree	Service	Trade	Professional
T=0	4830	23720	6015	34565	27533	7031	8853	10524	10357	4700	21440	6210
T=50	7060	24290	13400	44765	35179	9500	10588	13168	13939	6060	26465	8334

Figure 6.1 shows the STELLA graph for the Young, Middle, Old, and total population Base Case scenario over the 50-planning horizon. The Young and Middle age groups (curve numbers 1 and 2 of Figure 6.1) increase slightly over the 50 years of the planning horizon. The Old population (curve number 3 of Figure 6.1) more than doubles in size over the 50 years indicating the current trend in the progressively aging population of Charlottetown. Total population of urban Charlottetown (graph number 4 of Figure 6.1) increases slightly over the 50-year period from 34,565 (2011) to 44,765 projected for 2061.

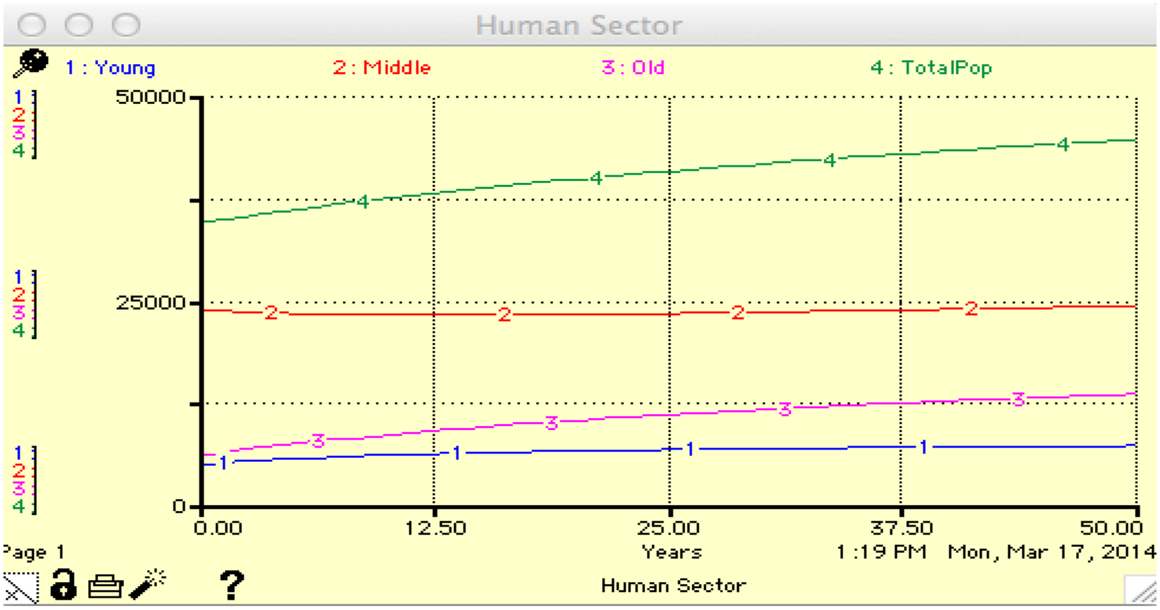

Figure 6. 1: STELLA Base Case Scenario Human Sector Summary Outputs over the Planning Horizon **(STELLA®, 2012)**

6.2. Land Use Sector Base Case Inputs and Outputs

The Land Use sector Base Case scenario of the SD for Charlottetown is divided into two subsections. The first subsection presents the input and output tables for the Commercial Area and the Residential Area components of Land Use. The second subsection presents the input and output tables for the alternate land uses.

6.2.1 Commercial and Residential area Input

The inputs for the Commercial and Residential areas consist of the net-flow of population into and out of the Middle and Old age groups. Charlottetown residential houses are occupied by either the Middle or the Old population age groups. The occupation of household housing units changes as people age from Young to Middle and Middle to Old people. For example, young couples are, on average, in need of a bigger house when they have children, whereas elderly people on average have reduced housing needs. Also, Commercial Area changes as the population ages. Table 6.5 presents a generic form of the input and output for Commercial and Residential areas.

Table 6. 5: Base Case Scenario Land Use Sector Summary Inputs and Annual Outputs for Residential and Commercial Areas

Residential & Commercial Inputs	Residential & Commercial Outputs
Net Flows: Young to Middle (persons) Middle to Old (persons)	Residential Housing units Residential Area (acres) Commercial Area (acres)
Ratios: # Residential Houses per Middle aged person # Residential Houses per Old aged person # Commercial acres per Middle aged person # Commercial acres per Old aged person	

6.2.2 Commercial and Residential Output

Table 6.6 presents the key outputs for the Commercial and the Residential Areas for the Land Use Sector of the SD model for the initial values and end values. This output for Commercial Area and Residential area are measured in acres.

Table 6. 6: Base Case Scenario Residential and Commercial Summary Outputs for Beginning (T=0), and Ending (T=50) Years of the Planning Horizon

	Residential Housing (numbers)	Residential Area (Acres)	Commercial Area (Acres)
T=0	15000	3225	2680
T=50	15600	3500	3100

Table 6.6 highlights the fact that Residential and Commercial Areas are a function of the City of Charlottetown population and that as the population moves toward the end of the 50-year planning horizon, it is aging. Therefore, and despite the fact that the modeled total population is increasing, the overall need for housing units is only increased slightly.

Figure 6.2 shows the graph for residential area and commercial area Base Case scenario over the 50-year planning horizon. The curves are for residential Area and Commercial Area (curve number 1 and 2 of Figure 6.2) increase slightly by 275 acres and 420 acres respectively over the 50 years of the planning horizon.

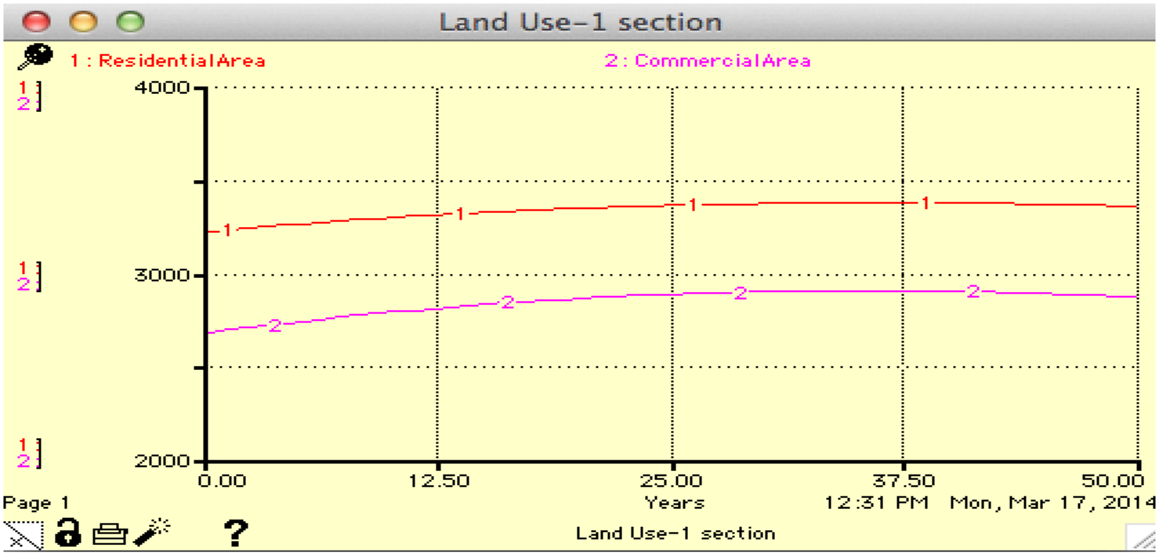

Figure 6. 2: STELLA Base Case Scenario sub-Land use Sector Summary Outputs over the Planning Horizon **(STELLA®, 2012)**

6.2.3 Alternative Land Use Input

Table 6.7 shows a generic form for the input and output for the model Base Case scenario alternative land use sector. Alternative land use refers to the definition of designated Charlottetown land use for: (i) Green Space, (ii) Industrial land, (iii) Cultural & Social land, and (iv) Public Works land. Annual updates to these alternative land use values are made by adjusting total land for Commercial and Residential Areas land use based on the changing population (section 6.2.2 above). Alternative land uses are then scaled based on their initial (2011) use proportionate values to maintain their same relative proportions throughout the forecast.

As an example, assume Residential and Commercial Areas change from 20% to 25% of the total area of City of Charlottetown set at 10954 acres (Charlotettown, 2013). If Green Space accounted initially for 10% of the remaining 80% of the initial land use (or 8%), then under the population shift change of the Residential and Commercial Areas (to 25%), the Green Space is adjusted so that it retains its 10% share of the remaining and lower total alternative land use share of 75% (or 7.5%). This proportionate shift applies to all initial values of the four alternative land use categories. Table 6.7 presents the key inputs and outputs for the alternative land use categories.

Table 6. 7: Base Case Scenario Alternative Land Use Summary Inputs and Annual Outputs

Alternative Land Use Inputs	Alternative Land Use Outputs
Total Land (acres)	Alternative Land Use Categories: Green Space, Industrial, Cultural & Social, Public Works (acres)
Residential Area (acres)	
Commercial Area (acres)	
Initial Alternative Land Use Categories: Green Space, Industrial, Cultural & Social, Public Works (acres)	

6.2.4 Alternative Land Use Output

Table 6.8 presents the outputs for the Base Case scenario results of the SD model for Charlottetown alternative land use. The initial value at time zero corresponds to the estimate of the designated alternative land use categories according to the GDP components (Table 5.1). Table 6.8 also provides the estimated alternate land use values for the end year of 2061 in the 50-year planning horizon. All data in Table 6.8 are in acres.

Table 6. 8: Base Case Scenario Alternative Land Use Summary Outputs for Beginning (T=0), and Ending (T=50) Years of the Planning Horizon

	Alternate Land Area (in Acres)			
	Green Space	**Industrial**	**Public Works**	**Cultural & social**
T=0	472	1239	2011	1326
T=50	406	1067	1732	1142

Figure 6.3 shows the stable trend of the dynamics of different Charlottetown land uses during the planning period of 50 years. While the Residential and Commercial land uses rise slightly, as can be seen in Figure 6.2 (because of population shifts), all the other land uses decrease slightly. Industrial land and Cultural & Social land (curve numbers 4 and 2 of Figure 6.3) decreased by 172 and 184 acres over the horizon, followed by a decrease of 279 acres (graph number 1 of Figure 6.3) and 66 acres (graph number 3 of Figure 6.3) of Public Works land and Green Space respectively. These decreases are attributed to the overall aging population of the City of Charlottetown.

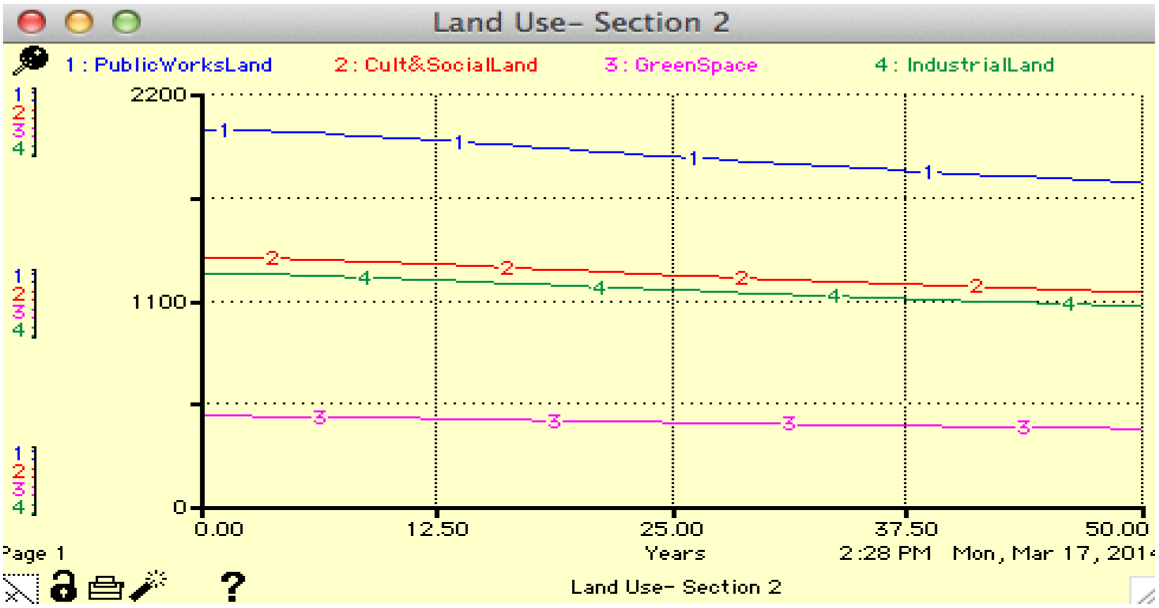

Figure 6. 3: STELLA Base Case Scenario Alternate Land Use Sector Summary Outputs over the Planning Horizon **(STELLA®, 2012)**

6.3. Cultural and Social Sector Base Case Inputs and Outputs

The Cultural and Social Sector of the SD model for the City of Charlottetown consists of three services: (i) Cultural and Social services (Cult&SocServices); (ii) Ecosystem Services; and (iii) Social Mapping (SocMapProd). The Base Case scenario values for these services are discussed in the subsections below.

6.3.1 Cultural and Social Services and Ecosystem Services Inputs

Table 6.9 shows the key inputs and outputs for the Cultural and Social sector in the SD model including the Cultural and Social Services and Ecosystem Services Inputs. These services share a similar input structure. The Cultural and Social and Ecosystem services are determined through a Cobb-Douglas production function of the form: $Y = AL^{\beta}K^{\alpha}$, where Y denotes total production. A denotes the total productivity scale factor and L represents labor or wage services inputs, and K represents the capital land use proxy.

The cultural and social, and ecosystem services output are annual value-based outputs. Table 6.9 presents the key inputs and key outputs of the Cultural & Social Sector services.

Table 6. 9: Base Case Scenario Cultural & Social and Ecosystem Services Summary Inputs and Outputs

Cultural & Social Services and Ecosystem Services	
Inputs	**Outputs**
Land Capital: Cultural & Social Land + Green Space Land (acres) Human Capital: Young, Middle, Old and Work Skills (population numbers) Labor Exponent $\alpha_L = \alpha_{11,}\alpha_{12,}\alpha_{13,}$ for each Population age group (parameter) Land Capital Exponent α_K=α_{14} Production Scale factor=D ($/labor*acres*year) (parameter)	Cultural & Social Service ($/year) Ecosystem Services ($/year)

6.3.2 Social Mapping Inputs

The inputs for the Social Mapping productivity of the City of Charlottetown include: (i) the strength of the City's social networks; (ii) the extent of social wellbeing; (iii) social collaboration measures; (iv) social labor, i.e. labor used as input in the social cultural sector; (v) social capital, i.e. acres used as input in the social cultural sector; and (vi) the scalar applied to the Cobb-Douglas production function. The strength of social networks deals primarily with the Young and Middle age groups of the population and their contributing education breakdown (high school, diploma, and degree). Social wellbeing is a function of the total population of Charlottetown, and the City's population health status. Collaboration is related to the numbers of residential housing units. Table 6.10 summarizes the key inputs and outputs for the Social Mapping sector of the SD model for Charlottetown. As before, the Cobb-Douglas production is a function with the three elasticity exponents summing to one; $\sum_{i=1}^{3} \alpha_i = 1$.

Table 6. 10: Base Case Scenario Social Mapping Production Summary Inputs and Outputs

Social Mapping Inputs	**Social Mapping Output**
Social networks Wellbeing Collaboration Labor $\alpha_L = \alpha_{15,}\alpha_{16,}\alpha_{17}$ (parameter) Scalar= F ($/labor*acres*year)(parameter)	SocMapProd Service ($/year)

6.3.3 Cultural and social Sector Outputs

Table 6.11 presents the outputs for the Base Case scenario results of the SD model for the Charlottetown Cultural and Social sector including the three component services: (i) Ecosystem Services, (ii) Cult&SocServices, and (iii) SocMapProduction The initial value for these services are derived from the Statistics Canada Table 379-0030 (Canada, 2012) with starting at time zero (2011) and ending at time 2061 after 50 years. The outputs of Table 6.11 are in dollars per year.

Table 6. 11: Base Case Scenario Cultural & Social Sector Summary Outputs for Beginning (T=0), and Ending (T=50) Years of the Planning Horizon

	Ecosystem Service ($M/year)	Cultural & social Service ($M/year)	Social Mapping Production (dimensionless)
T=0	169	1429	0.19
T=50	220	1860	0.18

Figure 6.4 shows the services of the Cultural and Social sector of the SD model for Charlottetown under the Base Case scenario. Cultural & Social services and Ecosystem services grew by $431 and $51 (all in millions of 2007 constant dollars) respectively over a period of 50 years. However, the Social Mapping production decreased since the impact of the slight increase in the Youth population age group (Figure 6.1) affects negatively Charlottetown social mapping as indicative of an aging community.

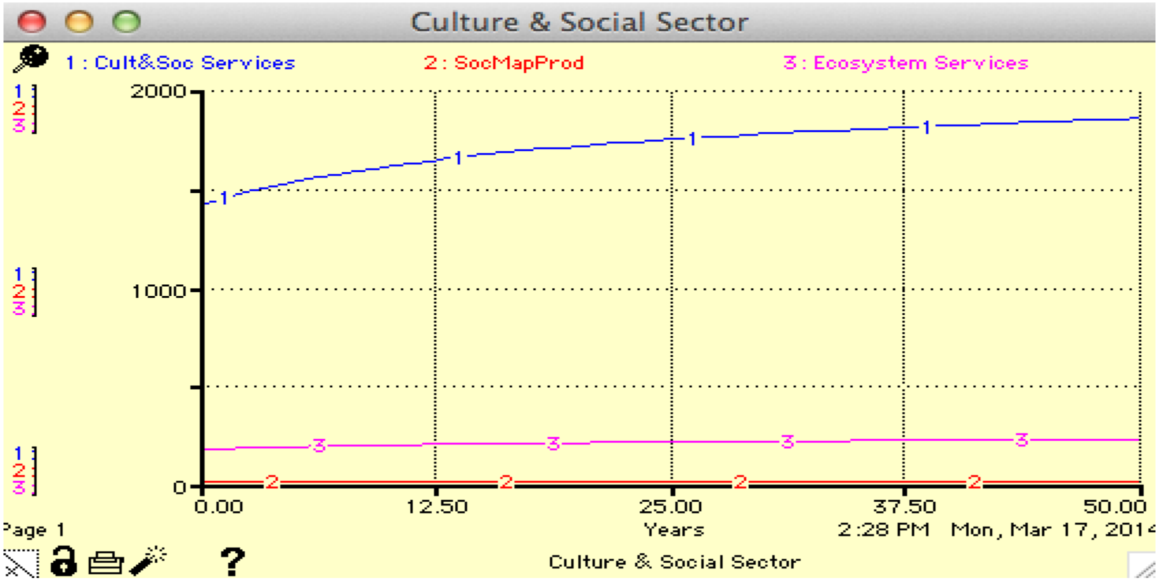

Figure 6. 4: STELLA Base Case Scenario Cultural and Social Sector Summary Outputs over the Planning Horizon **(STELLA®, 2012)**

6.4. Goods and Services Sector Base Case Inputs and Outputs

The general concept of the SD model Goods and Service sector is shown in Table 6.12 and illustrated by an example for Commercial services. There are three components to the City of Charlottetown Goods and Services sector: (i) Industrial production; (ii) Commercial services; and (iii) Public services. These annual statistics are measured in millions of dollars per year. Their key inputs and outputs are presented in Table 6.12. The inputs for each productive service are: (1) the land area (capital proxy) specified for the service; (2) the attributed labor to the service; (3) elasticities of capital and labor in the Cobb-Douglas production function, α_L and α_k (with sum of 1); and (4) a scalar A, total factor productivity. All these inputs are used to generate the outputs of total Charlottetown production including commercial services, industrial production, or public services.

Table 6. 12: Base Case Scenario Goods and Services Production Summary Inputs and Outputs

Goods and Services: Industrial, Commercial, and Public Works	
Inputs	**Outputs**
Land Capital (Commercial Land, Industrial Land, Public Works Land) Human Capital (Work Skills population attributes) Capital Exponent $\alpha_k = \alpha_2$(parameters) Labor Exponent α_L=α_1, (parameter) Scalar=A ($/labor*acres*year) (parameter)	Services ($/unit): Commercial Services Industrial Production Public Services

Table 6.13 shows the main components for each output sector. As can be seen in Table 6.13, manpower according to skills is matched to corresponding types of sectors. For example, for Commercial services, people with Work Skills in Service are the labor inputs to Commercial services. People who are skilled in the Trades are matched with industrial production. Manpower with Professional work skills is assigned to Public services.

Table 6. 13: Capital and Labor Attributes to the Goods and Services Sector

	Capital Land (Acres)	**Human Capital (#labor)**
Commercial Services	Commercial Land	Service
Industrial Production	Industrial Land	Trade
Public Services	Public Works Land	Professional

6.4.1 Output for Goods and Services Sector

Table 6.14 presents the output for the SD model for Charlottetown Goods and Services Sector for the Base Case scenario including the outputs for the three components of Commercial Services, Industrial Production, and Public Services. Table 6.14 shows the initial value (2011), and ending value. The output of each component is measured in million dollars per year ($M 2007/year). These results are calibrated to the initial year using the Statistics Canada data (Canada, 2012).

Table 6. 14: Base Case Scenario Goods and Services Sector Summary Outputs for Beginning (T=0), and Ending (T=50) Years of the Planning Horizon

	Commercial Services ($M/year)	**Industrial Production ($M/year)**	**Public Services ($M/year)**
T=0	3016	876	2155
T=50	3688	903	2316

Figure 6.5 represents existing services in goods and services sector of the model. All services increase over the 50-year planning horizon. Commercial services rise by $672 million per year and Industrial Production and Public services increased by $27, and $161 million per year all in 2007 dollars respectively.

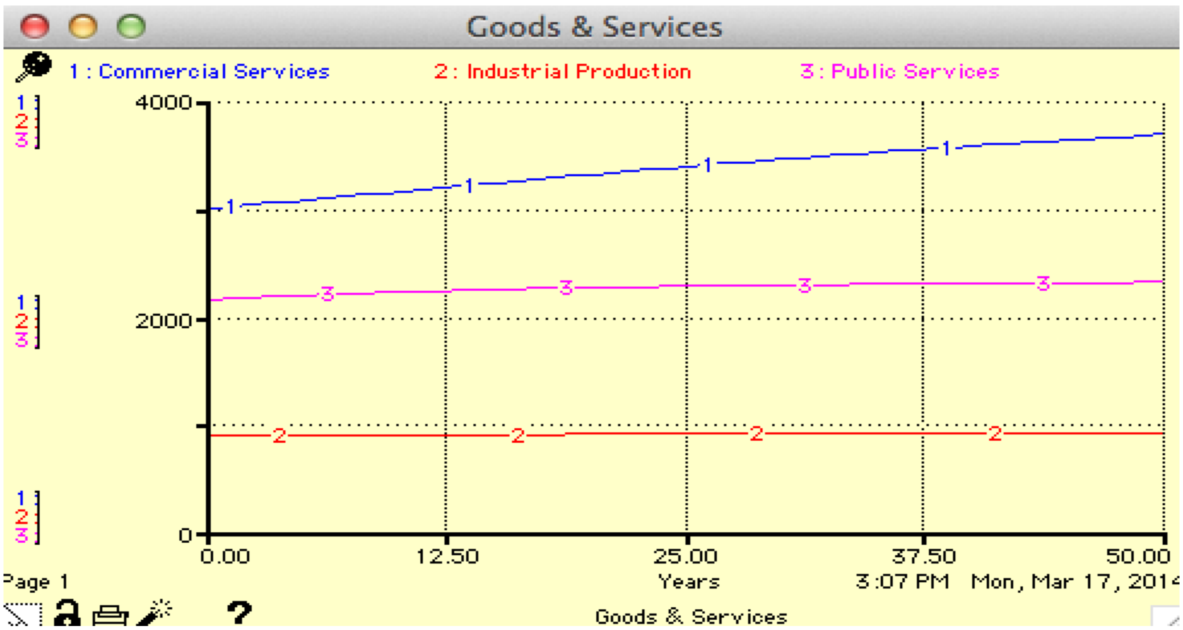

Figure 6. 5: STELLA Base Case Scenario Goods and Services Sector Summary Outputs over the Planning Horizon **(STELLA®, 2012)**

6.5. Summary of Models Sector Inputs and Outputs

In this chapter the Base Case scenario for the SD model, i.e. the scenario without storms, is described representing sector inputs, outputs and Cobb-Douglas parameter values for the four sectors: Human, Land Use sector, Cultural and Social, and Goods and Services. Given the breadth of the model and the extensive model inputs and outputs, a decision is taken to select a reduced set of key inputs and outputs in order to: (i) define the inputs to be used in developing adaptation strategies; and (ii) describe a set of outputs for ease of outcomes comparison among adaptive strategies to rising maximum water levels. Key inputs (and/or parameters) and outputs of the model are shown in Table 6.15.

Table 6. 15: Key Model Inputs and Outputs

Sectors		Key Input /parameters	Key Output key
1	Human	Birth rate Death rate Immigration rate Emigration rate	Young Middle Old High school Diploma Degree Service Trade Professional
2	Land Use	Ratio of acres per Middle subpopulation Ratio of acres per Old subpopulation	Commercial Area Residential Area Green Space land Industrial land Public Works land Cultural and social land
3	Cultural & Social	Scalar (parameter) Elasticity (parameter)	Cultural and social service Ecosystem services Social mapping production
4	Goods & Services	Scalar (parameter) Elasticity (parameter)	Commercial Services Public services Industrial Production

6.6. Controllable and Uncontrollable Variables

There are two major types of variables that need to be defined in the SD model before the simulation design and analysis can be developed. These variables are the controllable variables and uncontrollable variables. These variables all have a significant impact on the outcome of the simulations and on the damages resulting from severe storms including flooding from MOWL.

Controllable variables are variables that may be manipulated to define adaptation strategies to mitigate the impact of MOWL. The controllable variables are selected from the key input variables referred to above in Table 6.15, including key variable parameters.

For the SD model, uncontrollable variables are random variables that cannot be controlled. Uncontrollable variables are defined broadly as annual storm events. These storm events bring potential damage to Charlottetown. In the model, uncontrollable storm events are modeled as (MOWL) in the City of Charlottetown.

Storms within the SD model affect the Land Use sector. Total land is viewed as the sum of *Affected land* (by the storms), and *Unaffected land*. These two components interact by considering the storm as represented by the maximum observed water level. *Affected lands* by storms are determined by using the simulated annual MOWL random variable. The MOWL historical data is fitted in Chapter 4 with a Gumbel Max probability distribution function with two parameters of $\alpha = 2.99$ and $\beta = 0.3$ as location and scale parameters respectively. The "No Name 2000" January 21,2000 storm is regarded as Charlottetown's most severe storm with a record maximum observed water level of 4.23 meters above chart datum (Parkes, 2006), (Henstra, 2009). The total damage from this storm was estimated at $29.60 millions in 2010 dollars (Hartt, Master's Thesis, 2011). Another example of Charlottetown's storm was "Juan" September 29, 2003 with a maximum observed water level of 2.927 meters above chart datum and an estimated $10.1 million damage in 2010 dollars (Hartt, Master's Thesis, 2011).

Considering how MOWL affect different sectors such as Land Use sector, and Goods and Services sector, etc., the land area affected is crucial as it affects other sectors such as goods and services, or cultural and social services. Since land use is an input to the Cobb-Douglas functions of Goods and Services and Cultural and Social sectors, it has an impact on the production of the services. As an example, if total land area were 1000 acres of which total affected areas were 100 acres, then if green space land were 200 acres of the total land area before the storm, then (200/1000)*900=180 acres of total land area would remain as green space land after the storm. Thus, other sectors of the model such as cultural and social, and goods and services sector, are similar to the land sector, since the latter sectors have land as a component. Therefore it would have an affect on the production unit of each service.

Chapter 6 described the inputs, parameters, and outputs for the defined "Base Case" scenario, i.e. for the no storm scenario, in order to identify its variables and parameters and estimate the latter. Next, one introduces controllable variables to evaluate adaptation strategies while uncontrollable variables characterize alternative storm scenarios. The design and analysis of SD model scenarios involving adaptation strategies and simulated storms events are found in next Chapter.

7. The Analysis of System Dynamics Model Scenarios

Chapter 7 presents the analysis of System Dynamics model scenarios, which incorporate the adaptation strategy alternatives against the simulated storm events and their impacts. The purpose of this analysis is to examine the performance of the adaptation strategies in order to consider a preferred strategy and a strategy ranking for Charlottetown. The chapter is divided into subsections that present: (7.1) definition of the model scenarios (including the adaptation strategies for evaluation, and simulated storm events); (7.2) scenario model analyses; (7.3) comparative analysis and evaluation of adaptation strategies; and (7.4) summary of results.

7.1. Model Design

This section consists of two subsections. The first subsection describes the development and definition of model adaptation (control) strategies, while the second subsection categorizes the storm events (uncontrollable model inputs). The Cartesian product of the controllable adaptation strategies selected with the storm event will characterize the system dynamics model scenarios for evaluation and comparison.

7.1.1. Development of Adaptation Strategies

With respect to coastal communities' adaptation strategies, there are four broad categories: (1) protection; (2) accommodation; (3) retreat; and (4) status quo or "do nothing" (Pilkey & Young, 2009). Applications of strategies representing these categories of adaptation for the case of the City of Charlottetown as presented in the SD model are described below.

1) Protection

Protection involves the physical reinforcement of the coastlines. This approach can be carried out by engineered strategies such as “hard” or “soft” engineering. Hard engineering measures include for example, seawalls, riprap (i.e., rock or other material used to armor shorelines), breakwaters, gabions (i.e., free-draining walls that are constructed by filling large galvanized steel baskets with rock) and groins (i.e., a coastline structure vertical to the beach, usually made of large stones, concrete, steel, or wood). Soft engineering options include grading coastal cliffs, and planting or maintaining existing vegetation, e.g., Marram grass can be effective in coastal dune areas (Ollerhead, 2006). Generally, the objective of the protection option is to maintain the existing land use activities in spite of rising water levels, and storms. Protection measures can range from small-scale efforts by individual property owners to large-scale public projects (Pilkey & Young, 2009)

2) Accommodation

Accommodation involves constructing specific structures in view of reducing damages resulting from storms. This can be done by building houses on elevated towers, or improving land-use and zoning plans that accept and permit only those constructions that have to be built on the coastline such as port facilities or fish processing plants, and forbidding others such as private residences. Accommodation strategies involve continued occupancy of coastal land while adjustments are made to infrastructure and/or to human activities to accommodate sea-level rise and mitigate the overall severity of storm impacts (Mostofi Camare, 2011). Accommodation measures can involve redesigning existing structures, encouraging more appropriate land uses, and implementing legislation and increasing natural resilience by rehabilitating coastal dunes and wetlands. Examples of such measures can be elevation of buildings on pylons to let storm surge waters pass beneath the building; prohibiting or controlling the removal of beach sediment; shifting agriculture production to salt-tolerant crops; and development of warning systems for extreme events (Pilkey & Young, 2009).

3) Retreat

Retreat plans assume of unavoidability of coastal erosion and flooding, and involve the abandonment of the areas closest to the coastline, or the placing of temporary or dispensable structures only in these areas. Retreat means avoiding the risk of a direct impact from storms (McCulloch & Forbes, 2002) (National Resource Canada (NRC, 2010 a), 2010). Retreat can be in the form of migration, i.e., abandoning the land when recurrent impacts are no longer tolerable, or no development in the first place in known flood zone areas. The easiest achievement of this strategy by individuals is avoidance of buying high-risk properties. Another example of retreat puts restrictions on construction and development in flood and erosion hazard zones. Retreat can be promoted or enforced by public education, land swapping, or management strategies such as rezoning, insurance, denial, or tax policies.

4) Status Quo or "Do nothing"

This strategy effectively tolerates all losses without attempting to mitigate storm impacts. As its name implies, the decision is to "do nothing" to reduce the vulnerability and to absorb the cost of losses as they occur (McCulloch et al 2002). While this method does not invoke any adaptation, it is arguably a commonly used strategy adopted by several coastal communities in response to pending environmental change.

These strategies make up the controllable components of the SD model scenarios. The uncontrollable components of the model scenarios – the occurrence of severe storms – are discussed in the next subsection.

7.1.2. Categorization of Storm events

The SD model scenarios are defined by the controllable adaptation strategies and the uncontrollable storm events. The list of 3 uncontrollable storm events used in defining SD model scenarios is described below.

1) No storms

The case of "no storms" for Charlottetown is used in defining the Base Case of the SD model (Chapter 6). "No storms" for Charlottetown implies that the probability of a storm leading to a Maximum Observed Water Level (MOWL) equal or exceeding 1.4 meters is assumed to be zero. The Base Case is a benchmark against which the impacts of storms can be compared. As well, the Base Case results can become the target outcome for the scenarios (See also subsection 7.2.3 below for Scenario Interpretation).

2) Historical Storms

Historical storms for Charlottetown are defined for the historical period for which data is available from 1911 to 2005 based on the recorded Maximum Observed Water Levels (MOWLs) (Environment Canada, 2006). Chapter 4 elaborates on the historical analysis of this data for Charlottetown. From Chapter 4, an historical storms time-series for generating a single MOWL annually is contracted and fitted with a Gumbel Maximum distribution with location and scale parameters respectively of $\alpha = 2.99$m and $\beta = 0.3$m.

3) More Severe Storms

Analysis of the historical time series in the more recent years, e.g., from 1990 to 2005 indicates that Charlottetown has experienced higher MOWL than over the earlier part of the historical time series. Therefore, parameters for the later years sample are taken to be a better predictor of future annual MOWL for Charlottetown. The More Severe Storms category is described by a Gumbel maximum distribution with revised location parameter of $\alpha = 3.75$m and $\beta = 0.3$m to indicate the prediction of more severe storms over the 21st century (McCulloch & Forbes, 2002).

7.1.3. Scenario Interpretation

The Base Case is used as a benchmark for the impacts of storms and the relative capability of adaptation strategies to reduce their impacts. The relative difference between the SD model outcomes over time between the Base Case benchmark time-path, and the severe storms impact, time-path measures the relative vulnerability of Charlottetown to severe storms. This definition follows the general description of vulnerability described as the extent to which environmental change may damage a community (Watson 2000, Adger 2006).

The reduced negative impacts resulting from the adaptation strategies provide a relative measure of Charlottetown "resilience" attributed to the specific adaptation strategy. Finally, Charlottetown's "adaptive capacity" for a particular adaptation strategy is measured by the ratio of its resilience to its overall vulnerability as the percentage reduction in total storm vulnerability. The SD model provides a direct quantification of the key, contextual-based adaptation indicators of vulnerability, resilience, and adaptive capacity for the case of Charlottetown. These indicators provide additional information for evaluating adaptation strategies as described below.

Thus, for a storm scenario that causes overall storms impacts and damage level $V(0)$ which comes from un-mitigated scenario, and an adaptation strategy, *AS* for the same storm category that reduces damages to $V(AS)$, the resilience, $R(AS)$ is measured as

$$R(AS) = V(0) - V(AS) \qquad 7.1$$

And, the adaptive capacity of the adaptation strategy is given as the percentage:

$$AC(AS) = 1 - V(AS)/V(0) \ (\%) \qquad 7.2$$

The interpretation of these scenario indicators is illustrated in Figure 7.1 below.

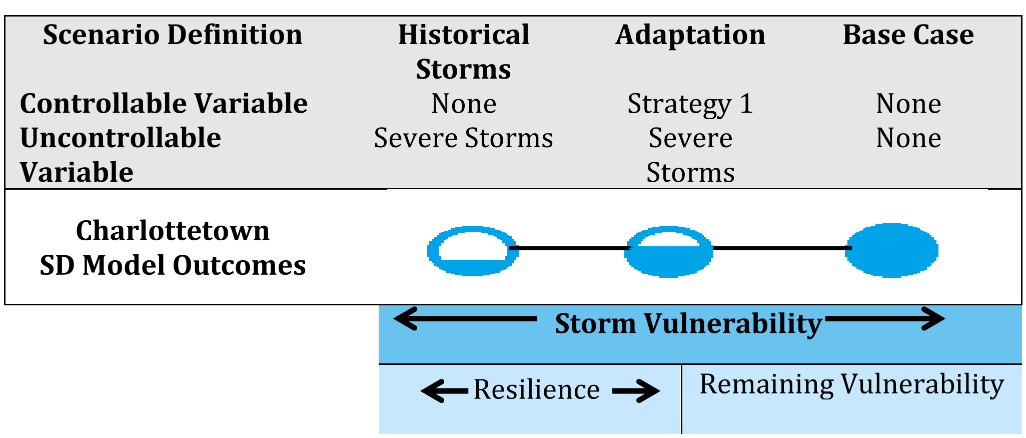

Figure 7. 1: Scenario Interpretation Indicators

7.2. Scenario Analysis

This section includes two subsections. The first subsection presents the suite of simulation scenario definitions to be applied to the SD model. The second subsection presents the model results of the simulation scenarios.

7.2.1. Simulation Scenarios Definitions

Table 7.1 presents eight different simulation scenarios that are applied to the SD model for analysis and evaluation. Table 7.1 identifies the 8 scenarios by name and with respect to their controllable and uncontrollable variables. The suite of 8 model scenarios is a selected subset of all of model variables. These scenarios are designed to SD model outcomes as well as a ranking of adaptation strategies.

Table 7.1: SD Model Scenario Definitions

No.	Scenario Name	Description	Controllable Variables	Uncontrollable Variables
I	Base Case (SQ/ Benchmark)	• No storms • No adaptation	Do nothing Key inputs Refer to (Chapter 6)	No storms
II	Worst Case	• No adaptation • More Severe Storms	Low inputs (Base case strategy- do nothing)	$\alpha = 3.75$ and $\beta = 0.3$
III	Protect - Historical Storms	• Protect • Historical Storms • Sea walls of 3.75 meters (70% protection)	Labor skills adjustment for sea walls construction (professional); ($100m in 5 year) Public Service increase in cost; Attributed land assigned to Public works	$\alpha = 2.99$ and $\beta = 0.3$ If MOWL<3.75 no effect Else MOWL (protect against the mode)
IV	Protect - More Severe Storms	• Protect • More Severe Storms	Same as III	$\alpha = 3.75$ and $\beta = 0.3$

		•Sea walls of 3.75 m		
V	Accommodation - Historical Storms	•Accommodation •Historical storms with 0.75 MOWL	Labor skills adjustment for planting, trees; ½* (Attributed land as Public works in III); ½*(Public service increase in cost of III) = $50m in 5 year	$\alpha = 2.99$ and $\beta = 0.3$
VI	Accommodation - More Severe Storms	•Accommodation •Severe storms with 0.75 MOWL	Same as V	$\alpha = 3.75$ and $\beta = 0.3$
VII	Retreat - Historical Storms	•Retreat •Historical storms •Move buildings from shore line •MOWL	Adjustment to work skills for move house from shore line; ($75m Invest in 5 years) public service increase in cost; Threefold increase of Green Space land	$\alpha = 2.99$ and $\beta = 0.3$
VIII	Retreat - More Severe Storms	•Retreat •Severe storms	Same as VII	$\alpha = 3.75$ and $\beta = 0.3$

The suite of scenarios represents the spectrum of best (Base Case) and worst (no adaptation and more severe storms) cases for Charlottetown dynamics. The remaining six cases examine the impacts of the 3 adaptation strategies (Protect, Accommodate, and Retreat) against each of the storm scenarios (Historical and More Severe storms). This boxed scenario design enables the analysis and comparison of the strategies for evaluation and ranking of overall performance. The results of the SD model scenarios are described in the section below.

7.2.2. Simulation Scenarios Results

This subsection presents the SD model results for the different scenarios of Table 7.1. The presentation of the scenario results follows the one for the Base Case, Scenario I, given in Chapter 6. The scenario results below are provided for Scenarios II to VIII.

Scenario II. Worst case (No adaptation – More Severe Storms)

In this scenario, it is assumed that the City of Charlottetown municipal government does not take any action to mitigate or adapt to the potential damages from severe storms. In this scenario, the occurrence of storms is an uncontrollable variable and it is deemed likely that storms are more severe than predicted by the long historical time series, so they are assumed to bring more severe damages to the land area and services as depicted in the SD model. For example, Figure 7.2 shows the combined STELLA graph for the Goods and Services sector and Cultural and Social sector of the SD model under Scenario II. The results are for one particular trial of the simulation analyses (seed for random number generator equal to 11119). In the graph of Figure 7.2, Commercial Services (curve number 1) is increasing over the 50-year simulation period whereas Industrial Production and Public Services (curve numbers 2 and 3) are declining slightly. The increase in Commercial Services reflects the increase in the population over the planning period. As noted in the Base Case analysis, Section 6.1.1 and Figure 6.1, the population grows by 22.78% over the 50-year planning period. This population growth is assumed to be independent of the Charlottetown severe storm regimes.

The slight decline in Industrial and Public Services is attributed to the affected areas by the more severe storm events that impact production negatively by effectively reducing the available capital (land) inputs of production (see also Figure 7.2 below). Industrial and Public Services are not noticeably affected by more severe storms because ultimately, these services are also recognized as being active in the storm recovery process by annual 10% recovery rate. The net slight decline in results here acknowledges these offsetting effects.

The Ecosystem Services curve (curve number 4 in Figure 7.2) is relatively stable and lowest in value compared to the other services of Figure 7.2. The Cultural and social Services curve (curve number 5) is increasing by $350 million dollars over 50-year horizon.

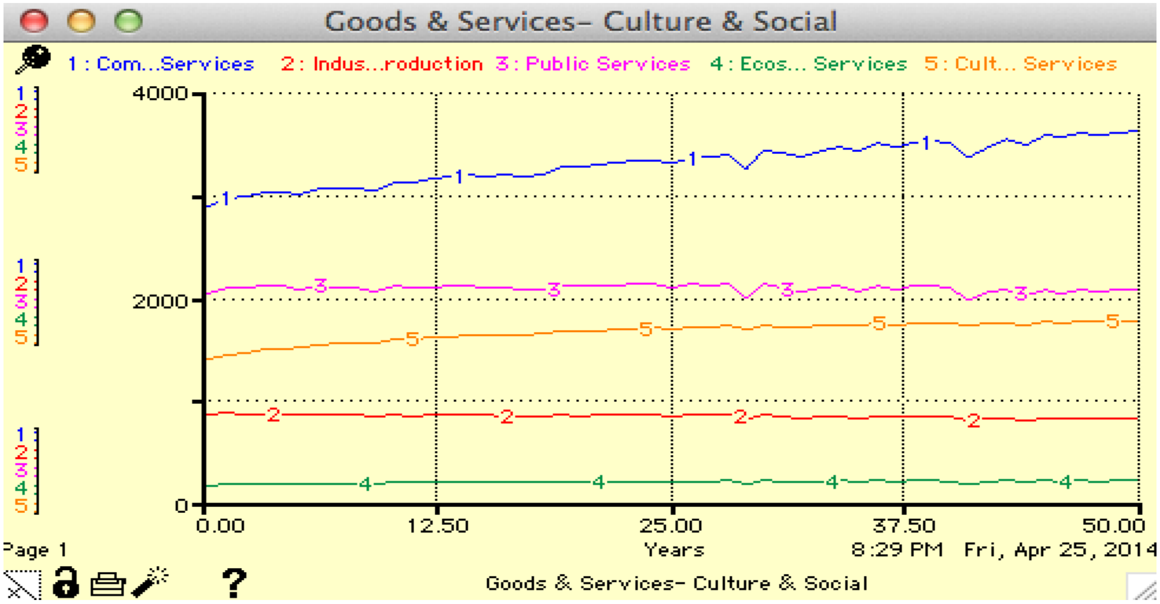

Figure 7. 2: Goods and Services and Cultural & Social Services sectors graph of Stella implementation for Scenario II – Worst Case **(STELLA®, 2012)**

Figure 7.3 shows the time-paths of the dynamics of different Charlottetown land uses during the planning period of 50 years for one trial of the simulation analysis (seed for random number generator value of 11119). All four curves of Public Works land, Cultural and social land, Green Space, and Industrial land (curves number 1,2,3,4) are affected by storms resulting in an effective decrease of approximately 530, 350, 120, 330 acres respectively over the planning horizon of 50 years. As noted above in Figure 7.2, these effective decreases in land impacts productivity accordingly.

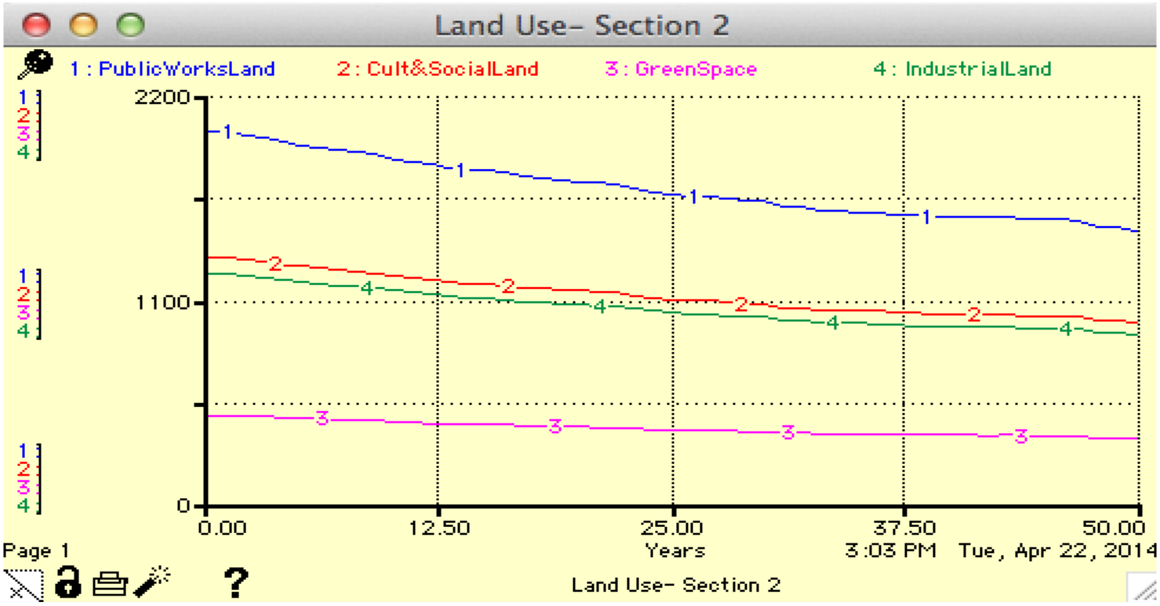

Figure 7. 3: Land Use sector graph of Stella implementation for Scenario II – Worst Case **(STELLA®, 2012)**

Figure 7.4 shows the curve for affected land and unaffected land area as a result of the severe storm incidents. Unaffected Area (curve number 1) shows the unaffected land declining over time while the Affected Area (curve number 3) rises as a consequence of the simulated more severe storm occurrences. The annual MOWL series (curve number 2) is for one particular trial over the 50-year horizon (seed for random number generator value of 11119). The highest point of MOWL shown in this graph is 5.14 meters occurring 40 years from the initial time. These MOWL results are within the limits defined in recent Charlottetown projections (Milloy & MacDonald, 2001) (Shaw & Team, 2001) (Thompson, et al., 2001).

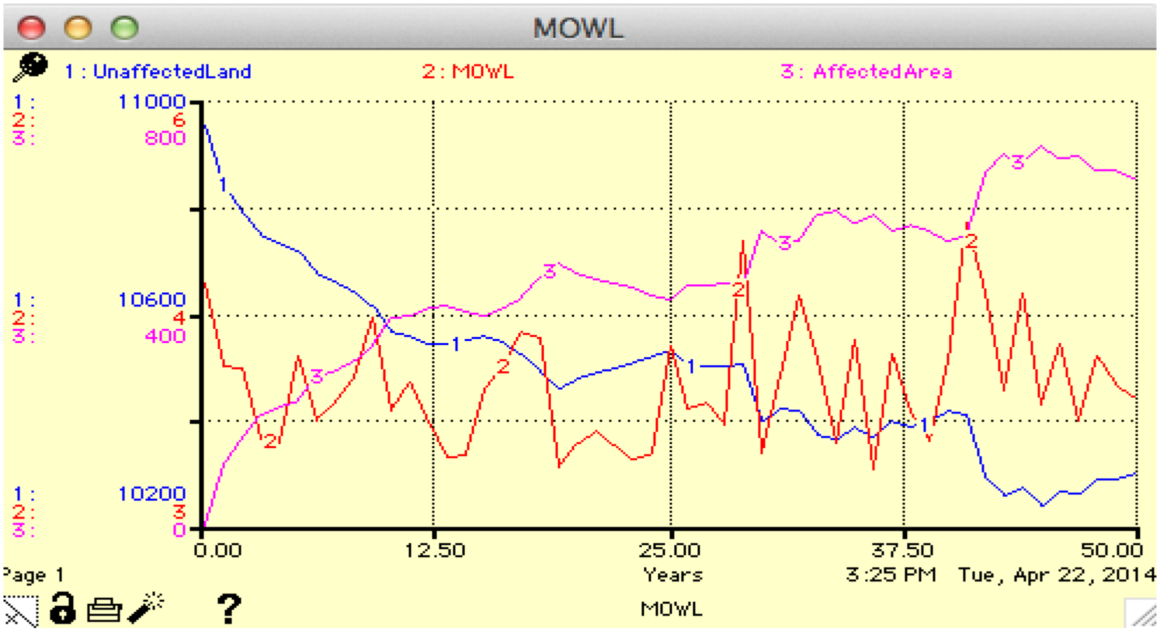

Figure 7. 4: MOWL graph of Stella implementation for Scenario II – Worst Case. **(STELLA®, 2012)**

The generated MOWL function (from the inverse cumulative function of the Gumbel distribution) is a random (uncontrollable) variable. A seed for random number generator is applied for 10 different simulation trials used to represent expected results. Table 7.2 shows the average and standard deviation of: (i) the Cultural and Social Services sector; (ii) the Goods and Services sector; and (iii) the Land Use Sectors that represent the SD model outputs of running the model for 10 trials at year 50 of the 50 year horizon (as also described re model outputs for the Base Case analysis of Chapter 6).

Table 7. 2: Average and Standard Deviation of Services and Land sectors SD Model Outputs for Scenario II-Worst Case

	Cultural and social Services ($)			Goods and Service Services ($)			Land Use Sectors (acres)			
	Cultural & Social Services	Ecosystem Services	Social Map Production	Commercial Service	Industrial Production	Public Services	Green Space	Industrial Land	Cultural & social Land	Public Work Land
Ave	1,760	190	0.26	3,587	806	2,047	345	908	972	1,474
SD	13.12	7.205	0.0206	36.853	12.757	38.3	7.534	19.776	21.163	32.099
BC	1,860	220	0.19	3,698	903	2,317	405	1,064	1,139	1,728

In comparison with the Base Case (BC) results of Chapter 6, Table 6.11, the Worst Case results for the last year of the planning period shows a 5.3% decline in Cultural and Social Services directly as a consequence of the more severe storms. Ecosystems Services decline by 13.6%. Collaboration and social networking actually show an increase in the face of more severe storms from Base case benchmark value of 0.19 to Worst Case value of 0.25.

With respect to Goods and Services, Base Case and Worst Case values for Commercial Services are relatively unchanged (as Charlottetown population shifts are assumed to be independent of Charlottetown storms). However, Industrial and Public Services decline under more severe storms by approximately 11%.

Finally, land use under more severe storms also declines relative to the Base Case benchmark across Green Spaces, Industrial, Cultural & Social and Public Works land by 14.6%.

Thus, these two cases define the overall Charlottetown damage due to more severe storms according to the SD model outputs summarized by the year 50 ending values as presented in Table 7.2. The range of damages in terms of output losses is the target of the adaptation strategies to manage and reduce.

Scenario III: Protect– Historical Storms

Protect Adaptation Strategy Definition: For this adaptation strategy, it is assumed that the City of Charlottetown municipal government takes specific action to reduce the damages from MOWL. The Protect adaptation strategy is evaluated against historical storm simulated data (Scenario III: Protect-Historical Storms) and against more severe storms (Scenario IV: Protect-More Severe Storms). The aim of the Protect adaptation strategy is to protect the shoreline maximum observed water levels. From an engineering perspective, it is assumed that the design of a "protective" seawall or sea gates will mitigate MOWL storm levels up to 70% of the likelihood of MOWL according to the Gumbel Max distribution. At the level of 70% protection, it is assumed Charlottetown is protected from MOWL that are less than 3.75 meters.

To define the Protect strategy, three controllable variables are set for both Scenario III (Protect-Historical Storms), and Scenario IV (Protect-More Severe Storms):

1) Work skill adjustment - it is assumed that an increase of the population of professional labors is required to build the sea wall project. Therefore, the ratio of professional and trade workers is adjusted in this scenario.
2) Capital investment - an investment of $100 million dollars in the first 5 years of the planning period is assumed to build the sea gates, and sea wall to protect the Charlottetown waterfront.
3) Acquired infrastructure capital - Building the seawall is assumed to increase the land area devoted to public works in the SD model.

These elements defining the Protect adaptation strategy are incorporated into Scenarios III and IV described below.

In the scenario III, storms occur as per the frequency of the historical time series. These storms bring damages to the land area and services as depicted in the SD model. Historical Storms are defined as per storms from 1911-2005 with Gumbel maximum location parameter: $\alpha = 2.99$ and scale parameter: $\beta = 0.3$.

Figure 7.5 shows the time path of the different Charlottetown land uses during the planning period of 50 years when historical storms occur in Scenario III for one trial of the simulation analysis (seed for random number generator value 11119). In Figure 7.5, the curve of Public Works land (curve number 1) increases during the first 5 years over the horizon reaching a peak of about 2700 acres after 5 years. This initial increase reflects the growth attributed to Public Works infrastructure for building the seawalls and sea gates of the Protect strategy. The increase is followed by a slight decrease over the rest of 45 years of the horizon as successive Historical Storms affect available Public Works land.

The other land uses decrease accordingly. Cultural and social land and Industrial land (curve numbers 2 and 4) decrease by approximately 400 acres over the horizon. Green space (curve number 3) declined slightly by 150 acres. These decreases in land impacts related services productivity accordingly.

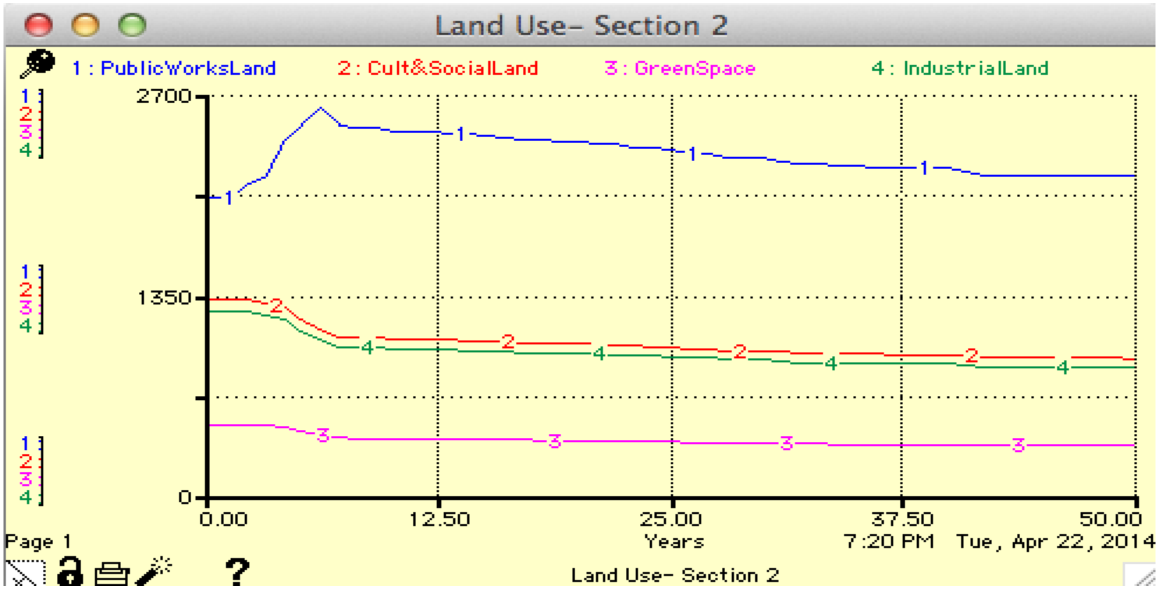

Figure 7. 5: Land Use sector graph of Stella implementation for Scenario III – Protect-Historical Storms **(STELLA®, 2012)**

Figure 7.6 shows the graph for the Goods and Services and the Cultural and Social sectors under Scenario III for one particular trial of the simulation analysis (seed for random number generator value 11119). In Figure 7.6, Commercial Services and Public Services (curve numbers 1 and 3) increase from approximately $2200 million dollars at the initial time period to about $2600 million dollars over the 50-year simulation period. However, Industrial Services (curve number 2) declines slightly especially over the first five years of the horizon. The reason for the increase in Commercial Services reflects the increase in the population over the planning period. The stable or slight decline in Industrial Production is attributed to the affected areas that impact production negatively by effectively reducing the (land) inputs of production. Ecosystem Services (curve number 5) is relatively stable and lowest in comparison to the other services. The Cultural and social services curve is increasing by $350 million over 50-year horizon, or approximately $70 million per year.

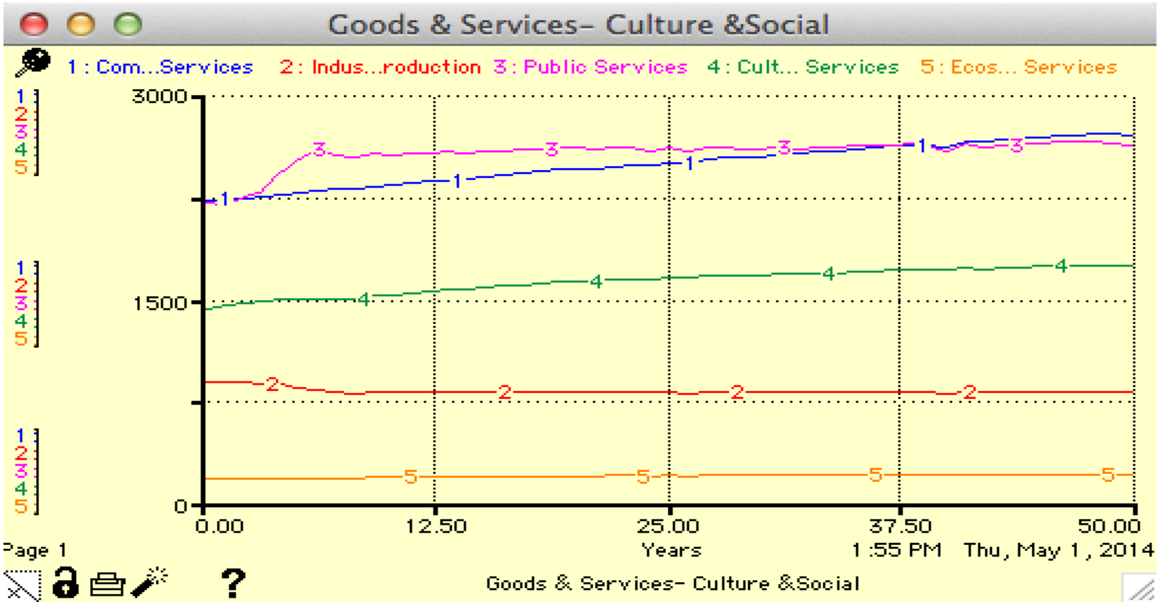

Figure 7. 6: Goods and services and Cultural and social sector graph of Stella implementation for Scenario III- Protect - Historical Storms **(STELLA®, 2012)**

Figure 7.7 shows the annual MOWL1 (curve number 2) over the 50 years horizon. In the model, the curve MOWL1 shows the annual MOWL; while the curve labeled MOWL (curve number 4) shows the maximum observed water level net of 3.75 meters after building the sea wall. This curve records any water level that is more that 3.75 meters and anything less than that is shown at zero (full protection assumed). In this simulation trial, Charlottetown is protected against about 74% MOWL.

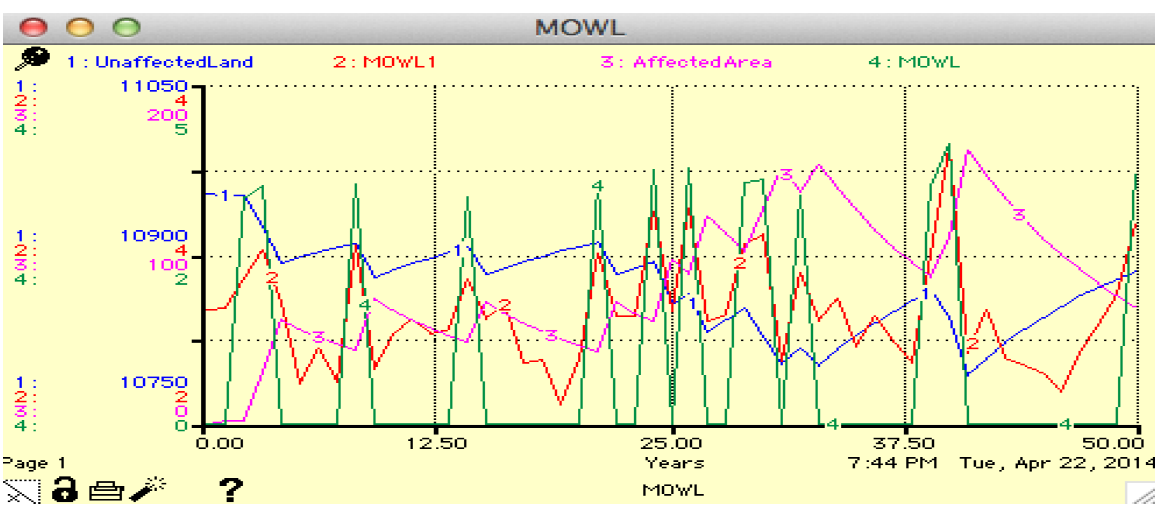

Figure 7. 7: MOWL graph of Stella implementation for Scenario III – Protect-Historical Storms **(STELLA®, 2012)**

Table 7.3 shows the average and standard deviation of the outputs of: (i) the Cultural and Social Services sector; (ii) the Goods and Services sector; and (iii) the Land Use Sectors after running the model for 10 trials of Scenario III at year 50 of the 50 year horizon.

Table 7. 3: Average and Standard Deviation of Services and Land Sector SD Model Outputs for Scenario III – Protect-Historical Storms

	Cultural and social Services ($)			**Goods and Service Services ($)**			**Land Sectors (acres)**			
	Cultural & social Service	Ecosystem Service	Social Map Production	Commercial Service	Industrial Production	Public Service	Green Space	Industrial Land	Cultural & social Land	Public Work Land
Ave	1,763	205	0.23	2,735	821	2,682	332	871	932	2,179
SD	6.44	2.84	0.00	11.86	6.07	20.23	4.80	12.59	13.48	31.55
BC	1,860	220	0.19	3,698	903	2,317	405	1,064	1,139	1,728

The Protect-Historical Storms scenario is approximately 6% below the Base Case scenario for Cultural & Social and Ecosystem services. Land for Green Space, Industrial, Cultural and Social are 18% lower for Protect-Historical Storms than in the Base case scenario.

The Protect-Historical Storms scenario is 7% improved for Ecosystem services compared to the Worst Case scenario and 31% better for Public service. Public Works land is 26% larger than Base Case due to the attribution of the Protect sea walls, sea gates to the public land base.

Scenario IV. Protect-More Severe Storms

As before, the City of Charlottetown municipal government takes protective action by building a seawall and sea-gates to reduce the damages resulting from severe storm surges. In this scenario, the occurrence of storms is deemed to be more severe than predicted by the long historical time series. Uncontrollable storm variables MOWL are defined for a Gumbel maximum with location parameter $\alpha = 3.75$ and scale parameter $\beta = 0.3$.

Figure 7.8 shows the graph for Goods and Services and Cultural and Social sectors under Scenario IV for one trial of the simulation analyses (seed for random number generator vale 11119) in 50 years horizon. As before, the increase in Commercial Services is attributed to the increase in the population over the planning period. The stable or slight decline in Industrial Production is attributed to the affected areas by the storm events that impact production negatively by effectively reducing the land inputs of production. The noticeable decline around years 4-7 is attributed to a successive series of severe storms (see also Figure 7.9 below).

The Cultural and Social services (curve number 4) curve is increasing by $280 million dollar over the 50-year horizon. As in previous scenarios, the Ecosystem Services curve (curve number 5) is stable compared to the other services curves in the scenario.

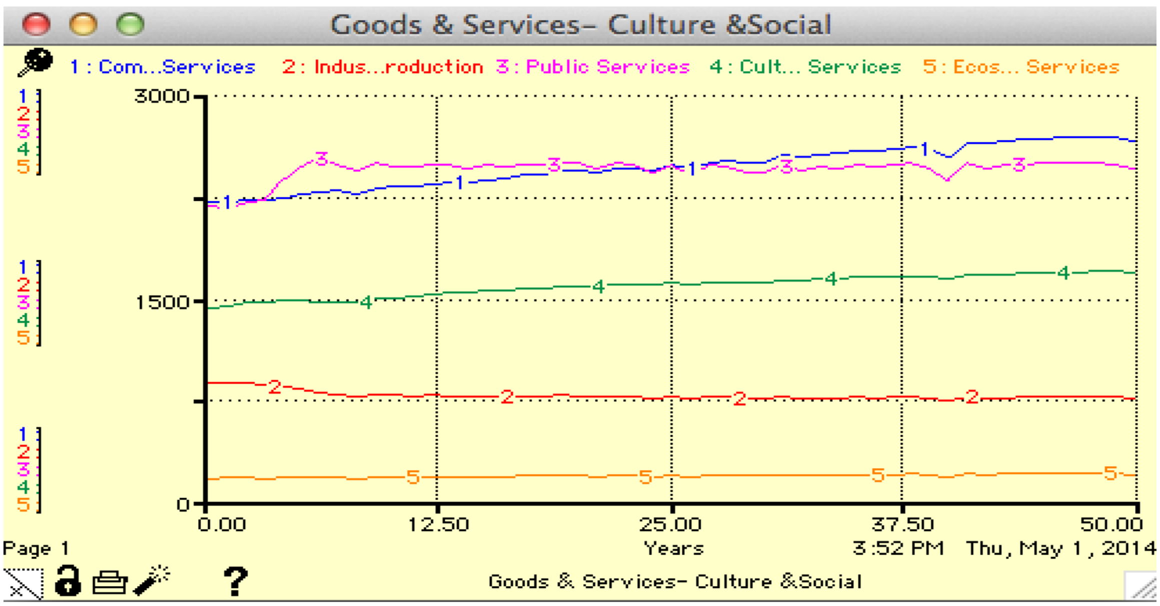

Figure 7. 8: Goods & services and Cultural & social sectors graph of Stella implementation for Scenario IV – Protect-More Severe Storms **(STELLA®, 2012)**

Figure 7.9 shows the time path of different land uses during the planning period of 50 years when more severe storms occur in Scenario IV for one trial of the simulation analysis (seed for random number generator value 11119). Results here are quite similar to the land use sector in Scenario III (Protection-Historical Storms).

Public works land (curve number 1) increased during the first 5 years of the horizon, however, it steadily declines over the balance of 45 years of the planning horizon. Cultural and Social land, Green Space, and Industrial land (curve numbers 2, 3, and 4) decrease by approximately 500, 180, 400 acres over the horizon. Their decreases impacts productivity accordingly.

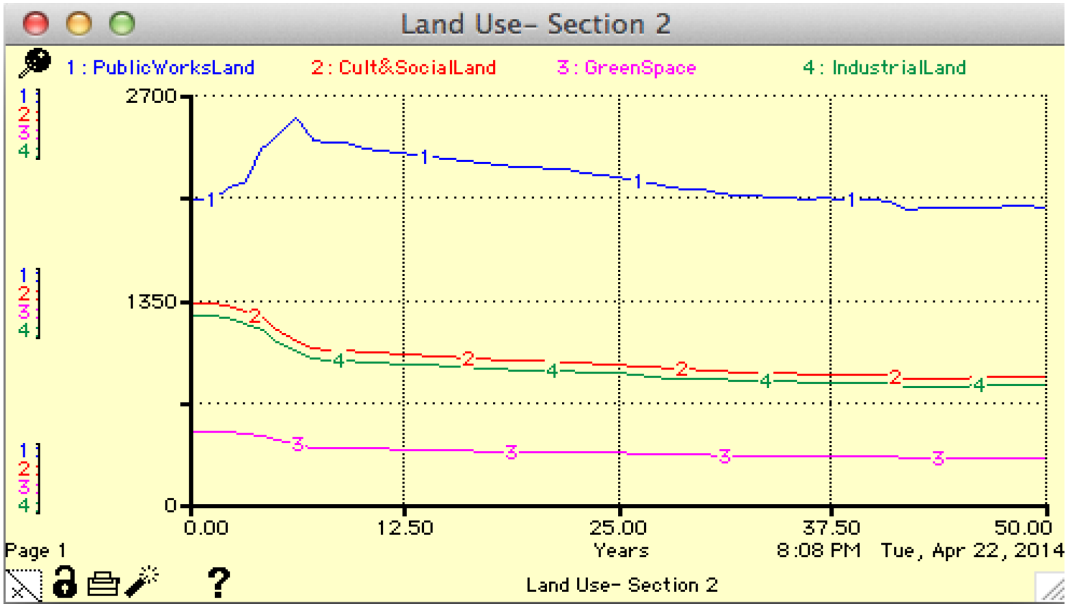

Figure 7. 9: Land Use sector graph of Stella implementation for Scenario IV – Protect-More Severe Storms **(STELLA®, 2012)**

Figure 7.10 shows the curve for affected land and unaffected land area as a result of the severe storm incidents. Unaffected Area (curve number 1) shows the unaffected land going down while Affected Area (curve number 3) rises as a consequence of the severe storm occurrences. MOWL (curve number 4) shows the maximum observed water level after applying sea wall of the height of 3.75 meters. This curve records any water level net of 3.75 meters and any point less than 3.75 meters will be shown as zero. However, as it is clear from this graph of Figure 7.10 (seed 11119), MOWL and MOWL1 mostly match with each other. This means the sea wall of 3.75 meters might not be able to protect severe storms since storms are mostly exceeding those 3.75 meters.

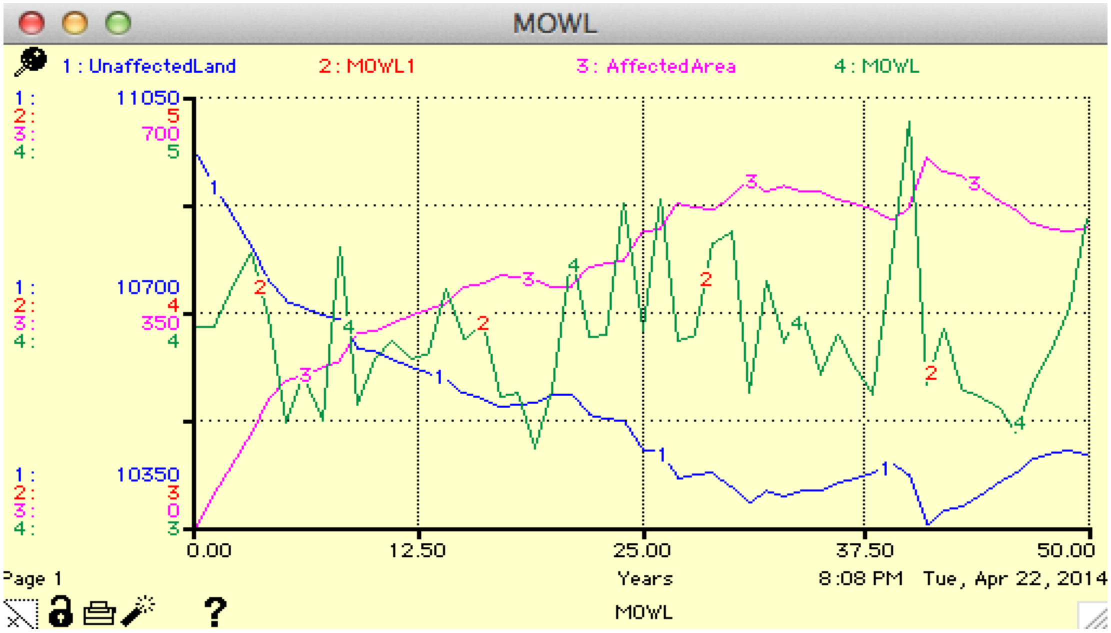

Figure 7.10: Land summary and MOWL graph of Stella implementation for Scenario IV – Protect-More Severe Storms **(STELLA®, 2012)**

Table 7.4 shows at year 50 of the 50 year horizon the results of Scenario IV, the average and standard deviation of: (i) the Cultural and Social Services sector; (ii) the Goods and Services sector; and (iii) the Land Use Sectors that represent the SD model outputs of running model for 10 trials.

Table 7. 4: Average and Standard Deviation of Services and Land Sector SD Model Outputs for Scenario IV – Protect-More Severe Storms

	Cultural and social Services ($)			**Goods and Service Services ($)**			**Land Sectors (acres)**			
	Cultural & social Service	Ecosystem Service	Social Map Production	Commercial Service	Industrial Production	Public Service	Green Space	Industrial Land	Cultural & social Land	Public Works Land
Ave	1,725	197	0.23	2,714	785	2,568	309	810	867	2,042
SD	11.01	6.29	0.02	25.37	10.35	38.44	5.95	15.62	16.72	40.61
BC	1,860	220	0.19	3,698	903	2,317	405	1,064	1,139	1,728

The Protect- More Severe Storms scenario is approximately 13% below the Base Case scenario for Industrial Production. Land for Green Space, Industrial, Cultural and Social are 10% smaller for Protect-More Severe Storms than the Base case scenario. The Protect- More Severe Storms scenario is 10% improved for Public service compared to the Worst Case scenario and 25% better compared to the Base Case scenario for Public service. The Protect-More Severe Storms scenario is approximately 7% below the Base Case scenario for Cultural & Social and Ecosystem services.

Scenario V. Accommodation-Historical Storms

Accommodation Adaptation Strategy Definition: For this adaptation strategy, it is assumed that the City of Charlottetown municipal government takes action to reduce the damages from severe storms. The accommodation action is designed to work with nature, e.g., planting trees near the shoreline to act as a natural barrier to flooding, a soil firmament to reduce erosion, and to reduce the damages from severe storms. The Accommodation scenario is evaluated below by considering performance versus historical storms data (Scenario V: Accommodation-Historical Storms) and, more severe storms (Scenario VI: Accommodation-More Severe Storms). The aim of the Accommodation adaptation strategy is to emphasize the shoreline against the impacts of damages from maximum observed water level.

As for the Protect strategy, three controllable variables are defined for both Scenario V (Accommodation-Historical Storms), and Scenario VI (Accommodation-More Severe Storms):

1) Work skill adjustment - it is assumed that an increase of the population of professional labors is required to plant trees or natural barrier project. Therefore, the ratio of professional and trade workers is adjusted in this scenario.
2) Capital investment - an investment of $50 million dollars in the first 5 years of the planning period is assumed to build the sea gates, to protect the Charlottetown waterfront. This investment is half of the investment in the Protect strategy.
3) Acquired infrastructure capital – land for Public Works is assigned to the built public infrastructure. Planting trees, forest or short sea gates will increase the land area specifically public work land area of Charlottetown city, P.E.I. It is assumed that the land is increased by half the amount of land increase in protection scenario.

These elements defining the Accommodation adaptation strategy are incorporated into Scenarios V and VI described below.

Figure 7.11 shows the time path of different Charlottetown land uses during the planning period of 50 years when historical storms occur in Scenario V for one trial of the simulation analysis (seed for random number generator value 11119). In Figure 7.11, Public Works land (curve number 1) increases during the first 5 years of the planning horizon, reaching a peak of approximately 2250 acres and after that decreases over the remaining 45 years of the horizon to 1920 acres by year 50. Cultural and Social land and Industrial land (curve numbers 2 and 4) decrease by approximately 300 acres over 50-year horizon. Green space (curve number 3) declines slightly by 100 acres over the horizon.

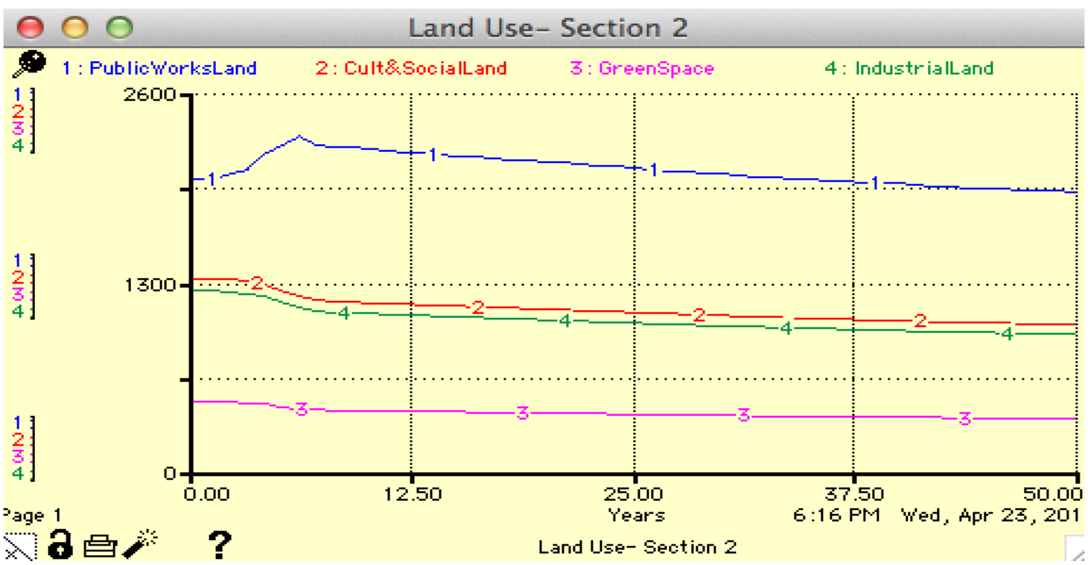

Figure 7. 11: Land Use sector graph of Stella implementation for Scenario V – Accommodation-Historical Storms **(STELLA®, 2012)**

Figure 7.12 shows the graph for Good and Services sector and Cultural and Social sector under scenario V for one particular trial of the simulation analyses. In this graph, Commercial Services and Public Services (curve number 1, and 3) increase by approximately $450 million dollars over the horizon. Industrial production remains quite steady over 50 years period of time. The reason for increase in Commercial Services and Public Services reflects the increase in the population over the planning period. The small decline in Industrial Production is attributed to the affected areas that impact production negatively by effectively reducing the land inputs of production. Cultural and Social services (curve number 4) is increasing by $370 million dollar over 50-year horizon. The Ecosystem Services curve (curve number 5) is quite steady compare to other services.

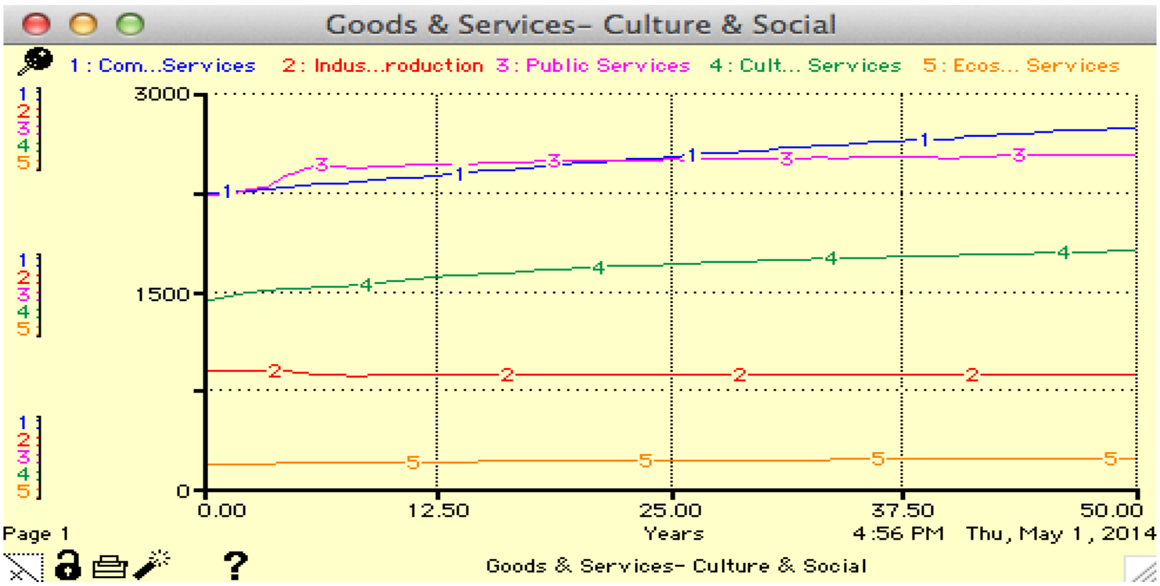

Figure 7. 12: Goods & Services and Cultural & social sectors graph of Stella implementation for Scenario V – Accommodation-Historical Storms **(STELLA®, 2012)**

Figure 7.13 shows the graph for unaffected area, affected area, and MOWL for scenario V for one particular trial over the 50-year horizon. While affected area (curve number 3) is changed from zero to 100 acres, unaffected area (curve number 1) changed from 10950 acres to 10840 acres.

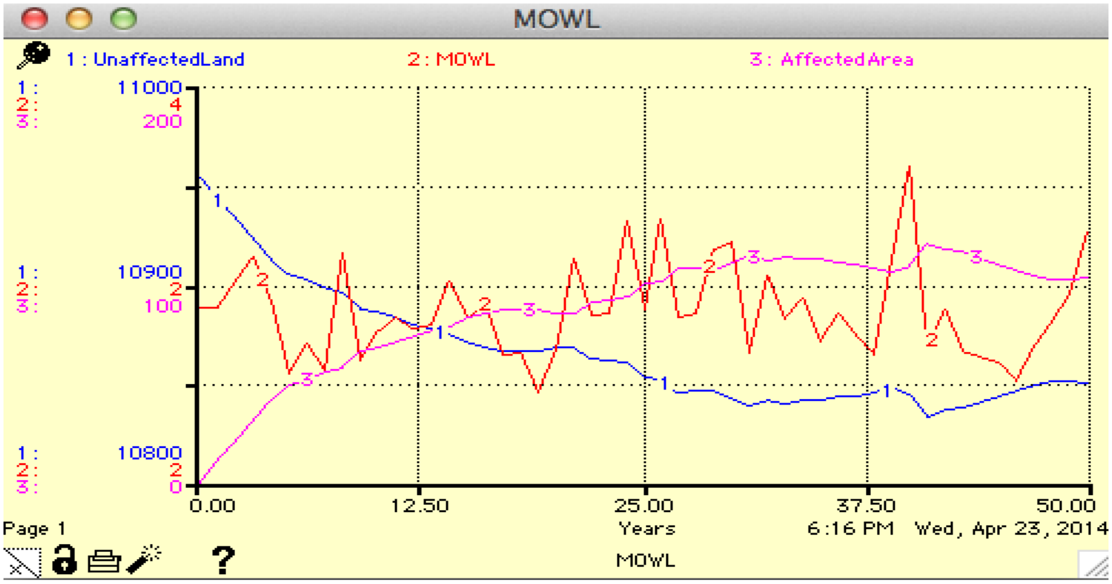

Figure 7. 13: MOWL graph of Stella implementation for Scenario V – Accommodation-Historical Storms **(STELLA®, 2012)**

Table 7.5 shows the average and standard deviation of: (i) the Cultural and Social Services sector; (ii) the Goods and Services sector; and (iii) the Land Use Sectors that represent the SD model outputs of running the model for 10 trials at year 50 of the 50 year horizon.

Table 7. 5: Average and Standard Deviation of Services and Land Sector SD Model Outputs for Scenario V –Accommodation-Historical Storms

	Cultural and social Services ($)			**Goods and Service Services ($)**			**Land Sectors (acres)**			
	Cultural & social Service	Ecosystem Service	Social Map Production	Commercial Service	Industrial Production	Public Service	Green Space	Industrial Land	Cultural & social Land	Public Work Land
Ave	1,801	212	0.23	2,745	858	2,537	359	942	1,008	1,928
SD	1.58	0.95	0.00	3.69	1.59	5.39	0.96	2.52	2.70	5.24
BC	1,860	220	0.19	3,698	903	2,317	405	1,064	1,139	1,728

Land for Green Space, Industrial, Cultural and Social are 11% smaller for Accommodation -Historical Storms than the Base case scenario. The Accommodation-Historical Storms scenario is 11.5% improved for Ecosystem service compared to the Worst Case scenario. Public service in

Accommodation-Historical Storm scenario improved by 9.4% better than Base Case and 24% better than Worst Case.

Severe VI. Accommodation-More Severe Storms

Figure 7.14 shows the graph for Goods and Services and the Cultural and Social sectors under Scenario VI, Accommodation-more severe storm, for one particular trial of the simulation analyses (seed for random number generator value 11119). In Figure 7.14, Industrial Production (curve number 2) is steady. Commercial services and Public Services (curve numbers 1 and 3) increase by approximately \$500, and \$200 million dollar over 50 years horizon. The reason for increase in the latter services is because there is an increase in services' components such as commercial land and public work land and also increase in shifting labors and professionals from other sectors to these sectors to build a sea wall. Cultural and social services (curve number 4) trend is increasing by \$360 million dollar over 50-year horizon. Ecosystem Services curve (curve number 5) is quite steady compared to the other services.

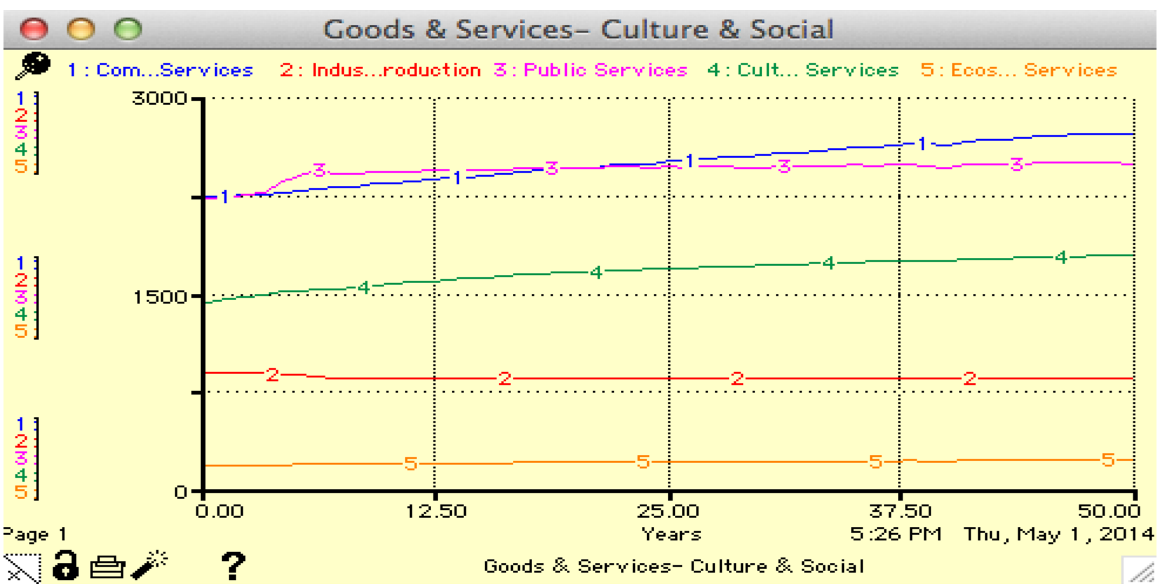

Figure 7. 14: Goods & Services and Cultural & Social sectors graph of Stella implementation for Scenario VI – Accommodation-More Severe Storms **(STELLA®, 2012)**

Figure 7.15 shows the land use section for accommodation scenario with severe storms. All four curves decrease over the 50 years planning horizon. The graph is similar to the

Accommodation-Historical Storms, Scenario V, however, the acreage of the land sectors is smaller than the acreage in Scenario V over 50 years horizon.

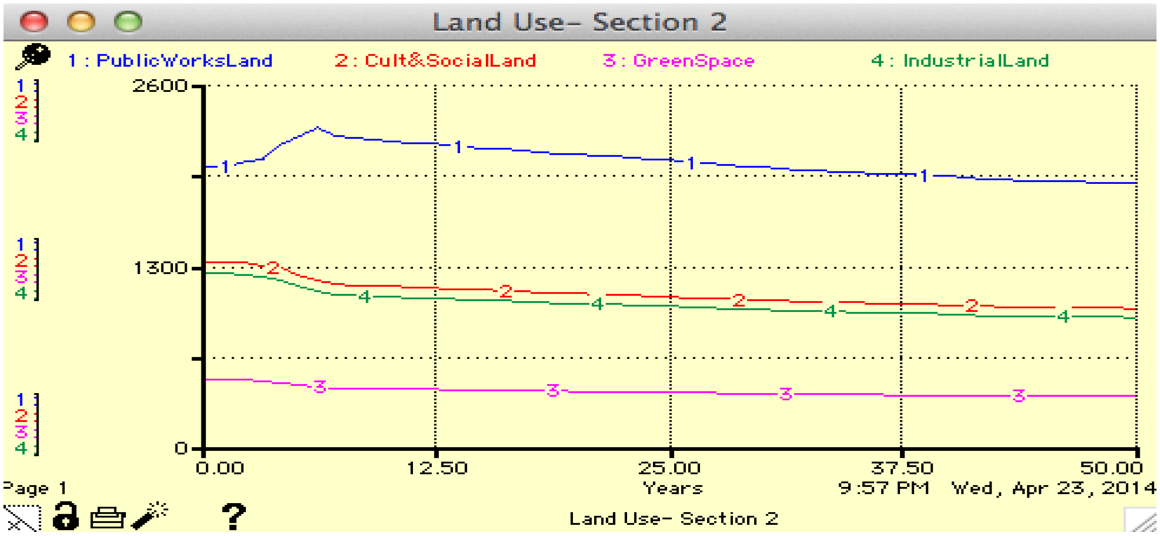

Figure 7. 15: Land Use sector graph of Stella implementation for Scenario VI – Accommodation-More Severe Storms **(STELLA®, 2012)**

Figure 7.16 shows the graph for MOWL (curve number 2). The highest peak of MOWL is 4.2 meters, however the balance of the peaks is less than 3.9 meters. MOWL is defined as 75% affection of the total MOWL in the worst-case scenario.

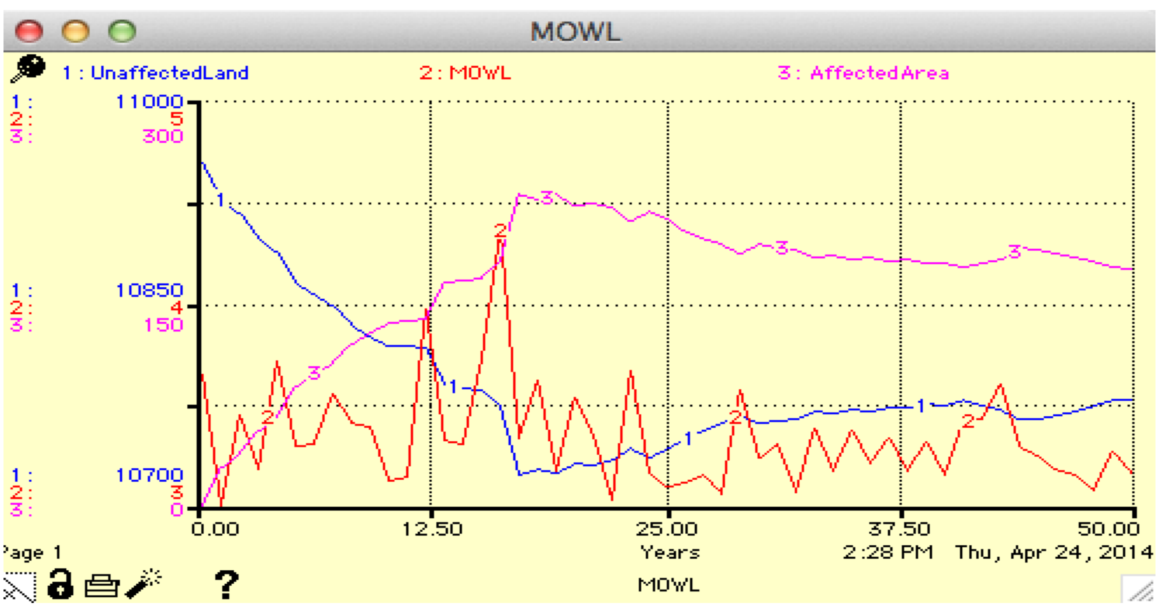

Figure 7. 16: MOWL graph of Stella implementation for Scenario VI – Accommodation- More Severe Storms **(STELLA®, 2012)**

Table 7.6 shows the average and standard deviation of: (i) the Cultural and Social Services sector; (ii) the Goods and Services sector; and (iii) the Land Use Sectors that represent the SD model outputs of running the model for 10 trials at year 50 of the 50 year horizon.

Table 7. 6: Average and Standard Deviation of Services and Land Sector SD Model Outputs for Scenario VI –Accommodation-More Severe Storms

	Cultural and social Services ($)			**Goods and Service Services ($)**			**Land Sectors (acres)**			
	Cultural & Social Service	Ecosystem Service	Social Map Production	Commercial Service	Industrial Production	Public Service	Green Space	Industrial Land	Cultural & social Land	Public Work Land
Ave	1,791	209	0.23	2,738	847	2,505	352	924	989	1,893
SD	2.79	1.64	0.00	6.49	2.78	9.45	1.69	4.42	4.73	9.20
BC	1,860	220	0.19	3,698	903	2,317	405	1,064	1,139	1,728

The Accommodation-More Severe Storms scenario is approximately 6% below the Base Case scenario for Industrial Production, while land for Green Space, Industrial, Cultural and Social are 13% smaller. The Accommodation-More Severe Storms scenario is 10% improved for Ecosystem service compared to the Worst Case scenario.

Scenario VII. Retreat - Historical storms

Retreat Adaptation Strategy Definition: For this adaptation strategy, the City of Charlottetown municipal government takes action to reduce the damages from storms. The Retreat strategy is evaluated against historical data (Scenario VII: Retreat-Historical Storms) and more severe storms (Scenario VIII: Retreat-More Severe Storms). The aim of the Retreat strategy is to move out residential and commercial places of residence from the shoreline of the City of Charlottetown to somewhere further than the shoreline to protect against maximum observed water levels.

Three controllable variables are defined for both Retreat model scenarios: Scenario VII (Retreat-Historical Storms), and Scenario VIII (Retreat-More Severe Storms). These variables are described below.

1) Work skill adjustment - it is assumed that an increase of the population of professional and trade labor skills are required to transport people and things. Therefore, the ratio of professional and trade workers are adjusted in this scenario. The adjustment in retreat scenario is similar to the adjustment in the protection and accommodation scenarios. It is assumed that more skilled workers are required to move out the buildings from the coastline area.
2) Capital investment - an investment of $75 million dollars in the first 5 years of the planning period is assumed to move people, and houses. The $75 million dollars is estimated from the number of houses (approximately 300) being around the Charlottetown's coastline, and the estimated value for residential and commercial housing in Charlottetown (estimated at $250,000 per property) (Delcan, 2012).
3) Acquired infrastructure capital - attributed increase in Green Space land as three times that of the previously occupied area makes more vacant or green space land available for the alternate lands use.

These elements defining the Retreat adaptation strategy are incorporated into Scenarios VII and VIII described below.

Figure 7.17 shows the time path of different Charlottetown land uses during the planning period of 50 years when historical storms occur in Scenario VII for one trial of the simulation analysis. In Figure 7.17, all land sections (curve number 1,2, 3, and 4) decrease over 50 years horizon. Public Works land and Green Space decreases by nearly 200 acres and Cultural and Social land and Industrial land declined by around 100 acres.

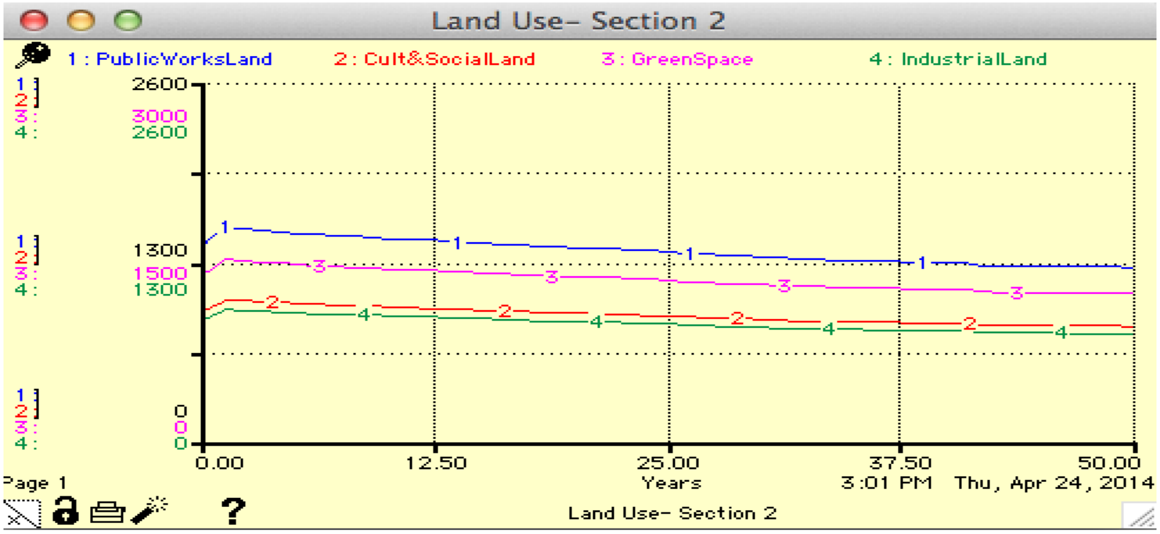

Figure 7. 17: Land Use sector graph of Stella implementation for Scenario VII –Retreat-Historical Storms **(STELLA®, 2012)**

Figure 7.18 shows graph for Good and Services sector and Cultural and Social sector under scenario VII for one particular trial of the simulation analyses. Commercial Services (curve number 1) rise steadily from $2200 to $2700 million dollars. Industrial production (curve number 2) is steady and Public Services (curve number 3) increase by $200 million dollars over 50 years horizon. Cultural and Social services (curve number 4) trend is increasing by around $400 million dollars over 50-year horizon. Ecosystem Services curve (curve number 5) is increased slightly by $60 million dollars over the horizon.

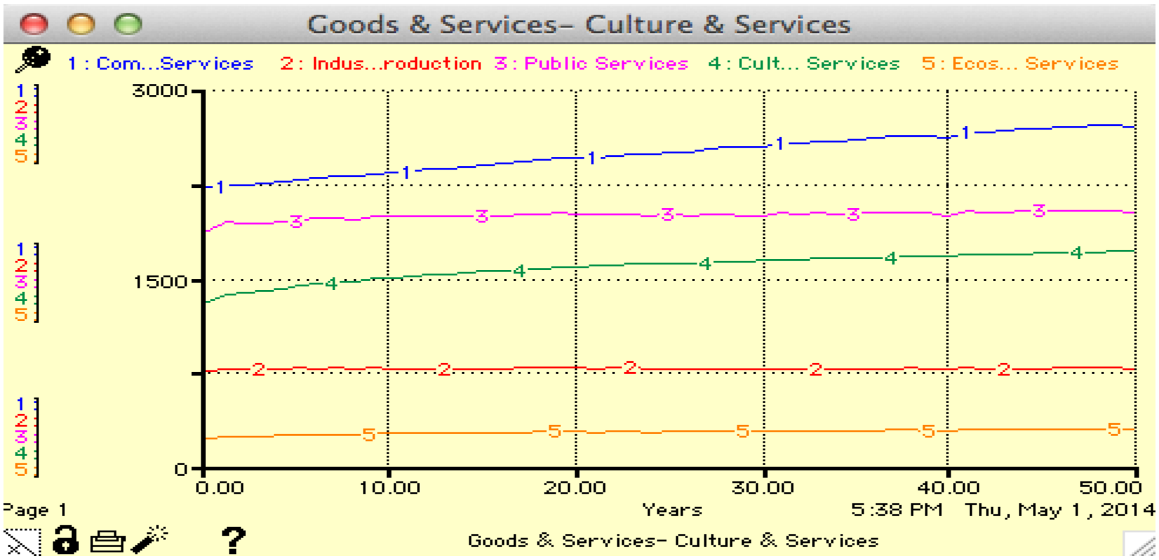

Figure 7. 18: Goods & services and Cultural & social sectors graph of Stella implementation for Scenario VII –Retreat-Historical Storms **(STELLA®, 2012)**

Figure 7.19 shows the graph for unaffected area, affected area, and MOWL for scenario VII. While affected area (curve number 3) is changed from zero to 230 acres, unaffected area (curve number 1) changed from 10720 acres to 10940 acres. MOWL trend (curve number 2) fluctuates mainly between 3 meters and 4 meters.

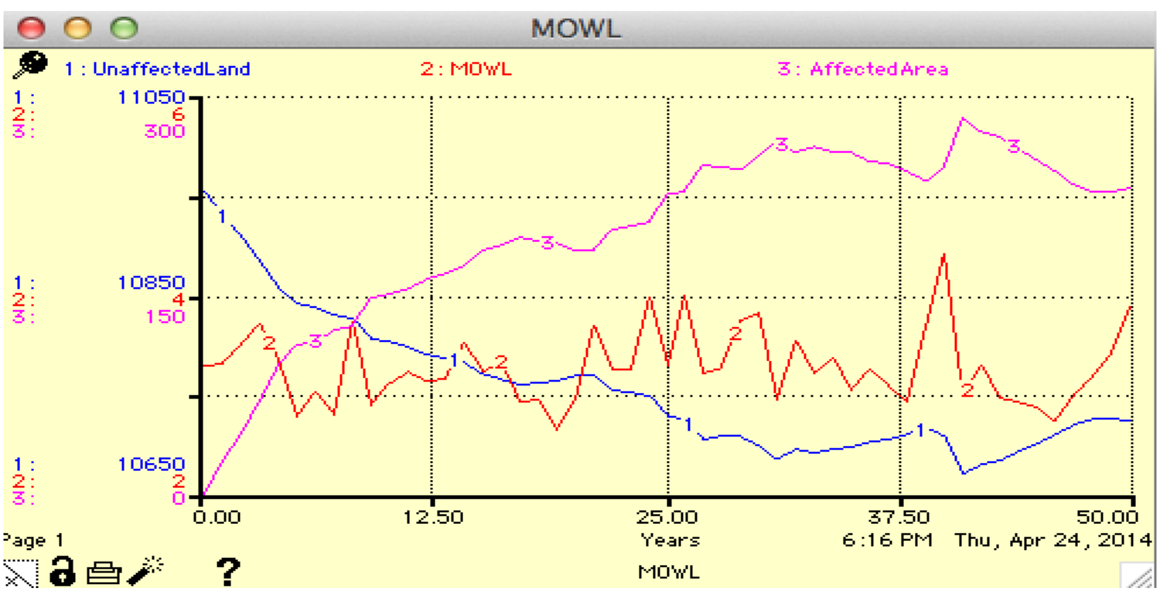

Figure 7. 19: MOWL graph of Stella implementation for Scenario VII - Retreat-Historical Storms **(STELLA®, 2012)**

Table 7.7 shows the average and standard deviation of: (i) the Cultural and Social Services sector; (ii) the Goods and Services sector; and (iii) the Land Use Sectors that represent the SD model outputs of running the model for 10 trials at year 50 of the 50 year horizon.

Table 7. 7: Average and Standard Deviation of Services and Land Sector SD Model Outputs for Scenario VII –Retreat-Historical Storms

	Cultural and social Services ($)			**Goods and Service Services ($)**			**Land Sectors (acres)**			
	Cultural & social Service	Ecosystem Service	Social Map Production	Commercial Service	Industrial Production	Public Service	Green Space	Industrial Land	Cultural & social Land	Public Work Land
Ave	1,714	286	0.23	2,735	776	2,042	1,236	778	833	1,263
SD	4.85	3.56	0.00	11.86	4.64	14.20	10.94	6.88	7.37	11.17
BC	1,860	220	0.19	3,698	903	2,317	405	1,064	1,139	1,728

The Retreat-Historical Storms scenario is approximately 8% below the Base Case scenario for Cultural & Social service. Land for Green Space, Industrial, Cultural and Social are 26% smaller for Retreat-Historical Storms than the Base case scenario. The Retreat-Historical Storms scenario is approximately 14% below the Base Case scenario for Industrial Production. The Retreat-Historical Storms scenario is 50% improved for Ecosystem service compared to the Worst Case scenario and 30% better compared to the Base Case.

Severe VIII. Retreat-More Severe Storms

Figure 7.20 shows the graph for Goods and Services sector and Cultural and Social sectors under Scenario VIII for one particular trial of the simulation analyses. The curve for Commercial Services (curve number 1) increases slightly. Industrial production and Public Services (curve number 2, and 3) are quite stable. Cultural and Social services (curve number 4) trend is increasing by $350 million dollar over 50-year horizon. The Ecosystem Services curve (curve number 5) is quite steady compared to the other services. These curves follow a trend similar to the one of the curves in scenario VII despite with a small decrease in their final value over a 50 years horizon. For example, commercial services increase by $400 million while in scenario VII it increases by $500 million over a 50-year horizon.

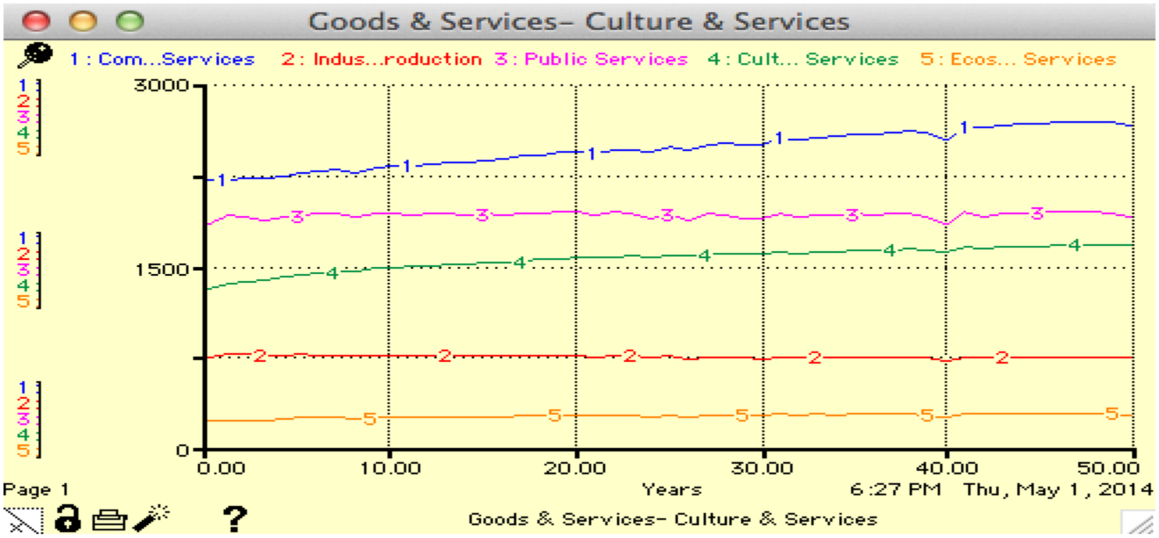

Figure 7. 20: Goods & services and Cultural & social sectors graph of Stella implementation for Scenario VIII - Retreat-More Severe Storms **(STELLA®, 2012)**

Figure 7.21 shows the land use sector for scenario VIII. Similar to scenario VII (Retreat-Historical Storms) these curves (curve number 1, 2, 3, and 4) increase slightly in 5 years and then decrease slightly for the last 45 years of the horizon. To compare with scenario VII, more damages coming from severe storm cause more damage and unusable land than the lands in scenario VII. For example, Green Space decreases from about 1400 acres to 1150 acres over 50 years horizon compare to Green Space in scenario VII which decrease from 1400 acres to 1240 acres.

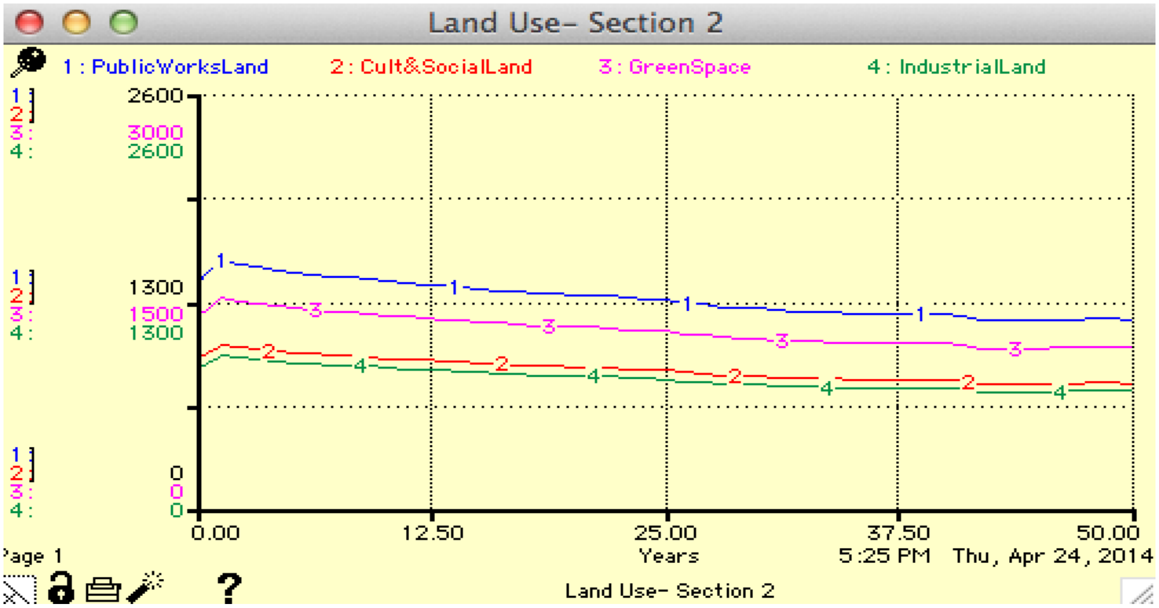

Figure 7. 21: Land Use sector graph of Stella implementation for Scenario VIII - Retreat-More Severe Storms **(STELLA®, 2012)**

Figure 7.22 shows the graph for MOWL (curve number 2). The highest peak of MOWL is 4.9 meters. MOWL fluctuate between 4 meters to 5 meters when severe storms occurred.

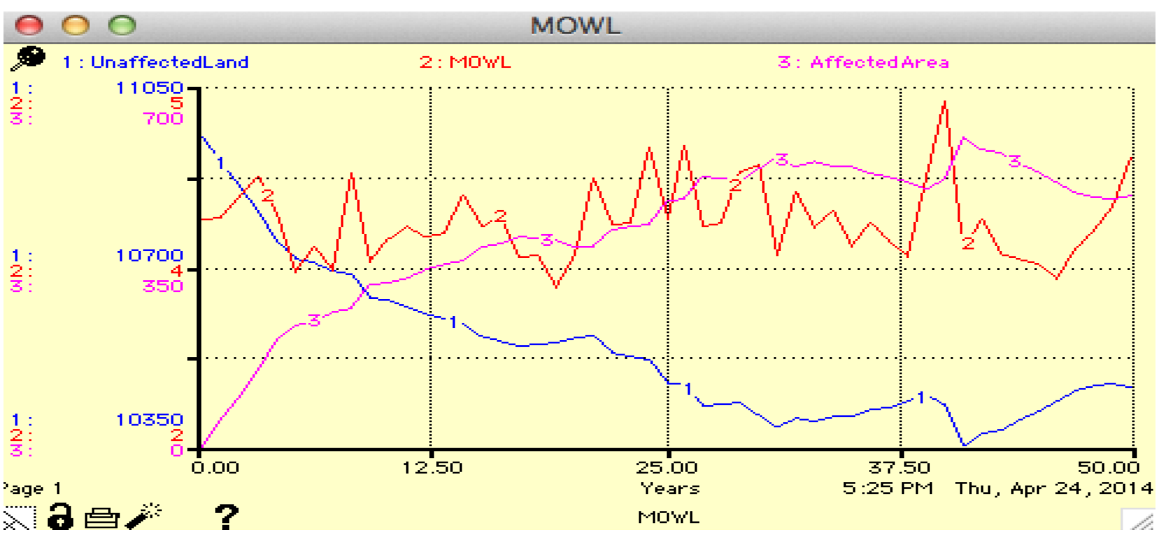

Figure 7. 22: MOWL graph of Stella implementation for Scenario VIII - Retreat-More Severe Storms **(STELLA®, 2012)**

Table 7.8 shows the average and standard deviation of: (i) the Cultural and Social Services sector; (ii) the Goods and Services sector; and (iii) the Land Use sectors that represent the SD model outputs of running the model for 10 trials at year 50 of the 50 year horizon.

Table 7. 8: Average and Standard Deviation of Services and Land Sector SD Model Outputs for Scenario VIII –Retreat-More Severe Storms

	Cultural and social Services ($)			**Goods and Service Services ($)**			**Land Sectors (acres)**			
	Cultural & social Service	Ecosystem Service	Social Map Production	Commercial Service	Industrial Production	Public Service	Green Space	Industrial Land	Cultural & social Land	Public Work Land
Ave	1,680	275	0.24	2,712	745	1,953	1,159	730	781	1,184
SD	10.54	7.66	0.02	25.37	9.79	29.89	23.15	14.57	15.60	23.64
BC	1,860	220	0.19	3,698	903	2,317	405	1,064	1,139	1,728

The Retreat-More Severe Storms scenario is approximately 17% below the Base Case scenario and 7% below the Worst Case for Industrial Production. Land for Green Space, Industrial, Cultural and Social are 31% less for Retreat-More Severe Storms than the Base case scenario. The Retreat-More Severe Storms scenario is 100% improved for Green Space compared to both Base Case and Worst Case scenario. The Retreat-More Severe Storms scenario is 20% improved for Ecosystem service compared to the Base Case scenario and 44% improved compare to the Worst Case.

7.3. Scenario Comparison and Results

Table 7.9 shows a summary of each scenario's outputs of running the SD model for 10 trials at year 50 of the 50-year horizon all together. The table is divided into three main sections. Two sections are related to services and production ($millions). The third section shows land sectors, which are; green space, industrial, cultural and social, and public work land (acres).

For example, alternate land acres in each section of retreat scenario are decreased except green space going up since moving people out of shore line create more green space. In services section, the base case scenario has the highest value since fewer dollars is spent when there is no storms. Worst case, Scenario II, or Do Nothing, is when severe storms occurred but no governmental adaptation action is carried out. Their production values are reduced because of damages resulting from storm events. Then, three main strategies each with historical storms and severe storms output are represented. Cultural and Social Services, and Goods and Services are in million dollar units and Land Sectors are in acres.

Table 7. 9: all scenario results at t=50 of 50 years horizon

	Cultural and Social Services ($)			Goods and Service Services ($)			Land Sectors (acres)			
	Culture & Social Service	Ecosystem Service	Social Map Production	Commercial Service	Industrial Production	Public Service	Green Space	Industrial Land	Culture &Social Land	Public Work Land
Base Case (Status Quo)	1860	220	0.19	3698	903	2317	405	1064	1139	1728
Worst Case	1760	190	0.26	3587	806	2047	345	908	972	1474
Protect-Historical	1763	205	0.23	2735	821	2682	332	871	932	2179
Protect-Worst	1725	197	0.23	2714	785	2568	309	810	867	2042
Accommodation-Historical	1801	212	0.23	2745	858	2537	359	942	1008	1928
Accommodation-Worst	1791	209	0.23	2738	847	2505	352	924	989	1893
Retreat-Historical	1714	286	0.23	2735	776	2042	1236	778	833	1263
Retreat-Worst	1680	275	0.24	2712	745	1953	1159	730	781	1184

Vulnerability (Opportunity costs):

Table 7.10 shows the vulnerability of scenarios for 4 services, Cultural & Social service, Ecosystem service, Industrial production, and Public service in addition to two section of alternate land uses which are Green Space and Public works Land.

In case of Cultural and Social service, the least vulnerable amount is related to Scenario V, and VI (Accommodation- Historical storms and Accommodation-More Severe storms) with vulnerability of $59 and $69 million dollars.

Considering Ecosystem service, scenarios V, and VI are the best option in comparison to scenario II (worst case) with vulnerability of only $8 and $11 million dollars. The second best option is related to Protect strategy of scenarios III, and IV with $15, and $23 million dollars of vulnerability.

For Industrial Production, Accommodation strategy (scenarios V, and VI) has the least amount of vulnerability. Then, scenario III (Protect- Historical storms) with $82 million dollars is the best second option. After that, Do Nothing (scenario II) with $97 million dollar of vulnerability.

In Public service, for protect and accommodation strategies (scenarios III, IV, V, and VII) respectively, not only vulnerability is 0 but also, the value of service is improved. The vulnerability of retreat strategy (scenario VII, VIII) is higher than Do Nothing (scenario II).

The vulnerability of Green space in retreat scenarios (VII, VIII) is zero. They even improved by 831 and 754 acres since moving people out of shoreline increases green space. Next, accommodation and protect strategies (scenario V, VI, III, IV) have the least vulnerability. In contrast, for Public works land, protect and accommodation strategies' vulnerabilities (scenario III, IV, V, V) are zero.

Table 7. 10: All scenario Vulnerability [opportunity costs] results at t=50 of 50 years horizon ($000s)

Scenario	Vulnerability	Cultural & Social Service	Ecosystem Service	Industrial Production	Public Service	Green Space	Public Works Land
I.	Base Case (Status quo)	$0	$0	$0	$0	0 ac	0 ac
II.	Worst Case	$100	$30	$97	$270	60 ac	254 ac
III.	Protect-Historical	$97	$15	$82	-$365	73 ac	-451 ac
IV.	Protect-Worst	$135	$23	$118	-$251	96 ac	-314 ac
V.	Accommodation-H	$59	$8	$45	-$220	46 ac	-200 ac
VI.	Accommodation-W	$69	$11	$56	-$188	53 ac	-165 ac
VII.	Retreat-Historical	$146	-$66	$127	$275	-831 ac	465 ac
VIII.	Retreat-Worst	$180	-$55	$158	$364	-754 ac	544 ac

Resiliency (Opportunity cost relative to worst case scenario):

Resiliency of three strategies each with either Historical storms, or More Severe storms is shown in table 7.11. For Cultural and Social service, the policy of Accommodation strategies (scenarios V, and VI) can be adopted by 41% and 31% of the total vulnerability.

In Ecosystem service, retreat policy (scenarios VII, and VIII) can be adopted by more than 100% of the total vulnerability. Accommodation policy (scenarios V, and VI) can be adopted by approximately 20% of the total vulnerability.

In Industrial Production, accommodation policy (scenarios V, and VI) is the best options to adopt by 54%, and 41% of vulnerability. In Public service, accommodation and protect scenarios (III, IV, V, VI) are the best to adopt respectively.

In land section, for Green space, retreat strategy by probability of more than 100% and then accommodation strategy (scenario V, VI) by 23% and 7% are best to adopt as the policy respectively. The same selection is true for the alternate land section, Public Works land, as well.

In general the higher the resiliency, the more likely a policy can be adopted. However, accommodation strategy robust across the board that should be consider into account.

Table 7. 11: All scenario resiliency and adaptation policy results at t=50 of 50 years horizon

Scenario	Resilience (Adaptation Capacity)	Cultural & Social Service	Ecosystem Service	Industrial Production	Public Service	Green Space	Public Works Land
II.	Worst Case	$1,760	$190	$806	$2,047	345 ac	1474 ac
III.	Protect-Historical	$3 (3%)	$15 (50%)	$15 (15%)	$635 (235%)	-13 ac (-22%)	705 ac (278%)
IV.	Protect-Worst	-$35 (-35%)	$7 (23%)	-$21 (-22%)	$521 (193%)	-36 ac (-60%)	568 ac (224%)
V.	Accommodation-H	$41 (41%)	$22 (73%)	$52 (54%)	$490 (181%)	14 ac (23%)	454 ac (179%)
VI.	Accommodation-W	$31 (31%)	$19 (63%)	$41 (42%)	$458 (170%)	7 ac (12%)	419 ac (165%)
VII.	Retreat-Historical	-$46 (-46%)	$96 (320%)	-$30 (-31%)	-$5 (-2%)	891 ac (1485%)	-211 ac (-83%)
VIII.	Retreat-Historical	-$80 (-80%)	$85 (283%)	-$61 (-63%)	-$94 (-35%)	814 ac (1357%)	-290 ac (-114%)

Production chart:

Figure 7.23 compares 5 main sectors in status quo (base case), worst case, and each strategy with its worst-case storm scenario. The aim is to compare all worst cases with base case scenario.

Commercial services in base case and worst case are $3698 m and $3587 m dollars respectively. However, their value is severely reduced in protect, accommodation and retreat scenarios since professional and workers trade would shift from other sectors to this sector to satisfy the workers' requirement. Public services, Industrial production, and Cultural & Social services in the accommodation and protect scenarios show a higher value than in the retreat scenario respectively. Ecosystem service has a minor role compared to other services, though it has a better value in accommodation and protect scenarios respectively than retreat scenario. Overall, the Accommodation adaptation scenario followed by the protect scenario are strategies preferable to the retreat scenario.

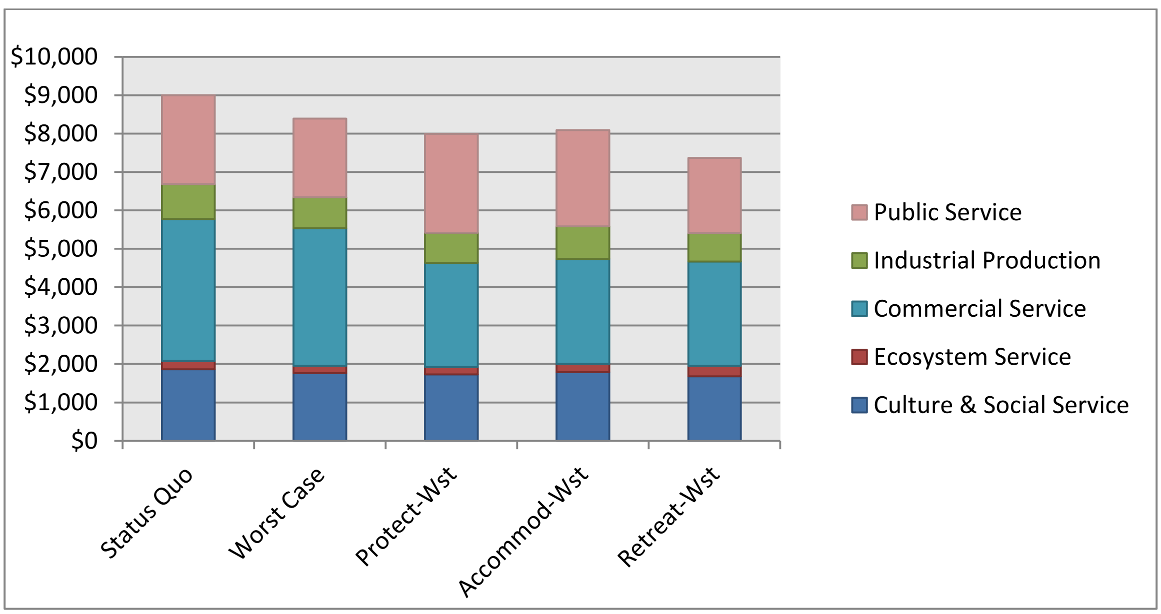

Figure 7. 23: production chart comparison of base case and Worst Case scenarios

Land Area:

Figure 7.24 compares alternate land sectors such as public works land, cultural & social land, industrial land, and green space regarding worst case of each scenario with base case scenario. The green space in the retreat scenario increases due to availability of land near the shoreline resulting from residential land being vacated. Aside from the retreat scenario, green space decreased its acreage in comparison to the base case. Industrial land and cultural & social land have a larger acreage in the accommodation scenario than in protect and retreat scenarios. Public works land has a larger acreage in protect and accommodation scenarios than the retreat scenario compared to the status quo and worst-case scenarios. In general, it seems that the accommodation scenario is the best option among other strategies for land section.

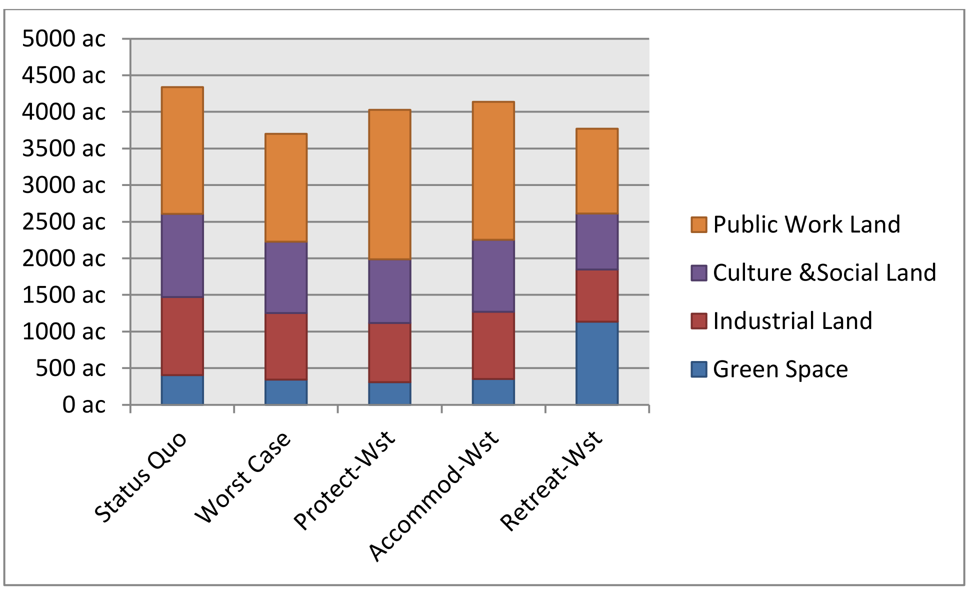

Figure 7. 24: Land area with worst base case scenario and worst-case scenarios

Compared Historical and more severe storm scenarios for 3 Services:

Figure 7.25 shows a comparison of ecosystem, commercial, and public services for both historical storm and more severe storm for each scenario. Compared to the historical storms of each scenario, more land is affected when severe storms occur. For ecosystem and public services adopting an adaptive strategy is better than doing nothing. In other words when an adaptive strategy is implemented, more land will be added to the public services land. Commercial services in the do nothing scenario are higher than in any other adaptive strategy because the hiring of professional and trade workers for undertaking environmentally motivated projects is at the expense of commercial services.

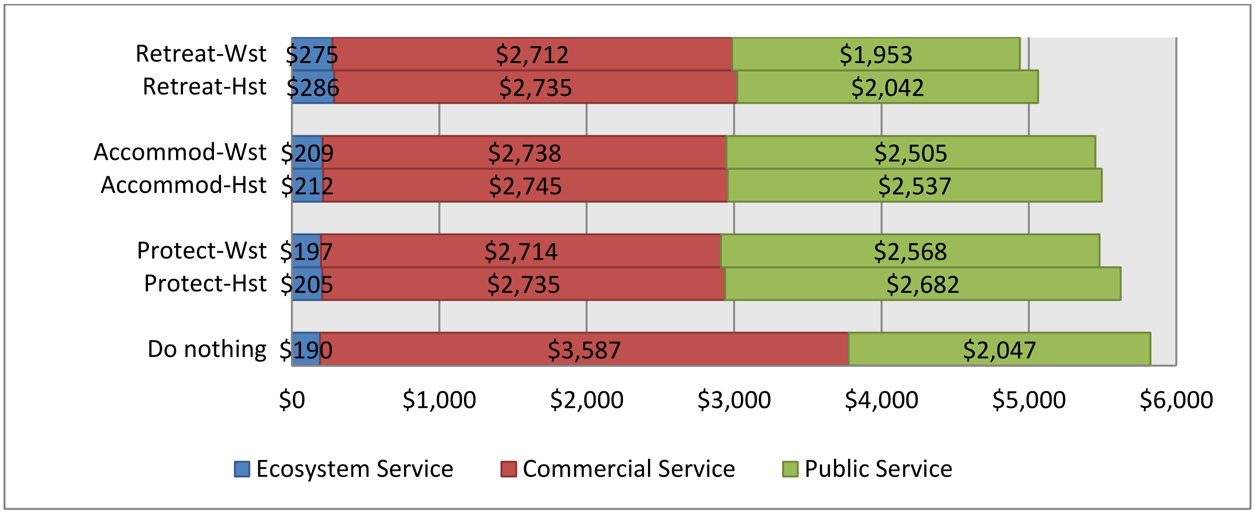

Figure 7. 25: Compare Historical and Worst Case for 3 Services

7.4. Summary

In Chapter 7 the analysis of the scenarios, i.e. adaptation strategies and simulated storm events were presented. Adaptation strategies, (Protect, Accommodate, Retreat, and Do Nothing) are defined in the first subsection, and the three alternative storm events (no storms, historical storms, and more severe storms), were developed in section 7.1. Then, in section 7.2 eight different simulation scenarios were defined (Status Quo, Worst case, and three main adaptation strategies each with historical storms and more severe storms). Selected scenarios represent a complete set of SD model outcomes providing results to assist the evaluation of the adaptation strategies over the 50 years of the planning horizon.

Section 7.3 compared the results of the scenarios' outcome at year 50 of the 50-year simulations. Table 7.9 showed the value of each production service and the acreage for each alternate land use. When the government does not take any action, production's value (services) falls dramatically when a severe storm occurred. After comparing the production's value results for three strategies (protect, accommodation, retreat), the accommodation and protect strategies are the best options respectively among the alternative strategies. Also, compared to the worst case, Accommodate appears to be the best option since the production values do not fall as much when severe storms occur as it does in the other scenarios. The alternate land uses' area (green space, industrial land, cultural and social land, public works land) decreased slightly compared to the base case scenario; however, it has the largest area among the other scenarios including the accommodation scenario with severe storms.

As a result, the suggested adaptation strategy to Charlottetown P.E.I. would be the Accommodation strategy followed by the Protect strategy. Both the Retreat and the Do Nothing strategies are to be avoided.

8. Conclusion and Recommendation

The first section of this chapter summarizes the results of this research in terms of the original research objectives (Section 1.2). The second section contains three subsections including policy recommendations for Charlottetown, limitations of the model, and recommendations for future research.

8.1. Conclusions

The thesis research objectives were stated in Chapter 1, Section 1.2. The following objectives were presented. These are discussed in terms of the thesis results:

Objective1: Model the coastal community with respect to its environmental, economic, social and cultural sustainability pillars.

To achieve this objective, the coastal community of Charlottetown, capital city of the province of Prince Edward Island, is selected as the case study. The four community pillars (Environmental, Economic, Social, Cultural) were modeled based on Charlottetown data, and a list of indicators was established for each "sustainability pillar" of the community as defined in the Integrated Community Sustainability Plan (ICSP) (City of Charlottetown, 2010) (See also Appendix C for the full community Profile pillars, and categories for Charlottetown).

The modeling for this coastal community required a system model with its components rooted in the sustainability pillars of the community. However, the pillars were adjusted from Environment, Economic, Culture, and Social pillars to Land-Use (Environmental), Goods and Services (Economic), Cultural and Social, and Human or population pillars. The model is driven by the population of Charlottetown. Specific indicators were developed for each pillar. These components are linked together over time and affect one another in a SD model. When storms occur, the pillars are impacted by storms, which cause damages to each pillar. Then options to reduce vulnerability against storms are identified. These options are adaptation strategies for the City of Charlottetown.

Objective 2: Define a stochastic process for maximum observed water levels events for Charlottetown based on a statistical analysis of historical data.

This objective is achieved by modeling the stochastic process that underlies maximum observed water level events for Charlottetown. Historical values for maximum observed water level are represented by fitted univariate probability density functions conditional upon the occurrence of a storm. The historical series of maximum water level data for Charlottetown (from 1911 to 2005) are sourced from the national dataset of Environment Canada (2006). Easy-Fit software is used as a tool to select the probability distribution depending on ranking probability distributions in terms of statistical fitness. Its common usage in hydrology is also considered. As a result, the Gumbel Min distribution is chosen as the best fit to all 589 data values recorded for MOWL occurrences in Charlottetown. The annual maximum are, in turn, fitted with the Gumbel Max distribution. (See also Chapter 4, Section 4.3 for details).

Objective 3: Develop a System Dynamics model to simulate, under different storm events and alternative adaptation strategies, the temporal impact of maximum observed water level damage on the interacting four sustainable development pillars of the community capital, namely: the environmental, cultural, social, and economic dimensions.

To achieve this objective, an integrated four-pillar Systems Dynamics (SD) model was designed and calibrated to simulate changes in Charlottetown in response to coastal storms over a 50-year time horizon. Annual storms were simulated to impact Charlottetown's four-community pillars using a stochastic model of historical storm activity (Chapter 5). Using the established community profile, the status quo of Charlottetown was defined and examined so that impacts to the community could be measured against the norm or community status quo. Current data for Charlottetown were used to characterize the initial conditions for the model. 8 different scenarios were defined for Charlottetown, called Status Quo (no storm), Worst Case (Do nothing), Protect-Historical Storms, Protect More Severe Storms, Accommodation-Historical

Storms, Accommodation-More Severe Storms, Retreat-Historical Storms, and Retreat-More Severe Storms.

Finally, strategic long-term adaptation strategies were determined for Charlottetown. Each scenario was evaluated and the results and outputs of these scenarios were reviewed according to the model simulations. Among three main strategies that were investigated in this research, the accommodation strategy looks like the best option. Accommodation outcomes were better than Worst Case ones and sometimes better than the status quo (Base Case) (for more detail see Chapter 6, and 7).

8.2. Recommendations

This section is divided into three subsections: (i) policy recommendations; (ii) limitations of the model; and (iii) recommendations for future research.

8.2.1. Policy recommendation

The total cost from storm damage for Charlottetown, was allocated among the four community sustainability pillars. Information about the relative cost by pillar allows local government leaders to focus on storm preparedness and storm recovery according to which pillars are more heavily prioritized and mostly affected by the storms. As shown in Table 7.9, costs are estimated for the Base Case, Worst Case and other scenarios. Model results show that the Do Nothing option - in the face of predicted more severe storms – defines the Worst Case outcomes. Adaptation strategies reduced Charlottetown's vulnerability. Among these adaptation strategies, Retreat decisions were considered to be the least favorable options for the local Charlottetown government to consider. However, the Accommodation adaptation decision was identified as the best of all adaptation strategies and one that may be considered by local government decision makers.

The second best adaptation strategy identified is the Protect strategy. The acquisition of better scenario cost information would be helpful to policy decision makers.

8.2.2. Limitations of the research

The research is limited by several factors: data, cost estimates, efficacy and flexibility of adaptation strategies, comprehensive information about storm damages, model limitations, SD as a practical selection tool for adaptation strategies and salience of climate change.

1) *Data*. One of the items that should be considered carefully in the modeling and model results is the availability and quality of data. The limitations of the data on services' production and their costs for Charlottetown require that all the production and services cost be estimated by the provincial P.E.I.'s budget. Subsequent values attributed to Charlottetown are scaled down based on population ratios of Charlottetown to the provincial totals. A recommendation to collect and produce data specific to Charlottetown for these production components is suggested as a consequence of this research. Also, the area of the alternative use land data is estimated according to production' proportions since there was not enough/ freely available data pertinent to each land section.

2) *Cost Estimation of adaptation strategies.* A second issue that limits the direct applicability of this research is estimation of the cost of the adaptation strategies. For example, for the Protect strategy, it is estimated that building a protective seawall and seagates, would cost approximately $100 million to protect against 3.75 meters of maximum observable water level for the City of Charlottetown (Delcan, 2012). However, a specific study could be undertaken by Charlottetown's municipal leaders in coordination with the Province of Prince Edward Island to determine where dikes are required, up to what level, at what cost, and how long their construction would take. At the same time, government leaders could cost alternative adaptation strategies complementary or substitutable to dike construction and determine the time requirement for these to be implemented.

3) *Estimation of damages from storms*. In this research, the damages from storms are estimated from earlier work of (Hartt, Master's Thesis, 2011), and (Mohammadi, 2014). It is recommended that research be undertaken to systematically collect storm damage data, their insurance cost, and assets at risk for various storm scenarios.

4) *Efficacy of Adaptation Strategies.* Empirical evidence is lacking as to the ability of alternative strategies to mitigate storm damage (Pilkey & Young, 2009). Further study is required to determine whether protect, accommodate, and retreat and/or combinations of these adaptation approaches are effective in achieving community sustainability.

5) *Planning horizon and flexibility for adaptation strategies* Adaptation to climate change requires longer horizons, such as the planning horizon for this research, than is customary in municipal decision-making. Further research, such as that of Mohammadi (2014), is needed to investigate whether adaptation strategies are able to be incremental (flexible).

6) *SD as a tool in practical decision-making.* The development and application of the SD model used in this research has been suggested to be a valuable tool for investigating complex decision problems. The challenge presented by this work – as part of a community-based research alliance – will be to explain this modeling effort to local government planners and demonstrate how it can be useful to them. In other words, who is going to use and apply this model to Charlottetown? Is the model sufficiently user-friendly? Does it allow easy modification according to new data, and generally new information? And generally, how useful is the model? Due to the inter-disciplinary nature of the SD model it can be used to discuss alternative strategies from clients who have different points of view.

7) *Climate planning as a priority.* This research stresses the importance of planning for pending storm impacts. However, it is a long-term issue, which tends to be buried under more immediate and pressing local issues, e.g., food security, personal safety, access to non-contaminated water, etc. However, climate change needs to be taken into consideration in Charlottetown's official plan and in municipal infrastructure decisions as well as in daily operations. Increasing the salience of climate change in the municipal population as a community issue and in schools is required as well. Children can bring the concern of Climate change as an individual priority to their home, families, relatives, and finally to their communities. In addition, creating a customized checklist, which includes climate considerations to guide the decision-making process for coastal issues can be another help.

8) *Model limitations*. The SD model is predicated upon four major assumptions: 1) the inverse relation between the age of the population and the sizes of the residential and commercial land. 2) The initial land allocation among the production activities reflects the current proportion of these activities in the Charlottetown GDP. Does this assumption bias the results? 3) The Charlottetown area is supposed to remain fixed despite the increase and the aging of the population. 4) Full-employment is assumed with the result that the implementation of a strategy requires the transfer of manpower and land form one sector to another one, transfer, which may cost in terms of sectorial productivity as they differ. Are these four assumptions reasonable?

9) Policy analysis. The policy application in this research is carried out at the local community level in the form of applied adaptation strategies and in the context of the problem situation. As such, policy does not apply to the international or national scales. Expansion of local policy to a broader level is not impossible, however, it is not the relevant concern of this community-based participatory research, which is focused on local issues, local data, local analyses, and local applications.

The following section presents recommendations for future research. These recommendations follow from identification of research gaps.

8.2.3. Recommendations for future research

This section presents a series of potential research questions aimed at developing, calibrating, and monitoring the model results and behavior.

1) Predicting climate and storm impacts. This research only models the annual maximum water levels and storm surges per year from 1911 to 2005. Storms could be modeled in the future. To do this, one needs to introduce winds and barometric pressure. One needs to study the frequency of storms as well as their severity.

2) *Data – collect, organize, institute for storm impacts, vulnerability.* In response to the limitations of the SD model data requirements, it is recommended that Charlottetown – as well as

all coastal communities in Prince Edward Island – develop a procedure and commit resources toward collecting, organizing, and producing storm impacts data. This municipal or provincial collection can be supplemented by volunteers or students by teaching them spatial techniques for mapping floods, data collection, and etc.

3) *Impact of Planning Periods for decision-making.* Evidence form the recent research by Mohammadi (2014) shows that the planning period for decision-making has an impact on the anticipated valuation of the mitigating strategies. When the planning period is short (i.e., 5 years or less), the Status Quo ("Do Nothing") appears to be preferable. When the planning period increases in length, and more and more storms provide evidence for accounting for these storms, the "Do Nothing" strategy (that epitomizes current decision making globally), recedes in attraction and the other adaptation strategies come to the fore.

4) *Adaptation strategies.* This study investigates a structured set of adaptation strategies that calls for a categorization of the decisions as defined in the work of (Pilkey & Young, 2009). Alternative adaptation strategies and mixed or combined adaptations are also possible decision options. Further work on defining the context of adaptation strategies remain to be defined.

5) *Application to other communities.* The work done in this thesis is applicable to the other communities in the C-Change project and could be used by other members of the C-Change team to describe and estimate community vulnerability and storm impacts. The modeling process of this thesis is designed to be helpful for policy and adaptation planning in the hands of community planners and decision makers.

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Appendix A

Probability Density Functions with their characteristic

Table A.1 in Appendix A shows the Probability Distribution Function (PDF) formulas, with their functions and parameters that is used as the best five fitted distributions for maximum observed water level data for City of Charlottetown.

Table A.1: PDF functions with their parameters definition **(MathWave Technologies, 2004-2013)**

PDF Name with their Function and Parameters	
Gumbel	
Function	$$f(x)=\frac{1}{\beta}e^{\left(\frac{x-\mu}{\beta}-e^{\frac{x-\mu}{\beta}}\right)}$$
Parameters	μ : mode (location parameter) β: scale parameter
Weibull	
Function	$$f(x)=\frac{\alpha}{\beta}\left(\frac{x}{\beta}\right)^{\alpha-1}e^{\left(-\left(\frac{x}{\beta}\right)^{\alpha}\right)}$$
Parameters	α : shape parameter β : scale parameter
Generalized logistic	
Function	$$f(x)=\begin{cases}\dfrac{(1+\kappa z)^{-1-\frac{1}{\kappa}}}{\sigma\left(1+(1+\kappa z)^{\frac{-1}{k}}\right)^{2}}, & \kappa\neq 0\\ \dfrac{e^{-z}}{\sigma(1+e^{(-z)})^{2}}, & \kappa=0\end{cases}$$ $$z\equiv\frac{x-\mu}{\sigma}$$
Parameters	κ : shape parameter σ :scale parameter μ: location parameter
Dagum	
Function	$$f(x)=\frac{\alpha\kappa\left(\frac{x}{\beta}\right)^{\alpha k-1}}{\beta(1+(\frac{x}{\beta})^{\alpha})^{\kappa+1}}$$
Parameters	X: random variable, α and κ: shape parameters β: a scale parameter
Burr (4 parameter)	
Function	$$f(x)=\frac{\alpha\kappa\left(\frac{x-\gamma}{\beta}\right)^{\alpha-1}}{\beta\left(1+\left(\frac{x-\gamma}{\beta}\right)^{\alpha}\right)^{\kappa+1}}$$
Parameters	κ and α : shape parameters β : scale parameter γ: location parameter

Appendix B

Charlottetown Storm surges and Water Level Data

B1. Raw Data from 1911-1960

Table B.1 shows the raw data for storm surge happening with the start and end date, duration of each storm surge, and water level at maximum surge in meter and observed water level in local Chart Data from 1911-1960.

Table B. 1: Raw data for MWL, Storm Surge height, Water level at Max Surge 1911-1960 **(Parkes, 2006)**

Start	End	Duration (Hours)	Surge Height (m)	Water Lvl at Max Surge	Maximum Water Level (m CD)
Oct 05, 1911 17:00	Oct 05, 1911 17:00	1	0.62	1.85	2.31
Oct 13, 1911 19:00	Oct 13, 1911 22:00	3	0.73	2.06	2.58
Nov 25, 1911 11:00	Nov 25, 1911 17:00	6	0.71	3.07	3.07
Nov 26, 1911 20:00	Nov 26, 1911 23:00	3	0.65	2.29	2.73
Dec 29, 1911 23:00	Dec 30, 1911 04:00	5	0.85	2.13	2.55
Jan 06, 1912 08:00	Jan 06, 1912 13:00	5	0.71	2.51	3.22
Mar 30, 1912 08:00	Mar 30, 1912 13:00	5	0.8	3.04	3.04
Apr 03, 1912 19:00	Apr 03, 1912 21:00	2	0.66	1.12	2.98
Nov 29, 1912 07:00	Nov 29, 1912 12:00	5	0.75	1.26	2.31
Nov 30, 1912 15:00	Nov 30, 1912 17:00	2	0.65	3.1	3.1
Dec 09, 1912 10:00	Dec 09, 1912 11:00	1	0.68	2.89	2.96
Dec 17, 1912 10:00	Dec 17, 1912 13:00	3	0.7	1.94	2.08
Dec 28, 1912 00:00	Dec 28, 1912 14:00	11	0.72	2.66	3.36
Jan 04, 1913 07:00	Jan 04, 1913 11:00	4	0.64	2.94	2.94
Jan 25, 1913 23:00	Jan 26, 1913 01:00	2	0.64	3.04	3.29
Feb 18, 1913 23:00	Feb 19, 1913 06:00	7	0.86	1.46	2.88
Feb 23, 1913 08:00	Feb 23, 1913 14:00	6	0.66	1.96	3.26
Apr 01, 1913 15:00	Apr 01, 1913 18:00	3	0.72	2.48	2.66
Dec 27, 1913 10:00	Dec 27, 1913 14:00	4	0.72	3.24	3.24
Jan 10, 1914 21:00	Jan 11, 1914 03:00	6	0.71	3.01	3.15
Jan 13, 1914 08:00	Jan 13, 1914 13:00	5	0.77	2.69	3.08
Jan 18, 1914 09:00	Jan 18, 1914 10:00	1	0.61	1.41	2.98
Jan 22, 1914 02:00	Jan 22, 1914 09:00	7	0.64	1.72	2.8
Jan 25, 1914 16:00	Jan 26, 1914 00:00	8	0.88	2.72	3.3
Feb 12, 1914 03:00	Feb 12, 1914 05:00	2	0.66	1.95	2.76
Feb 17, 1914 08:00	Feb 17, 1914 21:00	13	1.15	2.57	3.4
Feb 18, 1914 19:00	Feb 19, 1914 00:00	5	0.88	1.96	2.66
Mar 03, 1914 05:00	Mar 03, 1914 13:00	8	0.81	2.3	2.89
Apr 02, 1914 18:00	Apr 02, 1914 22:00	4	0.69	1.44	2.45
Dec 15, 1914 03:00	Dec 15, 1914 04:00	1	0.62	1.14	1.96
Mar 18, 1915 07:00	Mar 18, 1915 20:00	2	0.64	1.2	2.37
Nov 24, 1916 19:00	Nov 24, 1916 21:00	2	0.62	3.11	3.15
Dec 07, 1916 11:00	Dec 07, 1916 12:00	1	0.62	2.86	3
Dec 23, 1916 15:00	Dec 23, 1916 18:00	3	0.72	2.37	2.74
Feb 10, 1917 10:00	Feb 10, 1917 14:00	4	0.82	2.85	3.07
Mar 06, 1917 14:00	Mar 06, 1917 19:00	5	0.84	2.23	2.75
Dec 02, 1917 20:00	Dec 03, 1917 04:00	8	0.82	2.9	3.34
Jan 16, 1918 14:00	Jan 16, 1918 16:00	2	0.64	3.05	3.23
Feb 25, 1918 09:00	Feb 25, 1918 12:00	3	0.67	2.84	2.96
Mar 03, 1918 14:00	Mar 03, 1918 20:00	6	0.76	2.32	3.03
Mar 05, 1918 09:00	Mar 05, 1918 11:00	2	0.63	2.04	2.41
Mar 11, 1918 00:00	Mar 11, 1918 10:00	10	1.04	2.01	3

Mar 18, 1918 08:00	Mar 18, 1918 11:00	3	0.72	1.79	2.93
Mar 24, 1918 15:00	Mar 24, 1918 16:00	1	0.61	1.83	2.21
Dec 29, 1918 09:00	Dec 29, 1918 13:00	2	0.64	2.7	2.7
Jan 17, 1920 22:00	Jan 18, 1920 02:00	4	0.64	1.99	2.83
Mar 21, 1920 12:00	Mar 21, 1920 13:00	1	0.61	3.07	3.07
Oct 31, 1922 08:00	Oct 31, 1922 14:00	6	0.8	2.61	2.86
Jan 29, 1923 23:00	Jan 30, 1923 02:00	3	0.71	1.72	2.63
Mar 07, 1923 19:00	Mar 08, 1923 11:00	12	1.17	2.05	3.12
Mar 31, 1923 17:00	Mar 31, 1923 19:00	2	0.62	1.99	2.3
Oct 28, 1925 08:00	Oct 28, 1925 13:00	5	0.78	3.03	3.12
Dec 24, 1925 15:00	Dec 24, 1925 18:00	3	0.69	3.03	3.03
Dec 27, 1925 16:00	Dec 27, 1925 19:00	3	0.65	2.73	2.88
Feb 05, 1926 06:00	Feb 05, 1926 17:00	11	1.07	2.2	3.05
Feb 11, 1926 02:00	Feb 11, 1926 06:00	4	0.72	1.19	2.75
Feb 15, 1926 19:00	Feb 15, 1926 21:00	2	0.69	1.59	1.83
Feb 20, 1926 09:00	Feb 20, 1926 10:00	1	0.61	2.04	2.72
Feb 26, 1926 22:00	Feb 27, 1926 03:00	5	0.73	2.84	3.05
May 08, 1926 21:00	May 09, 1926 04:00	5	0.75	1.59	2.9
Dec 27, 1931 05:00	Dec 27, 1931 06:00	1	0.61	1.21	2.34
Feb 05, 1932 19:00	Feb 05, 1932 21:00	2	0.67	2.82	3.03
Feb 21, 1932 01:00	Feb 21, 1932 05:00	4	0.77	1.72	2.57
Mar 02, 1932 22:00	Mar 03, 1932 05:00	7	1	1.72	2.73
Mar 04, 1932 00:00	Mar 04, 1932 04:00	4	0.8	1.51	2.73
Apr 17, 1932 06:00	Apr 17, 1932 07:00	1	0.6	2.57	2.63
Nov 25, 1938 15:00	Nov 25, 1938 22:00	6	0.82	2.83	3.01
Nov 27, 1938 01:00	Nov 27, 1938 03:00	2	0.7	3.07	3.16
Nov 28, 1938 04:00	Nov 28, 1938 08:00	4	0.69	2	2.8
Nov 29, 1938 08:00	Nov 29, 1938 09:00	1	0.6	1.67	1.7
Dec 13, 1938 15:00	Dec 13, 1938 19:00	4	0.81	3.41	3.41
Jan 02, 1939 21:00	Jan 03, 1939 00:00	3	0.67	2.71	2.92
Jan 25, 1939 03:00	Jan 25, 1939 04:00	1	0.61	2.68	2.92
Feb 13, 1939 11:00	Feb 13, 1939 12:00	1	0.61	2.1	2.19
Feb 27, 1939 18:00	Feb 27, 1939 22:00	4	0.73	1.94	2.74
Mar 14, 1939 09:00	Mar 14, 1939 16:00	7	0.79	2.31	2.71
Oct 19, 1939 05:00	Oct 19, 1939 06:00	1	0.6	2.49	2.74
Oct 20, 1939 05:00	Oct 20, 1939 06:00	1	0.62	2.71	2.83
Feb 09, 1940 14:00	Feb 09, 1940 20:00	4	0.86	1.99	2.81
Feb 12, 1940 04:00	Feb 12, 1940 09:00	5	0.77	1.59	2.93
Sep 17, 1940 00:00	Sep 17, 1940 07:00	7	0.77	1.59	3.04
Oct 18, 1940 14:00	Oct 18, 1940 15:00	1	0.63	2.87	3.04
Oct 22, 1940 09:00	Oct 22, 1940 10:00	1	0.61	1.36	1.9
Nov 23, 1940 02:00	Nov 23, 1940 05:00	3	0.73	3.01	3.01
Jan 05, 1941 00:00	Jan 05, 1941 12:00	12	1.01	3.1	3.18
Jan 06, 1941 07:00	Jan 06, 1941 14:00	7	0.79	2.14	2.55
Jan 29, 1941 19:00	Jan 29, 1941 20:00	1	0.61	1.75	3
Feb 09, 1941 22:00	Feb 10, 1941 02:00	4	0.8	2.63	2.75
Feb 20, 1941 19:00	Feb 21, 1941 01:00	6	0.75	2.19	2.89
Sep 03, 1941 01:00	Sep 03, 1941 03:00	2	0.65	2.04	2.19
Sep 29, 1941 12:00	Sep 29, 1941 14:00	2	0.95	1.68	1.93
Oct 11, 1941 22:00	Oct 12, 1941 01:00	3	0.78	2.63	2.9
Nov 17, 1941 10:00	Nov 17, 1941 11:00	1	0.62	3.01	3.03
Dec 08, 1941 02:00	Dec 08, 1941 08:00	6	0.96	2.49	3.15
Jan 13, 1942 14:00	Jan 13, 1942 15:00	1	0.66	2.13	2.51
Feb 27, 1942 14:00	Feb 27, 1942 16:00	2	0.62	2.24	2.48
Mar 07, 1942 04:00	Mar 07, 1942 05:00	1	0.68	2.59	3.02
Mar 07, 1942 16:00	Mar 07, 1942 20:00	4	0.86	1.99	2.88
Apr 12, 1942 04:00	Apr 12, 1942 07:00	3	0.63	1.74	2.85
Oct 06, 1942 01:00	Oct 06, 1942 06:00	5	0.78	2.41	2.65
Oct 19, 1942 08:00	Oct 19, 1942 15:00	7	0.73	1.66	2.79
Dec 02, 1942 23:00	Dec 03, 1942 08:00	8	0.99	3.09	3.09
Dec 16, 1942 16:00	Dec 16, 1942 20:00	4	0.66	3.03	3.11
Jan 22, 1943 04:00	Jan 22, 1943 05:00	1	0.61	1.49	2.44
Feb 27, 1943 17:00	Feb 27, 1943 19:00	2	0.61	2.42	2.91
Apr 15, 1943 01:00	Apr 15, 1943 02:00	1	0.6	1.66	1.87
Nov 14, 1943 00:00	Nov 14, 1943 03:00	3	0.74	3.38	3.38
Nov 30, 1943 23:00	Dec 01, 1943 06:00	7	0.82	3.55	3.55

Dec 22, 1943 06:00	Dec 22, 1943 12:00	6	1.07	2.94	2.97
Feb 12, 1944 22:00	Feb 13, 1944 03:00	5	0.71	3.11	3.11
Feb 18, 1944 20:00	Feb 19, 1944 02:00	6	0.95	1.84	2.83
Mar 02, 1944 08:00	Mar 03, 1944 01:00	7	0.71	1.99	2.77
Oct 29, 1944 21:00	Oct 30, 1944 03:00	6	0.88	2.97	3.29
Nov 06, 1944 00:00	Nov 06, 1944 12:00	8	0.8	1.32	3.12
Dec 12, 1944 18:00	Dec 12, 1944 19:00	1	0.62	2.73	2.85
Dec 13, 1944 07:00	Dec 13, 1944 09:00	2	0.63	2.73	2.85
Dec 28, 1944 11:00	Dec 28, 1944 19:00	8	0.81	2.73	3.08
Dec 30, 1944 02:00	Dec 30, 1944 03:00	1	0.62	1.98	2.79
Jan 27, 1945 03:00	Jan 27, 1945 09:00	6	0.75	1.33	2.9
May 11, 1945 23:00	May 12, 1945 02:00	3	0.66	3.36	3.36
Nov 15, 1945 11:00	Nov 16, 1945 00:00	11	0.81	2.62	2.98
Dec 11, 1945 12:00	Dec 11, 1945 21:00	9	0.8	3.08	3.1
Dec 12, 1945 18:00	Dec 12, 1945 23:00	5	0.72	2.44	2.81
Dec 20, 1945 10:00	Dec 20, 1945 12:00	2	0.62	2.78	3.33
Dec 30, 1945 11:00	Dec 30, 1945 12:00	1	0.65	2.46	2.67
Dec 31, 1945 18:00	Dec 31, 1945 22:00	4	0.71	3.01	3.05
Jan 19, 1946 23:00	Jan 20, 1946 01:00	2	0.63	3.33	3.33
Feb 16, 1946 10:00	Feb 16, 1946 18:00	8	0.76	3.17	3.23
Feb 25, 1946 08:00	Feb 25, 1946 14:00	6	0.75	2.27	2.78
Mar 10, 1946 05:00	Mar 10, 1946 06:00	1	0.6	2.81	2.84
Mar 13, 1946 14:00	Mar 13, 1946 15:00	1	0.63	2.23	2.49
Mar 28, 1946 09:00	Mar 28, 1946 11:00	2	0.63	2.52	2.52
Apr 11, 1946 01:00	Apr 11, 1946 03:00	2	0.63	1.36	2.78
Dec 02, 1946 00:00	Dec 02, 1946 03:00	3	0.68	2.72	2.84
Feb 06, 1947 03:00	Feb 06, 1947 04:00	1	0.6	1.44	2.78
Feb 17, 1947 19:00	Feb 18, 1947 05:00	10	0.78	2.43	2.87
Feb 22, 1947 02:00	Feb 22, 1947 06:00	4	0.62	1.94	2.96
Mar 30, 1947 11:00	Mar 30, 1947 16:00	5	0.71	2.69	2.98
May 14, 1947 09:00	May 14, 1947 13:00	4	0.84	2.35	2.38
Oct 23, 1947 22:00	Oct 24, 1947 02:00	4	0.68	2.32	2.35
Nov 25, 1947 17:00	Nov 25, 1947 22:00	5	0.81	3.08	3.11
Jan 10, 1948 16:00	Jan 10, 1948 17:00	1	0.61	2.19	2.22
Jan 19, 1948 04:00	Jan 19, 1948 05:00	1	0.62	2.75	2.75
Feb 09, 1948 01:00	Feb 09, 1948 03:00	2	0.67	2.25	2.83
Feb 14, 1948 22:00	Feb 15, 1948 04:00	6	0.89	3.22	3.22
Apr 27, 1948 05:00	Apr 27, 1948 07:00	2	0.64	2.01	2.89
Aug 14, 1948 06:00	Aug 14, 1948 08:00	2	0.61	2.77	2.95
Dec 20, 1948 15:00	Dec 20, 1948 16:00	1	0.61	3.07	3.07
Feb 11, 1949 17:00	Feb 11, 1949 19:00	2	0.61	2.58	2.95
Mar 02, 1949 07:00	Mar 02, 1949 11:00	4	0.64	2.04	2.83
Mar 16, 1949 10:00	Mar 16, 1949 13:00	3	0.8	3.29	3.38
Apr 24, 1949 20:00	Apr 25, 1949 00:00	4	0.78	2.8	2.89
Aug 09, 1949 12:00	Aug 09, 1949 14:00	2	0.65	2.68	3.1
Aug 19, 1949 23:00	Aug 20, 1949 02:00	3	0.71	2.37	2.55
Nov 02, 1949 13:00	Nov 02, 1949 14:00	1	0.67	2.01	2.74
Nov 23, 1949 02:00	Nov 23, 1949 03:00	1	0.61	2.71	3.25
Dec 31, 1949 00:00	Dec 31, 1949 05:00	5	0.86	1.88	2.01
Jan 14, 1950 19:00	Jan 15, 1950 01:00	5	0.69	2.95	3.1
Jan 19, 1950 00:00	Jan 19, 1950 07:00	7	0.9	2.4	3.16
Feb 21, 1950 01:00	Feb 21, 1950 03:00	2	0.62	3.01	3.01
Feb 24, 1950 02:00	Feb 24, 1950 05:00	3	0.7	2.8	2.8
Feb 25, 1950 09:00	Feb 25, 1950 17:00	8	0.89	2.49	3.01
Apr 08, 1950 10:00	Apr 08, 1950 23:00	8	0.78	2.98	3.22
Dec 19, 1950 04:00	Dec 19, 1950 06:00	2	0.71	2.37	2.58
Jan 08, 1951 14:00	Jan 08, 1951 18:00	2	0.65	2.09	3.21
Jan 11, 1951 03:00	Jan 11, 1951 06:00	3	0.63	2.12	2.6
Oct 29, 1951 10:00	Oct 29, 1951 11:00	1	0.65	3.12	3.12
Nov 27, 1951 02:00	Nov 28, 1951 02:00	15	0.96	3.34	3.34
Dec 15, 1951 18:00	Dec 16, 1951 03:00	9	0.95	3.37	3.4
Dec 19, 1951 17:00	Dec 19, 1951 22:00	5	1.11	2.76	2.91
Dec 20, 1951 14:00	Dec 20, 1951 19:00	5	0.8	3.06	3.06
Dec 21, 1951 23:00	Dec 22, 1951 04:00	5	0.82	2.79	2.85
Jan 11, 1952 10:00	Jan 11, 1952 20:00	10	1.03	3	3.06
Feb 05, 1952 14:00	Feb 05, 1952 18:00	4	0.72	2.94	2.97

Feb 09, 1952 21:00	Feb 10, 1952 02:00	5	0.71	3.06	3.06
Feb 18, 1952 18:00	Feb 19, 1952 01:00	7	0.8	1.6	2.82
Feb 20, 1952 09:00	Feb 21, 1952 00:00	4	0.63	1.6	2.79
Feb 28, 1952 08:00	Feb 28, 1952 21:00	12	0.97	1.75	3.37
Feb 29, 1952 23:00	Mar 01, 1952 02:00	3	0.62	2.6	3.06
Mar 15, 1952 03:00	Mar 15, 1952 04:00	1	0.63	2.7	2.94
Nov 07, 1952 02:00	Nov 07, 1952 08:00	6	0.85	2.67	3.09
Jan 04, 1953 13:00	Jan 04, 1953 15:00	2	0.61	2.88	2.97
Jan 29, 1953 10:00	Jan 29, 1953 11:00	1	0.64	2.76	2.91
Feb 09, 1953 21:00	Feb 10, 1953 01:00	4	0.78	1.96	2.54
Feb 11, 1953 00:00	Feb 11, 1953 01:00	1	0.61	1.54	2.03
Mar 05, 1953 07:00	Mar 05, 1953 09:00	2	0.61	1.66	2.33
Mar 11, 1953 01:00	Mar 11, 1953 03:00	2	0.63	1.48	2.48
May 25, 1953 02:00	May 25, 1953 06:00	4	0.79	2.18	2.54
Dec 09, 1953 01:00	Dec 09, 1953 02:00	1	0.61	3	3.21
Jan 12, 1954 15:00	Jan 12, 1954 22:00	7	0.95	2.75	3.42
Jan 13, 1954 20:00	Jan 14, 1954 00:00	4	0.73	2.05	2.81
Jan 28, 1954 11:00	Jan 28, 1954 23:00	12	0.89	2.99	3.08
Jan 29, 1954 10:00	Jan 29, 1954 13:00	3	0.63	2.26	2.75
Feb 09, 1954 21:00	Feb 10, 1954 06:00	9	1.11	2.47	3.2
Feb 11, 1954 12:00	Feb 11, 1954 13:00	1	0.61	2.2	2.72
Feb 12, 1954 14:00	Feb 12, 1954 17:00	3	0.74	2.96	2.99
Mar 12, 1954 20:00	Mar 13, 1954 00:00	4	0.77	1.71	2.2
Mar 16, 1954 20:00	Mar 16, 1954 21:00	1	0.61	2.87	2.9
Sep 12, 1954 01:00	Sep 12, 1954 03:00	2	0.75	2.44	2.59
Sep 12, 1954 13:00	Sep 12, 1954 17:00	4	1.02	1.86	2.66
Nov 30, 1954 01:00	Nov 30, 1954 08:00	7	0.94	2.5	3.14
Dec 29, 1954 19:00	Dec 29, 1954 21:00	2	0.77	2.14	2.14
Jan 14, 1955 15:00	Jan 15, 1955 06:00	10	0.66	3.02	3.05
Jan 16, 1955 03:00	Jan 16, 1955 09:00	6	0.74	2.84	2.84
Mar 23, 1955 17:00	Mar 23, 1955 18:00	1	0.61	1.5	1.59
Sep 21, 1955 03:00	Sep 21, 1955 05:00	2	0.62	2.41	3.05
Oct 29, 1955 01:00	Oct 29, 1955 04:00	3	0.64	1.8	2.26
Nov 20, 1955 18:00	Nov 21, 1955 09:00	15	0.92	2.87	3.11
Nov 29, 1955 14:00	Nov 29, 1955 15:00	1	0.6	2.32	3.05
Jan 31, 1956 10:00	Jan 31, 1956 12:00	2	0.69	2.11	3.14
Mar 17, 1956 09:00	Mar 17, 1956 21:00	12	0.91	3.23	3.39
Dec 13, 1956 22:00	Dec 14, 1956 00:00	2	0.68	2.23	2.72
Jan 08, 1957 05:00	Jan 08, 1957 17:00	12	1.18	2.65	3.16
Jan 23, 1957 20:00	Jan 24, 1957 02:00	6	0.71	1.64	2.34
Feb 10, 1957 14:00	Feb 11, 1957 03:00	4	0.69	1.46	2.92
Feb 16, 1957 03:00	Feb 16, 1957 08:00	5	0.73	1.15	2.83
Feb 27, 1957 22:00	Feb 28, 1957 00:00	2	0.7	3.01	3.01
Mar 11, 1957 12:00	Mar 11, 1957 15:00	3	0.7	2.34	2.68
Apr 10, 1957 00:00	Apr 10, 1957 03:00	3	0.64	1.46	2.77
Sep 28, 1957 08:00	Sep 28, 1957 11:00	3	0.67	1.18	2.49
Dec 03, 1957 01:00	Dec 03, 1957 04:00	3	0.79	1.91	2.13
Dec 13, 1957 03:00	Dec 13, 1957 04:00	1	0.62	3.07	3.07
Feb 02, 1958 23:00	Feb 03, 1958 03:00	4	0.68	1.88	3.01
Feb 14, 1958 05:00	Feb 14, 1958 12:00	7	0.83	2.74	2.89
Feb 25, 1958 23:00	Feb 26, 1958 04:00	3	0.64	2.74	2.74
Mar 22, 1958 19:00	Mar 22, 1958 22:00	3	0.65	1.37	2.8
Apr 07, 1958 16:00	Apr 08, 1958 08:00	6	0.69	2.43	3.13
Sep 29, 1958 06:00	Sep 29, 1958 12:00	6	0.97	2.8	3.16
Nov 10, 1958 21:00	Nov 10, 1958 22:00	1	0.63	3.32	3.32
Nov 29, 1958 18:00	Nov 29, 1958 23:00	5	0.97	2.52	2.95
Nov 30, 1958 19:00	Nov 30, 1958 22:00	3	0.76	2.16	2.71
Dec 03, 1958 02:00	Dec 03, 1958 03:00	1	0.6	2.98	2.98
Jan 05, 1959 12:00	Jan 05, 1959 17:00	5	0.68	2.19	3.07
Feb 19, 1959 05:00	Feb 19, 1959 12:00	7	0.64	2.49	2.58
Feb 19, 1959 22:00	Feb 19, 1959 23:00	1	0.63	2.34	2.58
Mar 03, 1959 18:00	Mar 03, 1959 22:00	4	0.73	2.74	3.01
Mar 07, 1959 16:00	Mar 07, 1959 17:00	1	0.63	1.82	1.94
Mar 13, 1959 20:00	Mar 14, 1959 00:00	4	0.89	1.85	2.62
Jun 20, 1959 04:00	Jun 20, 1959 06:00	2	0.63	1.98	2.28

B.2: Raw Data from 1960-2005

Table B.2 shows all the raw data for storm surge events with the start and end date, duration of water level at maximum surge and maximum water level from local Chart Data from 1960-2005.

Table B. 2: Raw data for MWL, Storm Surge height, Water level at Max Surge 1960-2005 **(Parkes, 2006)**

Start Day	End Day	Start Time	End Time	Duration	Surge Height (m)	Surge Maximum	Maximum Water Level (m CD)
01/05/60	01/05/60			1	0.62	2.39	2.85
01/11/60	01/12/60	1/11/1960 23:00	1/12/1960 3:00	7	0.77	2.12	2.91
01/20/60	01/20/60	1/20/1960 15:00	1/20/1960 16:00	2	0.67	3.12	3.12
03/09/60	03/09/60	3/9/1960 12:00	3/9/1960 22:00	10	0.76	2.7	2.79
03/14/60	03/14/60			2	0.61	2.03	2.85
03/26/60	03/26/60	3/26/1960 0:00	3/26/1960 2:00	2	0.67	2.54	2.88
01/04/61	01/05/61	1/4/1961 19:00	1/5/1961 2:00	8	0.9	3.4	3.4
01/20/61	01/21/61	1/20/1961 16:00	1/21/1961 10:00	18	1.31	3.28	3.89
01/22/61	01/22/61			4	0.65	3.18	3.18
02/27/61	02/27/61	2/27/1961 2:00	2/27/1961 7:00	5	0.88	1.87	2.54
03/10/61	03/10/61	3/10/1961 8:00	3/10/1961 12:00	4	0.74	2.06	2.39
03/21/61	03/21/61	3/21/1961 6:00	3/21/1961 9:00	5	0.8	1.69	2.48
03/26/61	03/27/61	3/26/1961 22:00	3/27/1961 2:00	3	0.67	1.75	2.54
12/25/61	12/25/61	12/25/1961 9:00	12/25/1961 10:00	3	0.66	1.73	3.07
01/27/62	01/27/62	1/27/1962 17:00	1/27/1962 19:00	2	0.8	2.57	2.79
01/28/62	01/28/62	1/28/1962 19:00	1/28/1962 23:00	4	0.71	2.1	2.46
03/04/62	03/04/62	3/4/1962 0:00	3/4/1962 4:00	6	0.87	1.51	2.33
03/23/62	03/23/62	3/23/1962 16:00	3/23/1962 22:00	7	1.02	1.78	2.88
04/14/62	04/14/62	4/14/1962 17:00	4/14/1962 20:00	4	0.69	2.67	2.74
10/13/62	10/13/62			2	0.62	1.22	1.78
12/23/62	12/23/62			4	0.64	2.65	2.75
12/31/62	12/31/62			2	0.63	2.27	3.04
01/25/63	01/26/63	1/25/1963 18:00	1/26/1963 0:00	6	0.77	3.04	3.35
02/20/63	02/20/63	2/20/1963 12:00	2/20/1963 18:00	8	1.02	2.8	2.92
02/21/63	02/22/63	2/21/1963 21:00	2/22/1963 2:00	6	0.76	2.5	2.97
04/05/63	04/05/63	4/5/1963 10:00	4/5/1963 11:00	2	0.68	2.83	2.84
04/06/63	04/06/63	4/6/1963 15:00	4/6/1963 17:00	3	0.67	1.76	2.3
04/09/63	04/09/63	4/9/1963 2:00	4/9/1963 6:00	5	0.72	1.75	2.96
04/11/63	04/11/63	4/11/1963 13:00	4/11/1963 21:00	9	0.8	1.45	3.02
09/13/63	09/13/63	9/13/1963 11:00	9/13/1963 13:00	3	0.7	1.65	2.44
10/29/63	10/29/63	10/29/1963 19:00	10/29/1963 23:00	5	0.73	3.01	3.05
10/30/63	10/30/63	10/30/1963 9:00	10/30/1963 13:00	4	0.94	3.07	3.19
10/31/63	10/31/63			1	0.61	2.28	2.84
11/27/63	11/28/63	11/27/1963 22:00	11/28/1963 3:00	5	1.03	2.26	2.63
12/19/63	12/19/63	12/19/1963 16:00	12/19/1963 23:00	9	1.43	3	3.05
01/10/64	01/11/64	1/10/1964 20:00	1/11/1964 2:00	6	0.71	1.98	2.91
01/14/64	01/14/64	1/14/1964 17:00	1/14/1964 23:00	9	0.71	2.4	3.19
02/17/64	02/17/64	2/17/1964 5:00	2/17/1964 9:00	5	0.75	1.35	2.96
03/19/64	03/19/64	3/19/1964 20:00	3/19/1964 22:00	9	0.73	1.12	3.08
12/01/64	12/01/64	12/1/1964 15:00	12/1/1964 21:00	5	0.87	2.21	3.08
01/04/65	01/04/65	1/4/1965 1:00	1/4/1965 7:00	6	0.87	2.14	2.94
01/09/65	01/10/65	1/9/1965 23:00	1/10/1965 1:00	2	0.72	2.3	2.53
01/21/65	01/21/65	1/21/1965 2:00	1/21/1965 3:00	2	0.64	3.24	3.38
02/02/65	02/02/65			3	0.63	2.52	2.86
03/25/65	03/25/65			2	0.63	2.16	2.19
03/27/65	03/27/65			2	0.6	2.19	2.27
04/04/65	04/04/65	4/4/1965 6:00	4/4/1965 8:00	3	0.75	1.63	2.09
11/18/65	11/18/65			2	0.63	2.44	2.81
12/26/65	12/26/65	12/26/1965 16:00	12/26/1965 18:00	4	0.65	2.75	2.88
01/09/66	01/09/66	1/9/1966 11:00	1/9/1966 19:00	9	0.88	3.38	3.4
01/28/66	01/29/66	1/28/1966 10:00	1/29/1966 2:00	17	0.96	2.15	3.01

02/17/66	02/18/66	2/17/1966 21:00	2/18/1966 0:00	3	0.74	2.88	2.94
03/02/66	03/02/66	3/2/1966 9:00	3/2/1966 14:00	6	0.85	2.45	2.62
04/01/66	04/01/66			1	0.6	2.13	2.63
12/15/66	12/15/66	12/15/1966 7:00	12/15/1966 9:00	3	0.74	1.3	1.83
02/03/67	02/03/67	2/3/1967 13:00	2/3/1967 14:00	1	0.64	2.34	2.97
02/08/67	02/08/67	2/8/1967 3:00	2/8/1967 10:00	7	1.07	1.93	2.64
02/09/67	02/09/67	2/9/1967 8:00	2/9/1967 11:00	4	0.7	2.39	2.93
02/23/67	02/23/67	2/23/1967 12:00	2/23/1967 17:00	5	0.73	2.25	2.88
03/09/67	03/09/67			2	0.61	1.65	2.22
12/27/67	12/27/67	12/27/1967 0:00	12/27/1967 1:00	1	0.64	1.51	1.75
12/30/67	12/30/67			2	0.61	0.98	1.51
01/05/68	01/05/68	1/5/1968 19:00	1/5/1968 21:00	2	0.75	2.34	2.46
01/08/68	01/08/68	1/8/1968 2:00	1/8/1968 3:00	4	0.63	2.47	2.59
01/16/68	01/16/68	1/16/1968 4:00	1/16/1968 9:00	5	0.82	1.4	2.64
02/20/68	02/20/68	2/20/1968 20:00	2/20/1968 21:00	3	0.64	1.52	2.57
03/01/68	03/02/68	3/1/1968 23:00	3/2/1968 7:00	7	0.76	2.71	3.15
10/21/68	10/21/68	10/21/1968 13:00	10/21/1968 19:00	5	0.74	1.71	2.96
11/14/68	11/14/68			1	0.61	2.39	2.55
11/26/68	11/26/68	11/26/1968 8:00	11/26/1968 11:00	3	0.7	1.21	2.32
12/08/68	12/09/68	12/8/1968 21:00	12/9/1968 10:00	13	1.27	3.12	3.36
12/10/68	12/10/68	12/10/1968 6:00	12/10/1968 10:00	4	0.71	1.43	2.19
01/08/69	01/08/69	1/8/1969 3:00	1/8/1969 9:00	6	0.72	1.44	2.81
03/07/69	03/07/69			2	0.63	1.58	2.29
03/08/69	03/08/69	3/8/1969 8:00	3/8/1969 11:00	3	0.72	1.95	2.94
03/13/69	03/13/69	3/13/1969 1:00	3/13/1969 4:00	5	0.66	1.79	2.49
10/04/69	10/04/69	10/4/1969 12:00	10/4/1969 17:00	5	0.84	2.34	2.57
10/21/69	10/21/69	10/21/1969 2:00	10/21/1969 5:00	3	0.67	2.26	2.79
12/23/69	12/23/69	12/23/1969 13:00	12/23/1969 18:00	5	0.84	2.85	2.91
01/15/70	01/15/70	1/15/1970 8:00	1/15/1970 15:00	8	0.9	2.09	2.99
01/22/70	01/22/70			1	0.6	2.29	2.89
04/03/70	04/03/70	4/3/1970 14:00	4/3/1970 19:00	6	0.74	2.49	2.91
10/17/70	10/17/70	10/17/1970 18:00	10/17/1970 21:00	4	0.79	1.84	2.64
11/06/70	11/06/70	11/6/1970 4:00	11/6/1970 11:00	8	0.73	2.64	3.08
12/04/70	12/05/70	12/4/1970 20:00	12/5/1970 22:00	17	0.88	2.7	3.09
12/06/70	12/07/70	12/6/1970 21:00	12/7/1970 14:00	17	1	2.09	3.02
12/18/70	12/18/70	12/18/1970 11:00	12/18/1970 12:00	3	0.64	2.08	2.75
12/25/70	12/25/70	12/25/1970 0:00	12/25/1970 13:00	14	1.03	3.17	3.17
12/27/70	12/27/70	12/27/1970 0:00	12/27/1970 8:00	8	0.99	1.6	2.63
01/18/71	01/18/71	1/18/1971 7:00	1/18/1971 9:00	3	0.65	1.95	2.32
01/20/71	01/20/71	1/20/1971 18:00	1/20/1971 21:00	3	0.67	2.44	2.79
01/27/71	01/27/71	1/27/1971 17:00	1/27/1971 20:00	3	0.81	2.26	2.74
01/31/71	01/31/71	1/31/1971 2:00	1/31/1971 4:00	3	0.67	3.06	3.31
03/05/71	03/05/71	3/5/1971 9:00	3/5/1971 14:00	9	0.91	2.55	2.7
03/06/71	03/06/71	3/6/1971 3:00	3/6/1971 5:00	2	0.65	2.26	2.42
04/08/71	04/08/71	4/8/1971 7:00	4/8/1971 9:00	3	0.69	2.47	2.74
11/16/71	11/16/71	11/16/1971 3:00	11/16/1971 5:00	5	0.66	1.45	2.87
11/30/71	11/30/71	11/30/1971 16:00	11/30/1971 19:00	3	0.68	2.58	3.1
12/13/71	12/13/71			1	0.61	2.34	2.62
12/25/71	12/25/71	12/25/1971 10:00	12/25/1971 12:00	2	0.7	1.66	1.92
12/27/71	12/27/71	12/27/1971 0:00	12/27/1971 5:00	6	0.87	1.9	2.73
12/30/71	12/30/71			1	0.6	1.94	2.53
01/03/72	01/03/72			1	0.62	2.01	2.36
02/15/72	02/15/72	2/15/1972 1:00	2/15/1972 4:00	4	0.72	2.04	2.95
02/16/72	02/16/72	2/16/1972 14:00	2/16/1972 16:00	3	0.63	2.75	2.98
02/20/72	02/20/72	2/20/1972 13:00	2/20/1972 14:00	4	0.67	3.13	3.23
03/29/72	03/29/72	3/29/1972 2:00	3/29/1972 5:00	4	0.64	1.78	2.83
04/09/72	04/09/72	4/9/1972 12:00	4/9/1972 15:00	3	0.66	2.15	2.56
05/23/72	05/23/72	5/23/1972 18:00	5/23/1972 19:00	1	0.65	2.57	2.74
10/08/72	10/08/72	10/8/1972 16:00	10/8/1972 20:00	4	0.75	1.78	2.49
11/03/72	11/04/72	11/3/1972 21:00	11/4/1972 3:00	6	0.82	2.46	3.07
12/09/72	12/09/72	12/9/1972 21:00	12/9/1972 23:00	3	0.7	2.55	2.99
12/17/72	12/17/72	12/17/1972 9:00	12/17/1972 13:00	4	0.88	2.57	2.82
12/18/72	12/18/72	12/18/1972 1:00	12/18/1972 3:00	2	0.66	1.34	1.76
12/19/72	12/19/72	12/19/1972 0:00	12/19/1972 4:00	4	0.79	1.64	1.93
01/07/73	01/07/73	1/7/1973 19:00	1/7/1973 23:00	4	0.68	2.21	3.12
01/20/73	01/21/73	1/20/1973 20:00	1/21/1973 5:00	9	1	3.77	3.77

02/16/73	02/16/73	2/16/1973 16:00	2/16/1973 17:00	1	0.63	1.9	2.12
09/30/73	09/30/73	9/30/1973 7:00	9/30/1973 9:00	2	0.62	1	1.5
10/31/73	10/31/73	10/31/1973 22:00	10/31/1973 23:00	1	0.64	2.43	2.65
01/15/74	01/15/74	1/15/1974 10:00	1/15/1974 12:00	2	0.66	1.7	2.84
01/17/74	01/17/74	1/17/1974 21:00	1/17/1974 23:00	2	0.64	1.93	2.77
02/01/74	02/01/74	2/1/1974 11:00	2/1/1974 12:00	1	0.71	2.13	2.19
02/05/74	02/06/74	2/5/1974 15:00	2/6/1974 5:00	14	1.09	2.88	3.66
02/18/74	02/18/74	2/18/1974 2:00	2/18/1974 12:00	10	0.99	2.12	2.88
03/08/74	03/08/74	3/8/1974 0:00	3/8/1974 4:00	4	0.74	2.88	2.95
03/13/74	03/13/74	3/13/1974 17:00	3/13/1974 21:00	5	0.71	1.52	2.81
10/20/74	10/20/74	10/20/1974 13:00	10/20/1974 19:00	6	0.96	3.42	3.42
10/21/74	10/21/74	10/21/1974 20:00	10/21/1974 22:00	2	0.68	2.09	2.18
11/26/74	11/26/74			1	0.61	2.13	2.72
12/03/74	12/04/74	12/3/1974 22:00	12/4/1974 2:00	5	0.66	3.02	3.32
12/04/74	12/05/74	12/4/1974 21:00	12/5/1974 2:00	5	0.67	2.23	3.16
01/02/75	01/02/75	1/2/1975 9:00	1/2/1975 10:00	4	0.61	3.09	3.23
01/26/75	01/26/75	1/26/1975 18:00	1/26/1975 23:00	5	0.68	3.34	3.34
01/30/75	01/30/75	1/30/1975 8:00	1/30/1975 13:00	4	0.73	2.91	3.23
03/03/75	03/03/75	3/3/1975 12:00	3/3/1975 16:00	5	0.71	3.11	3.28
03/09/75	03/09/75	3/9/1975 4:00	3/9/1975 5:00	1	0.61	1.68	2.45
04/04/75	04/04/75	4/4/1975 9:00	4/4/1975 14:00	6	0.88	2.29	2.65
10/07/75	10/07/75	10/7/1975 14:00	10/7/1975 19:00	5	0.66	2.66	3.38
12/27/75	12/27/75	12/27/1975 15:00	12/27/1975 18:00	3	0.67	3.07	3.14
01/23/76	01/23/76	1/23/1976 1:00	1/23/1976 4:00	3	0.81	3.16	3.17
02/11/76	02/11/76	2/11/1976 21:00	2/11/1976 23:00	2	0.68	2.18	2.72
02/16/76	02/16/76	2/16/1976 13:00	2/16/1976 15:00	2	0.68	2.58	3.01
03/01/76	03/01/76	3/1/1976 4:00	3/1/1976 10:00	4	0.67	1.54	2.64
03/17/76	03/17/76	3/17/1976 6:00	3/17/1976 22:00	15	1.2	3.57	3.76
03/18/76	03/19/76	3/18/1976 19:00	3/19/1976 0:00	5	0.93	2.08	3.16
10/22/76	10/22/76	10/22/1976 3:00	10/22/1976 6:00	3	0.68	1.69	2.05
11/19/76	11/19/76	11/19/1976 9:00	11/19/1976 14:00	5	0.74	2.6	3.02
11/21/76	11/21/76	11/21/1976 0:00	11/21/1976 5:00	5	0.7	1.93	3.1
12/27/76	12/27/76	12/27/1976 7:00	12/27/1976 8:00	1	0.61	1.87	2.15
12/30/76	12/30/76	12/30/1976 7:00	12/30/1976 12:00	5	0.75	2.24	2.64
01/29/77	01/30/77	1/29/1977 23:00	1/30/1977 2:00	3	0.71	1.78	1.92
01/30/77	01/30/77	1/30/1977 20:00	1/30/1977 23:00	3	0.67	2.77	2.83
02/25/77	02/25/77	2/25/1977 17:00	2/25/1977 22:00	5	0.76	2.23	2.82
03/19/77	03/19/77	3/19/1977 10:00	3/19/1977 17:00	7	0.82	2.78	3.12
03/24/77	03/24/77	3/24/1977 3:00	3/24/1977 16:00	13	0.77	2.44	3.07
04/06/77	04/06/77	4/6/1977 12:00	4/6/1977 14:00	2	0.63	3.35	3.35
09/15/77	09/15/77	9/15/1977 4:00	9/15/1977 9:00	5	0.99	1.58	2.19
12/07/77	12/08/77	12/7/1977 1:00	12/8/1977 3:00	22	1.04	3.24	3.24
12/17/77	12/17/77	12/17/1977 10:00	12/17/1977 17:00	7	0.69	1.67	3.12
12/18/77	12/18/77	12/18/1977 11:00	12/18/1977 15:00	4	0.69	2.2	2.6
02/08/78	02/08/78	2/8/1978 4:00	2/8/1978 11:00	7	0.84	1.1	3.03
03/07/78	03/07/78	3/7/1978 0:00	3/7/1978 4:00	4	0.72	1.38	2.86
03/20/78	03/20/78	3/20/1978 2:00	3/20/1978 5:00	3	0.79	1.99	2.2
01/29/79	01/29/79	1/29/1979 7:00	1/29/1979 11:00	4	0.77	1.42	3.35
09/07/79	09/07/79	9/7/1979 15:00	9/7/1979 20:00	5	0.75	1.06	2.13
10/08/79	10/08/79	10/8/1979 19:00	10/8/1979 20:00	1	0.64	1.34	1.61
12/10/79	12/10/79	12/10/1979 16:00	12/10/1979 18:00	2	0.64	2.97	2.97
12/17/79	12/18/79	12/17/1979 17:00	12/18/1979 0:00	7	0.91		3.35
01/08/80	01/08/80	1/8/1980 8:00	1/8/1980 12:00	4	0.73	1.85	2.24
01/24/80	01/24/80	1/24/1980 5:00	1/24/1980 8:00	2	0.64	2.78	2.97
02/21/80	02/22/80	2/21/1980 21:00	2/22/1980 1:00	4	0.93	1.65	2.22
02/28/80	02/28/80	2/28/1980 15:00	2/28/1980 20:00	5	0.87	2.43	2.82
04/05/80	04/05/80	4/5/1980 21:00	4/5/1980 23:00	2	0.61	1.32	2.31
10/26/80	10/26/80	10/26/1980 20:00	10/26/1980 21:00	1	0.62	1.82	3
11/19/80	11/19/80	11/19/1980 6:00	11/19/1980 12:00	4	0.66	2.52	2.95
11/27/80	11/27/80	11/27/1980 7:00	11/27/1980 10:00	3	0.74	1.18	2.19
12/30/80	12/30/80	12/30/1980 19:00	12/30/1980 21:00	2	0.63	2.74	2.81
01/11/81	01/11/81	1/11/1981 2:00	1/11/1981 7:00	5	0.8	2.25	3.18
03/15/81	03/15/81	3/15/1981 5:00	3/15/1981 15:00	8	0.81	2.22	2.81
03/17/81	03/18/81	3/17/1981 12:00	3/18/1981 6:00	10	0.77	1.89	2.71
03/21/81	03/21/81	3/21/1981 6:00	3/21/1981 12:00	6	0.78	2.17	2.97
10/08/81	10/08/81	10/8/1981 11:00	10/8/1981 13:00	2	0.64	1.64	2.06

11/19/81	11/19/81	11/19/1981 10:00	11/19/1981 13:00	3	0.67	1.44	2.8
01/10/82	01/10/82	1/10/1982 7:00	1/10/1982 14:00	7	0.87	3.18	3.4
01/15/82	01/15/82	1/15/1982 1:00	1/15/1982 20:00	6	0.68	2.33	3.1
04/05/82	04/05/82	4/5/1982 4:00	4/5/1982 6:00	1	0.61	1.94	2.41
04/07/82	04/07/82	4/7/1982 5:00	4/7/1982 23:00	11	0.88	2.78	3.17
10/02/82	10/02/82	10/2/1982 14:00	10/2/1982 19:00	5	1.07	1.85	2.57
12/11/82	12/11/82	12/11/1982 6:00	12/11/1982 8:00	1	0.6	2.83	2.83
10/25/83	10/26/83	10/25/1983 18:00	10/26/1983 2:00	4	0.67	2.34	3.17
11/17/83	11/17/83	11/17/1983 16:00	11/17/1983 21:00	5	0.75	2.68	2.93
12/07/83	12/08/83	12/7/1983 20:00	12/8/1983 1:00	5	0.85	3.14	3.29
12/24/83	12/25/83	12/24/1983 20:00	12/25/1983 12:00	16	1.17	1.92	3.57
12/26/83	12/26/83	12/26/1983 10:00	12/26/1983 15:00	5	0.78	1.71	2.94
03/30/84	03/30/84	3/30/1984 16:00	3/30/1984 22:00	3	0.69	1.91	2.85
04/09/84	04/10/84	4/9/1984 21:00	4/10/1984 1:00	4	0.72	1.37	1.64
11/15/84	11/15/84	11/15/1984 6:00	11/15/1984 10:00	2	0.61	1.33	2.974
12/07/84	12/07/84	12/7/1984 8:00	12/7/1984 10:00	2	0.64	2.83	2.83
12/08/84	12/08/84	12/8/1984 15:00	12/8/1984 18:00	3	0.69	2.22	2.68
12/26/84	12/26/84	12/26/1984 17:00	12/26/1984 22:00	5	1.12	2.6	2.61
01/05/85	01/06/85	1/5/1985 17:00	1/6/1985 1:00	7	0.91	3.39	3.39
01/15/85	01/16/85	1/15/1985 19:00	1/16/1985 14:00	11	1.02	1.8	2.96
02/25/85	02/25/85	2/25/1985 15:00	2/25/1985 20:00	3	0.69	1.85	2.85
02/28/85	02/28/85	2/28/1985 5:00	2/28/1985 9:00	3	0.91	2.79	2.79
12/03/85	12/03/85	12/3/1985 3:00	12/3/1985 8:00	3	0.76	2.56	2.93
01/04/86	01/04/86	1/4/1986 5:00	1/4/1986 22:00	10	1.06	2.08	2.77
01/05/86	01/06/86	1/5/1986 21:00	1/6/1986 6:00	8	1.01	1.86	2.83
01/14/86	01/14/86	1/14/1986 11:00	1/14/1986 17:00	3	0.77	2.76	2.95
03/07/86	03/07/86	3/7/1986 12:00	3/7/1986 16:00	4	0.92	2.47	2.57
04/10/86	04/10/86	4/10/1986 9:00	4/10/1986 11:00	2	0.72	2.91	2.96
11/22/86	11/22/86	11/22/1986 0:00	11/22/1986 9:00	7	0.92	2.32	3
12/08/86	12/08/86	12/8/1986 10:00	12/8/1986 15:00	5	1.2	2.36	2.68
01/11/87	01/12/87	1/11/1987 19:00	1/12/1987 8:00	8	0.76	2.17	2.9
01/23/87	01/24/87	1/23/1987 21:00	1/24/1987 2:00	5	1.13	2.16	2.22
02/01/87	02/01/87	2/1/1987 10:00	2/1/1987 13:00	2	0.62	2.55	3.05
02/10/87	02/11/87	2/10/1987 17:00	2/11/1987 0:00	5	0.69	2.67	2.85
03/03/87	03/03/87	3/3/1987 6:00	3/3/1987 9:00	2	0.64	1.26	2.57
03/16/87	03/17/87	3/16/1987 5:00	3/17/1987 7:00	6	0.74	1.57	2.29
11/12/87	11/13/87	11/12/1987 16:00	11/13/1987 9:00	7	0.93	2.97	2.97
11/21/87	11/21/87	11/21/1987 14:00	11/21/1987 16:00	1	0.61	2.55	2.82
12/16/87	12/17/87	12/16/1987 23:00	12/17/1987 15:00	15	0.81	2.74	2.86
12/30/87	12/31/87	12/30/1987 1:00	12/31/1987 1:00	14	1.04	2.46	2.99
01/09/88	01/09/88	1/9/1988 16:00	1/9/1988 19:00	1	0.61	2.56	2.78
02/05/88	02/05/88	2/5/1988 12:00	2/5/1988 14:00	1	0.64	2.98	2.98
02/06/88	02/06/88	2/6/1988 14:00	2/6/1988 17:00	1	0.61	2.75	2.9
02/13/88	02/14/88	2/13/1988 22:00	2/14/1988 1:00	3	0.72	1.68	2.1
02/17/88	02/17/88	2/17/1988 2:00	2/17/1988 6:00	3	0.67	1.21	2.25
04/10/88	04/11/88	4/10/1988 11:00	4/11/1988 3:00	3	0.66	1.4	2.78
04/20/88	04/20/88	4/20/1988 21:00	4/20/1988 23:00	1	0.62	1.1	2.83
04/22/88	04/23/88	4/22/1988 22:00	4/23/1988 1:00	2	0.63	1.51	2.34
11/21/88	11/22/88	11/21/1988 10:00	11/22/1988 5:00	15	1.11	2.5	3.1
11/25/88	11/25/88	11/25/1988 5:00	11/25/1988 7:00	1	0.62	0.83	2.96
12/18/88	12/18/88	12/18/1988 10:00	12/18/1988 14:00	3	0.74	1.94	2.11
01/01/89	01/01/89	1/1/1989 3:00	1/1/1989 5:00	2	0.63	2.65	2.65
01/04/89	01/05/89	1/4/1989 21:00	1/5/1989 15:00	17	1.13	1.94	3.3
01/06/89	01/06/89	1/6/1989 12:00	1/6/1989 17:00	5	0.79	2.47	2.79
01/21/89	01/21/89	1/21/1989 11:00	1/21/1989 20:00	7	1	2.56	2.97
03/07/89	03/07/89	3/7/1989 15:00	3/7/1989 18:00	2	0.69	1.76	2.7
03/29/89	03/29/89	3/29/1989 11:00	3/29/1989 15:00	3	0.75	3.08	3.08
11/21/89	11/22/89	11/21/1989 13:00	11/22/1989 12:00	6	0.74	2.37	2.89
11/24/89	11/24/89	11/24/1989 4:00	11/24/1989 7:00	1	0.65	2.34	2.61
12/03/89	12/04/89	12/3/1989 19:00	12/4/1989 14:00	13	0.77	2.61	3.1
12/17/89	12/17/89	12/17/1989 16:00	12/17/1989 18:00	2	0.62	2.98	3.01
01/30/90	01/30/90	1/30/1990 14:00	1/30/1990 21:00	7	0.77	2.37	3.11
11/07/90	11/07/90	11/7/1990 9:00	11/7/1990 11:00	2	0.63	1.57	2.35
11/13/90	11/13/90	11/13/1990 1:00	11/13/1990 3:00	2	0.62	1.65	2.18
11/14/90	11/14/90	11/14/1990 0:00	11/14/1990 3:00	1	0.61	1.64	2.75
12/25/90	12/25/90	12/25/1990 2:00	12/25/1990 4:00	2	0.65	2.76	2.81

12/31/90	12/31/90	12/31/1990 11:00	12/31/1990 13:00	2	0.64	2.99	3.1
03/11/91	03/12/91	3/11/1991 21:00	3/13/1991 6:00	13	1.41	2.42	2.59
10/29/91	10/29/91	10/29/1991 10:00	10/29/1991 14:00	1	0.61	2.11	2.82
12/02/91	12/02/91	12/2/1991 13:00	12/2/1991 20:00	6	0.78	2.87	3.07
12/03/91	12/04/91	12/3/1991 17:00	12/4/1991 3:00	10	0.9	3.37	3.37
12/04/91	12/04/91	12/4/1991 18:00	12/4/1991 20:00	1	0.62	2.88	2.96
01/12/92	01/12/92	1/12/1992 6:00	1/12/1992 10:00	1	0.6	1.95	2.28
01/15/92	01/15/92	1/15/1992 9:00	1/15/1992 14:00	3	0.69	2.23	2.64
01/24/92	01/24/92	1/24/1992 16:00	1/24/1992 22:00	6	0.86	1.62	2.93
02/01/92	02/02/92	2/1/1992 11:00	2/2/1992 7:00	16	1.08	2.5	3.24
02/17/92	02/17/92	2/17/1992 4:00	2/17/1992 7:00	1	0.64	1.31	1.96
02/29/92	03/01/92	2/29/1992 11:00	3/1/1992 1:00	8	0.73	2.37	2.77
10/19/92	10/20/92	10/19/1992 18:00	10/20/1992 0:00	4	0.66	2.62	2.71
12/04/92	12/04/92	12/4/1992 0:00	12/4/1992 3:00	1	0.64	2.06	2.27
12/06/92	12/06/92	12/6/1992 1:00	12/6/1992 6:00	1	0.64	1.71	2.52
12/26/92	12/26/92	12/26/1992 9:00	12/26/1992 15:00	4	0.83	2.92	3.19
10/28/93	10/28/93	10/28/1993 4:00	10/28/1993 9:00	2	0.64	1.6	2.78
11/20/93	11/20/93	11/20/1993 19:00	11/20/1993 21:00	1	0.6	2.45	2.82
12/06/93	12/06/93	12/6/1993 7:00	12/6/1993 11:00	1	0.63	1.88	2.12
12/25/93	12/25/93	12/25/1993 16:00	12/25/1993 19:00	1	0.63	2.72	2.86
12/30/93	12/31/93	12/30/1993 15:00	12/31/1993 2:00	9	1.12	3.62	3.62
01/01/94	01/01/94	1/1/1994 1:00	1/1/1994 9:00	7	0.77	1.7	3.21
03/04/94	03/04/94	3/4/1994 17:00	3/4/1994 22:00	5	0.72	2.09	3.01
12/08/94	12/09/94	12/8/1994 19:00	12/9/1994 0:00	5	0.97	2.11	2.42
12/02/95	12/02/95	12/2/1995 16:00	12/2/1995 21:00	4	0.79	2.92	3.1
12/10/95	12/10/95	12/10/1995 21:00	12/10/1995 23:00	1	0.62	2.74	2.94
12/21/95	12/21/95	12/21/1995 8:00	12/21/1995 13:00	2	0.64	3.14	3.14
01/09/96	01/09/96	1/9/1996 5:00	1/9/1996 15:00	8	0.73	2.95	3.06
01/15/96	01/15/96	1/15/1996 5:00	1/15/1996 12:00	7	1.3	2.96	2.96
04/04/96	04/04/96	4/4/1996 1:00	4/4/1996 5:00	4	0.67	1.92	2.8
04/04/96	04/04/96	4/4/1996 17:00	4/4/1996 20:00	1	0.61	1.24	2.88
09/15/96	09/15/96	9/15/1996 2:00	9/15/1996 9:00	4	0.76	1.56	2.82
10/09/96	10/09/96	10/9/1996 14:00	10/9/1996 21:00	6	0.77	2.22	2.8
11/27/96	11/27/96	11/27/1996 2:00	11/27/1996 5:00	1	0.6	1.98	3.07
01/17/97	01/17/97	1/17/1997 9:00	1/17/1997 14:00	5	0.7	1.86	2.56
01/19/97	01/19/97	1/19/1997 0:00	1/19/1997 4:00	2	0.64	1.53	1.94
01/23/97	01/23/97	1/23/1997 17:00	1/23/1997 21:00	3	0.7	2.18	2.75
01/29/97	01/29/97	1/29/1997 4:00	1/29/1997 7:00	3	0.81	2.38	2.68
03/06/97	03/07/97	3/6/1997 18:00	3/7/1997 8:00	9	0.9	2.36	2.95
03/08/97	03/08/97	3/8/1997 5:00	3/8/1997 11:00	4	0.67	2.61	3.05
04/01/97	04/02/97	4/1/1997 20:00	4/2/1997 9:00	7	0.65	1.47	2.87
04/02/97	04/03/97	4/2/1997 19:00	4/3/1997 14:00	7	0.9	1.71	2.64
04/29/97	04/30/97	4/29/1997 21:00	4/30/1997 0:00	2	0.7	1.26	1.98
11/15/97	11/15/97	11/15/1997 1:00	11/15/1997 6:00	3	0.65	1.02	3.16
11/27/97	11/28/97	11/27/1997 17:00	11/28/1997 4:00	9	0.76	2.98	3.1
12/02/97	12/03/97	12/2/1997 0:00	12/3/1997 8:00	12	0.72	1.93	3.29
12/30/97	12/31/97	12/30/1997 23:00	12/31/1997 3:00	2	0.68	3.22	3.26
01/04/98	01/04/98	1/4/1998 14:00	1/4/1998 16:00	2	0.66	3.06	3.19
03/03/98	03/04/98	3/3/1998 23:00	3/4/1998 11:00	2	0.6	1.84	3.01
10/30/98	10/30/98	10/30/1998 9:00	10/30/1998 15:00	4	0.85	1.82	2.07
12/18/98	12/19/98	12/18/1998 17:00	12/19/1998 4:00	9	0.78	3.22	3.28
12/22/98	12/22/98	12/22/1998 21:00	12/22/1998 23:00	1	0.61	2.35	2.67
3/16/1999 16:00		3/16/1999 16:00	3/16/1999 21:00	5	0.82	2.77	3
4/5/1999 4:00		4/5/1999 4:00	4/5/1999 8:00	4	0.73	2.05	2.8
4/28/1999 11:00		4/28/1999 11:00	4/28/1999 14:00	3	0.65	2.44	2.86
10/18/1999 18:00		10/18/1999 18:00	10/18/1999 21:00	3	0.65	2.7	2.74
12/1/1999 20:00		12/1/1999 20:00	12/1/1999 21:00	1	0.6	2.71	2.94
1/18/2000 2:00		1/18/2000 2:00	1/18/2000 5:00	3	0.67	1.62	2.61
1/21/2000 14:00		1/21/2000 14:00	1/22/2000 4:00	14	1.37	4.15	4.15
3/17/2000 21:00		3/17/2000 21:00	3/18/2000 1:00	4	0.79	2.93	3.05
10/29/2000 0:00		10/29/2000 0:00	10/29/2000 20:00	13	1.3	1.81	3.25
12/1/2000 4:00		12/1/2000 4:00	12/1/2000 6:00	2	0.61	2	2.83
12/13/2000 2:00		12/13/2000 2:00	12/13/2000 5:00	3	0.67	2.4	3.27
1/7/2001 15:00		1/7/2001 15:00	1/7/2001 17:00	2	0.65	2.42	2.93
2/6/2001 13:00		2/6/2001 13:00	2/6/2001 20:00	7	0.75	2.99	3.17
2/12/2001 3:00		2/12/2001 3:00	2/12/2001 5:00	2	0.64	3	3.21

2/15/2001 19:00		2/15/2001 19:00	2/15/2001 23:00	4	0.96	2.38	2.61
2/18/2001 2:00		2/18/2001 2:00	2/18/2001 3:00	1	0.67	1.65	1.88
11/7/2001 18:00		11/7/2001 18:00	11/8/2001 1:00	7	0.89	2.43	2.96
12/19/2001 4:00		12/19/2001 4:00	12/19/2001 8:00	4	0.67	1.91	2.98
1/13/2002 23:00		1/13/2002 23:00	1/14/2002 5:00	9	0.68	1.76	3.16
1/22/2002 12:00		1/22/2002 12:00	1/22/2002 14:00	2	0.63	2.16	2.64
1/24/2002 2:00		1/24/2002 2:00	1/24/2002 6:00	4	0.68	2.42	2.54
2/2/2002 17:00		2/2/2002 17:00	2/2/2002 19:00	2	0.65	2.22	3.06
2/5/2002 11:00		2/5/2002 11:00	2/5/2002 17:00	6	0.67	2.06	3.07
2/11/2002 16:00		2/11/2002 16:00	2/11/2002 19:00	3	0.87	2.31	2.58
9/12/2002 2:00		9/12/2002 2:00	9/12/2002 10:00	8	1.35	2.55	3.41
11/3/2002 0:00		11/3/2002 0:00	11/3/2002 3:00	3	0.81	2.03	2.46
11/19/2002 4:00		11/19/2002 4:00	11/19/2002 6:00	2	0.65	1.41	1.41
12/15/2002 14:00		12/15/2002 14:00	12/15/2002 18:00	4	0.77	2.55	2.63
12/26/2002 12:00		12/26/2002 12:00	12/26/2002 20:00	8	0.77	3.19	3.19
2/2/2003 23:00		2/2/2003 23:00	2/3/2003 0:00	1	0.63	3.21	3.21
2/12/2003 11:00		2/12/2003 11:00	2/12/2003 18:00	7	0.95	2.66	2.88
3/3/2003 14:00		3/3/2003 14:00	3/3/2003 19:00	5	0.77	1.89	2.67
9/29/2003 3:00		9/29/2003 3:00	9/29/2003 6:00	3	1.1	2.41	2.85
9/29/2003 18:00		9/29/2003 18:00	9/29/2003 19:00	1	0.62	1.67	2.37
11/14/2003 8:00		11/14/2003 8:00	11/14/2003 12:00	4	0.8	1.64	2.4
12/7/2003 16:00		12/7/2003 16:00	12/7/2003 17:00	1	0.61	2.04	3.01
12/15/2003 18:00		12/15/2003 18:00	12/16/2003 12:00	13	0.9	1.92	2.82
1/16/2004 11:00		1/16/2004 11:00	1/16/2004 13:00	2	0.64	1.9	2.41
1/17/2004 8:00		1/17/2004 8:00	1/17/2004 18:00	10	1.53	2.82	3.22
1/18/2004 14:00		1/18/2004 14:00	1/18/2004 15:00	1	0.66	2.12	2.52
1/19/2004 15:00		1/19/2004 15:00	1/19/2004 18:00	3	0.63	2.38	3.12
1/21/2004 0:00		1/21/2004 0:00	1/21/2004 6:00	6	0.71	1.06	3.21
1/27/2004 8:00		1/27/2004 8:00	1/27/2004 9:00	1	0.62	1.48	1.96
2/19/2004 14:00		2/19/2004 14:00	2/20/2004 7:00	17	1.3	2.95	3.68
11/6/2004 7:00		11/6/2004 7:00	11/6/2004 8:00	1	0.64	2.27	2.33
12/27/2004 13:00		12/27/2004 13:00	12/27/2004 22:00	9	1.52	3.02	3.1
1/17/2005 10:00		1/17/2005 10:00	1/17/2005 21:00	11	0.86	2.51	3.22
1/23/2005 16:00		1/23/2005 16:00	1/24/2005 18:00	20	0.91	1.5	3.25
3/13/2005 8:00		3/13/2005 8:00	3/13/2005 10:00	2	0.62	1.4	2.57

B.3: Data from 1911-2005

Table B3 shows all the raw data for Maximum Observed yearly water level (from local CD) with their year occurring from the raw data (Parkes, 2006) from 1911-2005. This chronological data are used in all the research calculation.

Table B. 3: Maximum Observed water level (local CD) from 1911-2005 **(Parkes, 2006)**

Year	MOWL	Year	MOWL	Year	MOWL	Year	MOWL	Year	MOWL	Year	MOWL
1911	2.31	1942	2.79	1954	3.14	1967	2.64	1978	2.86	1992	2.77
1911	2.58	1942	3.09	1954	2.14	1968	2.55	1978	2.2	1992	3.19
1911	3.07	1942	3.11	1955	3.05	1968	2.59	1978	3.03	1992	2.93
1911	2.73	1943	2.44	1955	2.84	1968	2.57	1979	1.61	1992	3.24
1911	2.55	1943	2.91	1955	1.59	1968	2.32	1979	2.97	1993	2.82
1912	3.22	1943	1.87	1955	3.05	1968	2.19	1979	2.13	1993	2.12
1912	3.04	1943	3.38	1955	2.26	1968	2.96	1979	3.35	1993	2.86
1912	2.98	1943	3.55	1955	3.11	1968	2.46	1979	3.35	1993	2.78
1912	2.31	1943	2.97	1955	3.05	1968	3.15	1980	2.31	1993	3.62
1912	3.1	1944	3.11	1956	3.14	1968	2.64	1980	3	1994	3.01
1912	2.96	1944	2.83	1956	3.39	1968	3.36	1980	2.81	1994	3.21
1912	2.08	1944	2.77	1956	2.72	1969	2.29	1980	2.97	1994	2.42
1912	3.36	1944	3.29	1957	3.16	1969	2.49	1980	2.95	1995	2.94
1913	2.94	1944	3.12	1957	2.34	1969	2.79	1980	2.24	1995	3.14
1913	3.29	1944	2.85	1957	2.92	1969	2.81	1980	2.19	1995	3.1
1913	2.88	1944	2.85	1957	2.83	1969	2.94	1980	2.82	1996	3.07
1913	3.26	1944	3.08	1957	3.01	1969	2.57	1980	2.22	1996	2.88
1913	2.66	1944	2.79	1957	2.68	1969	2.91	1981	2.06	1996	2.8
1913	3.24	1945	2.9	1957	2.77	1970	2.89	1981	2.8	1996	3.06
1914	3.15	1945	3.36	1957	2.49	1970	2.75	1981	2.71	1996	2.82
1914	3.08	1945	2.98	1957	2.13	1970	3.08	1981	2.97	1996	2.8
1914	2.98	1945	3.1	1957	3.07	1970	2.91	1981	3.18	1996	2.96
1914	2.8	1945	2.81	1958	3.01	1970	2.64	1981	2.81	1997	1.94
1914	3.3	1945	3.33	1958	2.89	1970	3.09	1982	2.83	1997	2.87
1914	2.76	1945	2.67	1958	2.74	1970	2.99	1982	2.41	1997	3.16
1914	3.4	1945	3.05	1958	2.8	1970	2.63	1982	3.1	1997	3.05
1914	2.66	1946	3.33	1958	3.13	1970	3.02	1982	3.4	1997	3.26
1914	2.89	1946	3.23	1958	3.16	1970	3.17	1982	3.17	1997	2.56
1914	2.45	1946	2.78	1958	3.32	1971	2.53	1982	2.57	1997	2.75
1914	1.96	1946	2.84	1958	2.95	1971	2.62	1983	3.17	1997	1.98
1915	2.37	1946	2.49	1958	2.71	1971	2.32	1983	2.93	1997	3.29
1916	3.15	1946	2.52	1958	2.98	1971	2.42	1983	2.94	1997	3.1
1916	3	1946	2.78	1959	3.07	1971	2.87	1983	3.29	1997	2.68
1916	2.74	1946	2.84	1959	2.58	1971	2.79	1983	3.57	1997	2.95
1917	3.07	1947	2.78	1959	2.58	1971	3.31	1984	2.974	1997	2.64
1917	2.75	1947	2.87	1959	3.01	1971	3.1	1984	2.83	1998	3.01
1917	3.34	1947	2.96	1959	1.94	1971	2.74	1984	2.85	1998	2.67
1918	3.23	1947	2.98	1959	2.62	1971	1.92	1984	2.68	1998	3.19
1918	2.96	1947	2.38	1959	2.28	1971	2.74	1984	1.64	1998	3.28
1918	3.03	1947	2.35	1960	2.85	1971	2.73	1984	2.61	1998	2.07
1918	2.41	1947	3.11	1960	2.85	1971	2.7	1985	2.85	1999	2.94
1918	3	1948	2.22	1960	3.12	1972	2.36	1985	2.93	1999	2.86
1918	2.93	1948	2.75	1960	2.88	1972	2.98	1985	3.39	1999	2.74
1918	2.21	1948	2.83	1960	2.79	1972	2.83	1985	2.79	1999	2.8
1918	2.7	1948	3.22	1960	2.91	1972	2.74	1985	2.96	1999	3
1920	2.83	1948	2.89	1961	3.18	1972	2.56	1986	2.96	2000	2.83
1920	3.07	1948	2.95	1961	3.07	1972	1.76	1986	2.95	2000	2.61
1922	2.86	1948	3.07	1961	2.54	1972	3.23	1986	2.57	2000	3.27

1923	2.63	1949	2.95	1961	2.39	1972	2.99	1986	3	2000	3.05
1923	3.12	1949	2.83	1961	2.48	1972	2.95	1986	2.83	2000	3.25
1923	2.3	1949	3.38	1961	2.54	1972	2.49	1986	2.77	2000	4.15
1925	3.12	1949	2.89	1961	3.4	1972	1.93	1986	2.68	2001	3.21
1925	3.03	1949	3.1	1961	3.89	1972	3.07	1987	2.82	2001	2.93
1925	2.88	1949	2.55	1962	1.78	1972	2.82	1987	3.05	2001	1.88
1926	3.05	1949	2.74	1962	3.04	1973	1.5	1987	2.57	2001	2.98
1926	2.75	1949	3.25	1962	2.75	1973	2.12	1987	2.85	2001	3.17
1926	1.83	1949	2.01	1962	2.74	1973	2.65	1987	2.29	2001	2.96
1926	2.72	1950	3.1	1962	2.46	1973	3.12	1987	2.9	2001	2.61
1926	3.05	1950	3.16	1962	2.79	1973	3.77	1987	2.86	2002	2.64
1926	2.9	1950	3.01	1962	2.33	1974	2.72	1987	2.97	2002	3.06
1931	2.34	1950	2.8	1962	2.88	1974	2.77	1987	2.99	2002	1.41
1932	3.03	1950	3.01	1963	2.84	1974	2.84	1987	2.22	2002	3.07
1932	2.57	1950	3.22	1963	2.3	1974	3.32	1988	2.78	2002	3.16
1932	2.73	1950	2.58	1963	2.84	1974	3.16	1988	2.9	2002	2.54
1932	2.73	1951	3.21	1963	2.44	1974	2.18	1988	2.83	2002	2.63
1932	2.63	1951	2.6	1963	2.96	1974	2.19	1988	2.96	2002	3.19
1938	3.01	1951	3.12	1963	3.05	1974	2.81	1988	2.34	2002	2.46
1938	3.16	1951	3.34	1963	2.97	1974	2.95	1988	2.98	2002	2.58
1938	2.8	1951	3.4	1963	3.35	1974	3.42	1988	2.78	2002	3.41
1938	1.7	1951	2.91	1963	3.02	1974	2.88	1988	2.25	2003	3.01
1938	3.41	1951	3.06	1963	3.19	1974	3.66	1988	2.1	2003	2.37
1939	2.92	1951	2.85	1963	2.92	1975	3.23	1988	2.11	2003	3.21
1939	2.92	1952	3.06	1963	2.63	1975	2.45	1988	3.1	2003	2.67
1939	2.19	1952	2.97	1963	3.05	1975	3.38	1989	3.01	2003	2.4
1939	2.74	1952	3.06	1964	2.91	1975	3.14	1989	2.65	2003	2.82
1939	2.71	1952	2.82	1964	3.19	1975	3.34	1989	2.61	2003	2.88
1939	2.74	1952	2.79	1964	3.08	1975	3.28	1989	2.7	2003	2.85
1939	2.83	1952	3.37	1964	2.96	1975	3.23	1989	2.89	2004	1.96
1940	2.81	1952	3.06	1964	3.08	1975	2.65	1989	3.08	2004	3.12
1940	2.93	1952	2.94	1965	2.27	1976	2.15	1989	3.1	2004	2.41
1940	3.04	1952	3.09	1965	2.86	1976	2.64	1989	2.79	2004	2.33
1940	3.04	1953	2.97	1965	2.19	1976	2.72	1989	2.97	2004	2.52
1940	1.9	1953	2.91	1965	2.81	1976	3.01	1989	3.3	2004	3.21
1940	3.01	1953	2.54	1965	3.38	1976	2.05	1990	2.75	2004	3.68
1941	3.18	1953	2.03	1965	2.88	1976	3.1	1990	2.18	2004	3.1
1941	2.55	1953	2.33	1965	2.53	1976	3.02	1990	2.35	2004	3.22
1941	3	1953	2.48	1965	2.09	1976	2.64	1990	3.1	2005	3.22
1941	2.75	1953	2.54	1965	2.94	1976	3.17	1990	2.81	2005	3.25
1941	2.89	1953	3.21	1966	2.63	1976	3.16	1990	3.11	2005	2.57
1941	2.19	1954	3.42	1966	2.94	1976	3.76	1991	2.82		
1941	1.93	1954	2.81	1966	1.83	1977	3.35	1991	2.96		
1941	2.9	1954	3.08	1966	2.62	1977	2.83	1991	3.07		
1941	3.03	1954	2.75	1966	3.4	1977	3.12	1991	3.37		
1941	3.15	1954	3.2	1966	3.01	1977	2.6	1991	2.59		
1942	2.51	1954	2.72	1967	2.22	1977	1.92	1992	2.28		
1942	2.48	1954	2.99	1967	1.51	1977	2.82	1992	1.96		
1942	3.02	1954	2.2	1967	2.97	1977	3.07	1992	2.27		
1942	2.88	1954	2.9	1967	1.75	1977	3.12	1992	2.52		
1942	2.85	1954	2.59	1967	2.93	1977	2.19	1992	2.71		
1942	2.65	1954	2.66	1967	2.88	1977	3.24	1992	2.64		

B.4: Storm Surge Data from 1960-2005:

As similar to maximum observed water level distributions, one distribution is selected as the best fit for storm surge data from 1960 to 2005 (these data has a better quality and less missing compare to storm surge data from 1911- 1960). The best fit among examining more than 10 distributions such as Lognormal (3P), Johnson SB, Pearson 5(with 3 Parameters), Inverse Gaussian (3P), Fatigue life, Generalized Pareto distribution is Johnson SB distribution. The figure and the goodness of fit table for Johnson SB are shown in Figure B.1 and Table B.4.

Johnson SB Distribution (or alternatively the 4-parameter lognormal model)

Hafley and Schreuder (1977) first introduced the four-parameter Johnson SB distribution into the forestry literature (Schreuder & Hafley, 1977). Johnson SB is also appealing on theoretical grounds as a candidate probability distribution function for ratios. Although, the SB distribution is flexible and appealing on first principles, it is complex mathematically and its estimation has been somewhat problematic (Flynn, 2006). It has found application in a variety of fields. It can be used for rainfall distributions (Kottegoda, 1987). The Johnson distribution is widely used in forestry to represent the empirical distributions of forest tree variables such as diameter, height and volume (Rennolls & Wang, 2005), (Zhang, Packard, & Liu, 2003). This distribution has also been used for ambient air pollution (Mage, 1980).

The value of its parameters for 1960 to 2005 are: $\gamma = 1.844$, $\delta = 0.781$, $\lambda = 1.222$, $\xi = 0.598$. It was ranked second in terms of goodness of fit. The Graph for Johnson SB for 1960-2005 is shown in Figure B.1. The probability density function of Johnson SB is:

$$f(x) = \frac{\delta}{\lambda\sqrt{2\pi}\, z(1-z)} e^{\left(-\frac{1}{2}\left(\gamma+\delta\ln\left(\frac{z}{1-z}\right)\right)^2\right)}$$

$$\text{where } z \equiv \frac{x-\xi}{\lambda}$$

when its parameters are: γ and δ $(\delta > 0)$: shape parameters, λ : scale parameter ξ : location parameter

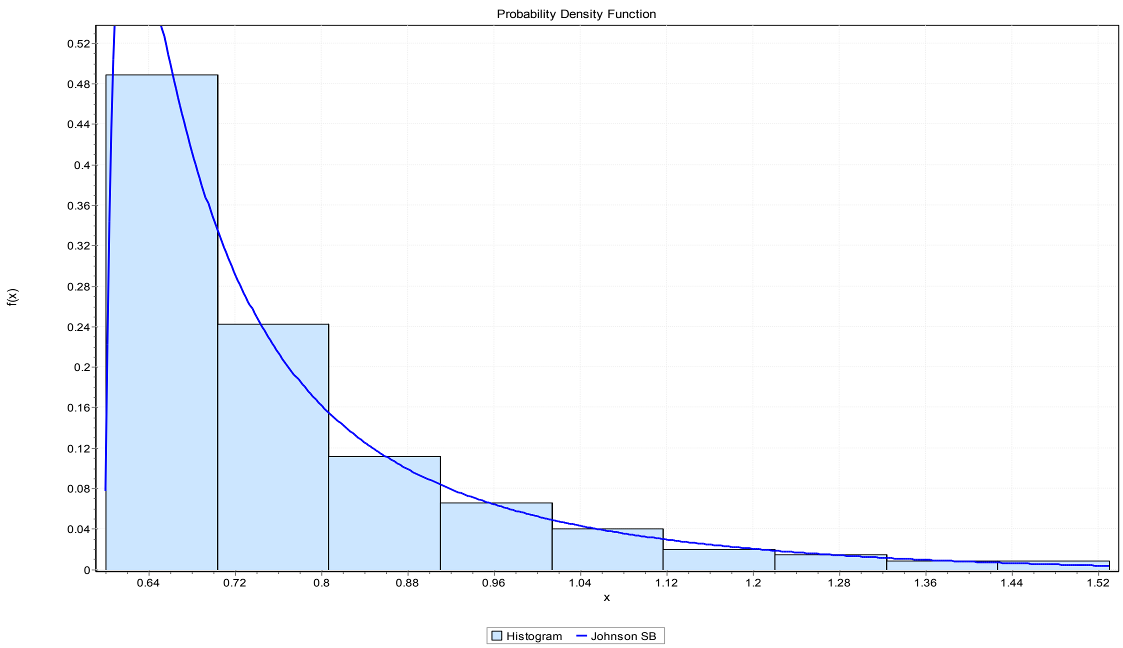

Figure B. 1: Johnson SB for 1960-2005 (MathWave Technologies, 2004-2013)

The detail of goodness of fit is shown in table B.4. (MathWave Technologies, 2004-2013)

Table B. 4: Goodness of fit for Johnson SB distribution from 1960 to 2005 (MathWave Technologies, 2004-2013)

Johnson SB					
Kolmogorov-Smirnov					
Sample Size	350		Statistic	0.054	
P-Value	0.245		Rank	4	
α	0.2	0.1	0.05	0.02	0.01
Critical Value	0.057	0.065	0.072	0.081	0.087
Reject?	No	No	No	No	No
Anderson-Darling					
Sample Size	350		Statistic	1.538	
			Rank	4	
α	0.2	0.1	0.05	0.02	0.01
Critical Value	1.374	1.928	2.501	3.289	3.907
Reject?	Yes	No	No	No	No
Chi-Squared					
Deg. of freedom	8		Statistic	7.040	
P-Value	0.532		Rank	2	
α	0.2	0.1	0.05	0.02	0.01
Critical Value	11.03	13.362	15.507	18.168	20.09
Reject?	No	No	No	No	No

The detail of the goodness of fit of the Charlottetown data to the Johnson SB distribution is shown in Table B.4. The distribution fit is not rejected based on Kolmogorov-Smirnov test for none of the α. Based on Anderson-Darling test, it is accepted for all α values except α= 0.2. For the Chi-Squared test, the Johnson SB distribution is accepted for all the values of α.

Appendix C

Community Profile Data

The "Community Profile Report", forms the basis for project community data for System Dynamics modeling and decision-making problem hierarchy. The main dimensions of the community profile are divided into "Categories" as shown in Table C.1 representing the different items explaining the community (Hartt, Master's Thesis, 2011), (Pakdel, 2011), and (Mostofi Camare, 2011), (Canada, 2012).

Table C. 1: Four Pillars (Canada, 2012)

Main Dimension	Categories
Environmental Pillar/ Land Use	• Land Cover & Land Use ○ Public Work land ○ Green Space ○ Cultural and social Land ○ Industrial Land ○ Residential Housing ○ Commercial Area
Economic Pillar/ Goods & Services	• Industrial Production ○ Mining, Oil, and Gas Extraction ○ Utilities ○ Construction ○ Manufacturing • Public Services ○ Waste Management and Remediation Services ○ Education Services ○ Public Administration ○ Other Services • Commercial Services ○ Wholesale trade ○ Retail trade ○ Transportation and Warehousing ○ Real State and Rental and Leasing ○ Finance and Insurance ○ Professional, Scientific and Technical services ○ Management of Companies and Enterprises
Human Pillar/ Population	• Education Status ○ High School

	○ Degree ○ Diploma • Age ○ Young ○ Middle ○ Old • Health Status ○ Healthy ○ Unhealthy • Work Skill Status ○ Service ○ Trade ○ Professional
Cultural & Social pillar	• Cultural & social Services ○ Health Care and Social Assistance ○ Arts, Entertainment and Recreation ○ Accommodation and Food Services ○ Information and Cultural Industries • Ecosystem Services ○ Agriculture ○ Forestry ○ Fishing, Trapping and Hunting • Social Mapping ○ Social Networks ○ Wellbeing ○ Collaboration

Appendix D

STELLA Model Equations

This appendix shows the computer code, which is developed using the STELLA software. STELLA is used for the building and application of the System Dynamics model.

Cultural_&_Social_Sector =

```
Cult&SocialLand(t) = Cult&SocialLand(t - dt) + (NetInOutCS) * dt
INIT Cult&SocialLand = 1326
INFLOWS:
        NetInOutCS = Cult&SocialLand*((UnaffectedLand-ResidentialArea-
        CommercialArea)/(GreenSpace+IndustrialLand+PublicWorksLand+Cult&SocialLand)-1)
GreenSpace(t) = GreenSpace(t - dt) + (NetInOutGS) * dt
INIT GreenSpace = 472
INFLOWS:
        NetInOutGS = GreenSpace*((UnaffectedLand-ResidentialArea-
        CommercialArea)/(GreenSpace+IndustrialLand+PublicWorksLand+Cult&SocialLand)-1)
Middle(t) = Middle(t - dt) + (yngtoMiddl + In_Migration - MiddltoOLd - Out_Migration) * dt
INIT Middle = 23720
INFLOWS:
        yngtoMiddl = YtoM
        In_Migration = In_Migration_Rate*Middle
OUTFLOWS:
        MiddltoOLd = MtoOld
        Out_Migration = Out_Migration_Rate*Middle
Old(t) = Old(t - dt) + (MiddltoOLd - deaths) * dt
INIT Old = 6015
INFLOWS:
        MiddltoOLd = MtoOld
OUTFLOWS:
        deaths = death
ResidentialHousing(t) = ResidentialHousing(t - dt) + (NewHouses - Demolitions) * dt
INIT ResidentialHousing = 15000
INFLOWS:
        NewHouses = gainHHMtoOld+gainHHYtoM
OUTFLOWS:
        Demolitions = lossHHMtoOld+LossHHOld
Young(t) = Young(t - dt) + (Births - yngtoMiddl) * dt
INIT Young = 4830
INFLOWS:
        Births = Middle*birthrate
OUTFLOWS:
        yngtoMiddl = YtoM
Young(t) = Young(t - dt) + (Births - yngtoMiddl) * dt
INIT Young = 4830
INFLOWS:
        Births = Middle*birthrate
OUTFLOWS:
        yngtoMiddl = YtoM
AA = 0.002
affbysector[SocialCult] = exp(MOWL)*Affectproportions[SocialCult]
affbysector[SocialCult] = exp(MOWL)*Affectproportions[SocialCult]
affbysector[SocialCult] = exp(MOWL)*Affectproportions[SocialCult]
affbysector[SocialCult] = exp(MOWL)*Affectproportions[SocialCult]
affbysector[SocialCult] = exp(MOWL)*Affectproportions[SocialCult]
affbysector[SocialCult] = exp(MOWL)*Affectproportions[SocialCult]
Collaboration = rho*AA*r*ResidentialHousing*(1-ResidentialHousing/K)
Degree = sum(EducationStatus[*, Degree])
Diploma = sum(EducationStatus[*, Diploma])
HealthStatus[Old, UnHealthy] = Old*splitage&healthstatus[Old, UnHealthy]
HealthStatus[Old, UnHealthy] = Old*splitage&healthstatus[Old, UnHealthy]
```

HealthStatus[Old, UnHealthy] = Old*splitage&healthstatus[Old, UnHealthy]
HealthStatus[Old, UnHealthy] = Old*splitage&healthstatus[Old, UnHealthy]
HealthStatus[Old, UnHealthy] = Old*splitage&healthstatus[Old, UnHealthy]
HealthStatus[Old, UnHealthy] = Old*splitage&healthstatus[Old, UnHealthy]
HighSchool = sum(EducationStatus[*, HighSchool])
K = 40000
MOWL = 0*(alphaGu+BetaGu)
r = 0.05
rho = if (MOWL < 2) THEN (1) else (if ((MOWL) < 4 AND (MOWL) >= 2) THEN (2) else (3))
Social_Networks = 3*(1*Young+3*HighSchool+3*Diploma+4*Degree)/(11*(Young+HighSchool+Diploma+Degree))
TotalPop = Young+Middle+Old
Wellbeing = 0.08*(1*HealthStatus[Young, Healthy]+4*HealthStatus[Middle, Healthy]+1*HealthStatus[Old, Healthy])/TotalPop*6

Goods_and_Services =

CommercialArea(t) = CommercialArea(t - dt) + (NewCommAc - DemolitionCA) * dt
INIT CommercialArea = 2680
INFLOWS:
NewCommAc = gainAcMtoOld+gainAcYtoM
OUTFLOWS:
DemolitionCA = lossAcMtoOld+LossAcOld
IndustrialLand(t) = IndustrialLand(t - dt) + (NetInOutInd) * dt
INIT IndustrialLand = 1239
INFLOWS:
NetInOutInd = IndustrialLand*((UnaffectedLand-ResidentialArea-CommercialArea)/(GreenSpace+IndustrialLand+PublicWorksLand+Cult&SocialLand)-1)
PublicWorksLand(t) = PublicWorksLand(t - dt) + (NetInOutPW) * dt
INIT PublicWorksLand = 2011
INFLOWS:
NetInOutPW = PublicWorksLand*((UnaffectedLand-ResidentialArea-CommercialArea)/(GreenSpace+IndustrialLand+PublicWorksLand+Cult&SocialLand)-1)
A = 0.85
affbysector[SocialCult] = exp(MOWL)*Affectproportions[SocialCult]
affbysector[SocialCult] = exp(MOWL)*Affectproportions[SocialCult]
affbysector[SocialCult] = exp(MOWL)*Affectproportions[SocialCult]
affbysector[SocialCult] = exp(MOWL)*Affectproportions[SocialCult]
affbysector[SocialCult] = exp(MOWL)*Affectproportions[SocialCult]
affbysector[SocialCult] = exp(MOWL)*Affectproportions[SocialCult]
Affectproportions[SocialCult] = .1
Affectproportions[SocialCult] = .1
Affectproportions[SocialCult] = .1
Affectproportions[SocialCult] = .1
Affectproportions[SocialCult] = .1
Affectproportions[SocialCult] = .1
alpha1 = 0.5
alpha2 = 0.5
alpha3 = 0.5
alpha4 = 0.5
alpha5 = 0.5
alpha6 = 0.5
B = 0.17
C = 0.61
Commercial_Services = A*(HKC)^alpha1*(CommercialArea*(1-affbysector[Commercial]/exp(5)))^alpha2
HKC = sum(WorkSkillsStatus[*, Service])
HKI = sum(WorkSkillsStatus[*, Trades])
HKP = sum(WorkSkillsStatus[*,Professional])
Industrial_Production = B*(IndustrialLand*(1-affbysector[Industrial]/exp(5)))^alpha3*(HKI)^alpha4
MOWL = 0*(alphaGu+BetaGu)
Public_Services = C*(PublicWorksLand*(1-affbysector[PublicWorks]/exp(5))) ^alpha5*(HKP)^alpha6
WorkSkillsStatus[Degree, Professional] = Degree*Spliteducation&workskills[Degree, Professional]
WorkSkillsStatus[Degree, Professional] = Degree*Spliteducation&workskills[Degree, Professional]
WorkSkillsStatus[Degree, Professional] = Degree*Spliteducation&workskills[Degree, Professional]

WorkSkillsStatus[Degree, Professional] = Degree*Spliteducation&workskills[Degree, Professional]
WorkSkillsStatus[Degree, Professional] = Degree*Spliteducation&workskills[Degree, Professional]
WorkSkillsStatus[Degree, Professional] = Degree*Spliteducation&workskills[Degree, Professional]
WorkSkillsStatus[Degree, Professional] = Degree*Spliteducation&workskills[Degree, Professional]
WorkSkillsStatus[Degree, Professional] = Degree*Spliteducation&workskills[Degree, Professional]
WorkSkillsStatus[Degree, Professional] = Degree*Spliteducation&workskills[Degree, Professional]

Human_Sector =

Middle(t) = Middle(t - dt) + (yngtoMiddl + In_Migration - MiddltoOLd - Out_Migration) * dt
INIT Middle = 23720
INFLOWS:
    yngtoMiddl = YtoM
    In_Migration = In_Migration_Rate*Middle
OUTFLOWS:
    MiddltoOLd = MtoOld
    Out_Migration = Out_Migration_Rate*Middle
In_Migration_Rate = 0.02
Out_Migration_Rate = 0.018
Spliteducation&workskills[Degree, Professional] = 0.6
Spliteducation&workskills[Degree, Professional] = 0.6
Spliteducation&workskills[Degree, Professional] = 0.6
Spliteducation&workskills[Degree, Professional] = 0.6
Spliteducation&workskills[Degree, Professional] = 0.6
Spliteducation&workskills[Degree, Professional] = 0.6
Spliteducation&workskills[Degree, Professional] = 0.6
Spliteducation&workskills[Degree, Professional] = 0.6
Spliteducation&workskills[Degree, Professional] = 0.6

Land_UseSector =

AffectedArea(t) = AffectedArea(t - dt) + (StormSurge - Recovery) * dt
INIT AffectedArea = 0
INFLOWS:
    StormSurge = Scalar*exp(MOWL)
OUTFLOWS:
    Recovery = AffectedArea*recoveryrt
CommercialArea(t) = CommercialArea(t - dt) + (NewCommAc - DemolitionCA) * dt
INIT CommercialArea = 2680
INFLOWS:
    NewCommAc = gainAcMtoOld+gainAcYtoM
OUTFLOWS:
    DemolitionCA = lossAcMtoOld+LossAcOld
alphaGu = 2.99
BetaGu = 0.303
death = Old*deathrate
death = Old*deathrate
MOWL = 0*(alphaGu+BetaGu)
MtoOld = Middle/D2
MtoOld = Middle/D2
MtoOld = Middle/D2
MtoOld = Middle/D2
recoveryrt = 0.1
ResidentialArea = ResidentialHousing*AcperHouse
Scalar = 0
YtoM = Young/D1
YtoM = Young/D1

Not in a sector

UnaffectedLand(t) = UnaffectedLand(t - dt) + (Recovery - StormSurge) * dt
INIT UnaffectedLand = 10954
INFLOWS:
    Recovery = AffectedArea*recoveryrt
OUTFLOWS:
    StormSurge = Scalar*exp(MOWL)
AcperHouse = 0.215
alpha10 = 0.25
alpha11 = 0.25
alpha12 = 0.25
alpha13 = 0.25
alpha14 = 0.25
alpha15 = 0.33
alpha16 = 0.33
alpha17 = 0.33
alpha7 = 0.25
alpha8 = 0.25
alpha9 = 0.25
birthrate = 0.02
Cult&Soc_Services = D*Young^alpha11*Middle^alpha12*Old^alpha13*(Cult&SocialLand*(1-affbysector[SocialCult]/exp(5)))^alpha14
D = 0.26
D1 = 15
D2 = 51
deathrate = 0.03
E = 0.04
Ecosystem_Services = E*(GreenSpace*(1-affbysector[Greenspace]/exp(5)))^Alpha7*Young^alpha8*Middle^alpha9*Old^Alpha10
EducationStatus[Old, Degree] = Old*splitage&education[Old, Degree]
EducationStatus[Old, Degree] = Old*splitage&education[Old, Degree]
EducationStatus[Old, Degree] = Old*splitage&education[Old, Degree]
EducationStatus[Old, Degree] = Old*splitage&education[Old, Degree]
EducationStatus[Old, Degree] = Old*splitage&education[Old, Degree]
EducationStatus[Old, Degree] = Old*splitage&education[Old, Degree]
EducationStatus[Old, Degree] = Old*splitage&education[Old, Degree]
EducationStatus[Old, Degree] = Old*splitage&education[Old, Degree]
EducationStatus[Old, Degree] = Old*splitage&education[Old, Degree]
F = 0.2
gainAcMtoOld = MtoOld*RatAcMtoOld
gainAcYtoM = YtoM*RatActoM
gainHHMtoOld = MtoOld*RatHHMtoOld
gainHHYtoM = YtoM*RatHHtoM
lossAcMtoOld = MtoOld*RatActoOld
LossAcOld = death*RatAcOld
lossHHMtoOld = MtoOld*RatHHtoOld
LossHHOld = death*RatHHOld
RatAcMtoOld = 0.1
RatAcOld = 0.1
RatActoM = 0.17
RatActoOld = 0.17
RatHHMtoOld = 0.3
RatHHOld = 0.3
RatHHtoM = 0.5
RatHHtoOld = 0.5
SocMapProd = F*Social_Networks^alpha15*Wellbeing^alpha16*Collaboration^alpha17
splitage&education[Old, Degree] = 0.46
splitage&education[Old, Degree] = 0.46
splitage&education[Old, Degree] = 0.46
splitage&education[Old, Degree] = 0.46
splitage&education[Old, Degree] = 0.46

splitage&education[Old, Degree] = 0.46
splitage&education[Old, Degree] = 0.46
splitage&education[Old, Degree] = 0.46
splitage&education[Old, Degree] = 0.46
splitage&healthstatus[Old, UnHealthy] = .3
splitage&healthstatus[Old, UnHealthy] = .3
splitage&healthstatus[Old, UnHealthy] = .3
splitage&healthstatus[Old, UnHealthy] = .3
splitage&healthstatus[Old, UnHealthy] = .3
splitage&healthstatus[Old, UnHealthy] = .3
SumHealthy = sum(HealthStatus[*,Healthy])
SumHealthy&Unhealthy = SumUnHealthy+SumHealthy
SumUnHealthy = Sum(HealthStatus[*, UnHealthy])

Appendix E

STELLA Model Results–Simulation Trial Results and Averages for a Single Model Scenario

Table E.1 shows the results from running the STELLA model for one trial with seed random number (56) of the STELLA model for Cultural and social services, Goods and Services sector, and Land area sectors. The selected model scenario is for the Protect adaptation strategy and the "more severe storms" storm events. Table E.1 presents the complete results for the 50 years planning horizon.

Table E. 1: One trail running model with seed for random number generator 56 for Protect-More Severe Storms scenario

	Cultural and social Sector ($)			Goods and Service Sector ($)			Land area sectors (acres)			
Year	Cult& Social Service	Eco-system Service	Social Map	Commer cial Service	Industria l Service	Public Service	Green Space	Industria l Land	Cult & Social Land	Public Work Land
0	1,408.11	151.44	0.28	2,183.57	858.3	2,150.53	472	1,239.00	1,326.00	2,011.00
1	1,444.17	162.79	0.24	2,223.52	873.61	2,179.34	472.09	1,239.25	1,326.26	2,011.40
2	1,463.96	166.47	0.24	2,239.45	870.66	2,233.56	463.85	1,217.59	1,303.09	2,076.26
3	1,477.22	169.05	0.24	2,254.32	862.17	2,277.49	450.56	1,182.71	1,265.76	2,116.78
4	1,486.35	167	0.24	2,251.99	850.39	2,404.26	441.63	1,159.27	1,240.67	2,374.81
5	1,477.37	161.53	0.27	2,244.26	820.03	2,452.23	416.08	1,092.20	1,168.90	2,487.43
6	1,459.19	149.4	0.27	2,213.32	781.44	2,456.12	391.85	1,028.61	1,100.84	2,592.61
7	1,475.17	168.03	0.24	2,295.57	785.4	2,500.19	367.32	964.22	1,031.92	2,430.30
8	1,483.06	169.93	0.24	2,311.30	779.58	2,486.85	358.54	941.16	1,007.24	2,372.17
9	1,496.25	169.7	0.24	2,315.29	779.9	2,488.77	359.55	943.83	1,010.10	2,378.91
10	1,500.51	162.85	0.27	2,295.31	770.97	2,452.33	360.31	945.81	1,012.23	2,383.91
11	1,523.47	172.12	0.24	2,335.36	784.19	2,507.84	360.84	947.19	1,013.70	2,387.39
12	1,532.22	174.67	0.24	2,353.64	782.66	2,508.25	355.34	932.77	998.27	2,351.04
13	1,539.02	173.89	0.24	2,358.47	779.31	2,498.05	352.78	926.04	991.07	2,334.08
14	1,553.61	177.29	0.24	2,377.45	784.92	2,521.27	353.61	928.22	993.39	2,339.56
15	1,554.47	172.56	0.27	2,368.03	776.2	2,488.66	350.91	921.13	985.81	2,321.70
16	1,573.50	180.32	0.24	2,403.62	787.77	2,536.49	351.64	923.04	987.86	2,326.52
17	1,574.96	177.76	0.24	2,403.16	780.9	2,512.77	347.67	912.62	976.70	2,300.25

18	1,572.83	168.89	0.27	2,376.90	770.11	2,467.02	348.45	914.67	978.89	2,305.41
19	1,586.45	175.92	0.27	2,411.74	777.3	2,500.75	345.59	907.18	970.88	2,286.54
20	1,596.62	182.89	0.23	2,448.30	781.49	2,524.91	339.67	891.65	954.25	2,247.38
21	1,598.84	181.72	0.23	2,453.00	777.09	2,510.58	336.25	882.65	944.63	2,224.70
22	1,605.66	180.53	0.23	2,455.11	777.39	2,510.45	337.65	886.34	948.57	2,234.00
23	1,612.90	180.08	0.27	2,460.13	778.45	2,513.68	338.79	889.34	951.78	2,241.56
24	1,623.40	185.68	0.23	2,490.14	783.75	2,538.96	335.98	881.95	943.88	2,222.95
25	1,608.35	171.23	0.27	2,444.37	762.17	2,451.68	332.85	873.74	935.09	2,202.25
26	1,628.89	181.86	0.27	2,491.12	778.01	2,516.98	334.12	877.07	938.66	2,210.65
27	1,633.42	186.08	0.23	2,517.87	778.06	2,524.12	327.9	860.73	921.17	2,169.46
28	1,630.37	181.46	0.27	2,508.77	769.88	2,492.78	325.21	853.67	913.62	2,151.68
29	1,643.96	186.5	0.23	2,534.24	778.85	2,528.23	326.91	858.15	918.40	2,162.95
30	1,641.13	182.62	0.27	2,528.01	771.33	2,499.94	323.9	850.24	909.94	2,143.01
31	1,649.51	183.79	0.27	2,538.54	775.13	2,513.76	325.52	854.50	914.50	2,153.76
32	1,641.41	176.04	0.27	2,517.37	762.54	2,463.81	322.41	846.33	905.76	2,133.17
33	1,663.34	192.09	0.23	2,587.77	781.29	2,545.79	319.59	838.92	897.82	2,114.48
34	1,658.24	188.8	0.23	2,584.78	772.34	2,514.00	314.47	825.48	883.44	2,080.61
35	1,668.11	191.01	0.23	2,598.74	778.09	2,535.24	316.64	831.19	889.55	2,095.00
36	1,674.29	190.65	0.23	2,602.79	780.15	2,541.43	318.51	836.08	894.79	2,107.33
37	1,677.80	188.51	0.23	2,599.94	779.59	2,536.83	320.09	840.24	899.24	2,117.82
38	1,689.78	193.35	0.23	2,624.46	787.95	2,569.98	321.43	843.75	903.00	2,126.67
39	1,688.78	191.64	0.23	2,625.73	783.49	2,554.06	318.68	836.53	895.27	2,108.45
40	1,687.29	186.03	0.27	2,609.15	778.1	2,529.26	319.98	839.95	898.93	2,117.09
41	1,700.31	194.92	0.23	2,651.48	788.2	2,573.92	317.88	834.44	893.03	2,103.20
42	1,695.54	191.58	0.23	2,646.79	780.31	2,545.01	313.92	824.05	881.92	2,077.02
43	1,704.66	194.27	0.23	2,662.45	786.03	2,566.78	315.46	828.07	886.22	2,087.14
44	1,691.45	182.85	0.27	2,624.67	769.53	2,498.97	313.25	822.29	880.03	2,072.57
45	1,711.86	194.6	0.23	2,675.90	786.85	2,570.18	314.69	826.06	884.07	2,082.09
46	1,706.41	192.22	0.23	2,675.51	778.82	2,542.16	309.43	812.25	869.28	2,047.26
47	1,709.35	190.12	0.27	2,671.73	778.44	2,537.92	311.1	816.63	873.97	2,058.30
48	1,716.83	195.27	0.23	2,699.26	783.27	2,560.66	308.8	810.59	867.51	2,043.09
49	1,712.82	192.18	0.23	2,694.35	776.62	2,535.75	305.77	802.64	859.00	2,023.05
Final	1,723.44	196.06	0.23	2,714.10	784.15	2,564.78	307.58	807.41	864.10	2,035.06

Table E.2 shows the result of all 10 random number trials for t=50 of the 50 years planning horizon for Cultural and Social sector, Goods and Service sector, and Land area sector. The selected model scenario is for the Protect adaptation strategy, and the "more severe storms" storm events. The second part of the table is the average and standard deviation of the 10 trials as a final output, which is repeated for each scenario of the simulation.

Table E. 2: Average and standard deviation of 10 trails for Protect- More Severe Storms scenario

	Cultural and Social Sector ($)			**Goods and Service Sector ($)**			**Land area sectors (acres)**			
Seeds	Cult& Social Service	Eco-System Service	Social Map	Commercial Service	Industrial service	Public Service	Green Space	Industrial Land	Cultural & social Land	Public Work Land
56	1,723.44	196.06	0.23	2,714.10	784.15	2,564.78	307.58	807.41	864.10	2,035.06
96379	1,722.71	194.27	0.23	2,706.08	783.22	2,561.46	308.89	810.84	867.78	2,047.30
153	1,721.62	197.55	0.23	2,722.10	782.75	2,559.27	304.47	799.24	855.37	2,009.21
11119	1,727.68	198.42	0.23	2,722.88	788.31	2,578.30	308.61	810.09	866.97	2,037.50
47854	1,728.39	196.22	0.23	2,712.12	788.6	2,576.52	311.59	817.91	875.34	2,058.09
100	1,725.24	191.32	0.27	2,690.92	785.04	2,560.85	314.24	824.89	882.81	2,080.06
13000	1,721.59	194.32	0.23	2,706.91	782.22	2,576.39	307.9	808.23	864.99	2,069.38
10012	1,723.37	198.21	0.23	2,724.26	784.43	2,566.48	305.23	801.23	857.49	2,015.93
5	1,725.85	195.82	0.23	2,711.67	786.27	2,571.88	309.86	813.38	870.50	2,051.66
4555	1,722.60	197.91	0.23	2,723.27	783.69	2,563.14	304.91	800.38	856.58	2,012.78
Seeds	Cult& Social Service	Eco-System Service	Social Map	Commercial Service	Industrial service	Public Service	Green Space	Industrial Land	Culture &Social Land	Public Work Land
Average	1,724.25	196.01	0.23	2,713.43	784.87	2,567.91	308.33	809.36	866.19	2,041.70
SD	2.43	2.23	0.01	10.47	2.21	7.23	3.08	8.08	8.64	24.16