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Thesis

Multicriteria decision evaluation of adaptation strategies for vulnerable coastal communities

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Abstract

According to the IPCC (2007) fourth assessment report, small islands and coastal communities have a set of characteristics that makes them very vulnerable to climate change impacts, mainly sea-level rise and storm surges.

Coastal hazards including inundation, salinisation of the water supply, and erosion threaten vital infrastructure that support coastal communities.

Although Canada has the longest coastline in the world, little work has been done on impacts of climate change and adaptation to these impacts in the Canadian coastal zones. This research is part of an International Community-University Research Alliance (ICURA) C-Change, project to develop a multicriteria decision evaluation and support for the systems analysis of adaptation options for coastal communities toward adapting to environmental changes. This study estimates the vulnerability of coastal communities with respect to their environmental, economic, social, and cultural dimensions. It also applies a group version of the Analytical Hierarchy Process for identifying decisions that various stakeholders make on suggested adaptation strategies. This study develops a methodological framework that is applicable to various coastal and small island contexts. The application of the proposed framework is further discussed in a case study conducted on the communities of Charlottetown, Prince Edward Island (PEI), and Little Anse on Isle Madame, Nova Scotia. Specifically, the state of the Little Anse breakwater is analyzed and new adaptation options are presented and evaluated.

This research has illustrated and applied a process of decision evaluation and support that explicitly engages multiple participants and critieria in complex problems situations involving environmental change in coastal communities.

Glossary

CD	Chart Datum
DA	Dissemination Area
DFO	Fisheries and Oceans Canada
DEM	Digital Elevation Model
AHP	Analytical Hierarchy Process
EC	Environmental Canada
FDT	Florida Department of Transportation
GIS	Geographic Information System
HURDAT	North Atlantic Hurricane Database
ICSP	Integrated Community Sustainability Plan
Km/h	Kilometres per Hour
Mb	Millibars
NHC	National Hurricane Center
NOAA	Natural Oceanic & Atmospheric Administration
NRC	Natural Resources Canada
MOWL	Maximum Observed Water Levels (in meters)

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1. Introduction

This document presents research in the Master's Program in Systems Science in the form of a thesis in partial fulfillment of the M.Sc degree in Systems Science at the University of Ottawa.

1.1 Motivation / Problem Definition

Among all the climate change impacts, the increase in sea level rise has received a great deal of attention. "Sea level rise involves elevated tidal inundation, accelerated erosion, increased saltwater intrusion, increased flood frequency, rising water tables, and significant ecological changes" (Dolan and Walker 2004). The increased frequency of climate change and potential consequences of its impacts on coastal communities has resulted in a substantial attention to vulnerability assessment of coastal communities. "However, the effects on the potential inequitable distribution of climate change impacts, particularly as it defines the vulnerability of isolated island communities, has received considerably less attention " (Dolan and Walker 2004).

Although Canada has the longest coastline in the world little work has been done on impacts of climate change and adaptation to these impacts in the Canadian coastal zones. Many of Canadian Arctic coastal communities are already experiencing climate change impacts in the form of melting of sea ice, rise in sea levels, permafrost thawing and coastal erosion (Dolan and Walker 2004).

According to the IPCC fourth assessment report (IPCC, 2007), small island communities have special characteristics that make them very vulnerable to climate variability. Among these characteristics are their limited size and susceptibility to extreme events that increase these communities's vulnerability to climate change impacts. In most of the cases these communities do not have adequate adaptive capacity and moreover costs of adaptations are high relative to their GDP (Gross Domestic Product) - (IPCC 2007).

"The rise in the sea-level is expected to worsen inundation, erosion, storm surge, and other coastal hazards, therefore threatening vital infrastructure, settlements and facilities that support the livelihood of island communities (very high confidence)" (IPCC 2007). Island infrastructures are mostly located near to the shoreline. For example, in the case of Pacific and Caribbean islands, more than half of the population live within 1.5 km of the shore. Infrastructures such as roads, airports, and capital cities in the small islands of the Pacific and Indian Oceans and the Caribbean are either located along the coast or on very small islands. Sea-level rise can intensify coastal hazards such as inundation and erosion, threaten important infrastructures and facilities, and as the result impact the socioeconomic well being of coastal communities (IPCC 2007).

In 2009, the UN climate change conference (COP 15) was held in Copenhagen. Research presented at International Scientific Congress on Climate Change revealed that previous prediction of sea level rise by the IPCC (2007) by the amount of 18-59 cm by 2100 is conservative. Based on new findings presented at this conference the upper limit of this spectrum will be possibly more than one meter by 2100, double the amount predicted by the earlier 2007 IPCC report. They also predict that it is unlikely that the lower level of this spectrum will be much less than 50 cm by 2100. The difference between the two projections is due to the fact that the earlier IPCC report did not take into account the melting of the Greenland and Antarctica ice sheets. Based on the new insights, there is ice loss from Greenland and Antarctica that contributes even more to a rise in the sea level. Even an optimistic rise in sea levels has severe impacts on exposed communities. Six hundred million people (about 10% of the world population) live in low lying areas which are vulnerable to flooding.

All the participants present at COP 15 agreed to an accord (the Copenhagen Accord) which they decided to operationalize immediately. Article 3 is of a particular interest for this research:

> “*Adaptation to the adverse effects of climate change and the potential impacts of response measures is a challenge faced by all countries. Enhanced action and international cooperation on adaptation is urgently required to ensure the implementation of the Convention by enabling and supporting the implementation of adaptation actions aimed at reducing vulnerability and building resilience in developing countries, especially in those that are particularly vulnerable, especially least developed countries, small island developing states and Africa. We agree that developed countries shall provide adequate, predictable and sustainable financial*

resources, technology and capacity-building to support the implementation of adaptation action in developing countries" (UNFCCC 2009, COP 15)

COP 16 was held in Cancun, Mexico in 2010. The Cancun Accord includes a $30 billion package for 2012 to assist nations taking urgent actions to stop the impacts of global warming, in addition to financing for long-term projects to protect the environment through a Green Fund. This fund will provide $100 million annually for adaptation and mitigation measures. The fund from all the bilateral, multilateral, public and private sources. Financial aids such as highly concessional loans and grants are necessary and essential for adaptation to climate change impacts particularly as it relates to Small Island Developing States (UNFCCC 2010, COP 16).

It is evident from the above statement that much attention has been put on adaptation to climate change as well as attention on required actions for reducing the vulnerability of small islands developing states. Climate change is serious and its impacts on coastal communities can be devastating.

A sensitivity analysis along the coast of Canada, Shaw et al (1998) concluded that the most sensitive region constituted most of the coasts of New Brunswick, Nova Scotia and Prince Edward Island. According to their study many small settlements are located in sensitive locations.

The Atlantic region of Canada is subject to impacts from a wide range of interannual and seasonal events such as tropical hurricanes, winter cyclonic storms, and flooding (Vasseur et al 2008). During the past 15 years storm surges have caused significant damage in all of the Atlantic Provinces. Hurricane season of 2010 has specially been a harsh year with frequent storm incidents in the region (Drye 2010).

Parts of eastern New Brunswick are especially susceptible to storm surges. In the Beaubassin area of southeastern New Brunswick claims from the government for the damages made to houses, wharves, cottages as the result of a storm surge of January 2000 winter storm exceeded $1.6 million Canadian dollars (Environmental Canada 2006). Historical events such as Great Hurricane of 1775 in eastern Newfoundland and Saxby Gale of 1869 in the Bay of

Fundy all provide strong evidence of severe impacts from dramatic storm surges in Atlantic Canada (Vasseur et al 2008). For example, Hurricane Juan in 2003 was the most economically damaging event in the history of Atlantic Canada - 8 people died and Prince Edward Island and Nova Scotia incurred around $200 million Canadian in damages (Environment Canada 2010). Continuation of sea level rise will intensify storm surges and floods in the Atlantic region of Canada (Vasseur 2008).

1.2 Research questions and objectives

The fundamental questions in this research are:

- How can we evaluate the vulnerability of coastal communities that are subject to rapidly changing environmental conditions including storm surges and sea level rise?
- How can community's strategies for adaptation be evaluated?

With respect to these issues, I focus on methodological development to link impact assessment from environmental change with evaluation of adaptation alternatives assisted by multicriteria decision making analysis and multi-stakeholder consultation for the case of vulnerable coastal communities.

In response to these research questions, the associated objectives are:

1) To define a set of indicators in order to determine the extent of vulnerability of coastal communities to various climate change scenarios.

2) To identify the social, economical, environmental and cultural impacts on coastal communities of environmental change scenarios.

3) To identify adaptation strategies and engage multiple community stakeholders to evaluate the desirability of such adaptation options and to provide decision support for action.

1.3 Outcome of this research

The outcome of this research is to develop a methodological framework that will provide decision making support applicable to coastal and small island communities.

Although any methodological framework is context specific, there are some aspects that are common between these communities. Community case studies will provide us with collective insight that in turn may be generally applicable to various coastal communities and their adaptation decisions.

1.4 Plan of the proposal

The structure of this document is as follows:

Chapter 1 – Introduction: includes the critical issue of environmental change occurring to our global communities and small islands.

Chapter 2 – Literature review: introduces the existing literature for multicriteria decision making methods, conceptual vulnerability frameworks, vulnerability of coastal communities in Canada to climate extremes, vulnerability indicators and adaptive capacity, and adaptation as strategies to decrease the vulnerability of these communities.

Chapter 3 – Methodology: the vulnerability framework is presented along with the utility function valuation of storm impacts and the general application of the Analytical Hierarchy Process (AHP) model. The notion of various severe storm scenarios applicable to the context of our communities is also discussed in this section.

Chapter 4 – The Case of Isle Madame: application of the developed decision support model to the case of Isle Madame is presented using storm damage estimates for the broad community.

Chapter 5 – Adaptation strategy evaluation and the case of the Little Anse breakwater: presents a detailed case study of the Little Anse community breakwater to demonstrate the specific application of the evaluation of adaptation strategies.

Chapter 6 – Considerations for future research: summary and limitations of this research and suggestions for future research are highlighted in this closing section.

The thesis also includes a series of appendices designed to provide the complete sets of data requirements and model results for the analyses presented in the thesis document for full disclosure of the work carried out in this research.

2. Literature review

The literature below is divided into six sections: (2.1) Multicriteria Decision Making (MCDM); (2.2) Vulnerability; (2.3) Adaptation Strategies; (2.4) Historical Storm Profiling; (2.5) Storm Surge; and (2.6) Summary of the Literature as related to the thesis research. Each main section is further subdivided into subsections of particular interest and literature related to this research.

2.1 Multicriteria Decision Making (MCDM)

The general MCDM problem evaluates *m* decision alternatives, among *n* problem criteria measures, and for one or more decision makers or participants. The objective of the MCDM problem is to determine which of the pre-specified alternatives is preferred, and how the alternatives are comparatively ranked (Zeleny 1982). There are number of methods that are noteworthy and include: Weighted Sum Model and Weighted Product Modeling Method (Triantaphyllou 2000), the families of outranking ELECTRE methods (Roy 1991), PROMETHEE (Brans et al 1986) and the Analytical Hierarchy Process (AHP) (Saaty 1980).

2.1.1 The Weighted Sum Model (WSM)

The Weighted Sum Model (WSM) is one of the most commonly used MCDM approaches for single dimensional problems - where the same unit of measure is available for all criteria (Triantaphyllou 2000). When there are *m* alternatives and *n* criteria, the best alternative is the one that satisfies the following weighted expression:

$$A_{WSM-Score} = \max_i \sum_{j=1}^{n} a_{ij} w_j \quad \text{for } i = 1,2,3,....,m \qquad (2.1)$$

where: $A_{WSM-Score}$ is the weighted sum model of the best alternative, *n* is the number of decision criteria, a_{ij} is the actual value of the i^{th} alternative in terms of the j^{th} criterion, and w_j is the weight of importance of the j^{th} criterion.

The assumption of this model is "*additive utility assumption*" meaning that as given by the formulation (2.1) the total value of each alternative is equal to the sum of the products (Triantaphyllou 2000). In cases with single dimensional problems, i.e., the same unit of measure for all criteria, there is no problem with scale. Scaling problems arise when MCDM problems are multi-dimensional, i.e., criteria with different units of measurement. In this case, the *additive utility assumption* is violated and the result is like adding “apples and oranges” (Triantaphyllou 2000). This approach has limited applicability in more complex problem situations that require the use of qualitative and quantitative data of mixed scales.

2.1.2 The Weighted Product Modelling Method (WPM)

In WPM each alternative is compared with other alternatives by multiplying a number of ratios, one per criterion. Each ratio is raised to the power which is equivalent to the relative weight of the related criterion (Triantaphyllou, 2000). The main difference between WSM and WPM methods is that instead of addition in the WSM model, there is multiplication. In general, to compare A_K and A_L alternatives, the following formula is calculated:

$$R(A_K / A_L) = \prod_{j=1}^{n} (a_{Kj} / a_{Lj})^{wj} \qquad (2.2)$$

where n is the number of criteria, a_{ij} is the actual value of the i^{th} alternative in terms of the j^{th} criterion, and w_j is the weight of importance of the j^{th} criterion.

İn the maximization case, if $R(A_K/A_L)$ is greater than or equal to one, then it indicates that alternative A_K is more favourable than alternative A_L. The preferred alternative is the one that is superior or at least equal to all the other alternatives.

This method is also called “*dimensionless analysis*” since it eliminates units of measurement as a result of the ratio calculations (Triantaphyllou 2000). This gives an advantage over the WSM method, as the WPM method can be used for both single dimensional (i.e., same unit of measure for all criteria) and multi dimensional (i.e., different units of measure for criteria) MCDM problems. Another advantage of WPM is that it can use relative values rather than absolute values. However, the assumption is that all data are quantitative. When data are qualitative as well as quantitative, then problems arise with this method.

2.1.3 ELECTRE

The ELECTRE method (*ELimination and Choice Translating Reality) is* a method to find outranking relations by using pairwise comparisons among alternatives under each criterion separately (Roy 1991). An outranking relation of $A_i \rightarrow A_j$ - also shown as $A_i S A_j$ - implies that A_i is preferred to A_j if A_i is at least as good as A_j on a majority of criteria, and if it is not significantly worse on any other criteria (the difference between the two is within a predefined threshold).

Alternatives are dominated if there is another alternative which surpasses them in one or more criteria and is equivalent in the remaining criteria. In the ELECTRE method, even if the A_i does not strictly dominate A_j quantitatively, the decision maker may still decide that A_i is preferred to A_j .

Using physical or monetary values denoted as $g_k(A_i)$ and $g_k(A_j)$ for alternatives *Ai* and *Aj* , and also by defining threshold levels for the difference between $g_k(A_i)$ and $g_k(A_j)$, the decision maker can declare for different decisions that there is (Milani et al 2006):

- indifference between the two alternatives
- strong or weak preference of one over another
- no specific preference

Establishing an outranking relation between alternatives *Ai* and *Aj* requires two sets of comparisons. One in which $g_k(A_i)$ is superior to $g_k(A_j)$ and another in which $g_k(A_i)$ is not superior to $g_k(A_j)$. Therefore, the ELECTRE method separately examines both the criteria that vote for $A_i S A_j$ and those that reject such dominance. These two sets of comparisons are based on two tests: concordance and discordance. The concordance test allows the decision maker to verify that if *Ai* is at least as good as *Aj*. The discordance test verifies if there exists a significant opposition to the outranking relation $A_i S A_j$ (Roy 1991; Milani et al 2006)

There are many variations of this method including: ELECTRE I, ELECTRE II, III, and IV (Milani et al 2006). For example, the main difference between ELECTRE I and II is that in the latter, we define two outranking relations instead of one - the strong and weak outranking (Milani et al 2006).

"The ELECTRE method results in a system of binary outranking relations between the alternatives, and the fact that this system is not necessarily complete; the ELECTRE method is sometimes unable to identify the best alternative. It merely identifies a set of leading alternatives" (Triantaphyllou 2000).

2.1.4 PROMETHEE

PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluations) is another outranking method. According to Brans et al (1986), this method is used to solve problems with the form below:

$$Max\{f_1\,(a), f_2\,(a), \dots \dots f_k\,(a) | a \in A\} \qquad (2.3)$$

where A is a finite set of actions and f_i *(i = 1,....., K)* are *K* criteria to be examined.

For each criterion, a utility function is identified to represent the decision maker's preference in respect to evaluation criteria. This function takes the values between (0, 1). Criteria can be in different units and by defining a utility function we eliminate the effects of different scales.

In PROMETHEE, a preferably weighted index (μ) is defined. This index defines the preferable percentile of alternative "a" with respect to alternative "b" – considering the attributed weights to each criterion. This index is calculated as follows:

$$\mu\,(a, b) = \frac{\sum_{i=1}^{k} W_i\; P_i(a,b)}{\sum_{i=1}^{K} W_i} \qquad (2.4)$$

The W_i are called weights and represent the importance of each criterion. Also P_i is the preference function that the decision maker defines. It is noted that:

μ (a, b) ≈ 0 denotes a weak preference of *a* over *b* for all criteria
μ (a, b) ≈ 1 denotes a strong preference of *a* over *b* for all criteria

This method defines three outranking flows: leaving flow($\emptyset^{+}$) and entering flow($\emptyset^{-}$).

$$\emptyset^{+}(a) = \frac{\sum_{b=1}^{n} \mu(a,b)}{n-1}\ , \emptyset^{-}(a) = \frac{\sum_{b=1}^{n} \mu(b,a)}{n-1}, \qquad (2.5)$$

The higher the leaving flow and the lower the entering flow the better the alternative (Brans et al 1986).

D-Sight is an example of software based on PROMETHEE methodology (Decision Sights, 2011). It relies on a group of visual tools that facilitate interactive analysis.

2.1.5 Analytical Hierarchy Process (AHP)

Developed by Saaty (1980), the Analytical Hierarchy Process (AHP) is one of the widely used methods for addressing decision making problems with multiple criteria and a mixture of qualitative and quantitative data inputs. This method is well suited for situations where criterions can be organized into a hierarchy by dividing the problem characteristics into sub-criteria. During the last two decades this method has been widely used by operation researchers and decision scientists particularly in the USA.

There are four stages involved in Analytical Hierarchy Process method:

Stage 1: Decompose the problem into a hierarchy of more comprehensive sub problems.

Stage 2: Collect trade-off data input by conducting pairwise comparisons among level problem hierarchy characteristics and problem alternatives.

Stage 3: Estimate relative weights of the hierarchy criteria.

Stage 4: Aggregate criteria by combining relative weights to perform an overall evaluation of alternatives.

The first stage involves structuring the problem objective to layers of sub-criteria in a form of hierarchy. Figure 2.1 below shows the general form for such a problem hierarchy as used in AHP.

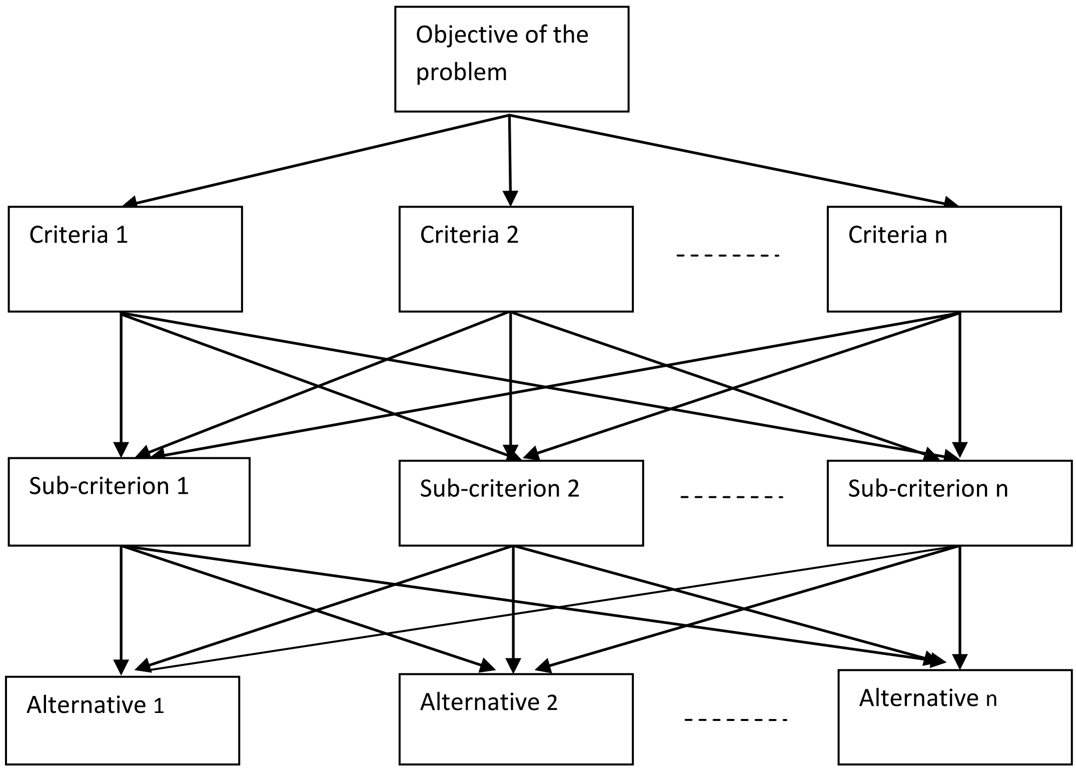

Figure 2.1: The general form of AHP hierarchy

Source: Saaty (1980)

First, the problem hierarchy is formed, and then in the second stage of this method, the decision maker performs the pairwise comparisons at each level of the hierarchy with respect to the higher level. In the second level of the hierarchy shown in Figure 2.1, all the criteria are compared with regard to their relative importance with first level (problem objective), then the derived sub-criteria in the third level are compared to parent criteria in the second level. This process is continued until all the components in the multi-level structure are compared.

These comparisons capture the relative significance of all the components of the hierarchy in order to make the final decision on the problem objective.

The numerical values used in the pairwise comparisons are extracted from the following 9-point scale table as first suggested by Saaty (1980).

Table 2.1 Saaty's AHP 9 point pairwise comparison scale

Source: Saaty (1980)

Value	**Definition**	**Explanation**
1	Equal importance	Two activities contribute equally to the objective.
3	Moderate importance	Experience and judgement moderately favour one activity over another.
5	Essential or strong importance	Experience and judgment strongly favour one activity over another.
7	Very strong importance	An activity is strongly favoured and its dominance demonstrated in practice.
9	Extreme importance	The evidence favouring one activity over another is of the highest possible order of affirmation.
2,4,6,8	Intermediate values between	These numerical values are used when the two adjacent judgments compromise is needed between the odd numbered relative values.

By using the relative importance of the alternative with respect to each criterion a matrix is constructed. For each *i*, the vector of (a_{i1}, a_{i2}, ...,a_{in}) is the principal eigenvector of an $n * n$ reciprocal matrix. This is evaluated by pairwise comparisons of the impact of the *m* alternatives on the i^{th} criterion Saaty (1980).

$$
\begin{array}{c} \\ A_1 \\ A_2 \\ \cdot \\ \cdot \\ A_N \end{array}
\begin{array}{c} \begin{array}{ccccc} A_1 & A_2 & . & . & A_n \end{array} \\
\begin{pmatrix}
w_1/w_1 & w_1/w2 & . & . & w_1/w_N \\
w2/w_1 & . & . & . & . \\
. & . & . & . & . \\
. & . & . & . & . \\
w_N/w_1 & . & . & . & w_N/w_N
\end{pmatrix}
\end{array}
\qquad (2.6)
$$

According to AHP (in the maximization case), the best alternative is indicated by the following relationship:

$$A_{AHP-Score} = \max_{i} \sum_{j=1}^{n} a_{ij} w_j \quad \text{for i = 1,2,3,......,m} \qquad (2.7)$$

The AHP method resemblances WSM with the deference that WSM uses actual values or scores, whereas AHP uses relative values based on decision maker's pairwise comparisons.

Apart from its vast popularity, there are criticisms and debates surrounding this method (Warren 2004; Doumpos and Zopounidis 2002). Warren (2004) devoted an article to criticize some of the fundamental mathematical aspects of this methodology.

The first issue is about rating scale type. A ratio scale should contain an absolute zero which then enables one to perform division and multiplication, subtraction and addition. As it is evident from the Table 2.1 (above), Saaty's AHP scales do not contain any absolute zero point. Warren (2004) debates the understanding that AHP takes ratio scales as input, when for example A may be mildly stronger than B, then the ratio scale interpretation is A is three times more important than B, however that is not how the numerical scale is explained to the involved decision makers.

The other argument is justification of using the right hand principal eigenvalue and corresponding eigenvector (Warren 2004). In AHP, the dominant right eigenvector corresponding to maximum eigenvalue is used to determine consistency. According to Warren (2004), alternative methods such as the Geometric Mean has been proposed in the literature, however the various simulation attempts to highlight the merit of these methods over one another have not shown any significant difference.

Another problem stated by Warren (2004) is the "rank reversal" problem. It refers to the change of order of preferences of alternatives when a new alternative is added to the problem. He discusses that this problem is due to the normalization of eigenvectors.

Overall, AHP has number of advantages that are relevant for this research. It is a relatively simple method to describe to decision makers and the collection of pairwise comparison data, especially in subjective cases, is an attractive aspect that involves the decision makers directly. It can also be used for group decision making – that is also important for this research - since different points of view of decision makers can be incorporated into the hierarchical structure of this model. There are many commercial software packages such as Expert Choice (2010) based on this methodology and used for applied decision making. The

AHP methodology and Expert Choice (2010) software has been used in many applied research problems. For example, Tayebi (2009) has used AHP and Expert Choice (2010) software to identify and characterize combinations of sensors and systems that will provide cost-effective options for Arctic maritime surveillance. The Expert Choice website (Expert Choice 2010) presents many examples of AHP and case studies on a wide range of multicriteria problems.

2.1.6 Group AHP

Most of the real life situations involve a group of decision makers striving to reach a consensus on a common objective. Most of the political and social issues involve a group of stakeholders which their insight should be somehow captured. Climate change is no exception. Local people, governmental institutions, NGOs and commercial organizations are examples of different stakeholders involved in adaptation practices as a response to climate change impacts. In these situations, the assumption of a solitary decision maker is no more appropriate. For this reason the incorporation of a mechanism to capture all these collective insights into our decision support system is inevitable.

AHP allows us to decompose a complex problem into a problem hierarchy. In this method, each characteristic of the problem and the solution can be identified and evaluated with respect to other factors of the problem. This ability to structure a complex system into a summary hierarchy and then focus attention on individual decision components amplifies a group decision making capabilities (Dyer et al 1992).

The AHP method can capture the group member's judgments about each facet of the decision problem. In this method, subjective judgments on individual components of the decision problem are easily accommodated. In fact, AHP has been used in number of group settings ranging from software selection (Lai et al 2001), higher education (Liberatore 1997), environmental conflict analysis (Malczewski et al 1997), selecting merged strategies for commercial banks (Wang el 2008) and evaluation of coastal zone sites for alternate marine use including aquaculture or fish farming (Ozer 2007, Zhao 2004, Zhao et al 2008).

In the group version of AHP there can be different approaches that group member's can use to determine the weights of components of the hierarchy: (1) Consensus, (2) Voting, (3) Geometric mean of the individual judgements, and (4) weighted arithmetic mean (Dyer et al 1992, Ramanathan et al 1994, Lai et al 2001, Condo et al 2003, Escobar et al 2006). To illustrate the differences between these methods consider *N* decision makers and in the pairwise comparison matrix of the alternative, *A*, a_{ij} illustrates the comparison between component *i* and *j*. In the consensus approach, the group members are required to reach a consensus on a_{ij} of matrix *A*. If the group fails to reach a consensus they use voting and/or a compromise approach. These two approaches may require a considerable amount of discussion and may contain initial disagreements between the participants (Condo et al 2003).

Now let us assume that in the pairwise comparison matrix *A*, $a_{ij}(k)$ illustrates the comparison of component *i* to *j* with respect to the k^{th} $(k = 1....N)$ decision maker. For computing a_{ij}, the individual judgments of all the participants are combined by using the geometric mean where:

$$a_{ij} = [a_{ij}^1 \times a_{ij}^2 \times \cdots \times a_{ij}^n]^{1/n} \quad (2.8)$$

Now if we also include the decision makers in our model and denote the weight *w(k)* to the decision maker *k* then we can combine the judgments of all the participants as follows:

$$a_{ij} = w^1 a_{ij}^1 + w^2 a_{ij}^2 + \cdots + w^n a_{ij}^n \quad (2.9)$$

Since this method calculates group priorities by using the weighted arithmetic mean of the individual priorities, is named Weighted Arithmetic Mean Method (Ramanathan et al 1994).

The necessity in this thesis research problem to consider multiple criteria (cultural, economical, social and environmental) when considering adaptation strategies, and involvement of various stakeholders such as NGOs, regional government, and local community members in the decision making process makes AHP and Group AHP a potential decision making support tool for this research.

2.2 Vulnerability

The following subsections of this literature review discuss conceptual frameworks on vulnerability, the vulnerability of coastal communities to climate change, and vulnerability measurement.

2.2.1 Conceptual frameworks on vulnerability

IPCC (2007) defines vulnerability to climate change "as the degree to which geophysical, biological and socio-economic systems are susceptible to and unable to cope with, adverse impacts of climate change."

Different disciplines such as economics, anthropology, psychology and engineering use the vulnerability term. Only in human–environment relationships the term vulnerability has a common meaning, although disputed. Areas of human ecology and geography have particularly conceptualized vulnerability to climate variability (Adger 2006).

Rather than being merely a question of definitions or semantics, the interpretation of vulnerability has consequences for how climate research is carried out within interdisciplinary research institutes, where scientists with differing backgrounds often use terminologies that are vaguely defined and lack shared meanings (O'Brien 2005). In this research, the concept of vulnerability is interpreted to have important implications for policy making– not only as it affects the diagnosis of the climate change problem, but also as it affects the potential solution of the problem, where the problem is considered as the vulnerability to climate change impacts.

Two major areas in vulnerability research acted as the basis for ideas that eventually led to existing research on vulnerability of physical and social systems in a holistic manner; analyzing vulnerability as the lack of entitlements to resources and the analyzing vulnerability to natural disasters (Adger 2006).

Many vulnerability studies draw on the entitlements literature regarding access to resources, on political economy in explaining the factors that lead to vulnerability, and on social capital as a means of claiming entitlements and pursuing coping mechanisms (O'Brien 2005).
The impetus for research on the subject of entitlements in livelihoods was to explain civil conflict, insecurity of food, and social turmoil (Adger 2006). In this approach the most important variables for explaining vulnerabilities are social realm of institutions, well being, social status, class and gender. From the entitlement theory perspective food insecurity vulnerability is explained as a set of linked institutional and economic factors.

Entitlements to resources can be the potential or actual resources available to people based on their own assets, production, or mutual arrangements (Adger 2006). Vulnerability is considered to be the result of processes in which people engage and which they can prevent. Entitlements approach focusing on vulnerability to famine, underplays environmental or physical risk but it succeeds in illuminating social differences in cause and outcome of vulnerability (Adger 2006).

Another approach categorizes vulnerability in terms of people‘s exposure to hazardous events (e.g. storms, floods, earthquakes) and the impact of these events on people and structures. These hazardous events put people and their communities at risk; therefore the aim is to find the vulnerable places. The basis for this approach is the physical elements of exposure, probability of hazards and their consequent impacts. In case of natural disasters the vulnerability of people is based on where the live, their use of natural resources and the available resources to them to cope with the impacts (Adger 2006). However the methods aiming to reduce this risk do not necessarily lessen the subsequent damage and sometimes they may even increase the vulnerabilities. For example, flood protection plans may not necessarily encourage people from leaving the vulnerable locations such as flood plains; in contrast, it may encourage further development and construction in those high risk locations which as a result increase vulnerability.

This interpretation of the vulnerability concept in a climate change context is based on the "end point" of the analysis, whereby "assessment of vulnerability is the end point of a sequence of analyses beginning with projections of future emission trends, moving on to the development of climate scenarios, thence to biophysical impact studies and the identification of adaptive options" (O'Brien 2005). Any residual consequences that remain after adaptation has taken place define the levels of vulnerability. Therefore vulnerability is the net impact of the climate change issue and it can be represented quantitatively as a damage to ecosystem, cost of impacts, casualties or as a change in yield or flow; or it can be presented qualitatively to describe comparative change (O'Brien 2005).

Yamin et al (2005) focuses on various factors such as probability, frequency, intensity and nature of physical hazards and consider them as the key components of vulnerability. Turner et al (2003) suggest some drawbacks of this approach: distinctive characteristics of sub components of the system may result in significant variations in the impacts of the natural hazards and the influence of the political economy, mainly social institutions, can shape different exposures and consequences.

The natural hazards and disasters approach to vulnerability ignores the existing vulnerabilities of communities and does not consider socio-economic conditions and power relations which shape these vulnerabilities. However, the merit of this approach is that it takes into account the extreme but infrequent events and their consequent vulnerabilities.

Another perspective to vulnerability assessment is from a social point of view or so called *social vulnerability approach*. This approach focuses on existing social and political vulnerabilities in the communities prior to any physical hazard. Coping strategies of communities and socioeconomic structures are important considerations in this approach. It sees people as vulnerable and victims who are forever trying to cope with problems (Yamin et al 2005).

This perspective considers the concept of vulnerability as not a physical one but a human relationship. In another word, rather than determining vulnerability by the occurrence of a physical event it should be considered as socially constructed (Dolan and Walker 2004).Vulnerability is a function of historical circumstances and social conditions which put people at risk to various stresses such as economical, political and climate change. From this point of view exposure is determined by unbalanced distribution of resources among different people. Some people may have more access to resources such as income, education and social security; therefore their vulnerability is lower relatively. Vulnerability originates from social processes which restrain the access to these various resources that people need to cope with impacts. Protection from these hindering social forces is as important as protection from natural hazards.

The social vulnerability approach places vulnerability as the “starting point” of the analysis. Rather than defining vulnerability by future climate change scenarios and anticipated adaptations, from this point of view vulnerability represents existing inability to cope with external pressures such as sea level rise or storm surges. In this approach vulnerability is a characteristic of social and ecological systems that is created by various factors and processes. The assumption here is that by addressing existing vulnerability we will reduce vulnerability under future climate conditions .One purpose of vulnerability assessments using this interpretation is to determine policies and measures that reduce vulnerability of the entity at hand, increase its adaptive capacity or illuminate adaptation options (O'Brien 2005). This is achieved by understanding the underlying causes of the vulnerability. For example, vulnerability mapping can be used to spot vulnerabilities to climate change and further case studies can provide us with an understanding of the root causes and structures that shape vulnerability. A critical prerequisite prior to taking actions to reduce vulnerability is to understand the biophysical, social, cultural and political factors that contribute to climate vulnerability.

The differences between social vulnerability and hazard and disaster approaches can be explained by research purposes from which they originated. The "end point" approach to vulnerability deals with vulnerability to climate change from a quantitative point of view. It tries to answer questions such as "What is the extent of the climate change problem?" and "Do the costs of climate change exceed the costs of greenhouse gas mitigation?" The focus has often been on biophysical vulnerability, whereby the most vulnerable are considered to be those living in the most precarious physical environments, or in environments that will undergo the most dramatic physical changes (O'Brien 2005). In contrast, the "starting point" approach has origins in assessments of social vulnerability with the purpose of identifying the character, distribution and causes of vulnerability (O'Brien 2005). This interpretation of vulnerability tries to answer questions such as "Who is vulnerable to climate change and why?" and "How can we reduce vulnerability?"

"Originating from disasters and entitlement theories, there is a newly emerging synthesis of systems oriented research that attempts to understand vulnerability in a holistic manner in natural and social systems" (Adger 2006). This new perspective is called the Integrative Approach which attempts to integrate not only the physical event but also the underlying characteristics of populations that may result in exposure to risk and limited capacity to respond. Therefore vulnerability can be considered as both a physical threat and a social response within a specific geographical context (Dolan and Walker 2004).

In the vulnerability assessment integrative approach PAR (Pressure and Release) model developed by (Blaikie et al 1994), the authors argue that disaster risk is directly affected by the hazard produced and the degree of hazard vulnerability experienced by exposed persons in a particular period of time and space. On one side of the PAR model natural hazards put pressure on vulnerable people and resources. From the other side of the model dynamic pressures, root causes and unsafe conditions additionally put pressure on vulnerable people. Dynamic pressures channel root causes within the PAR model. Examples of dynamic pressures in the context of this model are rapid urbanization, epidemics and war. Root causes such as limitation of power and resource accessibility, manifest a progression in vulnerability through dynamic pressures like inadequacies in training, local institutional systems, or ethical standards in government (Blaikie et al 1994). These dynamic pressures create unsafe conditions in both social and physical environments of those who are most vulnerable. Unsafe locations and unprotected buildings are examples of a physically unsafe condition. Local economies, inadequacies in disaster preparedness measures are examples of a socially unsafe condition. In the PAR model, pressure can be released on those vulnerable to risk by decreasing or eliminating the various root causes, dynamic forces, and/or present unsafe conditions (Blaikie et al 1994). This model is depicted in Figure 2.2 below.

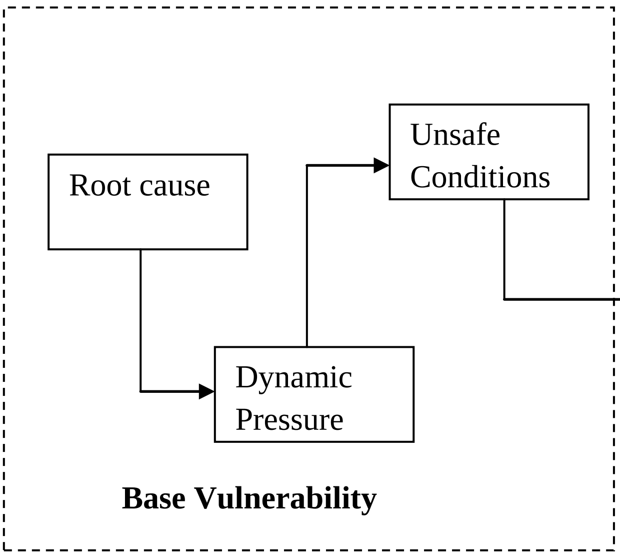

Figure 2.2: The PAR model (Source: Turner et al 2003)

The PAR model captures the essence of vulnerability from both *natural hazards and disasters* and *social vulnerability* approaches. Although this model gives equal weight to 'vulnerability' and 'hazard' as internal and external pressures, the model fails to provide a more systematic view for processes involved in shaping vulnerability (Adger 2006).

2.2.2 Vulnerability of coastal communities to climate change

In the case of small islands socio economic, natural resources and space limitations are among the factors contributing to the vulnerability of these communities (IPCC 2007). The socio-economic pressures on small island communities include terms of trade , the effect of globalization (positively and negatively), poverty, unemployment, the increasing difference between different levels of society, over exploitation of fisheries, forests and beaches for the sake of economical growth, rapid urbanization, weakening social capital and economic stagnation, financial crisis, debt, international conflicts, political instability and rapid population growth all together with interactions among each of these factors. These processes are related to getter and their complex interaction may lead to an increase in the vulnerability of these communities to climate change impacts.

The rapid and unplanned migration of the population from rural areas to urban areas have caused over population of major centers and this will eventually cause the lack of access to the resources and also the increasing of vulnerability to these populations in the case of storm surge or sea level rise (World Bank 2006).

Most small islands resources are located near the shore. Infrastructure such as ports, governmental buildings, roads, power plants and airports are mainly located in coastal areas. This means that most of these communities are over-dependant on coastal resources and this increases their vulnerability in case of any hazard which requires immediate access to these resources, as we have recently witnessed in the Sea of Japan earthquake and tsunami of March 2011. The likelihood of more extreme events such as hurricanes, earthquakes, and storm surges, along with anticipated sea level rise and floods, puts vital infrastructures such as roads, airports, port facilities, health and social services, essential utilities such as water and power, tourism related facilities and protection structure at higher risk (Hay et al 2003).

Small island communities have special characteristics which make them prone to a number of impacts as the result of climate change. Fresh water resources are limited in small islands because most of them do not have lakes or permanent water courses. Limestone and atoll islands have no surface water and they purely rely on rainfall and ground water. And, many small islands are under pressure due to the current inadequate amount of rainfall (IPCC 2007, Burns 2000).

The increase in sea levels may shift water tables to the surface, causing evaporation and eventually diminishing this vital resource (IPCC 2007). Rising sea levels is not the only threat to water resources. Storm surges could also damage freshwater supplies through salinization of freshwater supplies including near shore lakes, aquifers, and dug wells (Burns 2000).

The coastlines of small islands are diverse and rich in resources providing the community with a range of essential goods and services. Key impacts as the result of sea level rise will certainly include coastal erosion, increased flooding and saline intrusion to freshwater lenses (IPCC 2007). An extreme example of abandonment of Chesapeake Bay as the result of the rise in sea level has been shown by Gibbons and Nicholas (2006). Another example of abandonment, in this case Arctic based coastal village of Newtok, has been discussed by Ansari (2009) and Pilkey and Young (2009).

The effect of beach erosion and storms together can cause the erosion or inundation of other coastal systems. In Louisiana, for example, as the result of sandy barrier island erosion, wave heights in coastal bays have increased and these have enhanced erosion rates of bay shorelines, tidal creeks and adjacent wetlands (IPCC 2007).

Traditionally small islands have been dependant on cash crops and subsistence for living. The intrusion of sea water into coastal soils damages the fertility of these resources and as a result reduces the crop yield. Shoreline erosion also disrupts production of crops in coastal areas (Burns 2000).

Tourism is an important economical sector for many small islands (IPCC 2007). Due to this significant independence on tourism, the impact of climate change can have significant direct and indirect effects (Bigano 2005). Small island tourist attractions mostly comprise of beaches, coral reefs and mangroves and cultural heritage. It is projected that sea level rise will accelerate beach erosion, degrade the natural costal defences such as coral reefs and mangroves, as well as beach landing areas for marine life such as turtles using the eroding beaches as nesting areas, and effect the loss of cultural heritage sites as the result of flooding and inundation (IPCC 2007). Depletion of these attractions will impact the tourism industry of these communities.

2.2.3 Measuring vulnerability

Indicators are “quantitative measures intended to represent a characteristic or a parameter of a system of interest” using a single value. In this regard, vulnerability indices can guide policy development on vulnerability reduction at national and sub-national scales, and serve as a means of measuring progress towards that specific goal (Cutter et al 2009).

However, there are some problems that make the developing process of vulnerability indexes very difficult. To develop vulnerability indexes one requires a rational model of vulnerability which then other indicators can be selected from, but since the concept of vulnerability along with contributing processes are very complex in nature and its difficult to distinct between processes from their outcomes, fundamental vulnerability models are unavoidably flawed (Barnrett et al 2008). Cutter et al (2009) also discusses the definitional ambiguity along with the dynamic nature and changing scale of analysis (temporal and spatial) of constructing a global measurement tool for vulnerability assessments across all disciplines as a difficult task.

Selecting indicators is also a difficulty since the relevant data might be unavailable or available but with a poor quality. The model might also lead to redundancy of indicators, implying that indexes should use fewer vulnerability indicators which are based on robust and commonly available data (Birkmann 2007, Barnett et al 2008).

The scale of the system has important implication for vulnerability assessment. Systems with larger scales are favoured because of their relevance to policy making, however the larger the scale of the system, the less the specificity of threats and their impacts (Barnett et al 2008). In large scale systems, stakeholders’ risk perception aggregates to a point that vulnerability becomes merely a generic condition with a little meaning or relevance to anyone (Birkmann 2007). In addition, determining processes of vulnerability become so abundant that the quality and availability of data become major limitations. The process to weight, aggregate and standardize the data also gets more difficult. Moreover, with respect to large scale systems the social–ecological interactions become so complex that uncertainties may lead to an extensively flawed index (Birkmann 2007). Therefore, a major impetus for downscaling of global approaches is to support high risk countries with information and capacities to recognize hotspots at different levels in order to prioritize risk reducing strategies and to show that risk management can be improved by evidence of risks and losses (Birkmann 2007).

The question of how useful a global indicator is for a lower scale system depends on the specific function that it intends to fulfil. Therefore, an important challenge in downscaling of indicators is to contextualise the global indicators and vulnerability assessment approaches to the lower levels (local and sub-national).

Birkmann (2007) defines the concept of contextualisation as “means to adjust indicator and index approaches to the specific socioeconomic context they are applied to and to the function (e.g. spatial comparison, guiding risk-management actions, and evaluation of policy interventions) they are intended to serve”.

Social vulnerability describes those populations characteristic that influence the capacity of the community for preparation, responding and recovering from hazards and disasters (Cutter et al 2009). The relevant literature on indicators of social vulnerability is discussed further below and summarized in Table 2.2.

Socioeconomic status influences the ability of individuals and communities to absorb the losses from hazards (Cutter el al 2003, 2009). Generally, the poor are more vulnerable than the more affluent people to hazard impacts (Adger 1999). Poverty is an important factor of vulnerability since it determines both the baseline vulnerability and also the inability of coping to any extreme event (Adger 1999). Poor people have less resources than wealthy people, to use for emergency related supplies, preventative measures, and recovery from impacts. Although comparatively the losses of the wealthy people (monetary value) may be greater than poor people, in relative terms the losses sustained by poor people are far more devastating (Cutter et al 2009). It is more likely that poor people live in below par housing, which can be a major disadvantage. Moreover, during disasters poor people are less likely to have access to critical resources such as transportation and communication.

Demographic factors are also important indicators of vulnerability. For example women may be more vulnerable to disasters since it is more likely that women, particularly single mothers, live in poverty. Moreover women are more likely to work in low status jobs in service industries, that often disappears in the aftermath of disasters (Cutter et al 2003, 2009). Being mothers and having family responsibilities also make women more vulnerable to disasters, when disaster strikes, women have restricted ability to seek safety since they are responsible for both infants and elderly that require help and supervision (Cutter et al 2009).

Race and class (socioeconomic status) have a long history of producing social inequalities (Cutter et al 2009). Discrimination may increase the vulnerability of ethnic and racial minorities. Discrimination related to real states may cause minorities to reside in certain areas that are prone to hazards or prohibit them to obtain insurance from more reliable companies. Minorities are often economically and geographically isolated from jobs, services and institutions (Cutter et al 2009). Moreover non English speaking minorities may be more vulnerable to disasters.

Without outside support the young and the elderly people may not be able to respond to disasters. Children who do not have sufficient support from their families are at a major disadvantage when it comes to responding to disasters. Disruptions created by a disaster can have major physical and/or psychological impacts on this group (Cutter et al 2009). Moreover, the elderly may have insufficient access to economical and physical resources to effectively respond to a disaster. The elderly also tend to stay home and are reluctant to leave their residences in the case of a disaster. Furthermore, people with physical or mental disabilities may be unable to effectively respond to disasters, therefore assistance in preparing for and recovering them from threats is required.

The density of industrial and commercial buildings is an indicator of the economic health of a community. Therefore, it is also indicative of the potential losses in the commercial sector in case of a disaster and longer term issues with recovery after a disaster (Cutter el al 2003). The additional unemployment as the result of a disaster adds to the overall costs, further slowing down the recovery from disasters.

Rural residents, that are dependent on fishing and farming, and have a relative lower income level, may be more vulnerable to disasters. Also high density urban areas complicate evacuation procedures (Cutter et al 2003).

The density, quality and value of the residential infrastructure influence the potential losses and recovery from hazards. For example, it is more costly to replace high priced houses along the coast, whereas mobile homes can be easily destroyed by a disaster and are less resilient to hazards. Significant damage to or loss of important infrastructures such as bridges, sewers, water, communications and roads, significantly increase the vulnerability of the community. These losses may place an overwhelming financial burden on communities that are small and lack the required resources to recover (Cutter el al 2003).

People rent houses because they are either staying temporarily or do not have the financial resources to own a home (Cutter el al 2003). They often have insufficient access to financial aid information during recovery. If accommodation options become uninhabitable or too expensive then renters won’t have adequate shelter options.

Education is related to socioeconomic status (Adger et al 2004, Cutter et al 2003) and higher educational achievement results in more lifetime earnings. Lower level of education limits the ability to access recovery information and understanding of warning information.

Single parent families as well as families with large number of dependants often lack financial resources to outsource their responsibilities to outside care. This results in their juggling between their work and home responsibilities, which in turn affects the recovery from disasters and resilience to hazards.

Communities with rapid population growth may not have enough available quality accommodation, and increased populations may have hindered the social services network to adjust (Cutter el al 2003).

Health care providers such as hospitals, physicians, and nursing homes are important sources of recovery from disasters. The lack of proximate health care providers lengthens immediate and longer-term recovery from disasters. People with poor health and people who are undernourished are more vulnerable to the immediate and secondary impacts of extreme events, whether it be a direct physical injury or another impact (e.g. food shortage or famine) (Adger et al, 2004). Community members who are very dependent on social services are considered already as socially and economically marginalized, and may require further support after the disaster (Cutter el al 2003). Due to their invisibility in communities, special needs populations comprising of infirmed, transient, homeless people and institutionalized, are mostly ignored during recovery (Cutter el al 2003).

A summary of the listed social vulnerability metrics discussed is provided in Table 2.2.

Table 2.2: Social vulnerability concepts and metrics

Source: Cutter et al 2003

Concept	Increase(+)/Decrease(-)
Socioeconomic status (income, political power, prestige)	High status(+/-) Low income or status (+)
Gender	Gender (+)
Race and Ethnicity	Non white (+) Non-Anglo (+)
Age	Elderly (+) Children (+)
Commercial and industrial development	High density (+) High value (+/-)
Employment Loss	Employment loss (+)
Rural/urban	Rural (+) Urban (+)
Residential Property	Mobile homes (+)
Infrastructure	Extensive infrastructure (+)
Tenants	Renters (+)
Occupation	Professional or managerial (-) Clerical or labourer (+) Service sector (+)
Education	Little education (+) Highly educated (-)
Family Structure	High birth rates (+) Large families (+) Single-parent households (+)
Population Growth	Rapid growth (+)
Medical services	Higher density of medical (-)
Social Dependence	High dependence (+) Low dependence (-)
Special needs Populations	Large special needs population (+)

Institutions play a major role in determining vulnerability. Poverty, access to resources, and the asset and income distribution within a community are determined in part by its institutions, and because of this it is essential analysis of vulnerability from the perspective of political economy. “It is the formal political institutions that plan and implement the legal enforcement of property rights and therefore all economic structures can be conceptualized as dependent on the institutional structure" (Adger 1999).

Corrupted or inefficient institutions are associated with a lack of adequate healthcare, housing, sanitation and also low levels of general development (Adger et al 2004). It is also possible that an inefficient, weak or corrupted institutional infrastructure leads to neglecting physical infrastructure and to increase of inequality since specific groups may be favoured through systems of patronage. Moreover, these weak and corrupted institutions may lead to inefficient and insufficient responses to disaster events and the probability that international assistance gets delayed and aid not necessarily going to those who most need it. Table 2.2 summarizes social vulnerability concepts and their metrics.

An important vulnerability assessment study was conducted by Adger et al (2004). Some of the variables discussed are only applicable on national basis, nevertheless it is a very complete study and some of the aspects may be contextualized at local level if appropriate. Most of the rationale behind choosing the indices has already been discussed in previous paragraphs. The vulnerability indices and their proxies as discussed by Adger et al (2004) are presented below.

1. *Economic Wellbeing:*

At the national level, economic well-being may be represented by the proxy variables: Gross Domestic Product (GDP) per capita, repayments of debts as a percentage of GDP and Gini Index (Adger et al 2004). Local scale variables are: per capita income (Cutter et al 2003, 2009); Percent of owner-occupied households with mortgages 35 % or more of household income (Clark et al 1998); and Housing tenure (ownership) (% renters, % homeowners) (Cutter et al 2009, Wu et al 2002).

2. *Health and Nutrition:*

The health and nutrition indices may be represented by proxy variables: health expenditure per capita (percentage of GDP), calorie intake per capita, disability adjusted life expectancy, AIDS/HIV infection (percentage of adults) - Adger et al (2004).

At local scale: Number of residents without family doctor; Number of hospitals/clinics/health care facilities per capita (Cutter et al 2009).

3. *Education:*

The education index may be represented by these proxy variables: education expenditure (percentage of government expenditure); literacy rate (percentage of population over 15) - Adger et al (2004). Possible proxies at local scale are: Percentage of education less than high school (Cutter et al 2009, Clark et al 1998).

4. *Physical Infrastructure:*

Physical Infrastructure may be represented by proxy variables such as roads (km) since isolation of rural communities depends on the nature of these networks (Adger et al 2004).

5. *Institutions, Governance, Conflict and "Social Capital"*

Governance-related factors may be represented by proxies such as internal refugees (percentage of population), corruption control, effectiveness of government and political stability (Adger et al 2004).

6. Geographic and Demographic Factors

The demographic and geographical factors may be represented by: kilometre of coastline (percentage of population within 100 km of coastline; population density (Adger et al 2004); race (e.g. African-American, Hispanic) (Cutter et al 2003, Clark et al 1998); Family structure (% single parent households) (Cutter el 2003); special needs population (% homeless, nursing home residents) (Cutter et al 2009, Clark 1998); and number of females (Wu et al 2002), number of people over 60 (Wu et al 2002).

7. Dependence on Agriculture

The major impact of climate change on agriculture is due to drought that is not directly related to sea level rise or storm surge. However, drought can result in coastal inundation, and intrusion of seawater into water resources, and can have an adverse effect on agriculture. The following proxies are useful in representing dependence on agriculture: agricultural employees, rural population and agricultural exports (percentage of GDP) - Adger et al (2004). This can be expanded to single sector dependence of the population: (% employed in hyper active industries) (Cutter et al 2003). Ecosystems and natural resources can be represented by the following proxies: protected land area, forest cover, forest change rate (per year), water resources per capita, groundwater recharge per capita and unpopulated land area.

8. Technical Capacity

To a certain extent, adaptation depends on the ability of a country to carry out different studies of the processes that determine vulnerability (Adger 2004). Proxies can include: investment on R&D (percentage of GNP), number of engineers and scientists in R&D (per million population) and tertiary enrolment (Adger et al 2004).

One way to make a more meaningful local scale indicator is to include input from those stakeholders who have the most knowledge about or those who have the most stake in the exposed entity, in the form of involving them to weight the various sub-components of an index (Birkmann 2007). This is to ensure the conderation of the values and knowledge of stakeholders who otherwise would have been populated implicitly in the index and to enhance the legitimacy of the index to the stakeholders.

2.3 Adaptation Strategies to Reduce Vulnerability

In this section, adaptive capacity and adaptation as strategies to reduce the vulnerability of coastal communities to climate shifts as presented in the literature are discussed.

2.3.1 Adaptive capacity

IPCC (2007) defines adaptive capacity as “the ability or potential of a system to respond successfully to climate variability and change which includes adjustments in behaviour, resources and technologies”. Studies involved in the facilitation of adaptation strategies and improvement of adaptive capacities, usually start with vulnerability assessment of the system of interest to climate change. As noted in section 2.2 above, there is a broad agreement that vulnerability of a system is linked to both its exposure to climate change impacts and on its capacity to cope or deal with those risks (Smit and Pilifosova 2003).

Vulnerability to climate change impacts can either be reduced by increasing the adaptive capacity and/or reducing the exposures (Smit and Pilifosova 2003). Exposure reduction opportunities such as resettlement and development control can be limited in many countries. In this case enhancing adaptive capacity becomes a priority. Adaptive capacity is closely related to concepts of coping ability and resilience (Smit and Wandel 2006).

Determinants of adaptive capacity include those forces that can influence the capacity of the system to adapt (Smit and Wandel 2006). Systems have specific characteristics that influence their ability to adapt. These so called adaptive capacity determinants are: technology, economic wealth, infrastructure, social capital, institutions, skills and information. While these determinants can be considered separately, in practice they are closely interconnected.

Economic wealth of nations, whether expressed in terms of assets, financial means, capital resources can facilitate the preparation and recovery process, hence they are a major determinant of adaptive capacity. Technology is also an important determinant since it can expand or impede the range of access to adaptations strategies. Efficient cooling systems, desalination technologies, improved seeds and other solutions are examples of adaptation options that can lead to better coping under climate change condition. Although technological capacity is an important indication of adaptive capacity of nations, many technological adaptation strategies to tackle climate change impacts are closely associated with a particular impact such as decreased rainfall or higher temperatures (IPCC 2007). There should also be a sense of necessity for adaptation, awareness of available options, capacity for assessment and the ability to implement the most suitable options.

Ability to adapt is dependent on effective social networks and infrastructure. Furthermore adaptation is related to stability and capacity of institutions to manage the risks associated with climate change. Adaptive capacity is higher also when political institutions ensure that access to resources and allocation of power is distributed equitably (Smit and Pilifosova 2003).

Adaptive capacity determinants can be local (e.g. strong kinship network) while some determinants can relate to a more general political and socioeconomic systems (e.g. crop insurance) - Smit and Wandel, 2006.

The determinants of adaptive capacity are dependant. For example, a kinship network that is strong increases adaptive capacity by providing more access to resources, increase in managerial ability, and mediating psychological stress (Smit and Wandel 2006). Access to more resources may also make the new technology development and more access to training possible. It may even go as far as increasing the political influence. Therefore, these determinants are dependant. “Adaptive capacity is generated by the interaction of determinants which vary in space and time” (Smit and Wandel 2006).

Adaptive capacity is specific to the context of the system under study. It varies from community to community, country to country, among social groups and individuals and it also varies from a temporal perspective. It varies both in value and its nature. These scales are dependant. For instance capacity of a household to adapt or cope to climate change impacts is dependent on the enabling environment of the community and this environment is also dependent on the processes and resources of the region (Smit and Wandel 2006).

Most communities and sectors can adapt to or cope with normal climate related conditions and acceptable deviations from this normal state. However, extreme events may expose communities to risks outside their coping range or their adaptive capacity. Some authors use the term “coping ability” for the ability to just survive – short term capacity, and use the term “adaptive capacity” for longer term capacity (Smit and Wandel 2006).

A system’s coping range and adaptive capacity are not static. Over time, they react to economical, political, social, and institutional changes. For example, depletion of resources and population pressure may gradually diminish the system’s coping capacity and limit the system’s coping range, on the other hand economic growth, technology or institutions improvements may increase adaptive capacity (Smit and Wandel 2006).

For variety of reasons the coping range can decrease or increase over time. Political and external socio-economic factors such as war, loss of a major decision maker and collapsing of an institution may lead to a narrower coping range (Smit and Wandel 2006). As the frequency of natural hazard increases their collective impact also increases and if close to the system's coping range limit, may cause a decrease in threshold to a point that the system can no more cope or adapt. For instance, two successive years of extreme moisture deficit which may not necessarily be over the thresholds of the normal coping range of the system, may not considered to be a serious problem now, however they necessitate consumption of resources, and this reduction of resources may narrow this coping range, therefore a longer lasted deficit of moisture with the same magnitude may go beyond the already smaller coping range (Smit and Wandel 2006).

2.3.2 Adaptation to climate change and variability

Adaptation to climate change is increasingly considered in academic research and its importance as a way to tackle climate change related issues is being recognized internationally (Smit et al 2000; IPCC 2007; UNFCCC, COP 15). Adaptation to climate change is important for two distinct and dependant reasons:

(1) Climate change is taking place and its impacts can be dangerous. This danger can be modified by different kind of adaptation. Most impact studies now make assumptions about expected adaptations in the system of interest (Smit et al 2000). This is a predictive perspective toward adaptation and the key question involved here is what adaptations are expected? How and under what circumstances is the adaptation expected to occur? The challenge here is to determine what might be regarded as dangerous. The extent that societies are exposed to risk of climate change is partly related to magnitude and rate of this change and partly related to the system's capacity to adapt to these changes. In order to judge the dangerousness of climate change, the adaptive capacity of the system should be explicitly addressed when we are conducting impact assessments of the system. Such adaptations distinguish "initial impacts" from "residual impacts" (Smit el al 2000). Therefore, for *impact assessment,* the main interest is in understanding adaptations, estimating the circumstances

under which they can be expected, and forecasting their implications for the systems or regions of interest (Smit el al 2000).

(2) Adaptation is a significant response strategy to climate change related issues (Smit el al 2000). Adaptation to climate extremes and their impacts is receiving growing attention as a complementary or an alternative response strategy to mitigation strategies (reducing greenhouse gases net emissions). This is an advisory perspective and the key question involved here is what adaptations are recommended? Furthermore this exercise requires information on possible adaptation strategies or measures and also principles for evaluation their merit.

Compared to the analysis of adaptation as part of impact assessment, the formulation and implementation of adaptation policies and measures involves one additional analytical step. For both implementation and assessment purposes it is important to know the forms of adaptation and the conditions under which they are expected to occur. However, analysis for implementation also requires an evaluation of measures, strategies or options (Smit el al 2000). For implementation purposes, it is not sufficient to specify an adaptation and its likelihood. We also require some judgement on how good or appropriate the adaptation is such that we recommend adaptations that are in accordance with the goals of public policy.

“Adaptation to climate change is already taking place, but on a limited basis (very high confidence)” - IPCC (2007). Societies have a long history of adapting to climate change through a various practices such as management of water resources, irrigation, disaster risk management, crop diversification and insurance. However climate change often exposes societies to something higher than they can usually adapt to. Impacts as the result of drought, heatwave, hurricane, flood, accelerated glacier retreat poses huge risks on societies beyond their range of experience.

Adaptation to climate change is undertaken by reducing vulnerability or increasing resilience (IPCC, 2007). Adaptation can be related to social, cultural, ecological and physical systems. It involves changes to environmental and social processes, practices to reduce the potential damages and taking advantage of opportunities, perceptions of climate risk. Adaptations include public and private initiatives, reactive and anticipatory actions and also anticipated changes in temperatures and other climate variations that have a potential to be altered as the result of climate change. The important point here is that adaptation is an ongoing process and is not specific to climate change and can encompass many stresses and factors (Smit et al 2000).

Adaptation has been differentiated and categorized in different ways. Based on timing, adaptation can be categorized as reactive or anticipatory. Based on the degree of spontaneity, it can be planned or autonomous. Adaptation can refer to socio-economic or natural systems and be targeted at different climatic variables or weather events. Adaptations can also take economic, technological, institutional and legal forms (Smit et al 2000).

There are various categorizations of adaptation measures throughout the literature (IPCC 2007, McCulloch et al, 2002, World Bank 2008) which they are discussed in following paragraphs.

According to IPCC (2007) we can differentiate adaptations practices along several dimensions:

- *Spatial scale:* national, regional, local.
- *Sector:* agriculture, tourism, water resources, health.
- *Type of action:* technological, physical, investment, regulatory market.
- *Actor:* national government, local government, NG, international donors, private sector, local communities and individuals.
- *Climate zone:* floodplains, dryland, Arctic, mountains.
- *By income or development level of the system they are being implemented to:* developed and least developed countries, middle income countries.

According to the World Bank (2008) adaptation practices can be categorized as “(a) providing public goods, (b) making public infrastructure more resilient, (c) enabling or promoting private adaptation, and (d) providing a safety net for the most vulnerable”.

(a) public goods constitutes of these adaptation practices (World Bank 2008):

1) *"Investments on early warning systems (better weather forecasts to farmers; enhanced surveillance and monitoring programs for waterborne diseases; more targeted support for surveillance of fires, pests, and diseases in forests)".*

2) *"Investments in new technology development (more drought-resistant crops vaccines for dengue and other vector borne diseases, etc.); (c) public infrastructure (water storage, rainwater harvesting, sea-walls, etc.); and (d) helping populations in situations of extreme vulnerability and climate stress to relocate".*

Adaptation measures falling under category (b), public infrastructure, generally require modifications of infrastructure investments in order to make them more resilient.

Adaptation measures falling under category (c), private adaptation, are those that promote autonomous adaptation. For example, "policy initiatives by the government to develop insurance markets can give farmers access to weather-indexed insurance which enables them to cope with weather-related productivity shocks" (World Bank 2008).

Adaptation measures implemented by both private and public sector may be inadequate to allow a given community to cope with the consequences of extreme climate hazards. Therefore, governments should also create institutions to help with response to natural hazards and devise plans that can provide an additional income for vulnerable. Employment creation by the government and construction of emergency shelters in regions prone to hurricanes are examples of such adaptation practices (World Bank 2008). Measures such as these will fall under category (d), providing a safety net.

McCulloch et al (2002) categorize adaptation options into the following categories:

1) Prevention of loss: adoption of measures that reduce the vulnerability to climate change.
2) Tolerate the loss or do nothing: do nothing to reduce the vulnerability and absorb the cost of losses as they occur.

3) Share or spread the loss: do nothing to reduce the vulnerability, however spread the burden of the losses over different systems. An insurance system is an example of such an option.
4) Change the affected activity: stop doing things that have difficulty to cope with climate change impacts and substitute other activities.
5) Change the location of the activity: move the activity or the vulnerable location to a more favourable location.

With respect to coastal communities there are three broad categories of adaptation strategies: (1) protection or “attack” , (2) accommodation or “defend”, and (3) retreat (McCulloch et al 2002).

1) Protection/Attack

It’s an approach that deals with sea level rise by protecting the coastline with the aid of engineered strategies such as seawalls, breakwaters, revetments and groins (NRC, 2010a, McCulloch et al 2002). In general, the aim of the protection option is to allow existing land use activities to continue in spite of rising water levels. Protection measures can range from small scale efforts by individual property owners to large scale public projects (NRC, 2010a, McCulloch et al 2002).

2) *Accommodate/Defend*

Accommodation strategies involve continued occupancy of coastal land while adjustments are made to infrastructure and /or human activities to accommodate sea level rise and by this means mitigate the overall severity of the impacts (NRC, 2010a). These strategies are somewhere in between “protection/attack” and “retreat” strategies (McCulloch et al 2002). Accommodation measures can include redesigning existing structures, encouraging appropriate land use and development by implementing legislation and increasing natural resilience by rehabilitating coastal dunes and wetlands. Examples of such measures are elevation of buildings, prohibiting or controlling the removal of beach sediment, shifting agriculture production to salt-tolerant crops, and development of warning systems for extreme events (NRC, 2010a; McCulloch et al 2002).

In contrast to hard protection measures we also have soft adaptation or natural measures such as beach nourishment and wetland creation or renewal. Soft measures have become popular due to their cost efficiency. Soft protection measures have the capacity to enhance the natural resilience of coastal zones and generally are less expensive than hard protection options (NRC, 2010a).

3) *Retreat*

Retreat means avoiding risk in order to eliminate a direct impact (NRC, 2010a; McCulloch et al 2002). This can be in the form of migration, i.e. abandoning the land when impacts are no more tolerable or no development at the first place in flood zone areas. A simplest form of this strategy can be avoidance of purchase the high risk properties by individual buyers. Another example is putting 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 zoning, insurance or tax policies.

The adaptation level we choose has significant implications for how to allocate ones limited resources to extreme events while at the same time meeting other societal needs as well. Moreover, the amount of feasible adaptation and desirable adaptation is dependent on the level of income and resources available, and these two factors are dependent on climate change impacts.

2.4 Historical Storm Profiling

The implications of sea level rise and storm surges for coastal communities have been discussed previously in subsection 2.2.2. However, an important question remains: has the community of interest experienced such events in the past? What were the impacts of such events on the community? In this section, we examine two of the C-Change ICURA project communities, namely, Charlottetown, Prince Edward Island, and Isle Madame, Cape Breton, Nova Scotia as examples of two Canadian coastal communities. The historical storm profiles of these communities are examined.

The two communities are chosen because of their membership in the C-Change project, the availability of data on historical storms, and their rich association as coastal communities with recent significant storms and damages. Further, in subsequent chapters of this thesis we apply the methodology and scenario analysis based on Charlottetown's historical storms, and subsequently use this exercise for a more detailed Isle Madame scenario analysis.

2.4.1. Data sources for historical storms and impacts

In this section, sources of data for extraction of historical storms and impacts are discussed. The two main sources of storm data for analysis consist of (i) the HURDAT database, and (ii) Environmental Canada's Climatology of Hurricanes for Eastern Canada (CHC) archive on historical impacts of storms. These will be further discussed in the following paragraphs.

HURDAT, The North Atlantic Hurricane Database, is the official database for tropical storms hurricanes and tropical storm of Atlantic Ocean, Caribbean Sea and Gulf of Mexico, including those storms that made landfall in the terrestrial United States of America (NOAA, 2010). The HURDAT database has been used for a variety of purposes: risk assessment in emergency management, potential loss analysis for insurance sector, setting of proper building codes for coastal zones, intensity forecasting techniques and climatic change studies (NOAA, 2010).

The HURDAT or "Best Track" database dates back to 1851. At the end of each hurricane season the database is updated. A particular storm is assigned to a hurricane forecasting specialist and is reviewed for all observational data with respect to that storm.

The original HURDAT database is in a text format which is hard to work with, however an easier to read version of the HURDAT archive is available which makes the tasks for researchers much easier. This format is depicted in Table 2.3 and is explained below (hypothetical data are presented in the table below under each column for illustration purposes):

Table 2.3. The data layout of HURDAT

Source: NOAA (2010)

Month	Day	Hour	Latitude	Longitude	Direction	Speed	Wind	Pressure	Type
September	15	12 UTC	40.2 N	60.6 W	25 deg	20 mph or 33kph	85 mph or 140kph	950mb	Hurricane Category 1

All times are in UTC (Universal Coordinated Time) which was previously called GMT (Greenwich Mean Time). In order to convert to Eastern Standard Time and Eastern Daylight Savings we have to add five and four hours respectively. Hemispheres are shown as “N” or “S” for North or South and “E” or “W” for East or West. Latitude and Longitude are to the nearest tenth of a degree. Direction of Wind is degrees clockwise from the north (0 deg.). Storm speed is in both miles per hour (mph) and kilometres per hour (kph). Within-storm wind speed is also in both miles per hour (mph) and kilometres per hour (kph). Pressure is given in millibars (mb). Storm type is designated as Tropical Disturbance, Tropical Depression, Tropical Storm, or Hurricane. If it is a Hurricane, its category on the Saffir-Simpson scale is listed. The Saffir-Simpson scales and within storm wind speed ranges (in contrast to storm speed) are shown in Table 2.4:

Table 2.4. Wind speed classification ranges.

Source: Environment Canada (2010)

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

CHC. Another data source that is used for constructing community's extreme events profile is Environment Canada's Climatology of Hurricanes for Eastern Canada (CHC) archive on impacts of storms. This archive is a detailed climatology of tropical cyclone impacts in Canada and its waters during the period 1900-2004. Data sources used for constructing this database includes major Canadian newspapers, the Canadian Disaster Database, and the Canadian Hurricane Centre archives.

2.4.2. Charlottetown historical storm profile and damages

In the previous section we introduced two main sources used for extracting historical storm profiles.

The HURDAT database can be used for extracting the indicators of the storm at the time of impact on a designated community. When a given storm has been found to have an impact on the given community then its indicators can be extracted from the HURDAT database. This can be done by matching the "Latitude" and "Longitude" columns of HURDAT database with our community's coordinates. The matching for Charlottetown coordinates at 46.233 degrees latitude and 63.133 degrees of longitudes shown in Appendix B and C by highlighting the appropriate entries in the "best track" database of HURDAT. In situations that a perfect match has not been found (coordinates of the community with those of HURDAT), the closest entry has been chosen for recording the storm indicators. The Environmental Canada archive on impacts of storms on Eastern Canada provides us with further details on such impacts for the designated community.

Table 2.5 shown below is Charlottetown's storm profile from 1950 until 2010. The period of 2005-2010 was not covered in Environment Canada's database and the researcher has utilized other sources to fill this gap. Data sources are provided as appropriate. The complete HURDAT file set used for constructing the profile for the community of Charlottetown, P.E.I. is found in Appendix B- HURDAT files of Charlottetown's related storms (Best tracks).

Table 2.5. Charlottetown's historical storm profile and their impacts (1950-20)

Name	Date	Speed	Wind	Pressure	Category
Able	08/1950	44kph	55kph	-	Tropical Depression
Impacts • Many main streets in Charlottetown and throughout the province were flooded and impassable. • It took three to four days before every home in the province had their power restored. Environment Canada (2010), Accessed 02/06/10: http://www.ec.gc.ca/hurricane/default.asp?lang=En&n=A0AC0965-1					

Name	Date	Speed	Wind	Pressure	Category
Carol	09/1953	63kph	110kph	-	Extratropical

Impacts

- Winds cut telephone and power lines and tossed down trees.
- Roofs were blown off, and a chimney was toppled over from a residences home.
- Charlottetown had power outages.
- Both Prince Edward Island–Nova Scotia and Prince Edward Island–New Brunswick ferries were unavailable during the height of the storm

Environment Canada (2010), Accessed 02/06/10: http://www.ec.gc.ca/hurricane/default.asp?lang=En&n=57B70220-1

Name	Date	Speed	Wind	Pressure	Category
-	04-04-1962	-	-	-	-

Impacts

- 180mm rainfall over snow, causing washouts and damages to paved highways in many areas of the province.
- Estimated $300,000 damage as the result of heavy rain and melting snow.

Environment Canada (2010), Accessed 02/06/10: http://www.ec.gc.ca/hurricane/default.asp?lang=En&n=4FCB81DD-1k

Name	Date	Speed	Wind	Pressure	Category
Ginny	10/1963	61kph	150kph	-	Extratropical Storm

Impacts

- Power outages all over the island.
- Ferry service from Prince Edward Island to Nova Scotia was halted.

Environnent Canada (2010), Accessed 02/06/10 :
http://www.ec.gc.ca/hurricane/default.asp?lang=En&n=C81C5991-1

Name	Date	Speed	Wind	Pressure	Category
-	02 Dec 1964		160kmh(Gust)	-	-

Impacts

- Three fishing boats as well as two large draggers were lost in the storm resulting in loss of 23 lives.

Environnent Canada (2010), Accessed 02/06/10:
http://www.ec.gc.ca/meteo-weather/default.asp?lang=En&n=6A4A3AC5-1

Name	Date	Speed	Wind	Pressure	Category
Blanche	07/1975	68kph	110kph	992mb	Extratropical Storm

Impacts

- Disruption in telephone communications across the province.
- All Air Canada flights to and from Charlottetown were cancelled along with ferry services to Nova Scotia.

Environnent Canada (2010), Accessed 02/06/10:
http://www.ec.gc.ca/hurricane/default.asp?lang=En&n=65057B76-1

Name	Date	Speed	Wind	Pressure	Category
Hortense	09/1996	48kph	130kph	970mb	Hurricane Category 1

Impacts

- Power in Charlottetown and the western part of the island was lost.
- for most of the weekend the Prince Edward Island ferry service was cancelled
- 3 million damage throughout Nova Scotia

Environment Canada (2010), Accessed 02/06/10: http://www.ec.gc.ca/hurricane/default.asp?lang=En&n=B4BCC134-1

Name	Date	Speed	Wind	Pressure	Category
-	21-Jan-2000			951 mb	

Impacts

- A storm surge of 1.37m (Parkes, et al 2006) which coincided with high tide and resulted in a new record of water level in Charlottetown (4.23 metres above Chart Datum).
- Considerable flooding damage occurred at Charlottetown and other communities in Prince Edward Island.
- During this surge event at Charlottetown, a power generating station, a lighthouse, wharves, several gas stations, municipal and private properties got damaged.
- About 460 properties were either flooded or at risk of flooding.
- Estimated damage was $20 million for all the areas impacted by this surge event.

NRC2 (2010), Accessed 17/06/10: http://atlas.nrcan.gc.ca/site/english/maps/environment/naturalhazards/storm_surge/1

Name	Date	Speed	Wind	Pressure	Category
Subtrop	10/2000	61kph	100kph	978mb	Subtropical storm

Impacts

- 30–60 mm of rain was recorded in the province.
- 1.30m of storm surge (Parkes, et al 2006) with water levels risen about 1.5 m.
- As the result of high winds and high tides bridges were closed, roads were washed out, complicating highway travel.
- Roofing shingles, fallen trees and eroded sediment were scattered across the province.
- Oyster Bed Bridge got damaged.
- The storm dumped thousands of pounds of lobsters along the coast of the province.

Environment Canada (2010), Accessed 02/06/10: http://www.ec.gc.ca/hurricane/default.asp?lang=En&n=88E8D42D-1

Name	Date	Speed	Wind	Pressure	Category
Gustav	09/2002	74kph	150kph	962mb	Hurricane-Category1

Impacts

- 61 mm of rain in Charlottetown.
- Power was lost throughout the province.
- During the height of the storm one man was killed and another injured in a vehicle accident. It is believed that the heavy rain and wind played a part in the accident.

Environment Canada (2010), Accessed 02/06/10: http://www.ec.gc.ca/hurricane/default.asp?lang=En&n=91CCCE08-1

Name	Date	Speed	Wind	Pressure	Category
Juan	09/2003	59kph	120kph	982mb	Hurricane-Category1

Impacts

- Storm surge in Charlottetown was 1.25m.
- Waterfront sustained heavy wave damage to sea walls and pleasure craft.
- Considerable damage to the older urban forest in city's downtown core.
- Widespread tree damage was reported across the island in addition to damage to barns and silos.
- Most of the PEI lost electricity (up to five days).
- Immediately after the hurricane, Prince Edward Island pledged $200,000 (PEI, 2010).

Environment Canada (2010), Accessed 02/06/10: http://www.novaweather.net/Hurricane_Juan_files/Juan_Summary.pdf.

Name	Date	Speed	Wind	Pressure	Category
White Juan	19 Feb 2004	-	-	-	-

Impacts

- Storm surge of 1.3m.
- Extensive flooding was reported.
- Charlottetown waterfront must have flooded to some degree; however because of all the snow the Emergency Measures Organization could not confirm it officially at the time.

Reference: Parkes, et al (2006)

Name	**Date**	**Speed**	**Wind**	**Pressure**	**Category**
Hanna	09/2008	64kph	85kph	995mb	Extratropical

- 90mm rainfall in Charlottetown.
- Several streets, roads and highway in Charlottetown had to be closed due to flooding causing major problems with rush hour traffic.
- Parts of Joe Ghiz Park were submerged under half a metre of water.

Accessed 12/09/10: http://www.cbc.ca/canada/prince-edward-island/story/2008/09/08/pe-hanna-flooding.html#ixzz0vaHTAHrC

2.4.3. Isle Madame historical storms

In this section we discuss historical storms applicable to Isle Madame, Cape Breton. However, as discussed, Isle Madame is less data rich than Charlottetown a thorough analysis as the conducted in previous sections is not possible for this island community. As before, (section 2.4.1), two primary sources are used for extracting historical storms along with their impacts – (i) HURDAT or best track database, and (ii) Environment Canada's Climatology of Hurricanes for Eastern Canada (CHC).

Regarding HURDAT files, a similar approach has been used for Isle Madame in this section. The HURDAT database was queried for historical storms relevant to the community and Table 2.6 for Isle Madame is constructed similar to the format of Table 2.5 for Charlottetown. The main difference between these two tables is that Environmental Canada's Climatology of Hurricanes for Eastern Canada (CHC) archive does not have any reported impacts on the Isle Madame. This researcher has not also been able to find such information from other resources; therefore this information is not reflected in Table 2.6. An online tool from National Oceanic and Atmospheric Administration (NOAA) has been used to make the task of querying HURDAT database easier. This online tool can be accessed from the NOAA website (NOAA, 2010).

The search parameters used for such a search are Isle Madame coordinates (Latitude: 45° 32' 60 N, Longitude: 61° 0' 0 W), the distance to the community (50 Nautical Miles) and time period (1975-2010). The results are presented in table 2.6.

Table 2.6. Isle Madame historical storms profile (1975-2010)

Storm name	**Date**	**Category**	**Speed (kph)**	**Wind (kph)**	**Pressure (mb)**
BILL	23Aug 2009	Hurricane- Category 1	53	120	970
NOT NAMED	18July 2006	Tropical Storm	35	65	1007
ALBERTO	16June 2006	Extratropical Storm	38	100	969

OPHELIA	18Sept 2005	Extratropical Storm	42	85	1000
GUSTV	12Sept 2002	Hurricane - Category 1	74	140	962
ALLISON	19June 2001	Extratropical Storm	50	35	1012
SUBTROP	29Oct 2000	Extratropical Storm	72	95	980
MICHAEL	19Oct 2000	Hurricane - Category 2	87	160	965
HORTENSE	15Sept 1996	Hurricane – Category1	31	120	970
BARRY	9July 1995	Tropical Storm	40	95	991
ALLISON	8June 1995	Extratropical Storm	40	85	989
LILI	15Oct 1990	Extratropical Storm	70	75	995
BERTHA	2Aug 1990	Hurricane- Category 1	35	130	973
CHRIS	30Aug 1988	Tropical Depression	68	45	1008
SUBTROP	20June 1982	Subtropical Storm	81	110	984
EVELYN	15Oct 1977	Hurricane- Category 1	59	130	996

2.5 Storm surge

Along the coastline, storm surge is often considered the greatest risk to property and life from a hurricane (FEMA 2010; NHC 2010). Surges associated with hurricanes cause a significant amount of death. Hurricane Katrina is a primary example of the potential damage that can be caused by surge. Approximately 1500 people lost their lives as the result of Hurricane Katrina and majority of those casualties, directly or indirectly, were the result of storm surge (NHC 2010).

Canada's ocean shoreline is about 243,000 km long consisting of Atlantic, Arctic and Pacific coasts. It's known that storm surges have occurred on all three coasts; however in most areas the details of these events are poorly known (NRC 2010b).

"Storm surge is an unusual rise of water generated by a storm, over and above the predicted astronomical tides" (NHC 2010). During storms, strong winds blow onshore and push water against the coast resulting in storm surges. During storms, low pressure also plays an important role by further raising the level of water at the coast. Another factor is underwater slope of coast which also impacts the height of surge - higher surges occur on gently sloping coasts compared to steep coasts (NRC 2010b).

The combination of surge with normal tides creates the "hurricane storm tide", which has the potential to increase the mean water level to critical heights causing significant damage to critical infrastructure and people (NHC 2010).

Therefore, storm surge is distinguished from storm tide which is defined as the rise in water level due to the combination of astronomical tide and storm surge (NHC 2010). Such a rise in water level can cause tremendous flooding in coastal areas. If such a surge concurs with normal high tide it has the potential to result in storm tides reaching up to 6 meters or more (NHC, 2010). Figure 2.3 illustrates the difference between storm surge and storm tide.

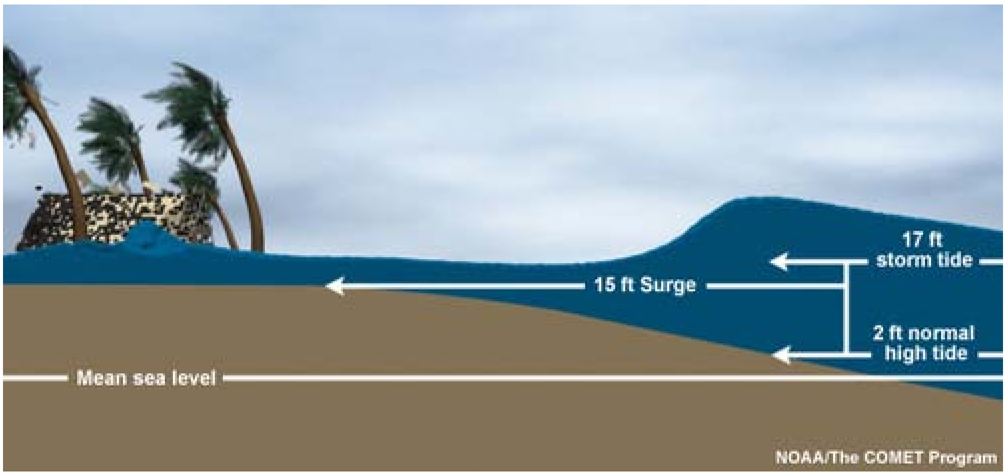

Figure 2.3. Storm surge vs. storm tide

(Source: NHC 2010)

For the purpose of this research we consider storm tides as a better representative of a threat than storm surges. This is due to the fact that astronomical tides can significantly impact the potential water levels and their subsequent impacts and therefore the chance of coincidence of storm surges with high tides should not be ignored.

2.6 Summary of the literature

The discussion above leaves us no doubt on the seriousness of climate change and its severe consequences for small islands and coastal communities. The impacts such as coastal erosion, inundation and flooding, saline intrusion can have severe and multidimensional consequences on various sectors (industry, tourism, agriculture), on the environment (resources, water quality), on people (access to services, health, activities) of these communities. Some of these communities are highly dependent on tourism and agriculture as a major income source and they are also in lack of fresh water. Any severe impact on these resources can put the livelihood of these people to a serious danger.

With respect to the multiple impacts, this research engages the methods of multicriteria decision making to account for the multiple dimensions of the coastal community profile under threat from storms. Various MCDM methodologies were reviewed. From this review, the MCDM approach of Saaty(1980), AHP offers the most direct, intuitive and most easily conveyed approach for this problem and AHP and Group AHP will be used in this work to model the multicriteria for decision support. The importance of engaging stakeholders in ranking the various adaptation options available to them requires a method which is easy to use and interpret. Also, using a hierarchical model to break down vulnerable sectors to their indicators is a valuable option. The availability of the *Expert Choice* software is an added advantage to ease the computations.

We discussed conceptual frameworks of vulnerability and showed how this concept has evolved from considering vulnerability as the result of impacts of climate change (IPCC 2007) toward considering social vulnerability of communities (Adger 2006, Yamin et al 2005) and integrated approaches (Blaikie et al 1994, Turner et al 2003).

In this problem, we use the interpretation of the vulnerability concept in the climate change context as for O'Brien (2005), i.e., the assessment of the biophysical impacts and the identification of adaptive options will be part of this research work. Consequences that remain after adaptation has taken place define the community's vulnerability, i.e., the net impact of the climate problem represented as the value loss (in monetary terms) or the resulting change in yield or flow, human mortality, ecosystem damage. This research seeks to understand the biophysical, social, cultural and political factors that contribute to climate vulnerability through a defined spatial context evaluation and mapping. Vulnerability indices (Cutter et al 2009, Cutter et al 2003, Adger et al 2004) can be used to evaluate available strategies of communities to reduce their vulnerability to climate extremes.

The adaptive capacity considerations of Smit and Pilifosova 2003, and Smit and Wandel (2006), and the adaptation practices Smith et al 2000 will be considered in the evaluation of alternative strategies.

Adaptation strategies are regarded as a significant policy option or response strategy to climate change impacts. Moreover, analysis for implementation of adaptation practices also requires an evaluation of measures, strategies or options. It is not sufficient for this implementation role to specify an adaptation and its likelihood; it also requires some judgement as to how appropriate it is, such that adaptations are recommended in accordance with the goals of public policy.

Historical storm profiles and storm data sources (HURDAT and CHC) were discussed for two Canadian communities of Charlottetown located in Prince Edward Island and Isle Madame located in Nova Scotia. We also discussed storm surges and their potential impacts and distinguished between storm surge and storm tide. The next chapter presents the methodology of the thesis research work.

3. Methodology

This chapter presents the research methods used in this research. These methods are based on the extensive analysis of the literature discussed in the previous chapter.

The purpose of this research is to identify the potential impacts of modelled extreme storm scenarios events and furthermore to evaluate the adaptation options available to vulnerable coastal communities for decision support. The framework provided in this chapter depicts the research process developed to examine and measure the major vulnerable sectors of coastal communities and the methods by which these measures are used to evaluate and support adaptive strategies.

The severity of storm scenarios is important since the vulnerability of coastal community resources can be considered as a function of these scenarios. Equipped with the information on impacts, the various stakeholders are better able to evaluate and devise adaptation options as a way to increase their adaptive capacity. In the sections to follow in this chapter, the vulnerability framework devised for this study is developed through value-based general utility functions in the application of multicriteria decision support using the Analytical Hierarchy Process. To this end, the following subsections are presented for describing the research methodology:

3.1) Coastal community profiling;

3.2) The presentation of problem concepts including definitions and notation of input and output model parameters for measuring community status, vulnerability, resilience, and adaptive capacity to storms;

3.3) The general community AHP formulation (hierarchy, data grid, alternatives and utility valuations) for storm scenario analysis;

3.4) Defining Charlottetown storm scenarios; and,

3.5) Defining Isle Madame storm scenarios.

With this methodology defined, the succeeding Chapters 4 and 5 apply these methods to specific problem contexts such as that of the case study of the Isle Madame (Chapter 4), and the Little Anse breakwater (see Chapter 5 of this document).

3.1 Community Profiling

This research is an integral component of the C-Change International Community-University Research Alliance (ICURA) project. The C-Change project entitled, "Managing Adaptation to Environmental Change in Coastal Communities: Canada and the Caribbean" seeks to provide an evaluation process for communities' consideration of adaptation options in the face of more frequent and more severe coastal storms. An initial and important role of the C-Change project toward this end is the development of a C-Change community profile data template that permits the full, multidimensional analysis of coastal communities. This template is based on the community Integrated Community Sustainability Planning (ICSP) process and is realized in the community profile framework as described in the C-Change working paper (Hartt et al 2011). This work is also defined in the M.Sc. Systems Science thesis work on the C-Change project for Charlottetown, P.E.I. (Hartt 2011) and for Isle Madame (Pakdel 2011). The detailed data template for the Community Profile is provided in this thesis in Appendix A, "C-Change Community Data Profile – Template".

The community data provided and studied in this research are presented in terms of the four communities "pillars of sustainability", namely:

(1) Environmental pillar, denoted *EN(i)* for the indicators, i, $i=1,\ldots n_{en}$;

(2) Economic pillar, denoted *EC(i)* for indicators, i, $i=1,\ldots n_{ec}$;

(3) Social pillar, denoted *S(i)* for indicators, i, $i=1, n_s$; and

(4) Cultural pillar, denoted *C(i)* for indicators, i, $i=1,\ldots n_c$..

These four community pillars and their associated indicators (Appendix A) are the key community dimensions by which the community defines itself. There is a precedent for this characterization of the community that is required of municipalities across the country through applications for "federal gas tax revenue sharing agreement" (Infrastructure Canada, 2011).

As noted for the C-Change community of Isle Madame, "An Integrated Community Sustainability Plan is a long term plan, developed in consultation with community members, which provides direction for the community to realize sustainability objectives it has for the environmental, economic, social, and cultural dimensions of its identity" (Richmond ICSP, 2010).

The four defined pillars are used in this research to define the status of communities such as Isle Madame. The details of selected indicators, *i*, for each of the pillars *EN*, *EC*, *S*, and *C* are community context-based. These indicators are taken from the set of indicators provided in Appendix A and are developed in the applications analyses for Isle Madame and the Little Anse breakwater (Chapters 4 and 5).

3.2 Vulnerability, adaptive capacity and utility concepts

Section 2.2 of this thesis documents various frameworks on vulnerability. In section 2.3 literature on measuring adaptation and adaptive capacity concepts were presented. The following terms are based on what has already been discussed in the aforementioned sections building toward a vulnerability framework of this research that enable the multicriteria evaluation of adaptation alternatives for the community in question. This framework is the basis for the case study conducted on the Little Anse community breakwater (Chapter 5) and is explained fully below.

The following paragraphs define the terms and notation for the key indicators in the analysis framework. These terms are followed by their use in the developed methods of analysis presented in this chapter.

- **Community Status Quo (No Storm Scenario),** SQ^0

This concept of Community Status Quo quantifies the multidimensional valuation of the community of interest in terms of each of the four pillars of the Community Profile, namely, Environmental, Economic, Social, and Cultural. The Community Status Quo is a value measure assigned to community assets for each indicator by pillar. For example, residential housing structures are an economic asset of the community as part of the *EC* dimension, "Built Environment" category, "Private Dwellings" indicator (Appendix A, Table A1). The total value of all residential housing in the community - independent of storms – is included as part of the total asset value for the Community Status Quo position. Let SQ^0 denote the vector of Community Status Quo total asset position for all indicators, at initial time, $t=0$, and prior to any severe storm where:

$$SQ^0 = \{EN^0, EC^0, S^0, C^0\} \qquad (3.1)$$

and:

SQ^0 = Community status quo position prior to the event of any severe storm.
EN^0 = is a vector of total asset value of Environmental pillar's indicators, where
$EN^0 = EN^0(EN_1, EN_2, EN_3, \ldots EN_{en})$;
EC^0 = *is a vector of total asset value of Economic pillar's indicators, where*
$EC^0 = EC^0(EC_1, EC_2, EC_3, \ldots EC_{ec})$;
S^0 = *is a vector of total asset value of Social pillar's indicators, where*
$S^0 = S^0(S_1, S_2, S_3, \ldots S_s)$;
C^0 = *is a vector of total asset value of Cultural pillar's indicators, where*
$C^0 = C^0(C_1, C_2, C_3, \ldots C_c)$.

- **Severe Storm Damage Impacts, D^j**

Severe coastal storms are expected to impact the community's status quo asset position by inflicting storm damage from high winds and coastal flooding. Estimated damage from severe storms on the community is a function of the severity of the storm, indicated by superscript index j, $j=I,II,\ldots N_S$ (note: $j=0$ denotes the "no storm" scenario as in equation (3.1) above). Severe storm damage from Storm Scenario j, D^j is a vector representing the costs and losses to the value measures attributed to each of the relevant indicators in the Community Profile vector. As such, the vectors for the Status Quo or the pre-storm position of the community, SQ^0, and the value losses resulting from the storm damage estimates, D^j, are directly comparable. Thus, for all indicators, i,

$$0 <= D^j <= SQ^0 \qquad (3.2)$$

for all i indicators across the Community Profile dimensions.

- **Post Severe Storm Status, SQ^j**

Severe storm damage is represented by a loss position for a subset of the Status Quo Community Profile indicators used to describe the initial status of the community. These impacts and damages result in a new and reduced state of Community Profile valued assets, denoted vectorally by SQ^j. It is noted that these storm damages and the move to a new Community Profile status position assumes no previous application of any adaptation strategies that may be considered or expressly put in place to alleviate potential severe storm damages. Thus,

$$SQ^j = SQ^0 - D^j \qquad (3.3)$$

- **Total Asset and Damage Valuations, TA , TD^j**

Inasmuch as the asset positions of the Community Profile are determined by value based measures (e.g., measured in $), then the individual indicators by dimension can be summed to obtain total asset value and the total damage estimate. Thus, assuming each Community Profile indicator is measured in common value terms, e.g., current dollar values, then, the total asset position indicator, TA and the total damage valuation indicator, TD^j from storm j is

$$TA = \sum_j SQ^j \text{ over all indicators, } i \text{ and for } j=0,I,II,\ldots N_S \qquad (3.4)$$

$$TD^j = \sum_j D^j \text{ over all indicators, } i \text{ and for } j=0,I,II,\ldots N_S \qquad (3.5)$$

where $j=0$ denotes the Status Quo position of the community prior to any storm (with $TD^0=0$) and assuming there is no adaptive action in place.

- **Community Asset at risk valuation, AR^j**

Let AR^j denote the valuation of community assets that may be affected by severe storm j. For example, if we consider a house along the shore of the community as an economic asset, the market value of the house can be considered as an "at risk" value. While the entire house is considered "at risk", the actual damage may be considerably less and is maximised only if the house is completely destroyed. In most cases, the damage to the property is a portion of "at risk" value. Thus,

$$TD^j <= AR^j <= TA \quad (3.6)$$

- **Utility Valuation of Indicator Shifts**

A fundamental topic in our multicriteria decision making framework is the notion of utilities where, “Utility is an abstract measure of the relative strength of preference/desirability for a particular outcome” (Lane and Stephenson, 1998). The value of changes to coastal community indicators are assumed to be described more effectively by a utility function that captures decision makers’ perceptions and importance of system changes. Utility curves obviate the constant marginal utility assigned to dollar valuations, e.g., TA^j, TD^j. As well, utility curves standardize indicators at different scales and permit their direct comparison.

Figure 3.1 depicts the general marginal decreasing “risk averse” (concave) utility function adopted for determining the valuation of each of the Community Profile indicators in this study.

It is understood that this assumptions about “risk averse” utility is a strong assumption. Further it is used as a means of adopting Expert Choice modelling options and assuming that the indicator utility curve exists. The latter assumption is further noted in the context of preference reversal and the existence of the utility curve (Kahneman and Tversky 1979).

The “risk averse” function form is used as the best means of reflecting the general risk attitude of the overall community with respect to indicators. While it is recognized that some community groups and members have different risk attitude, the “risk averse” format is used to represent the valuation of changing indicator values for the community as a whole.

The choice of “risk averse” or decreasing marginal utility as the value of the indicator increases, favours the initial state of assets compared to the reduced state of the assets following a severe storm. The upper bound of this utility function for a single indicator is represented by SQ^*, the pre-storm community status where all assets are assumed to be currently intact and at their highest realizable level. This is considered as the “ideal state” for each indicator and therefore represents the maximum utility anchor point for the construction of the utility curve, i.e., utility equals 1. The lower bound of this indicator’s utility function is represented by SQ^{NS} which is the new status of the community following the most severe storm and assuming storm impacts are not the result of any new and applied adaptation strategy. This “worst case” indicator value represents the minimum utility anchor point for the construction of the utility curve, i.e., utility value of 0. Adaptation strategies effectively move the community away from the minimum utility anchor point, SQ^{NS} the status of the community following the most severe storm, to approach the anchor point at SQ^{0}, the pre-storm community status.

Figure 3.1 depicts the general marginal decreasing “risk averse” (concave) utility function adopted for determining the weighted valuation of each of the Community Profile indicators in this study. It is understood that this assumptions about “risk averse” utility is a strong assumption. Further it is used as a means of adopting Expert Choice modelling options and assuming that the indicator utility curve exists. The latter assumption is further noted in the context of preference reversal and the existence of the utility curve (Kahneman and Tversky 1979).

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Figure 3.1 also illustrates the example indicator value for alternative adaptation strategies labelled “Strategy 1” and “Strategy 2”. As noted in the figure, Strategy 2 has an improved indicator value (x-axis value of Strategy 2 exceeds that of Strategy 1). Since the utility function is monotonically increasing, this also means that *u(2) > u(1)* for this indicator. Applying the indicator priority weight, and the weight of the Community Profile dimension to the overall utility value of alternative strategies provides comparative evaluation. This evaluation is discussed further below with respect to these defined elements and in the context of actual problem settings.

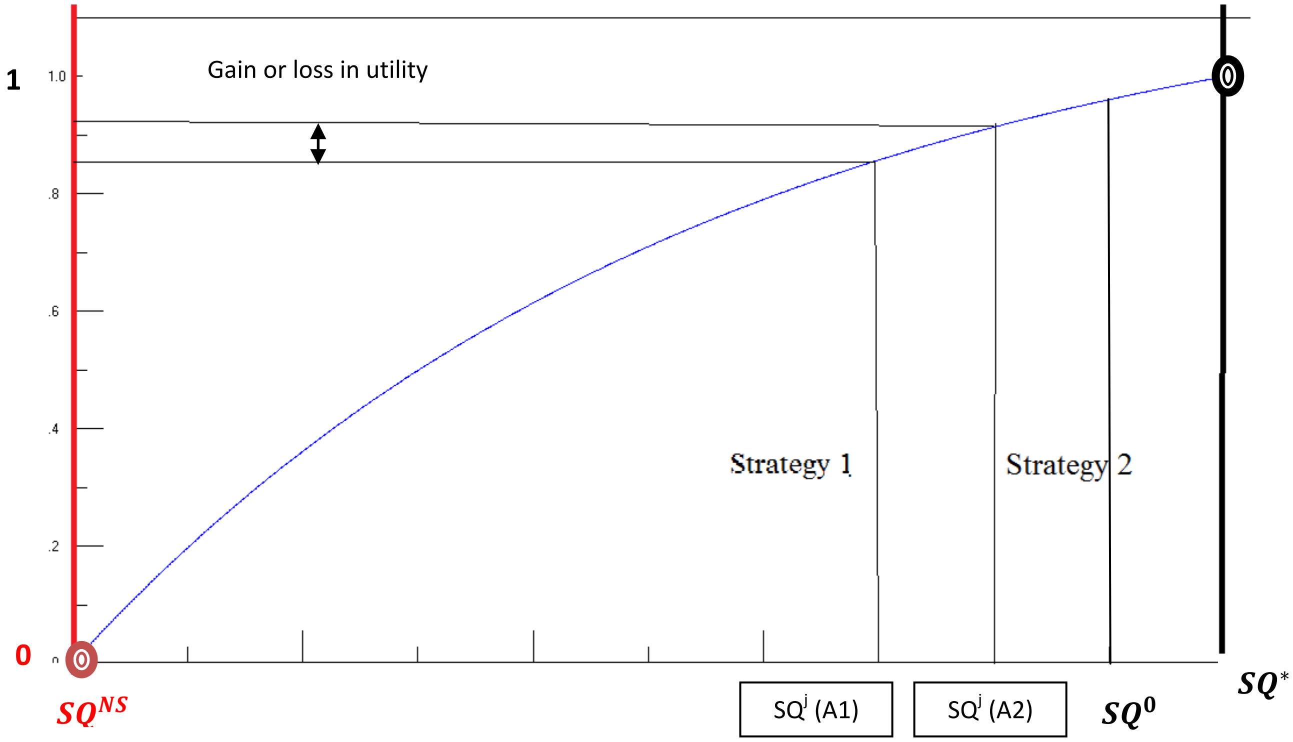


Figure 3.1. The general utility function considered for this study

Thus, indicator utility values transform the indicator scale to a unique and comparable dimensionless scale that can be used, together with user defined priority weights applied for the dimensions of the Community Profile to determine the overall utility value over all indicators.

In previous paragraphs, the difference between the two value-based states for community pre-storm status and post-storm status indicated damage from storms. Storm damage is a measure of how vulnerable the community is to the severe storm event. The objective is to adopt strategies, prior to the storm event, in order to reduce the expected impacts of the storm. Strategies which are effective at reducing the community's vulnerability are indicative of a resilient strategy for the community. The extent of resilient strategies indicate the community's adaptive capacity. The concepts of vulnerability, resilience, and adaptive capacity are defined further below.

- **Vulnerability**

The concept of vulnerability is presented as the difference between the aforementioned pre-storm and post-storm Community Profile states in terms of the weighted utility values of the indicators. Let $V^j(u)$ denote a single-valued measure of the vulnerability of the community to severe Storm Scenario j as a function of the indicators in terms of their respective utility values, u, and the AHP hierarchy weights, where

$$V^j(u) = SQ^0(u) - SQ^j(u) => 0 \qquad (3.6)$$

- **Adaptation Strategies**

If we introduce adaptation strategies to mitigate the impacts of storm damages, then a reduction is expected in the coastal community's level of vulnerability. The introduction of these strategies will protect the assets of the community from storm impacts and therefore result in less loss on initial asset values. Consider the set of community adaptation strategies, A_i, $i=1,2,...n_A$ where the A_i's represent additional planned strategies designed to reduce the damages expected from severe storms. Thus, applying adaptation strategy A_i means that the new status of the community in the face of severe storm j will be given by $SQ^j(A_i, u)$, the modified community status such that:

$$SQ^j(A_i, u) < SQ^0(u) \qquad (3.7)$$

$$SQ^j(A_i, u) > SQ^j(u) \qquad (3.8)$$

- **Resilience**

Let $R^j(A_i, u)$ denote the resilience of the community under the adaptive strategy, A_i in terms of the utility measures for indicators, u. Thus, $R^j(A_i$, u) is given by:

$$R^j(A_i, u) = SQ^j(A_i, u) - SQ^j(u) \qquad (3.9)$$

where $R^j(A_i, u) > 0$ *assuming (3.7), and* $R^j(A_i, u) < V^j(u)$.
Figure 3.2 below depicts the concepts discussed above.

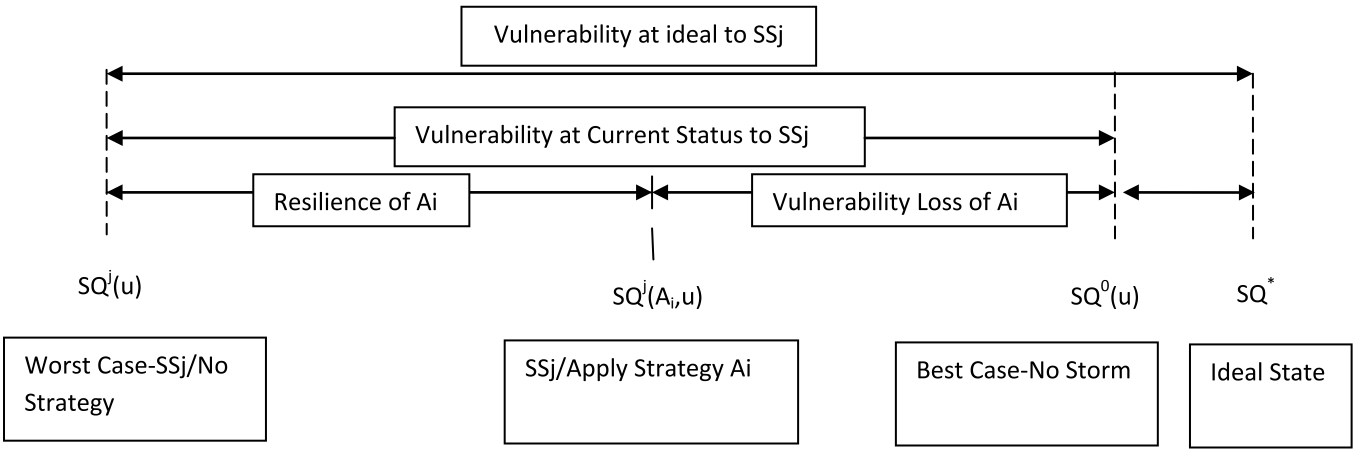


Figure 3.2. Storm Scenario j effects

We can see from figure 3.2 that the concept of vulnerability can also be presented as the difference between the aforementioned "Best Case" (i.e., current) – No Storm status of the indicators, or the "Ideal" state ($SQ*$) versus the "Worst Case" (and no assumed strategy) status of the community indicators.

- **Ideal State (SQ^*)**

As can be seen from both Figures 3.1 and 3.2 the concept of "Ideal" state or SQ^* is introduced. The "Ideal" value corresponds to the upper bound value of the utility function of each indicator. This state is highly subjective to the decision makers' perspective on what their ideal state of assets would want to be. For example it may be decided that more houses is something that stakeholders favour for the designated community and therefore this new asset value will be the basis for upper bound of that asset's utility function (in this case houses). The same evaluation can be made for other indicators.

It is understandable that such evaluations for determining the “Ideal” state for each indicator is highly subjective and it has to be done in a group setting. For the purpose of this thesis we have not conducted a group based decision analysis for determining these “Ideal” indicator statesAs time and resources allows, it is recommended that this process be analyzed from a group perspective.

- **Adaptive Capacity**

Finally, community adaptive capacity, $AC^j(A_i,u)$ is determined for each adaptive alternative, A_i, and for all adaptive options of the community as the ratio of resilience to vulnerability for the specified storm scenario, *j*, *j=I,II,...VI*, and the adaptive alternative strategy, A_i, i.e.,

$$AC^j(A_i,u) = R^j(A_i\,,u)/V^j(u) \qquad (3.10)$$

where $0 < AC^j(A_i,u) < 1\ or\ 100\%$. Average $AC^j(A_i,u)$ or *AC* is determined by averaging the adaptive capacity results of all available strategies in a given context or case for Storm Scenario *j=I,II,...VI*.

The above framework is similar to the natural disaster and hazards framework approach (Yamin et al 2005, O’Brien 2005) - Subsection 2.2. The framework presented here is unique in that it has a holistic approach toward exposed dimensions of the community, namely, Economic, Environmental, Social and Cultural. As such, the measures of vulnerability, resilience, and adaptive capacity defined above can be applied to each of the Community Profile pillars. Moreover, being framed as a multicriteria approach, this approach also permits various stakeholders’ perspectives on the community priorities. The application of these parameters is discussed in detail in Chapters 4 and 5 of the thesis for which the developed case studies for Isle Madae and the Little Anse community breakwater are presented.

3.3 General AHP model utilized for this study

This section presents the methodology of the Analytical Hierarchy Process (AHP) including problem formulation and sample analysis. Application of this methodology is presented in further detail in Chapters 4 and 5 in which these concepts form the basis for the case studies on Isle Madame and the Little Anse breakwater.

As discussed previously in Chapter 2, AHP has been utilised as a tool to assist with multicriteria decision analysis, especially when criteria and indicators are a mixture of quantitative and qualitative values. Figure 3.2 shows the general hierarchy utilised in AHP for this problem and corresponding to the dimensions, categories and indicators of the Community Data Profile (Appendix A). This figure is a screen image from the *Expert Choice* AHP software package that is used in this thesis as the basis for formulation and solution of the group decision multicriteria problem (Expert Choice 2000).

As can be seen from the Figure 3.3, the hierarchical focus corresponds to the four different pillars of the community namely: Economical, Environmental, Social and Cultural. Each pillar is further broken to its subcomponents “categories”. Finally, the Community Profile indicators by dimension are represented by the utility values of the indicator set for each of the pre-storm Status Quo (No storm) valuations, the post-storm Status Quo (No strategy) valuations, and the indicator outcomes assuming the intermediate adaptive strategies, n_A.

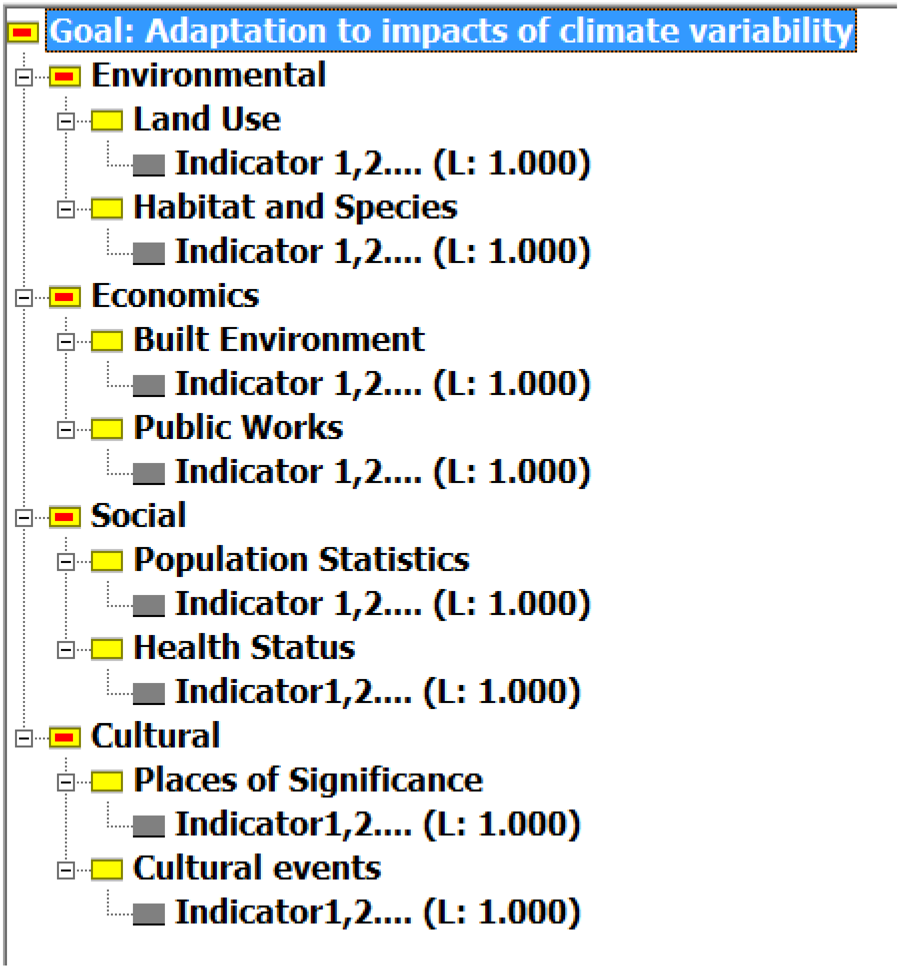


Figure 3.3. The general AHP hierarchy adopted for this research

Source: Expert Choice AHP software, Expert Choice (2000)

This general hierarchy is the basis for the pairwise comparison by decision makers for the construction of the priorities associated with the pillars and subcriteria of the hierarchy. This comparison allows us to assign weights from pairwise comparisons to these elements of the hierarchy. As discussed in Chapters 4 and 5, these weights are different from the perspective of different decision makers who participate in the same decision making process (with the same hierarchy and indicator values). Such discrepancies in preferences are the basis for group decision making. AHP based software such as Expert Choice allows different stakeholders to easily perform their pairwise comparison and assign weights to components of the same hierarchy in a group multicriteria decision support.

There are many ways to conduct such a pairwise comparison process in Expert Choice (Expert Choice 2000) software. Decision makers can choose among numerical, verbal and graphical methods to conduct this process. An example of a verbal method is shown in figure 3.4. It shows a strong preference of Economics over Environmental pillar from the point of view of this decision maker.

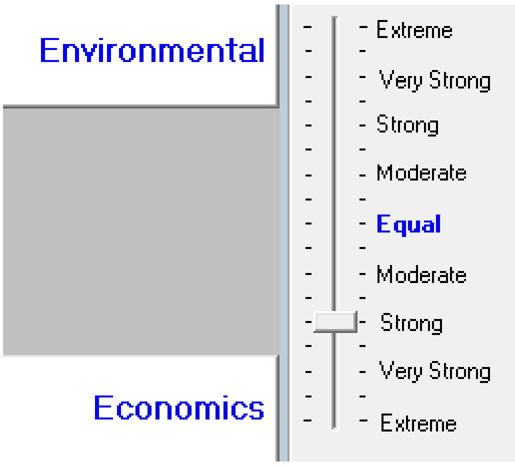


Figure 3.4 Pairewise comparisons of Environmental and Economics pillars

Source: Expert Choice AHP software, Expert Choice (2000)

After all the pairwise comparisons are conducted by the decision maker, the weighted hierarchy can be derived as depicted for the illustrative case in Figure 3.5. These are the normalized weights calculated by Expert Choice software based on AHP methodology (Chapter 2).

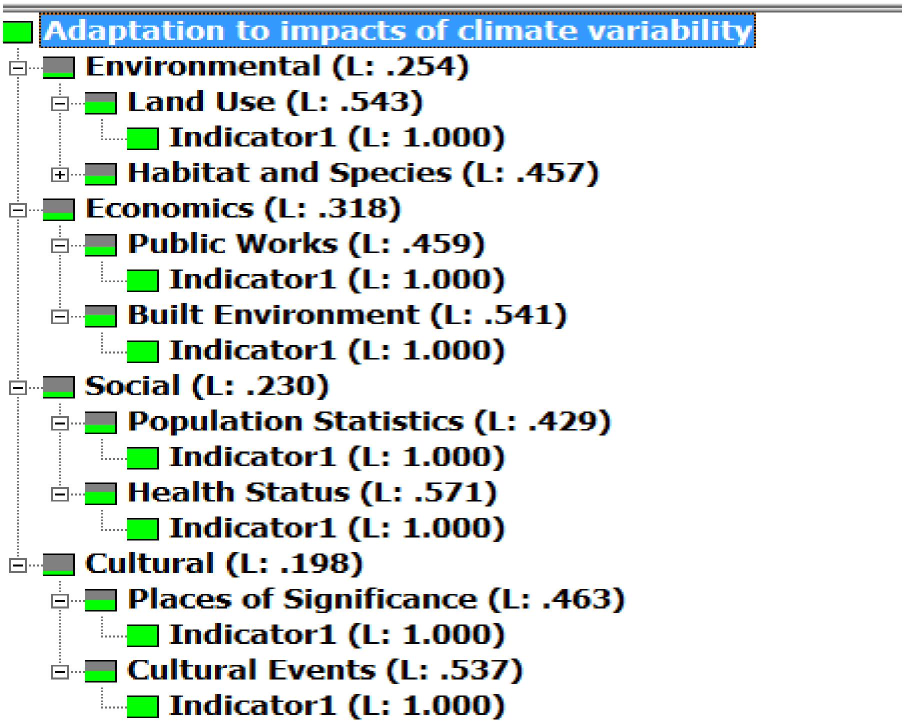


Figure 3.5. Weighted hierarchy of the hypothetical AHP problem

Source: Expert Choice AHP software, Expert Choice (2000)

Based on the figure above, it is noted that with respect to first level of the hierarchy this particular decision maker has put more weights on Economics pillar followed by Environmental, Social and Cultural. Similar observations can be made with respect to other components of the hierarchy.

One important feature in *Expert Choice* is what is called the Data Grid that is attached to the hierarchy at the lowest level. *Expert Choice*'s Data Grid provides us with an environment to define the adaptive alternatives in terms of their indicator value set. The Data Grid also permits the construction of utility functions assigned to the relevant range of each indicator value which provide the basis for evaluating these alternatives. Figure 3.6 depicts an example of the *Expert Choice* Data Grid in AHP.

Alternative	Total	Environmental Land Use Indicator1 (L: 1.000)	Environmental Habitat and Species Indicator1 (L: 1.000)	Economics Public Works Indicator1 (L: 1.000)	Economics Built Environment Indicator1 (L: 1.000)	Social Population Statistics Indicator1 (L: 1.000)
No Storm	.799	1800	1800	1700	1800	60
Storm Impacts Without Adaptation	.517	1000	1200	1400	1200	40
Attack	.606	1200	1400	1600	1400	50
Retreat	.619	1300	1400	1650	1300	52
Protect	.663	1300	1600	1680	1450	58

Figure 3.6. An example of Expert Choice's Data Grid

Source: Expert Choice AHP software, Expert Choice (2000)

This example shows a set of general adaptation alternatives along with "No storm" and "Storm impact without adaptation" scenarios. As mentioned above, the Data Grid provides an environment to define utility functions and by doing so provide a basis for evaluating different strategies. As can be seen from above example the "No Storm" scenario gets a higher score along vulnerability indicators whereas "Storm impact without adaptation" does worse along those indicators. Other strategies may get a high score on one indicator and low score on another.

The Data Grid values combined with the weights associated to different levels of the hierarchy - associated by the decision maker - result in a final score of adaptation strategies. Figure 3.7 depicts the final scores based on the weighted hierarchy and Data Grid values shown above.

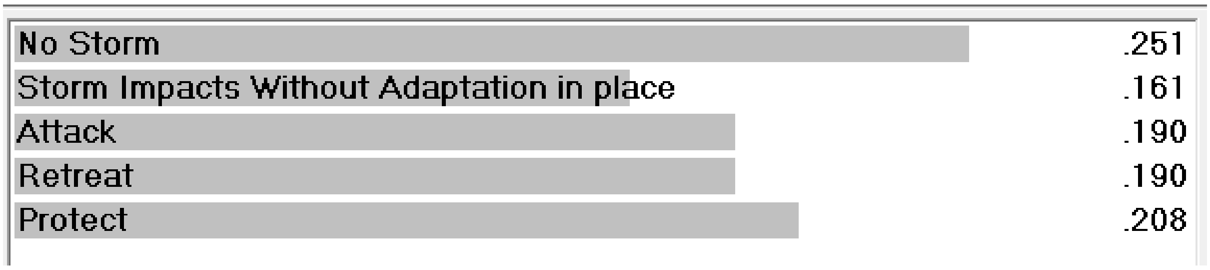


Figure 3.7. Final score of adaptation strategies

Source: Expert Choice AHP software, Expert Choice (2000)

From Figure 3.7 above the "No Storm" scenario has the highest score among all strategies and the "Do Nothing" strategy (i.e., Storm impacts without adaptation in place) has the lowest. Among other strategies, the “Protect” strategy is assigned the highest (most preferable to decision makers) score.

The scores shown above are based on a single decision maker. In the case that we have multiple decision makers; each participant may have a unique perspective toward the issue, therefore weights the hierarchy differently. It is assumed that all participants agree that there is a unique hierarchy that is formulated to describe the problem. Thus, while the weights differ for each participant, the hierarchy - e.g. Figure 3.5 - is assumed to be same for all participants. Similarly, the Data Grid is assumed to be the same for all participants. Expert Choice (2000) facilitates the group decision making process by providing an environment to define various participants, capturing their unique pairwise comparisons and combine their evaluations in order to achieve one final score. A discussion on group decision making with AHP was presented in the literature review of Chapter 2.

3.4 Modeling storm Scenarios

As mentioned before, Charlottetown, P.E.I., being a data-richer community (in terms of data on historical storm and their impacts), is utilized as a case study on how scenario analysis can be put forward. This practise can be used as a model for building such scenarios for other communities.

The main question of this section is how we categorize aforementioned empirical data on storms and their impacts in order to model and prepare for future storms? As we discuss in the following paragraphs, this is not a straight-forward task and some judgment has to be made on part of this researcher to develop the storm scenario model.

Scenarios can be used for multiple purposes (Bizikova, 2010): living the future in advance, understanding the world better and as the result making better decisions, triggering discussions and raising awareness.

The approach taken for extracting such scenarios is based on the previously discussed storm indicators, including storm speed, wind speed and pressure. The speeds are measured in kilometres per hour, and the pressure is measured in millibars. The ranges of these indicators are the basis for categorizing severe storms affecting coastal communities.

For the case of Charlottetown, the maximum and minimum values of these indicators are found and historical storms, discussed in subsection 2.4.2 above, are further broken down to six separate storm scenario categorizes.

Among these storms, Tropical Depression Able had the lowest storm speed of 44kph and Hurricane Gustave had the highest storm speed value of 74kph. From these maximum and minimum values we defined six non-overlapping scenarios for increasing storm speed. These ranges are as follows: (1) 45 – 50, (2) 50 – 55, (3) 55 – 60, (4) 60 – 65, (5) 65 – 70 and (6) 70 – 75.

The “No Name 1964” storm that hit Charlottetown has the highest historical wind speed of160kph, and Tropical Depression Able had the lowest value of 55kph. From these maximum and minimum values we defined six non-overlapping scenarios for increasing wind speed. These ranges are as follows: (1) 55 – 75, (2) 75 – 95, (3) 95 – 115, (4) 115 – 135, (5) 135 – 155, and (6) 155 – 175.

The “No Name 2000” storm has the lowest historical pressure of 945 millibars for storms that struck Charlottetown, and Extratropical Storm Hanna has the highest pressure of 995 millibars. From these maximum and minimum values we defined six scenarios for pressure. These ranges are as follows: (1) 1000 – 990, (2) 990 – 980, (3) 980 – 970, (4) 970 – 960, (5) 960 – 950 and (6) 950 – 940.

These scenarios are summarized in Table 3.1 below to define the input characteristics of six modelled Storm Scenario, denoted Storm Scenario I through VI as follows:

Table 3.1. Categorization of six storm scenarios

	Speed (kph)	Wind (kph)	Pressure (mb)
I	45-50	55-75	1000-990
II	50-55	75-95	990-980
III	55-60	95-115	980-970
IV	60-65	115-135	970-960
V	65-70	135-155	960-950
VI	70-75	155-175	950-940

The scenarios are sorted based on the intensity of the storms, meaning that as you move from Storm Scenario I to Storm Scenario VI, the storm indicators intensify across all three storm inputs. The storm and wind speeds gradually increase as the pressure gradually decrease as we move from one scenario to another. The aim is to fit the empirical storms of section 2.4.2 into these six categories. As expected, the “fit” is not “perfect” and some judgments are needed. Table 3.2 shows historical storms sorted out based on these six scenarios.

Table 3.2 Categorization of historical storms based on the six storm scenarios

Scenario	Storm	Speed (kph)		Wind (kph)		Pressure (mb)	
		Scenario	Storm	Scenario	Storm	Scenario	Storm
I	Able	45-50	44	55-75	55	1000-990	-
	Hanna		64		85		995

II	NN1962	50-55	-	75-95	-	990-980	-
	NN1964		-		160		-
	Hortense		48		130		970
III	Juan	55-60	59	95-115	120	980-970	982
	Carol		63		110		
IV	Ginny	60-65	61	115-135	110	970-960	
	Subtrop		61		100		978
	Gustav		74		150		962
V	White Juan	65-70	-	135-155	-	960-950	-
	Kennedy		-		-		-
VI	NN2000	70-75		155-175	70	950-940	945

As already mentioned above it is not possible to fit the historical storms perfectly into these six scenarios. The fact that some of the storms have missing data on their respective indicators (Storm speed, Wind Speed and Pressure) makes this task even harder. For example, by observing the table you can see that Tropical Depression Able and Hurricane Hanna have both been categorized under Storm Scenario I. Able has a storm and wind speed within the range, but Hanna has only the recorded pressure value within the range. Also as is noticeable, some storms such as “No Name 1962”, “White Juan” and the “Kennedy Inaugural Storm” do not have any entry on any of the indicators. Moreover “Subtrop” with values of 61kph for storm speed, 100kph for wind speed and a pressure of 978 millibars was placed at scenario IV; however, it may be argued that this storm would better suit in Storm Scenario III.

The reason for such judgments on part of this researcher is based on the combined storm inputs (shown in Table 3.1) as well as the storm output, i.e., the recorded storm damages of such storms. Apart from the intensity of a storm, there are other reasons that can affect the actual impact of a storm such as seasonality and coincidence of a high tide at the time of impact. For example, in colder seasons due to the accumulation of ice in water, the ice acts as an obstacle for a potential storm surge that can mitigate the impact of a storm. Therefore you can argue that if such a storm with its specific indicators had happened in a warmer season (or a colder season with little ice), it would probably have had a more severe impact. Moreover, if a storm surge coincides with a high tide, full moon, or a “spring tide”, it could cause more extreme flooding than otherwise.

In preceding paragraphs, a categorization of various historical storms into their respective scenarios was presented. Furthermore, it was noted that a perfect match could not be attained for historical storms and modelled storm inputs, and for such reason, the impacts of these storms have been used as a way to place those storms in their respective categories. The next step is to categorize these impacts with respect to these Storm Scenarios expected damages for particular Storm Scenario.

In Chapter 2, subsection 2.5, storm surges and storm tides were distinguished, and water levels stressed as a more valuable indicator. Therefore, water level information has been captured for the entire Charlottetown historical storms (with the exception of “Extratropical Storm Blanche” - which had no recorded maximum observed water level), by accessing Charlottetown’s tide-gauge data. Water-level data from these tide gauges were accessed from Fisheries and Oceans Canada – Canadian Tides and Water Levels Data Archive (FOC, 2010).

Table 3.3 below summarizes observed water levels and a summary of impacts of storms for the Charlottetown historical set, section 2.4.2.

Table 3.3. Maximum observed water levels and summary of damages

Scenario	**Storm**	**Maximum Observed Water Level (m)**	**Damages** (Environment Canada, 2010; Hartt, 2011)
I	Able	2.52	- street flooding - power outage
	Hanna	2.462	- heavy rainfall - street closure due to flooding - half meter water in Joe Ghiz Park

			(Grafton St)
II	NN1962	2.55	- damaged and washed out streets and highways - Estimated $300,000 in damages
	NN1964	2.47	- most damage at sea - 3 fishing boats capsized
	Hortense	2.89	- All power in Charlottetown lost - many power lines destroyed - ferry service halted
III	Juan	2.927	- extensive tree damage - barn and silo damage - flooding - power outages lasting up to 5 days - Estimated $200,000 in damages
	Carol	2.95	- large trees knocked over - roofs blown off - chimney knocked off - power outage due to destroyed power lines - ferry service halted
IV	Ginny	3.15	- extensive power outages - ferry service halted
	Subtrop	3.32	- many roads and bridges flooded - trees knocked over - roofing shingles pried off - thousands of pounds of lobster beached along coast

	Gustav	3.489	- power lost across PEI - vehicle accident cause by storm killed a man
V	White Juan	3.772	- widespread flooding
	Kennedy	3.84	- widespread flooding
VI	NN2000	4.216	- severe damages to public and private properties - damaged wharves in Charlottetown Harbour - damaged a power-generating station - dislodged a lighthouse - damaged numerous gas stations - Estimated at $20 million in damages

Not all the impacts are as the result of flooding, for example impacts such as power outages or roof tops being blown off are related to wind.

Based on Tables 3.1 to 3.3, more detail is provided with respect to our initial six storm scenarios. These scenarios are as follows:

<u>Storm Scenario I</u>

Storm Scenario I has speed of 45 kph to 50 kph, wind speeds of 55 kph to 75 kph, and atmospheric pressure of 1000 mb to 990 mb and maximum water level between 2 and 2.5 meters above chart datum. We can expect similar impacts to that of Extratropical Storm Hanna (September 7, 2008) and Tropical Depression Able (August 21, 1950) which are characterized by heavy rainfall, street flooding and power outages.

<u>Storm Scenario II</u>

Storm Scenario II has speed of 50 kph to 55 kph, wind speeds of 75 kph to 95 kph, and atmospheric pressure of 990 mb to 980 mb and maximum water level between 2.5 and 3 meters above chart datum. For Storm Scenario II, it is expected that similar impacts to that of

No Name 1962 (April 4, 1962), No Name 1964 (December 2, 1964), and Hurricane Category 1 Hortense (September 15, 1996) which are: flooding of street and highways, power outages, and ferry service cancelation. The empirical data suggests that the monetary damages of such impacts can be up to $300,000.

Storm Scenario III

Storm Scenario III has speed of 55 kph to 60 kph, wind speeds of 95 kph to 115 kph, and atmospheric pressure of 980 mb to 970 mb and maximum water level between 3 and 3.5 meters above chart datum; Similar impacts are expected to that of Extratropical Storm Carol (September 8, 1953) and Post-Tropical Storm Juan (September 29, 2003) which are ferry service cancellation, power outages, closure of many roads and bridges due to high winds and flooding, trees being knocked over, roofs blown off and chimneys knocked over and damages to weaker buildings such as barns and silos.

Storm Scenario IV

Storm Scenario IV has speed of 60 kph to 65 kph, winds of 115 kph to 135 kph and atmospheric pressure of 970 mb to 960 and maximum water level between 3.5 and 4 meters above chart datum. Extratropical Storm Ginny (October 30, 1963), Subtropical Storm Subtrop (October 29, 2000) and Hurricane Category 1 Gustav (September 12, 2002) storms in this category have impacts which are roads and highways being washed out as the result of flooding, the cancellation of ferry services, trees being knocked over, pleasure crafts damaged, roofs blown off, small fishing vessels damaged, power outage and structural damage to weaker buildings.

Storm Scenario V

Storm Scenario V has maximum speed of 65 kph to 70 kph, winds of 135 kph to 155 kph, and atmospheric pressure of 960 mb to 950 mb and maximum water level between 4 and 4.5 meters above chart datum. We can expect similar impacts to that of Kennedy Inaugural Storm (January 21, 1961) and White Juan (February 19, 2004) which are severe widespread flooding in the city washing out and damaging many roads, highways and bridges, roofs being blown off, the cancellation of ferry services, many large old trees knocked over, damage to fishing vessels, power outage across the city, and structural damage to weaker buildings.

Storm Scenario VI

Storm Scenario VI has speed of 70 kph to 75 kph, winds of 155 kph to 175 kph and atmospheric pressure of 950 mb to 940 mb and maximum water level above 5 meters about chart datum. Impacts expected are similar to, and perhaps worse, than No Name 2000 storm (January 21, 2000). This is the worst storm recorded in Charlottetown's history with respect to maximum observed water level, lowest pressure and overall monetary damage. A storm of this magnitude would have impacts that include severe flooding to private and public properties -an estimate of 460 properties were either flooded or at risk because of this storm - which would necessitate evacuations; beaches, roads, and highways, buildings would be severely flooded, power loss, trees being knocked over, roofs being damaged or blown off, fishing vessels damaged, wharves being damaged and destroyed, ferry service being cancelled. The estimated cost of the damages in the No Name 2000 storm was more than $2 million. Probably such a storm could have had more severe impacts if it had not formed in a January. This is due to the fact that accumulation of ice sheets can act as a blockage of waves and therefore mitigate its subsequent flooding. Therefore scenario six has the potential to have more severe impacts compared to this storm.

3.5 Isle Madame storm scenarios

The approach taken for extracting such scenarios is based on the discussion in section 3.3 above. As before, the storm and wind speeds are measured in kilometres per hour and the pressure is measured in millibars. The ranges of these indicators are the basis for categorizing storms. For the case of Isle Madame, the maximum and minimum values of these indicators are found (subsection 2.4.3) and the historical storms are further broken down to six categorizes.

Among these storms Hurricane Hortense had the lowest storm speed of 31kph and Hurricane Michael has the highest value of 87kph. From these maximum and minimum values we defined six scenarios for storm speed. These ranges are as follows: (1) 30 – 39, (2) 40 – 49, (3) 50 – 59, (4) 60 – 69, (5) 70 – 79 and (6) 80 – 89.

Hurricane Michael has the highest wind speed of160 kph, and Extratropical storm Allison has the lowest value of 35kph. From these maximum and minimum values we defined six scenarios for wind speed. These ranges are as follows: (1) 35 – 56, (2) 57 – 78, (3) 79 – 100, (4) 101 – 122, (5) 123 – 144, and (6) 145 – 166.

Hurricane Gustave has the lowest pressure of 962 millibars, and Extratropical storm Allison has the highest pressure of 1012 millibars. From these maximum and minimum values we defined six scenarios for pressure. These ranges are as follows: (1) 960 – 969, (2) 970 – 979, (3) 980 – 989, (4) 990 – 999, (5) 1000 – 1009 and (6) 1010 – 1019.

Similar to Table 3.1 for Charlottetown, Table 3.4 is constructed for Isle Madame historical storms which categorizes these into six Storm Scenarios I through VI.

Table 3.4. Categorization of six storm scenarios (Isle Madame)

Scenario	Speed (kph)	Wind (kph)	Pressure (mb)
I	30 – 39	35 – 56	1010 – 1019
II	40 – 49	57 – 78	1000 – 1009
III	50 – 59	79 – 100	990 – 999
IV	60 – 69	101 – 122	980 – 989

V	70 – 79	123 – 144	970 – 979
VI	80 – 89	145 – 166	960 – 969

Similar to Charlottetown's Storm Scenario analysis (Section 3.4), the Storm Scenarios are sorted based on the intensity of the storms, meaning that as you move from Storm Scenario I to Storm Scenario VI, the storm indicators intensify. The storm and wind speeds increase as the pressure decreases as we move on from one more severe Storm Scenario to another. The aim is to fit the empirical storms discussed in this section to these six categories. Although as discussed in the previous section, it is not possible to have a perfect fit since one indicator for an historical storm may fit into the category and one may not. In the case of Charlottetown, information about the damages of the storms was managed to place the historical storms subjectively into Table 3.2 above. Due to the lack of data, however, such categorization is more difficult for the historical analysis of Isle Madame storms. Categorization of 16 Isle Madame historical storms into the six defined Storm Scenario categories is presented in Table 3.5.

Table 3.5.Categorization of Isle Madame historical storms in six storm scenarios and their water levels

Scenario	Storm	Water level	Speed (kph)		Wind (kph)		Pressure (mb)	
			Scenario	Storm	Scenario	Storm	Scenario	Storm
I	Allison (2001)	**-**	**30-39**	50	**35-56**	35	**1010-1019**	1012
II	Chris	**-**	**40-49**	68	**57-78**	45	**1000-1009**	1008
	No Name 2006	-		35		65		1007
	Ophelia	-		52		85		1000
	Bertha	1.48		35		130		973
III	Allison (1995)	**-**	**50-59**	40	**79-100**	85	**990-999**	989

	Lili	1.63		70		75		995
	Barry	-		40		95		991
	Albert	-		38		100		969
IV	Subtrop 1989	-	**60-69**	81	**101-122**	110	**980-989**	984
	Hortense	-		31		120		970
	Bill	-		53		120		970
V	Evelyn	2.05	**70-79**	59	**123-144**	130	**970-979**	996
	Subtrop 2000	-		75		95		980
	Gustave	-		74		140		962
VI	Michael	-	**80-89**	87	**145-166**	160	**960-969**	965

Sixteen historical storms above have been fitted into the above table. As already discussed, without little information on the damages caused by these storms it is not possible to validate the categorization of these storms. For example, in the case of Charlottetown, winter storm January 2000 has the most damages recorded in the history of the community, therefore we easily positioned this storm in the Storms Scenario VI category even though it did not perfectly fit into this category in terms of its storm input indicators. In Table 3.5, if only one indicator of the storm fits the range, the priority has been given to pressure or wind speed – with the exception of Bertha.

In order to obtain the maximum water levels at the time of the Isle Madame storms, the Fisheries and Oceans Canada - Canadian Tides and Water Levels Data Archive was searched. In the contrast to the case of Charlottetown, there is no single marine observation stations that has the complete information on water level digital data for Isle Madame. Therefore we listed the most relevant stations to the community and examined the coverage date of their digital data. Table 3.6 summarises the name of the stations along with their coverage digital data and Figure 3.8 depicts the map of permanent water level gauge stations around Isle Madame.

Station list and water-level data were accessed from Fisheries and Oceans Canada – Canadian Tides and Water Levels Data Archive (FOC, 2010).

Table 3.6.Water level gauge station names and digital data coverage

Community Name	**Year**	**Start Date**	**End Date**
ARICHAT	1952	1952/07/01	1952/11/30
	1953	1953/06/01	1953/10/30
	1954	1954/05/01	1954/09/30
	1955	1955/05/01	1955/09/08
PETIT DE GRAT	1967	1967/06/12	1967/07/11
SAND POINT	1968	1968/05/16	1968/07/05
PORT HAWKESBURY	1962	1962/05/29	1962/06/13
POINT TUPPER	1971-1992	1975/01/01	1975/12/17
• Except the dates mentioned the rest of the years are complete		1978/01/01	1978/11/21
		1979/02/02	1979/12/31
		1984/01/01	1984/12/01
		1985/07/08	1985/11/01
		1986/01/29	1986/11/07
		1992/01/01	1992/04/08
CANSO HARBOUR		1975/06/04	1975 1975/07/14

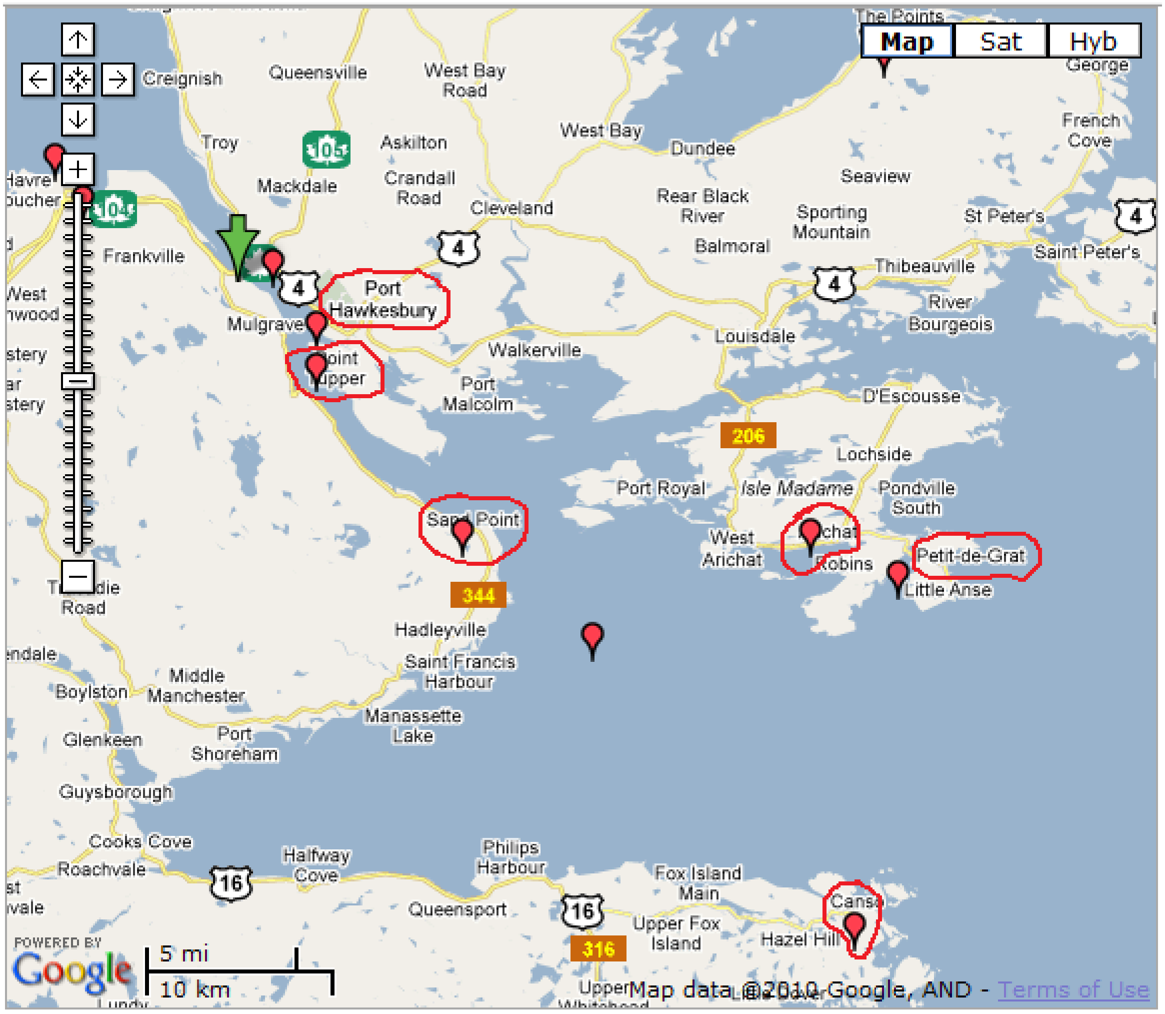


Figure 3.8. Map of permanent water level gauge stations around the Isle Madame

(Source: Google Map, 2010)

As is evident from Figure 3.8, the most relevant stations to our community are the "Arichat" and "Petit-de-Grat" stations. Albeit most relevant, from Table 3.6, it is noted that these two stations have very limited digital data coverage. From all the historical storms only three of them have their water level recorded. Therefore based on these entries we interpolate other Storm Scenarios water levels as presented in Table 3.7.

Table 3.7.Maximum Observed Water level for each scenario

Storm Scenario	Maximum Observed Water level (meter)
I	1- 1.25
II	1.26 – 1.5
III	1.51 – 1.75
IV	1.76 – 2.00
V	2.01 – 2.25
VI	More than 2.25

Although we have estimated the following water levels for all scenarios the ability to simulate these with ArcGIS depends on the resolution of Digital Elevation Model (DEM). The current DEM available for Isle Madame only allows us to simulate 1 and 2m water levels (Scenario I and V respectively) in ArcGIS and therefore these are the basis for the case study on Little Anse (Chapter 4).

3.6 Application of research methods

Application of the research methods is carried out in Chapters 4 and 5 to follow. In Chapter 4, the case of Isle Madame is examined and the application of the AHP model to the Status Quo (No storm) benchmark view is provided. The comparison of the status quo with the expected damage reporting by Storm Scenario is also presented. This chapter includes group decision making aspects of AHP, however does not discuss utility functions and adaptation strategies. Chapter 4 discussions and conclusions pave the way for the subsequent discussions in Chapter 5.

In Chapter 5 the case of Little Anse breakwater is examined where we also apply the group AHP model to the Status Quo (No storm) benchmark and the comparison of the status quo with the expected damage reporting by Storm Scenario. However in this chapter we evaluate utility functions of each vulnerability indicator and introduce and discuss the impact of adaptation strategies on vulnerability in detail.

4. The case of Isle Madame

The case of Isle Madame is presented here with respect to estimating the concept of Isle Madame vulnerability as a whole for the entire archipelago. This Chapter is a prelude to Chapter 5, where we present the decision case of Little Anse with more detail including the determination of the resilience and the adaptive capacity measures. The current chapter is necessary since conclusions discussed here are important to illustrate the application of the methodology of Chapter 3 and to prepare the analysis of specific adaptive strategy analyses.

Isle Madame is situated at southeast of Cape Breton Island in Nova Scotia, Canada. Isle Madame consists of three main island communities: Isle Madame, Petit-de-Grat to the east, and Janvrin's Island to the west. Isle Madame also consists of a number of small communities such as: Little Anse; Arichat; Petit de Grat; Lennox Passage; West Arichat and Janvirin's Harbour; Alderney Point; Boudreauville; Cape Auguet; Cap La Ronde; D'Escousse; Lochside; Martinique; Poirierville; Pondville; Pondville South; Port Royal; Poulamon; Rocky Bay; Samson's Cove; and St. Marys. (See also Figure 3.4 above for details.)

The island has a length of 16km and is 11 km wide (approximately 176 square km). Jurisdictionally, Isle Madame is part of Richmond County, Cape Breton, and is separated from Cape Breton Island by a narrow strait called Lennox Passage located in the north side of Isle Madame (Figure 3.4). Isle Madame is home to 3,455 residents, of which 85.5 % of them are over the age of 15 (Grow Isle Madame, 2010).

The Data Grid values for the data of the AHP hierarchy built here for the case of Isle Madame rely on the work conducted by Pakdel (2011) that estimated asset values, at risk values, and Storm Scenario damages for Isle Madame. Therefore, in this chapter the details behind the Storm Scenario damage estimations are not detailed, but taken from these earlier works. However, in Chapter 5, these estimations are derived and discussed thoroughly for the case of Little Anse.

This chapter is also a showcase of the application of the vulnerability framework (subsection 3.1) and the role of AHP and Expert Choice (2000) software in evaluating alternatives and facilitating support for group decision making (subsections 2.1.5, 2.1.6 and 3.2).

The evaluation of alternatives requires a more focused perspective in terms of the vulnerable community chosen for study. For stakeholders to understand properly the tradeoffs of choosing one adaptation strategy over another, these strategies need to be tangible and focused in such a way that their contributions toward mitigating the impacts of extreme events can also be analyzed.

In Chapter 3 a brief introduction of the AHP hierarchy and Expert Choice (2000) software was presented. Based on those discussions and the work conducted by Pakdel (2011), the AHP hierarchy for the case of Isle Madame is depicted below (Figure 4.1), vulnerability indicators have been listed under their respective Community Profile pillars.

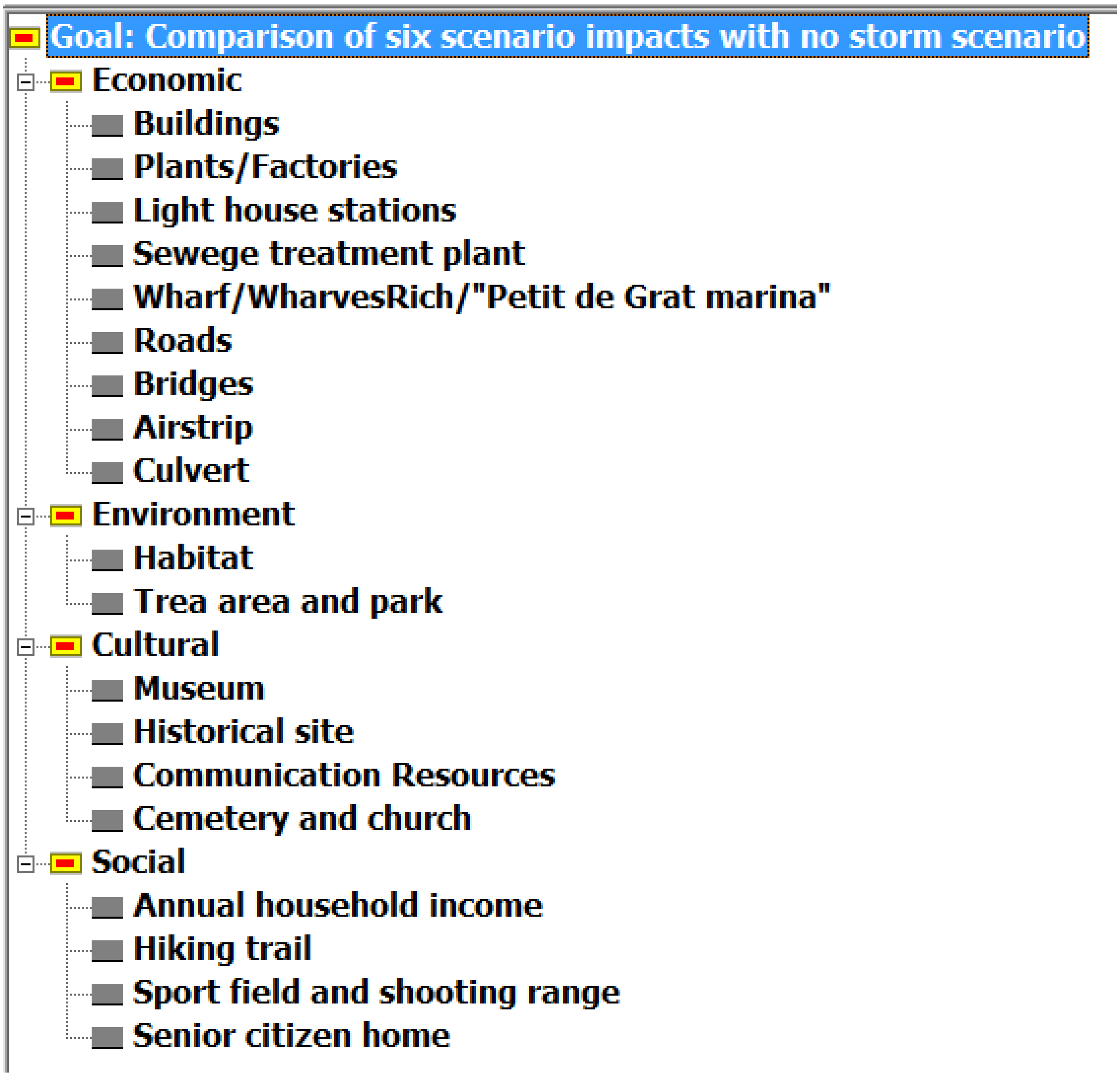


Figure 4.1. The AHP hierarchy of Isle Madame

Based on discussions in subsection 2.1.5, a pairwise comparison of components of the hierarchy are conducted to derive the respective weights of the Community Profile indicators used to determine relative vulnerability when comparing values and overall weighted results to “storm” versus “no storm” status quo. Moreover, based on subsection 2.1.6, the perspective and priorities of the various stakeholders of Isle Madame is taken into account, and this requires a group decision framework.

4.1. Introducing stakeholders and the pair-wise comparison

The analysis of Isle Madame situation is captured by considering five different stakeholders:

1) Community: these are the representatives of the community, including community social clubs such as the Knights of Columbus, the Ladies Auxiliary, and church groups.
2) Local Government: representative of local government, namely, the Regional Municipality of Richmond County.
3) Business/Industry: delegates of the local industries including the fisheries industry managers, local contractors, restaurant and hotel owners, hardware and grocery store owners and operators.
4) Professional: Community professionals including but not limited to lawyers, nurses, doctors and hospice workers, engineers and academics.

For each of these illustrative stakeholders it is assumed that each group holds a unique perspective toward the importance weights of the components on the Isle Madame Community Profile pillars as described in AHP hierarchy. In this case pairwise comparisons are provided for each group to indicate their anticipated tradeoffs and the result of these tradeoffs are illustrated below for each stakeholder group.

Local Government:

Figure 4.2. Weighting allocation to pillars of the study by Local Government

For local government, the order of importance of the Community Profile pillars is (1) Social, (2) Economic, (3) Environment and (4) Cultural. Among all other decision makers, local government gives the maximum weight to the Community Social pillar.

Business/Industry:

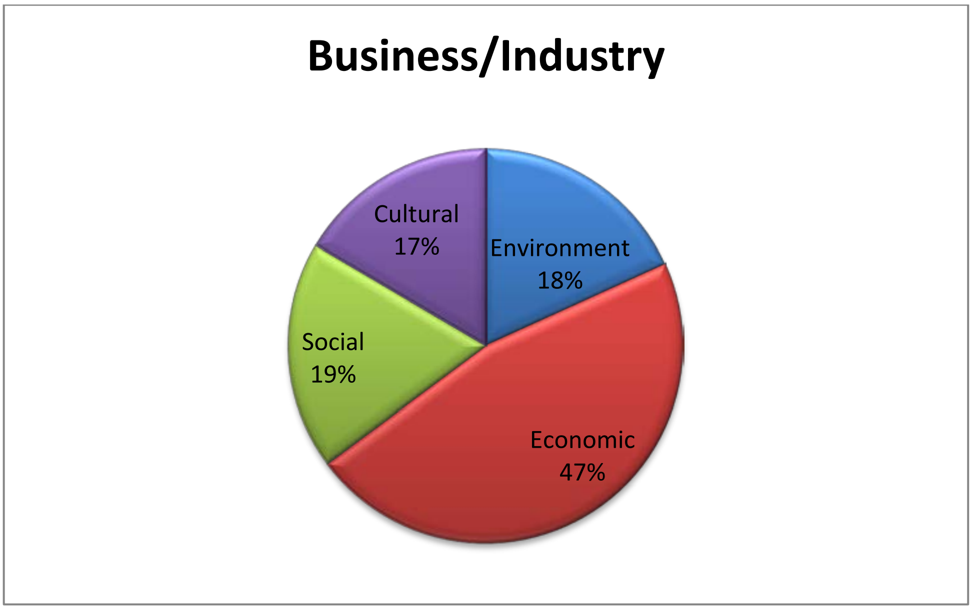


Figure 4.3. Weighting allocation to pillars of the study by Business/Industry

For the business/industry sector, the order of importance is (1) Economic, (2) Social, (3) Environment and (4) Cultural. The business sector is assumed to give its maximum weight to the Economic pillar of the community.

Community:

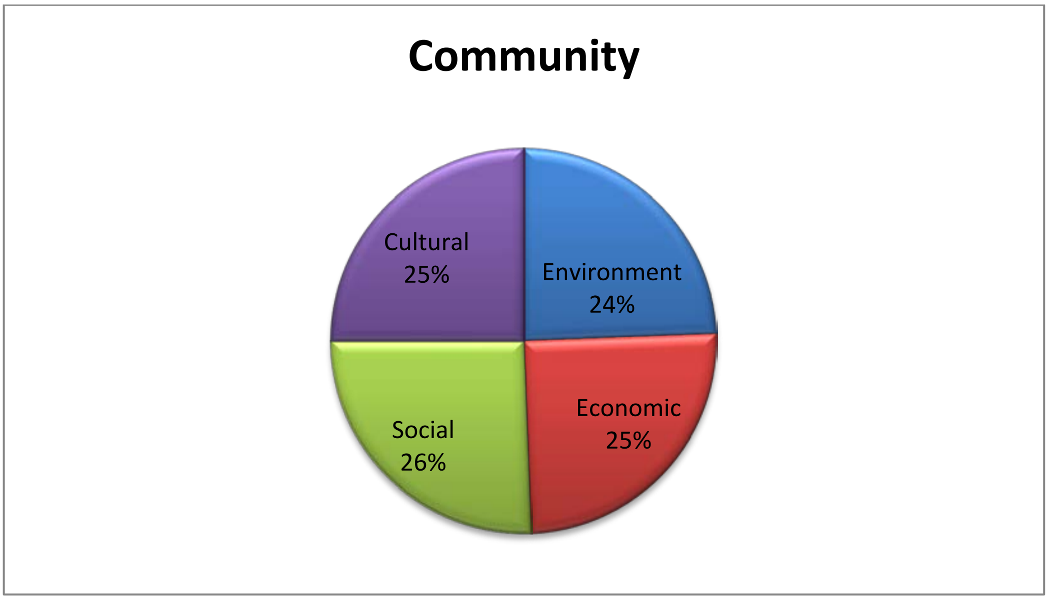


Figure 4.4. Weighting allocation to pillars of the study by Community

Community is assumed to have a more balanced perspective toward the Community Profile pillars with each pillar receiving an equal share of the pie. Accordingly, there is no ordering of the selected pillars – all are assumed to be equally valued.

Professional:

Figure 4.5. Weighting allocation to pillars of the study by Professionals

For professionals, the order of importance of the weights stemming from the pairwise comparisons of this group is: (1) Environment, (2) Economic, (3) Social and (4) Cultural. Among all other decision makers, the Professionals group is assumed to provide the maximum weight to Environment pillar.

The analysis of the group AHP model combines the weights of each stakeholder into a single weighted hierarchy set by pre-weighting the individual group inputs by calculating the geometric means of the pariwise comparison in the hierarchy (see also section 2.1.6). This approach is one of many options for combining the feedback from multi-participant groups. The following results for the case of Isle Madame present the results of the group AHP rankings for storm verus no storm impacts on the community indicators.

4.2. Analysis of "No Storm" scenario with six scenarios' impacts.

In Chapter 2 (subsection 2.1.5) the combined version of the AHP methodology to assist with group decision making was discussed. In the previous section, it is noted that each stakeholder holds a unique perspective with respect to the evaluation of the problem that is reflected in the weights of the AHP hierarchy. Combined group decision making using AHP takes into consideration the differences of each participant through the pairwise comparisons of the elements of the hierarchy. In this section, the "no storm" or "status quo" community scenario results are evaluated as a function of the combined participants' weighting and compared to the results of the six expected Storm Scenarios impacts. The results compare the favorability of the "no storm" status quo with the increasing intensities of storms as an overall single measure to capture the relative differences between the status of the "no storm" versus the Storm Scenario. Although this is rather intuitive it is useful to depict this by use of graphs (Figure 4.6 to 4.12) to capture the overall expected impacts of the storm together with the importance weightings of the decision participants. All numbers have been acquired using the AHP model of the community through the *Expert Choice* (2000) Software.

As we move from Storm Scenario I to Storm Scenario VI, the impacts are expected to be larger and therefore make the "Do Nothing" strategy less favourable.

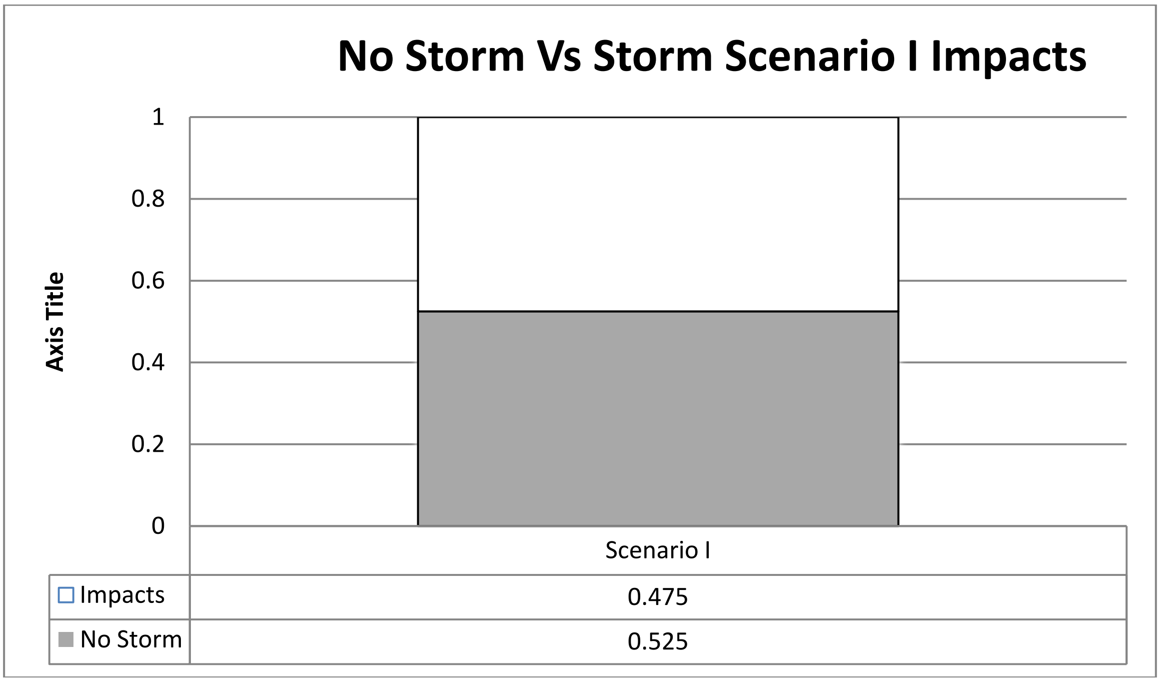


Figure 4.6. Comparison of "No Storm" scenario and storm scenario I impacts

Since the damages are relatively low for Storm Scenario I, the difference between "No Storm" and "Do Nothing" options is only 0.05 (0.525-0.475).

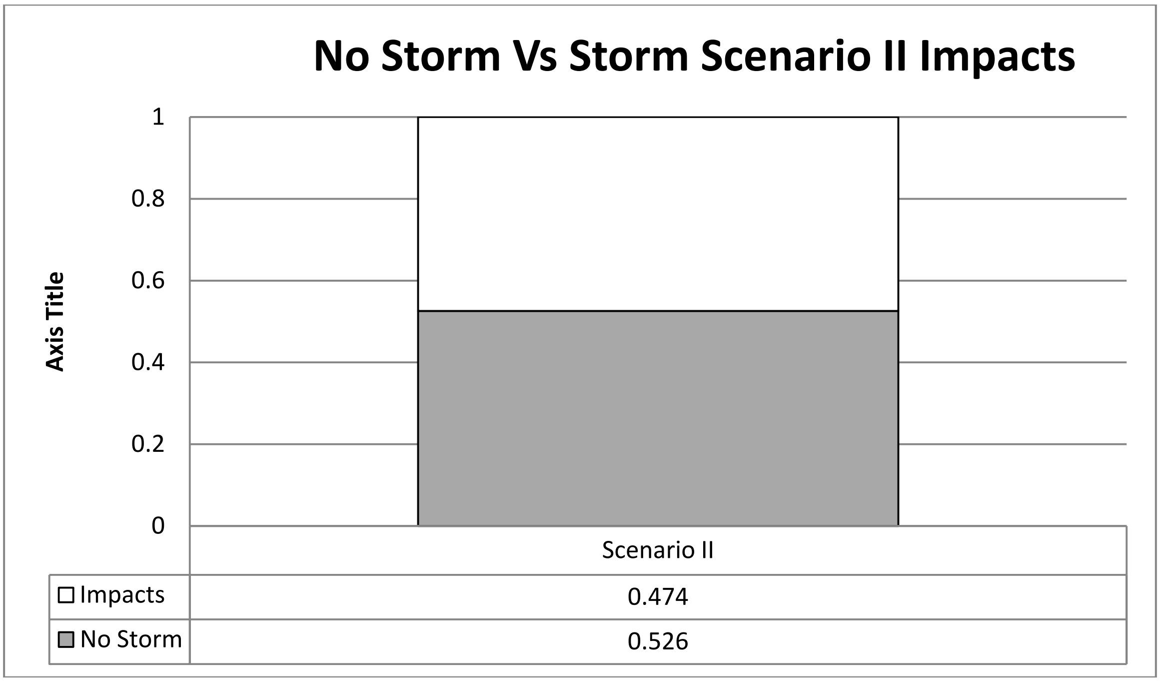


Figure 4.7 Comparison of "No Storm" scenario and Storm Scenario II impacts

Damages from Storm Scenario II are more significant than Storm Scenario I (Figure 4.6 above) and for Storm Scenario II represent a simple weighted difference of 0.052 (0.526-0.474) in comparing the "No Storm" and "Do Nothing" scenarios.

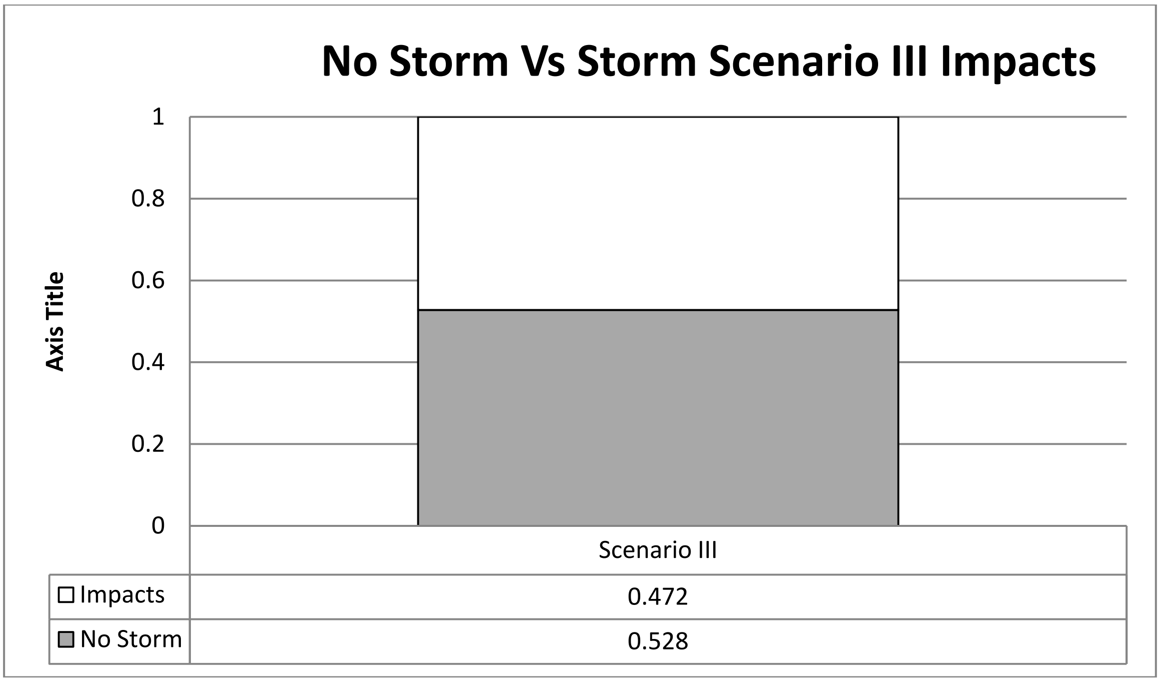


Figure 4.8. Comparison of "No Storm" scenario and Storm Scenario III impacts

Damages from Storm Scenario III are more significant than Storm Scenario II (Figure 4.7 above) and for Storm Scenario III represent a simple weighted difference of 0.056 (0.528-0.472) in comparing the “No Storm” and “Do Nothing” scenarios.

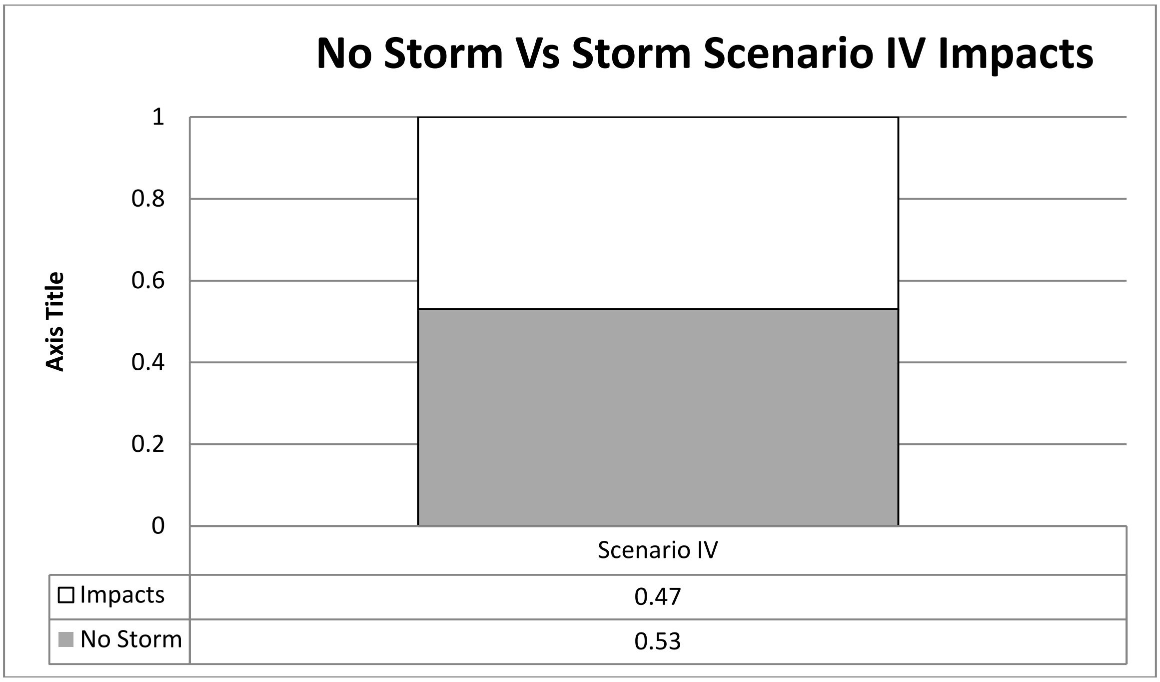


Figure 4.9. Comparison of “No Storm” scenario and Storm Scenario IV impacts

Damages from Storm Scenario IV are more significant than Storm Scenario III (Figure 4.8 above) and for Storm Scenario IV represent a simple weighted difference of 0.06 (0.53-0.47) in comparing the “No Storm” and “Do Nothing” scenarios.

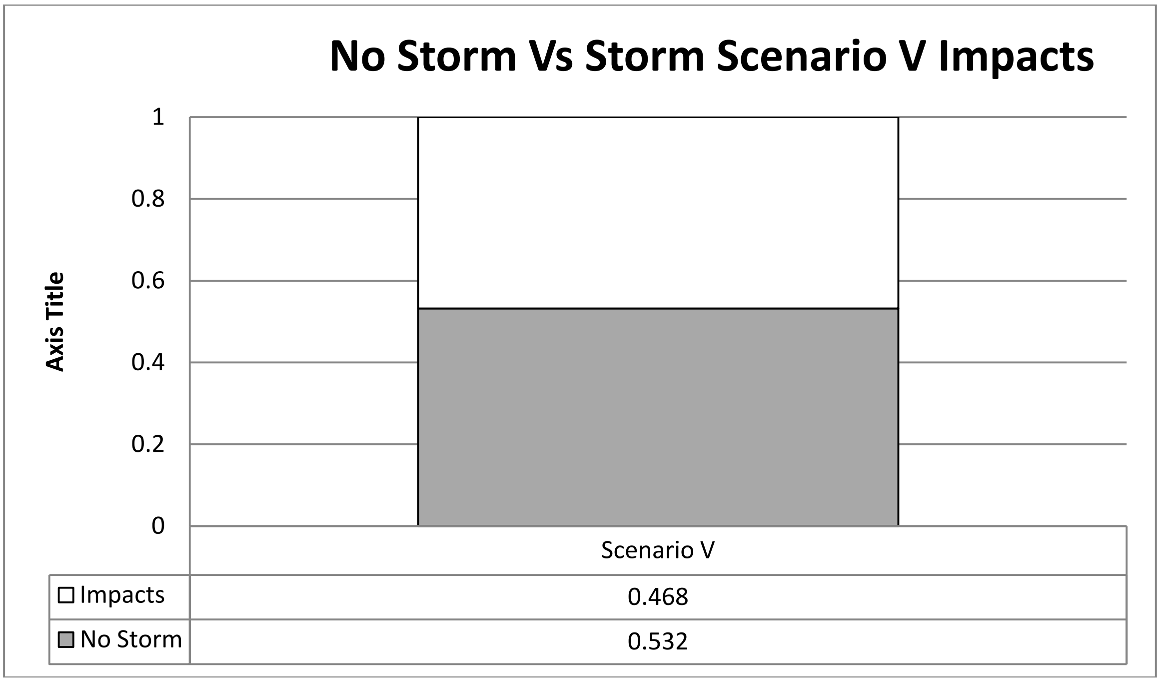


Figure 4.10. Comparison of "No Storm" scenario and Storm Scenario V impacts

Storm Scenario V Damages from Storm Scenario V are more significant than Storm Scenario IV (Figure 4.9 above) and for Storm Scenario V represent a simple weighted difference of 0.064 (0.532-0.468) in comparing the "No Storm" and "Do Nothing" scenarios.

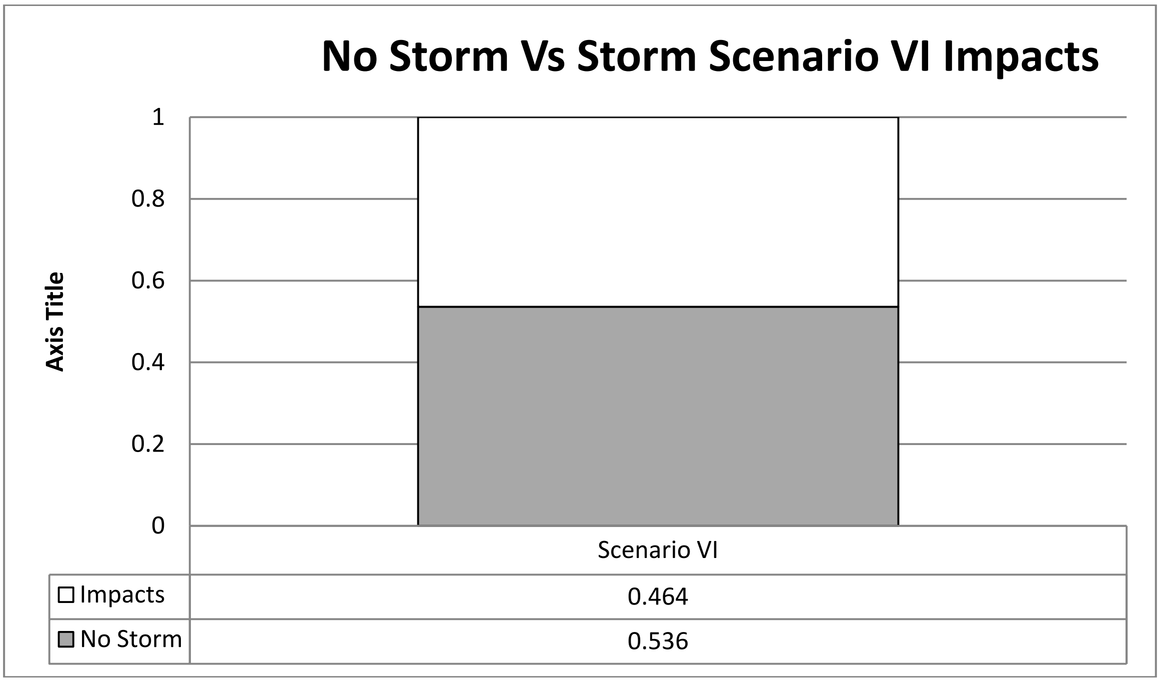


Figure 4.11. Comparison of "No Storm" scenario and Storm Scenario VI impacts

Storm Scenario VI Damages from Storm Scenario VI are more significant than Storm Scenario V (Figure 4.10) and for Storm Scenario VI represent a simple weighted difference of 0.072 (0.536-0.464) in comparing the “No Storm” and “Do Nothing” scenarios.

From Figures 4.6 to 4.11 above, moving from the fixed “No Storm” scenario to the six Storm Scenarios diminishes the rankings of the storms denoting the decision makers’ declining preferences from the increased expected storm damages. A large difference between total asset values (TA) and maximum impacts combined with the relatively small difference in impacts among scenarios result in low relative utility changes as you move from one Storm Scenario to another.

Moreover, as discussed at the beginning of this chapter the scale of Isle Madame community – involving many communities within the archipelago - does not allow for the application of specific adaptation strategies. The only adaptation strategy included here is the “Status Quo” or “Do Nothing” strategy, which is not an adaptation at all. More meaningful application of adaptation strategies occur at the smaller community level, such as Little Anse where more tangible and specific options can be introduced (Chapter 5).

4.3. Isle Madame Vulnerability

Next the vulnerability of the Isle Madame community is evaluated based on the methodology of Chapter 3 and the results of Figures 4.6 to 4.11 above.

Figure 4.12 shows the comparison of the “No Storm” scenario with “Ideal” scenario along with the other six Storm Scenarios I through VI. Figure 4.13 shows the comparison of the “Ideal” scenario with the “No Storm” scenario along with all other six Storm Scenarios.

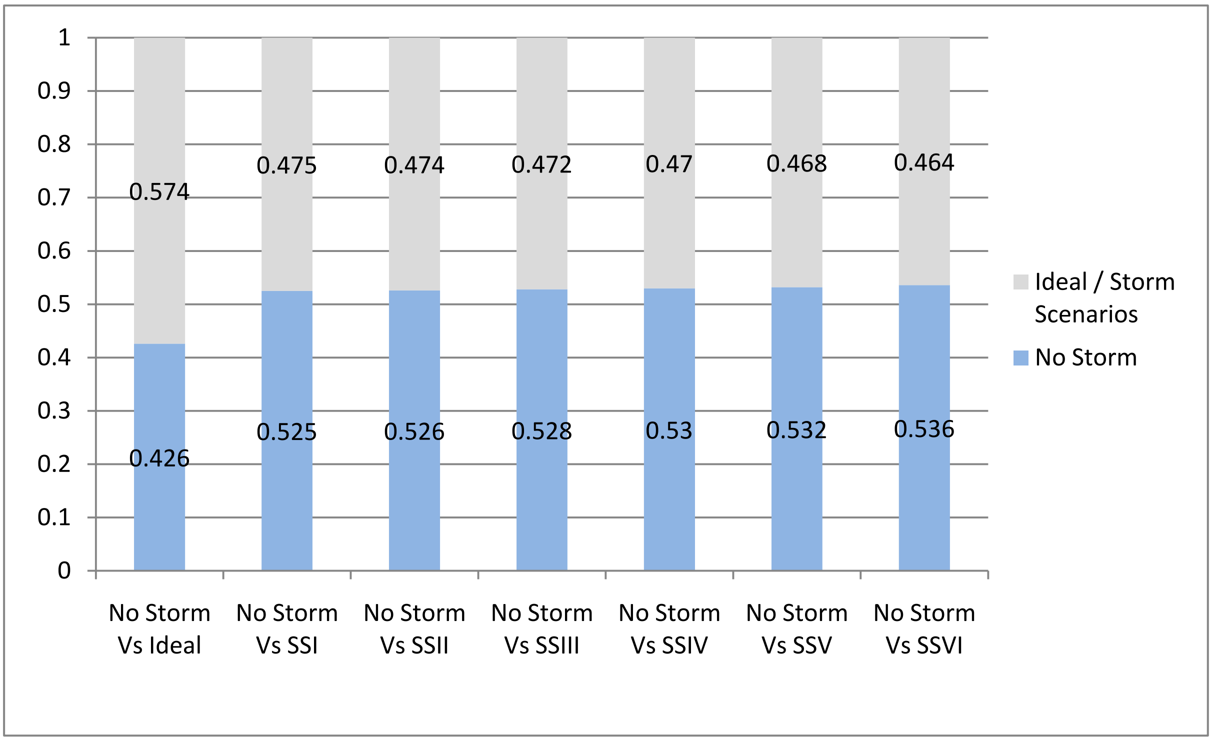


Figure 4.12. Comparison of "No Storm" scenario with "Ideal" and all six scenarios impacts

In Chapter 3, the concept of vulnerability was defined as the difference between the pre-storm and post-storm Community Profile states in terms of the weighted utility values of the indicators (equation 3.6). Based on this definition, the vulnerability of the community with respect to each storm scenario can be evaluated. The difference between "No Storm" and each scenario's final score determines the vulnerability of the community with respect to that scenario. Move from Storm Scenario I to VI, the difference between the weighted utility values - No Storm and corresponding scenario – increase; therefore the community becomes more vulnerable as the intensity of scenarios increase. The differences reflect the overall users weighted comparison of the community status quo with the consequences of severe storms of varying intensity. For example, the vulnerability of Isle Madame to Storm Scenario I according to the results of Figure 4.12 is:

$$V^{I}(u) = SQ^{0}(u) - SQ^{j}(u) = 0.525 - 0.475 = 0.050 \qquad (4.1)$$

Similarly, for Storm Scenario VI, the vulnerability is: $V^{VI}(u) = 0.536 - 0.464 = 0.072$ that results from comparing the combined participants' weighted values for storms versus no storms. Moreover, these comparative measures of vulnerability can likewise be applied to each of the four Community Profile pillars, as well as for individual indicator values. This information is useful in the analysis of community preparedness.

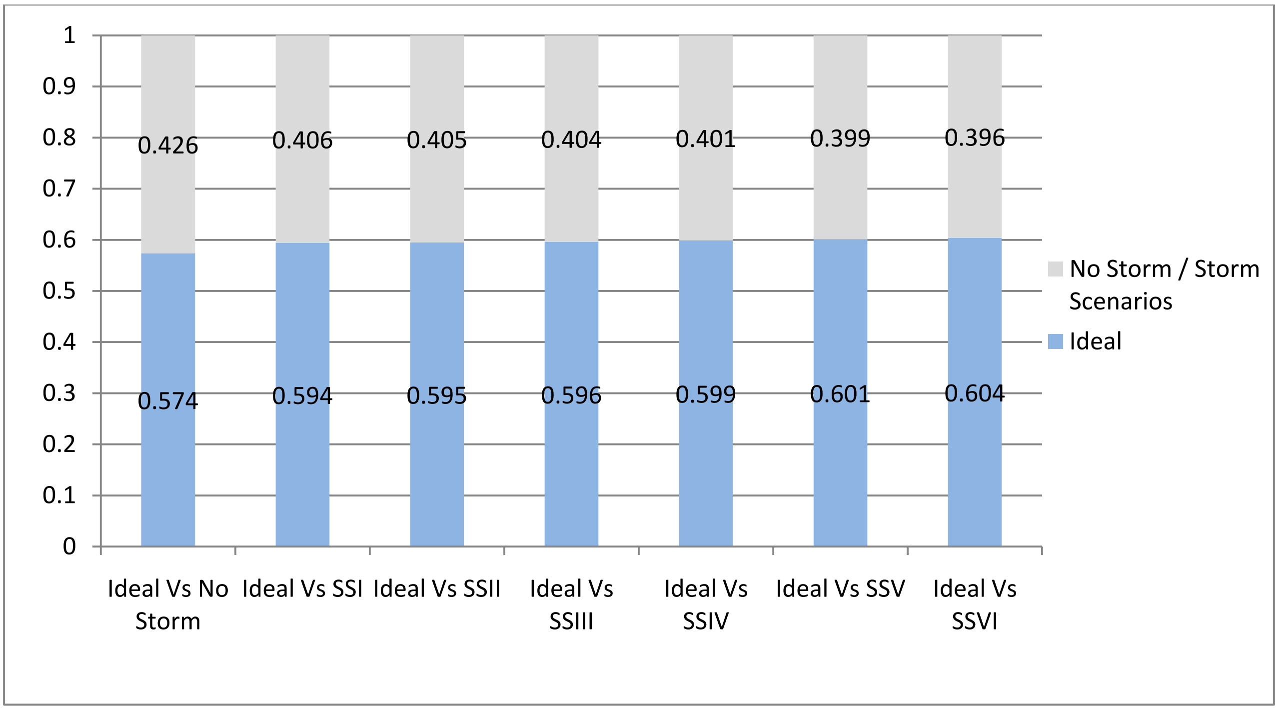


Figure 4.13. Comparison of "Ideal" scenario with "No Storm" and all six scenarios impacts

If vulnerability is analyzed as the difference between "Ideal" state and each scenario weighted utility values, then such comparison results in a larger difference between these two values - compared to the "No Storm" comparative results and therefore suggests a higher valuation of "vulnerability" of the community. However the trend is the same as discussed in the previous paragraph, in a sense that as the Storm Scenario's intensity increases, the community becomes measurably more vulnerable. For example, for Storm Scenario VI versus the Ideal indicator set for Isle Madame, the vulnerability is: $V^{VI}(u) = 0.604 - 0.396 = 0.208$ that results from comparing the combined participants' weighted values for storms versus no storms.

The concepts of resilience and adaptive capacity require the introduction of adaptation strategies as the means of comparing their effectiveness versus no action. For this broader case of Isle Madame, the notion of adaptation strategies are not well-defined for the archipelago as a whole. These measures of resilience and adaptive capacity are further developed in Chapter 5 where different adaptation strategies for the case of the Little Anse breakwater are developed and evaluated.

5. Adaptation strategies – the case of Little Anse breakwater

Based upon the methods applied in the previous chapter, the case of the community of Little Anse on Isle Madame is presented here. This case evaluates a set of specific adaptation options for the community and illustrates the multicriteria and multi-participant perspectives of this research applied to this specific case as an example of how adaptation strategies can be analysed and decision support provided.

5.1. Introduction

The community of Little Anse is located at the southestern end of Petit de Grat Island. Figure 5.1 depicts the location of the Little Anse community (noted by the arrow).

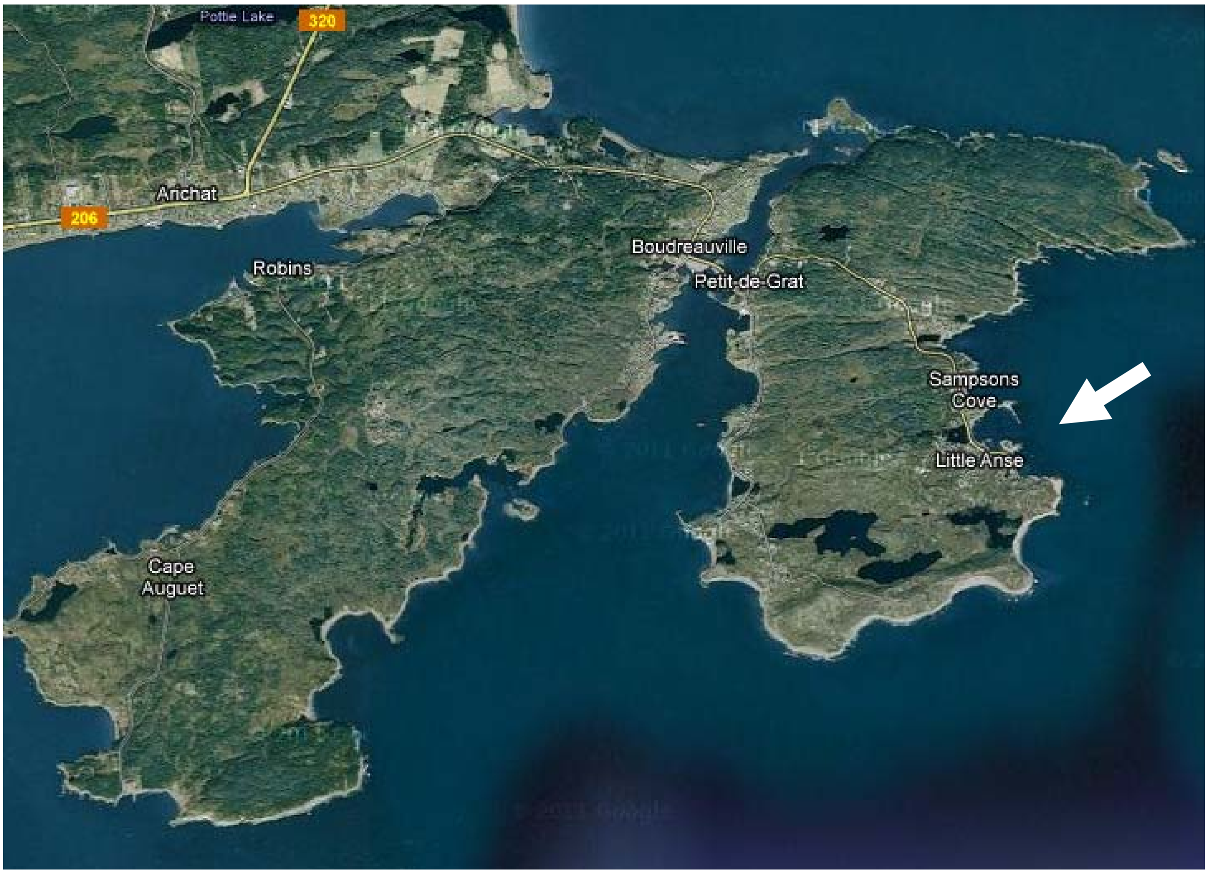


Figure 5.1. The location of the community of Little Anse on Petit de Grat Island

(Source: Google Earth, 2011)

The Little Anse harbour and the community itself are regularly flooded as the result of storms from the seaward side. The existing breakwater, situated at the Little Anse harbour is no longer capable of containing the situation. The existing breakwater is in an inferior state and is no longer providing the desired level of protection from storms. The breakwater structure allows a great amount of wave energy to get through, resulting in undesirable wave agitations in the boat mooring areas as well as allowing debris and wave damage to occur on the low lying road in the lee of breakwater. The situation of the existing breakwater structure is such that the entrance channel of the harbour is exposed to major storm events. Figure 5.2 depicts a close-up view of the Little Anse Harbour and the current breakwater circled in red.

The deficiencies of the existing breakwater are dependent on various reasons such as displaced armour stone, concrete and stone quality, and lack of maintenance. Due to these deficiencies and the ineffectiveness of the existing breakwater to adequately protect the community from major storm events, the introduction of a set of alternatives to the breakwater is inevitable for the protection of the Little Anse community.

Figure 5.2. The location of the existing breakwater in Little Anse Harbour

(Source: Google Earth, 2011)

As mentioned above, the Little Anse community is vulnerable to storm surges. These events result in floods which close the seaside road cutting off the inhabitants to the south, and soaking properties, basements, and damaging houses and out-buildings as important parts of the community’s resources. In order to identify which resources are most vulnerable to these storm surge events, ArcGIS was used to simulate flood scenarios on Little Anse. As mentioned in section 3.5 above, the indicator used is the “Maximum Observed Water level” (MOWL) at the time of storms. Also in section 3.5, these maximum water levels were estimated to range between 1m and just over 2 m for Isle Madame (Table 3.5). Due to the lack of quality of the DEM map of Isle Madame (1:50,000 scale, Source: NS Data Locator – GeoNova, 2011), simulation scenarios are restricted to integer MOWL values (1 or 2 meters) only. Therefore water level scenarios of 1m and 2m are adopted for the analysis of the case of the Little Anse community breakwater. Figure 5.3 depicts the ArcGIS map of Little Anse prior to applying the simulated flooding and storm surge scenarios.

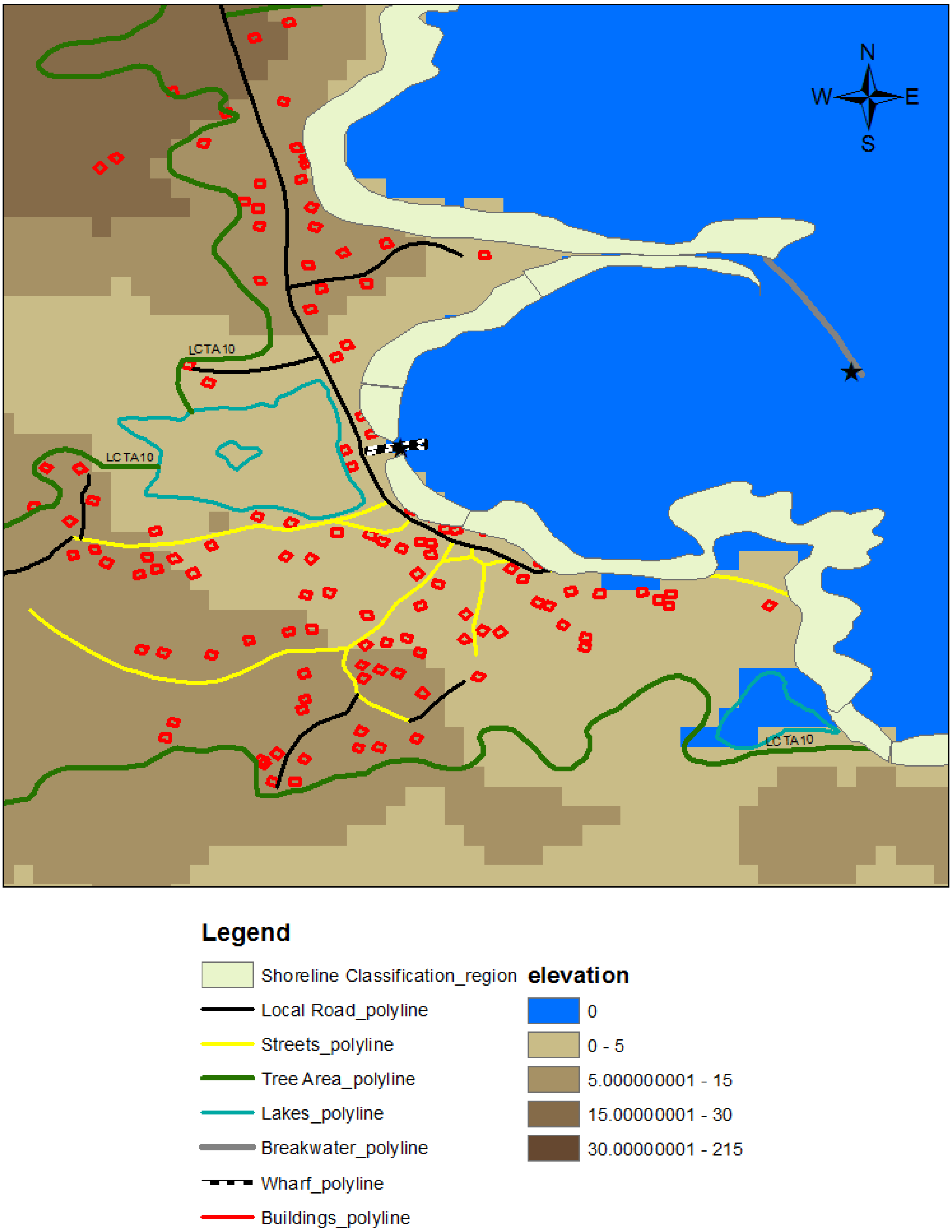


Figure 5.3. ArcGIS map of Little Anse community

(Source: GeoNova, 2011)

The 1 m and 2 m water levels are illustrated by the respective "buffer lines" in the Figures 5.4 and 5.5. The buffer line situates the limit of the flooding scenario based on the community elevation data provided.

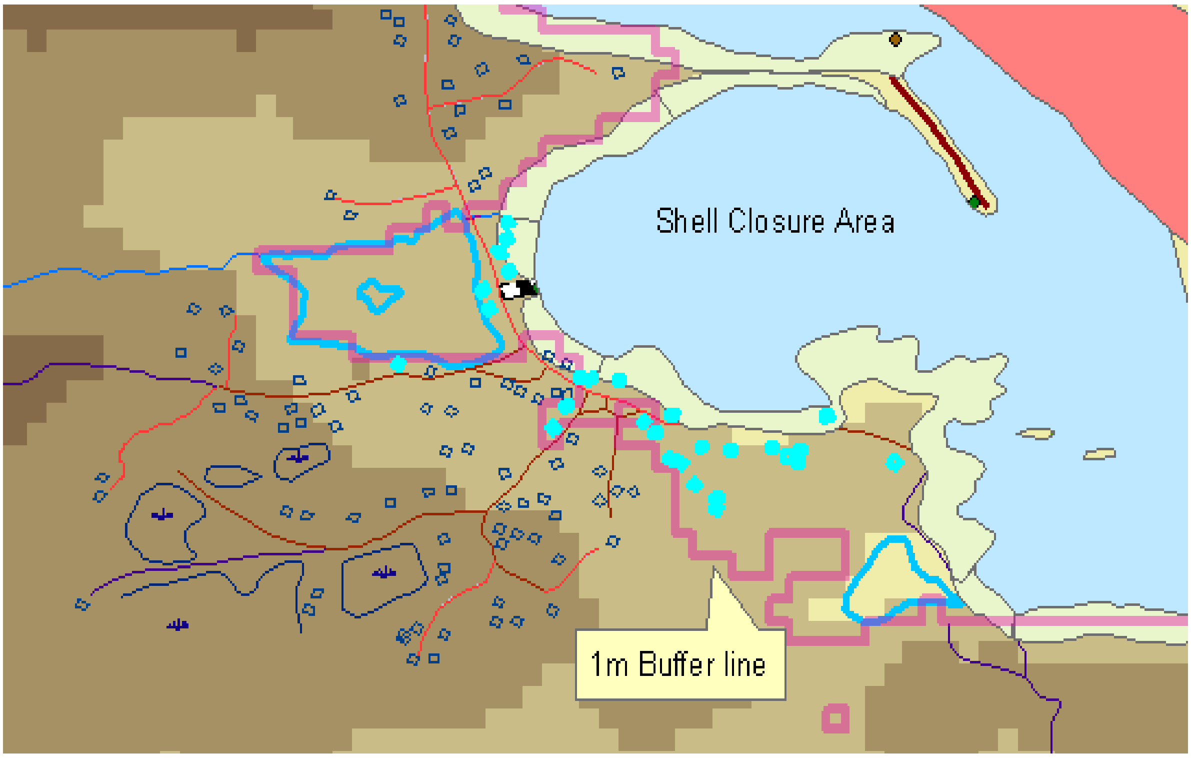


Figure 5.4. Little Anse, 1 meter flooding buffer line

(Source: GeoNova, 2011)

The 1m flood lines shown in Figure 5.4 implies that properties, roads, and the wharf, on the seaward side are flooded by the 1m storm maximum observed water level. These elements of the community are therefore "at risk" from the storm surge and likely are damaged as a consequence of being on the seaward side of the buffer line.

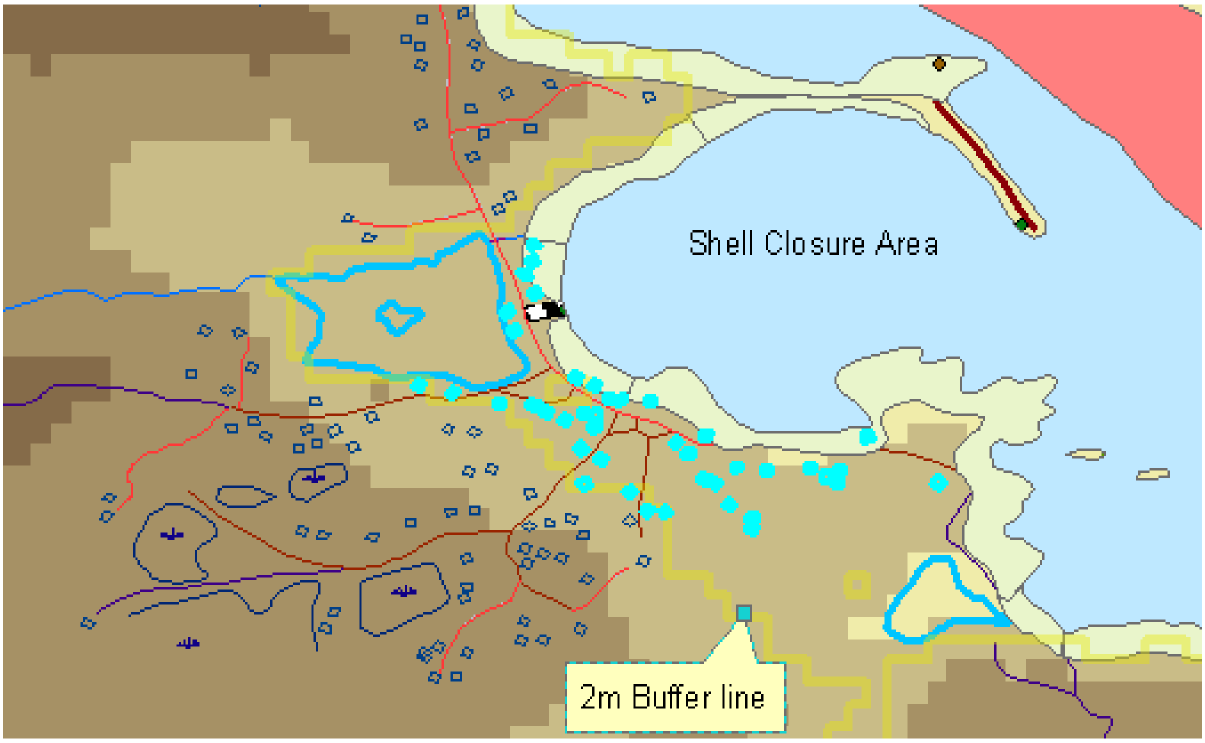


Figure 5.5. Little Anse, 2 meter flooding buffer line

(Source: GeoNova, 2011)

In comparison with Figure 5.4, Figure 5.5 shows the higher 2m buffer line. As it is obvious from both figures, there is a difference of what is included on the seaward (flooded) side between two scenarios. The differences noted and captured here in terms of community resources on the seaward side illustrate the differences in “at risk” and estimated damages from these water levels. The buffer lines differences are the result of storms of increasing severity. The estimated damages are determinable as the basis for better preparation against such events through developing adaptation strategies. These are analysed using the multicriteria decision analysis framework of the AHP model presented above.

Based on the information provided by Figures 5.4 to 5.5 and the estimated damages from the maximum observed water levels from the Storm Scenarios, the AHP hierarchy of Table 4.1 for Isle Madame is modified for the case of Little Anse and presented in Table 5.1 below. The main pillars of the hierarchy of Table 5.1 have been extracted from the general Community Profile template (Appendix A) and the indicators of the Data Grid to describe the community have been chosen based on the specific context of Little Anse Community versus the larger Isle Madame framework of table 4.1.

Table 5.1. AHP hierarchy of the Little Anse community

- Goal:Adaptation of Little Anse community to storm surge events
  - Environment
    - Land Use
      - Residential Land
      - Lake
      - Trees
  - Economic
    - Built Environment
      - Houses
      - Buildings
    - Public Works
      - Roads
      - Wharfs
      - Wells
    - Adaptation cost
  - Cultural
    - Community Centre
    - Church grounds
  - Social
    - Income loss
    - Safety at risk (people over 60)
    - Safety at risk (people under 14)

The following sections identify the assets (total and at risk) of Little Anse in the face of the modeled Storm Scenarios. These are required for the Data Grid indicator values of the AHP model for Little Anse. The AHP model is used to determine the vulnerability, resilience, and adaptive capacity measures of Little Anse including evaluating the adaptive strategies with respect to the breakwater.

5.2. Total assets and assets at risk estimations

The procedure followed here is based on the framework presented in section 3.1 above for determining the community asset position. In this section, Total Assets, Assets at Risk (from Storm Scenarios) and Total Estimated Damages as the result of each Storm Scenario I through VI are calculated for the case of Little Anse. ArcGIS is used to simulate the impact of each scenario on the resources of the community by determining the buffer line and capturing those community resources that are on the seaward side of the line.

Table 5.2 summarises the Total Assets evaluations for Little Anse. The basis for these indicator evaluations are presented below and in the following paragraphs.

Table 5.2. Total assets (TA) estimations for the Little Anse community

Indicator	Number/Length/Area of assets	Total monetary value of assets ($)
Houses	100	$3,175,000
Buildings	8	$64,000
Roads	2093 meters	$2,272,998
Wharf	30 meters	$25,000
Wells	45	$427,500
Breakwater	1	$1,350,000
Residential Land	0.155411 sq km	$1,864,932
Community Centre	1	$242,700
Church grounds	1	$800,000
Water Bodies	19221 sq m	$19,221
Trees	200,000 sq m	$54, 800
Income	100 households	$3,497,000
No. People over 60 yrs of age	67	-
No. People under 14 yrs of age	33	-

The next step after evaluating the total assets of the community is to measure the "assets at risk" from storms. In order to do so, what is and what is not impacted as the result of each Storm Scenario in identified using the mapping of the buffer lines. From the ArcGIS simulation results for the cases of 1 m and 2 m MOWL, the Storm Scenarios I (1 m MOWL) and V (2 m MOWL) values are defined (Figures 5.4 and 5.5, respectively). The remaining Storm Scenario values are interpolated and extrapolated based on these two Storm Scenario values for I and V. Table 5.3 summarizes these impacts followed up by a discussion on the impacts.

Table 5.3. Impacts of water level scenarios on community resources (Number/Length/Area flooded)

	Storm Scenario I	Storm Scenario II	Storm Scenario III	Storm Scenario IV	Storm Scenario V	Storm Scenario VI
Houses	21	25	29	32	36	40
Buildings	8	8	8	8	8	8
Roads	558m	649m	740m	831m	923m	1014m
Wharf	100% flooded	100% flooded	100% flooded	100% flooded	100% flooded	100% flooded
Wells	10	12	14	16	18	20
Residential Land	22243 sq m	27639 sq m	33035 sq m	38431 sq m	43826 sq m	49222 sq m
Water Bodies	19221 sq m	19221 sq m	19221 sq m	19221 sq m	19221 sq m	19221 sq m
Trees	2000 sq m	2425 sq m	2850 sq m	3275 sq m	3700 sq m	4125 sq m
Community centre	Not impacted	Not impacted	Not impacted	Not impacted	Not impacted	Not impacted
Income at risk	$13,660	$20,490	$27,320	$34,150	$40,980	$47,810
People at risk of flooding (over 60)	14	16	18	20	24	27
People at risk of flooding (under 14)	7	8	9	10	12	14

In the paragraphs below the estimated value of Little Anse Assets at Risk by Storm Scenarios I to VI apply the approach of McCulloch et al (2002) and Pakdel (2011). Values of Assets at Risk are different from Total Damages to those assets in that not necessarily all the values of a vulnerable “at risk” asset is damaged as the result of different Storm Scenarios. For example, only in extreme cases can we imagine a house or a road get destroyed completely to an extent that repair is no longer possible. Therefore, as discussed in section 3.1, these two terms are distinguished: (i) Assets at Risk and (ii) Damages for a given Storm Scenario. For comparison purposes, both values (asset values at risk) and its subsequent (damages) are estimated below by major element in the AHP hierarchy.

Houses

The question being asked in this section is that “what is the at risk value of the flooded houses and buildings in Little Anse?” In order to answer this question, there is a need to know: (1) the average value of a house in Little Anse; and (2) the number of houses flooded by the Storm Scenario, i.e., on the seaward side of the buffer line.

In order to estimate the average values of houses this researcher has used real estate values (MLS, 2010) for Little Anse, as well as valuations from the Property Valuation Service Corporation (PVSC) database. A value of $31,750 (Canadian Dollars) is estimated for a house (regardless of its type) in Little Anse in 2010.

Table 5.4 records the number of houses and buildings impacted as the result of each Storm Scenario. The assets at risk estimations for houses of Little Anse for 1m and 2 m water levels are presented in Table 5.4.

Table 5.4. Assets at risk estimations for Little Anse's houses

Storm Scenario	Number of houses flooded	Total cost at risk ($CDN)
I	21	$666,750
II	25	793,750
III	29	920,750
IV	32	1,016,000
V	36	1,143,000
VI	40	1,270,000

Buildings

These are non residential properties along the shoreline. With the help of Google Map (http://maps.google.ca/) eight buildings were identified along the shoreline. The value of each building property is assumed to be $8,000 dollars (CDN) which gives the total asset at risk value of $64,000 dollars (CDN).

Roads

The question here is "what is the asset at risk value of flooded roads?" In order to answer this question it is required to know: (1) the length of the flooded road; and (2) the cost of constructing a road.

Road construction cost estimations are provided by the database of Florida Department of Transportation (FDT, 2010). The FDT database categorizes generic costs based on model (rural, suburban and urban) and based on the type of road. This detailed categorization helps derive the closest type of road to existing roads at Little Anse. Cost of construction per meter is estimated at $1,086 CDN. At the time of this research, one US dollar is traded at 1.02 Canadian dollars. Table 5.5 summarizes the assets at risk estimations for the roads of Little Anse.

Table 5.5. Assets at risk estimations for Little Anse's roads

Storm Scenario	Length of the roads flooded (meters)	Total cost at risk ($CDN)
I	558	$605,988
II	649	$706,761
III	740	$803,640
IV	831	$902,244
V	923	$1,002,378
VI	1014	$1,101,204

Wharf

There is one wooden wharf located at little Anse community. Like many other construction projects this cost varies based on the type and quantity of material needed and labour costs. The cost of constructing a similar wooden wharf per linear foot is estimated at an average of CDN $250 for labour and materials. This evaluation is highly subjective and was devised due to the lack of data with the hope that future research can utilize an engineering input toward such estimations. Based on Table 5.3, the Little Anse wharf gets completely flooded and damaged as the result of all water levels surges from the Storm Scenarios. The asset at risk estimation for the Little Anse wharf is summarized in Table 5.6.

Table 5.6. Assets at risk estimations for Little Anse's wharf

Storm Scenario	Length of the Wharf (meter)	Cost of constructing per meter ($CDN)	Total cost at risk ($CDN)
All	30	$833.33	$25,000

Wells

As the result of flooding and storm surge, wells can be salinized by seawater and contaminated to a point of uselessness of fresh water supply to homes. Although this is not always the case, in some cases, contaminated water can be pumped out from the well in order to restore the freshwater. In this research, for the purpose of estimating damages and assets at risk, the costs of reconstituting water well in the case of flooding in the seaward side of the buffer zone establishes the value of the asset. However, it may also be argued that the value of a well is equal to the value of the freshwater it provides to a household. Due to the difficulty in estimating how much water would be contaminated and what impacts this would have and furthermore how much pumping and test/retest is required to restore the freshwater, the asset value is estimated as the cost of constructing the water well. If the well is contaminated to a point that makes a well useless, constructing a new well may be necessary.

The cost of well construction depends upon how deep one has to drill to reach the water table, how much casing is required, and labour/contractor and equipment rental fees. Construction costs of a water well is estimated at between $7,000 and $12,000 CDN (HubPages, 2010; Well Drilling Contractor, 2010). The average value of $9,500 CDN has been considered as the asset value for wells from houses in the seaward side of the buffer zone for this study.

The next question would be how many water wells may get flooded as the result of a storm scenario? In order to answer this question; water well logs of Little Anse community were extracted from well logs database of the Nova Scotia Environment (NSE). At the time of this research there are a total of 45 well logs registered for Little Anse (Nova Scotia Environment, 2010).

As there are approximately 100 residential houses at the community, that gives us an average of one water well per two houses. Table 5.3 above presented the number of houses flooded for each scenario. Table 5.7 summarizes the assets at risk estimation for water wells of Little Anse.

Table 5.7. Assets at risk estimations for Little Anse's water wells

Storm Scenario	Number of wells flooded	Total cost at risk ($ CDN)
I	10	95,000
II	12	114,000
III	14	133,000
IV	16	152,000
V	18	171,000
VI	20	190,000

Breakwater

From Table 5.3 in the case of both 1m and 2m flooding scenarios, the breakwater in Little Anse is completely flooded. In Section 5.4, the state of the existing breakwater and the options for rehabilitating it are discussed. Since the current structure is unable to provide the needed protection to the community of Little Anse, it is not considered as a significant valued asset of the community. Therefore total assets, asset at risk and damage values are not estimated for the existing structure. However in Section 5.4 where we introduce adaptation strategies for the breakwater in the form of improved breakwater structures for which the cost of these adaptation options are included in the asset valuation.

Residential Land

As for the analysis for houses above, real estate registries are used to determine residential land values. First, the previously estimated houses and buildings values are deducted from the real estate values estimates to avoid redundancy in calculations. The assumption here is that half of the overall real estate value is attributed to residential building and half to residential land. The lot size value per square meter was then estimated and averaged from all registries (MLS, 2010; PVSC, 2010). This gives an estimation of $12 CDN per square meter of residential land. Furthermore, based on Figures 5.4 and 5.5, the lot size flooded as the result of each scenario is calculated. The asset at risk estimations for residential lands in Little Anse are summarized in Table 5.8.

Table 5.8. Assets at risk estimations for residential lands in Little Anse

Storm Scenario	**Total land flooded sq m**	**Total cost at risk ($CDN)**
I	22243	$266,916
II	27639	$331,668
III	33035	$396,420
IV	38431	$461,172
V	43826	$525,912
VI	49222	$590,664

As discussed in Chapter 2 (subsection 2.2.4), vulnerability indicators which have social implications are dependent on census demographic data. For the case of Little Anse, census data is obtained from the Statistic Canada (2006) - Richmond county subdivision C – Dissemination Area 12160031. It is noted that this dissemination area encompasses Little Anse as well as surrounding communities.

Water Bodies

The GPI Atlantic Water Quality Accounts (2000) estimate the value of coastal wetlands at approximately $1 per square meter per year. This amount is an estimated measure of their valued contribution to ecosystem. This value has also been used by McCulloch et al (2002) for their at risk value estimations of areas of wetlands. The same value is assigned to the brackish water areas of Little Anse. With an area of 19,221 sq m, the “asset at risk” value is estimated at $19,221 CDN.

Trees

McCulloch et al (2002) establish that forested watershed values derived by GPI Atlantic Water Quality Accounts (2000) use water based values to approximate the value of ecosystem services provided by forests. They break these values into three different contributions of forests to ecosystems, and then sum these up to derive a single value for their “at risk” forested land estimations. These values are comprised of: (1) water filtration - estimated at $2,587 per hectare of forested area per year; (2) air pollutants removal - estimated at $75 per hectare per year; and (3) the value of interception water and control of runoff at $86 hectare per year. These values sum up to $2,748 per hectare of forested area per year which is equivalent to $0.2748 per square meter per year. With the information provided in Table 5.3 on forested area in Little Anse, the estimates of $548, $664, $781, $897, $1,014 and $1,130 CDN per year for Storm Scenarios I to VI, respectively.

Community Centre

There is one community centre in Little Anse community and it’s at risk value has been estimated by the use of Property Valuation Service Corporation database (PVSC, 2010) as $242,700.

Church Grounds

It is not easy to estimate a value for such property since apart from its real estate value it also carries a higher sentimental value for the people of the community. Therefore, with these difficulties at hand, a value of $800,000 dollars is considered for this property emphasizing that it should be valued more than a typical property in the community as a cultural asset

Income at risk

The main argument here is that, as the result of severe storms, the community daily activities are interrupted and therefore for the course of such an event they incur losses to income from the inconvenience of restricted road access and travel to work, or emergency care requirements. To estimate community income loss from storms, the census data is used to determine: (1) how many households are affected? (2) what is the median income of a household in Little Anse? and (3) how long does each Storm Scenario persist?

As discussed in previous paragraphs, the main road of Little Anse regularly floods during each storm scenario due to the failure of the breakwater. Any extensive damage to this road - being the only main road into and out of the community – implies that community members are isolated from outside during the main road cut-off. This isolation is assumed to disrupt the daily income earning lives of the community.

It is also assumed that in the course of a storm, the road is inaccessible and only after the storm proper arrangements can it be made accessible again.

The median income of private households in Little Anse is estimated at $34,970 per year (Statistic Canada (2006) - Richmond county subdivision C – Dissemination area 12160031).

Thus, the total yearly income of the Little Anse population is:

*Median income of private households (2006 Census) * Number of Households in Little Anse = $34,970 * 100 = $ 3,497,000*

The daily loss of income of the Little Anse population is:

Total yearly income of Little Anse population / Number of working days in fiscal year = $3,497,000 / 256 = $ 13,660 / day

where the working days in a fiscal year is assumed to be 256 days.

The duration of storms was estimated by the HURDAT files for historical Isle Madame related storms (Appendix C).Without sufficient data on historical storms and their impacts, these set of estimations can be considered as a starting point to model short term impacts of storms on community's resources. Storm Scenario duration is estimated at 1, 1.5, 2, 2.5, 3 and 3.5 days for Storm Scenarios I through VI respectively.

The estimated loss of income by Little Anse community members is summarized in Table 5.9.

Table 5.9. Loss of income estimations for Little Anse's population

Storm Scenario	Duration of storm (days)	Total Loss of income in the course of the storm ($CDN)
I	1	$13,660
II	1.5	$20,490
III	2	$27,320
IV	2.5	$34,150
V	3	$40,980
VI	3.5	$47,810

Safely at risk

This indicator reflects the vulnerability of that portion of the population that are over 60 years of age and under 14 years of age and susceptible to health care requirements over the course of the storm that may be problematic in the case of isolation caused by the storm. From (Statistic Canada (2006) - Richmond county subdivision C - Dissemination area 12160031) it is noted that for Little Anse and the surrounding communities:

Population over 60 (male and female) = 275

Population under 14 (male and female) = 115

Total number of private households = 385

Households / people over 60 ratio = Number of DA households / Population of people over 60 = 1.4

Households / people under 14 ratio = Number of DA households / Population of people under 14 = 3.34

Therefore, for Little Anse proper, it is assumed (as per the entire Dissemination Area statistics) approximately every 1.5 household includes 1 community member over sixty years of age, and for every 3 households there is 1 citizen under the age of 14. Table 5.10 summarises the percentage of the population over 60 of age at risk and under the age of 14.

Table 5.10. Safety at risk estimations

Storm Scenario	Number of houses flooded (private buildings subtracted)	Estimated Number of people over 60 at risk	Estiamted Number of people under 14 at risk
I	21	14	7
II	25	16	8
III	29	18	9
IV	32	20	10
V	36	24	12
VI	40	27	14

5.3. Storm damage estimations

After evaluating the Total Assets of the community (Table 5.2) and the follow up for Total Assets at Risk (Tables 5.3 to 5.11) as the result of each Storm Scenario, the estimated actual damages can be determined. This estimation is necessary since in reality only a portion of the community's assets are damaged and therefore damages should be a fraction of the Total Assets at Risk evaluations. The procedure followed here for storm damage estimation is based on the framework presented in section 3.1. Moreover this task is made difficult since there are no storm damage reports available for the community of Little Anse. In fact, there are no systematic and community-based storm damage estimates for any storm situations, typical community storm estimates are most often reported by the media or on the basis of partial impacts only including insurance claims. The lack of reported storm damage data obliges us to estimate the damages for the case of Little Anse. In the following paragraphs the damages of six scenarios are estimated.

Houses

In subsection 5.3 the Asset at Risk estimations for households and buildings were presented. In this section, the probable damage costs to households and buildings as the result of each storm surge and maximum observed water level from the Storm Scenarios I through VI are estimated. According to Canada Mortgage and Housing Corporation (CMHC, 2010), one of the most frequent damages to any building as the result of flooding, is damage to standing water in basements. According to the same source (CMHC, 2010); the average cost per flooding incident to a basement is between $3,000 and $5,000 CDN (average of $4,000 CDN). However, as the Storm Scenario's intensity increases from I to VI, an increase in damages is expected. Therefore, the initial $4,000 dollars is adjusted to incorporate the increase in storm intensity. Without having any historical damage reports this amount is considered to be an additional $1,000 CDN per Storm Scenario increase. Based on these evaluations in Table 5.3, estimated damage to households by Storm Scenario for Little Anse is presented in Table 5.11).

Table 5.11. Damage estimations for Little Anse's houses

Storm Scenario	Number of houses flooded	Damage per House ($CDN)	Total damage ($CDN)
I	21	$4000	$84,000
II	25	$5000	$125,000
III	29	$6000	$174,000
IV	32	$7000	$224,000
V	36	$8000	$288,000
VI	40	$9000	$360,000

Buildings

Damage to each building is assumed to be $1,000 with $500 increase in damage to compensate for increasing intensity of the six storm scenarios. This is assumed to be a high value since these structures (fish houses, garages, barns, out buildings) normally do not have strong enforcements. This gives us damage values based on replacement values of $8,000; $12,000; $16,000; $24,000; $28,000 and $32,000 for Storm Scenarios I to VI respectively.

Roads

What is the damage to the flooded roods? In order to answer this question it is necessary need to know: (1) the length of the flooded roads; and (2) the estimated cost of repairing a damaged road by length. The cost of repairing a road similar to the roads of Little Anse has been estimated with aid of Florida Department of Transportation database (FDT, 2010). As mentioned before, the FDT database categorizes generic costs based on model (rural, suburban and urban) and based on the type of road. This detailed categorization helps us to derive the closest type of road to existing roads at Little Anse. Table 5.12 summarizes the damage costs to roads. The cost of repairing the road per meter is estimated at $264 CDN. An increase of $50 CDN per meter is assumed to compensate for the increasing intensity of storms. Damage estimations have been adjusted to Canadian dollars (at the time of this research one US dollar is traded at 1.02 Canadian dollars).

Table 5.12. Damage estimations for Little Anse's roads

Storm Scenario	Length of the roads flooded (meter)	Cost of repairing per meter ($CDN)	Damage ($CDN)
I	558	$264	$147,312
II	649	$314	$203,786
III	740	$364	$269,360
IV	831	$414	$344034
V	923	$464	$428,272
VI	1014	$514	$521,196

Wharf

Wharf damage estimation cannot be properly achieved without an engineering input. Nevertheless, an estimated base (Storm Scenario I) of 20% of total wharf value is assumed to be damaged and in need of repair relative to the total value of the asset. An assumed 2.5% increase in damage is made to compensate for the increasing intensity of storm scenarios. This evaluation is highly subjective and was devised due to the lack of data with the hope that future research can utilize an engineering input toward such estimations. Table 5.13 summarises damage estimations to the wooden wharf of Little Anse.

Table 5.13. Damage estimations for Little Anse's wharf

Storm Scenario	**Percentage of Asset damaged (%)**	**Damage estimations ($CDN)**
I	20%	$5000
II	22.5%	$5625
III	25%	$6250
IV	27.5%	$6875
V	30%	$7500
VI	32.5%	$8125

Wells

Well construction costs were used to determine asset value at risk. Well damages estimates need to consider the impacts of flood on the quality of water. Contamination of drinking water as the result of flooding can have major impact on public health especially to those people who draw their water from wells. Dirty flood seawater can wash up the well's lid and leak inside the system, contaminating the water system.

For those people who draw their drinking water from a private well, intruding seawater can contaminate the source with bacteria or parasites without the owner knowing about it. Flood waters can also be contaminated with chemicals such as automotive fluid, fertilizer, animal wastes and other bacteria living in the ground.

However, it is very difficult to make a connection between contamination and its extent of impact on community's health and its eventual costs, therefore for damage cost estimations how much would it cost to decontaminate the water by means of improvements such as backflow valve needs to be estimated. This can be considered an adaptation strategy to flooding and the cost of such action is taken into account for our storm damage estimations. Backflow valve is used to protect water supplies from pollution and contamination. In this sense it can be considered as a flood proofing devise. The cost of having a plumber install such a devise plus costs of excavation and backfilling are estimated at $500 US Dollars (FEMA, 2008). At the time of this research one US dollar is traded at 1.02 Canadian dollars. Damage cost estimations are presented in table 5.14.

Table 5.14. Damage estimations for Little Anse's water wells

Storm Scenario	Number of wells flooded	Total damage costs ($CDN)
I	10	$5100
II	12	$6120
III	14	$7140
IV	16	$8160
V	18	$9180
VI	20	$10200

Breakwater

In previous section, it was noted that the existing breakwater is not functioning effectively for the community, and therefore, it is not considered as a significant asset. Therefore, damages are not estimated for this current structure.

Residential Land

In previous related section, the residential value at risk was assessed. With respect to actual estimated damages to land,

It is noted that a property is considered to be in a "flood zone" if any part of it falls within the seaward side of the buffer line. Some studies suggest that the proximity of a property to a flood zone lowers its value (Bin et al 2004, Science Daily 2008). Other studies suggest the opposite (Shrubsole et al 1997). Bin et al (2004) suggest a 5.7% drop, while Science Daily (2008) suggests a 7.3% drop in property values situated in flood potential zones. For the purpose of this study, an average of 6% drop in property values is used for the estimations of damages to residential land. Based on Table 5.8 above, the estimated drop in property values are determined as $16,015; $19,900; $23,785; $27,670; $31,555 and $35,440 dollars for Storm Scenarios I to VI respectively.

Water Bodies

Although there are evidence of potential damages to freshwater wetlands (BBC, 2010) such as erosion and loss of habitat, it does not necessarily translate to the case of salt water brackish lakes such as those in Little Anse. Potential damages to such an ecosystem resource require a more scientific study which is beyond the scope of this researcher. Moreover such ecosystems, to some extent, may be resilient to potential damages which should be considered for a more thorough study. For the purpose of this research, the considered damage estimate is a value of 5% of the "asset at risk" value which increases by the same amount to compensate for the intensity of the six storm scenarios. Therefore we have damage estimates of $961; $1,922; $2,883; $3,844; $4,805 and $6,727 for Storm Scenarios I to VI respectively.

Trees

Damage to forested land and trees in general is a common impact during severe storm events. In Chapter 2 (section 2.4) we have provided evidence of such impacts. Among all components of a storm (surges, precipitation, and wind), wind speed has the most contribution to such damages. Historical evidence suggests that high winds have the potential to knock down trees. However, the only way to establish a relationship between wind speed and fallen trees is through historical evidence, which is non-existent for Little Anse. Therefore, an initial damage estimated of 10% to forested land and the considered increase by the same amount to compensate for the increasing intensity of our six storm scenarios. That gives tree damage estimates of: $55, $133, $234, $359, $507 and $678 dollars for Storm Scenarios I to VI respectively.

Community centre

As mentioned above, there is a community centre located in Little Anse. This is the one and only community centre in the area. However this centre is not impacted as the result of our scenarios but is included in this thesis for informative purposes.

Church grounds

There is one church in Little Anse community which gets flooded as the result of our scenarios. In lack of ground for damage estimations for such property we are assuming an arbitrary value of 10% damage to the property and an increase of 5% to compensate for the intensity of storms. Based on our estimation of $800,000 as asset at risk value in section 5.2, the estimated damages are: $80,000; $120,000; $160,000; $200,000; $240,000 and $280,000 dollars for Storm Scenarios I to VI respectively.

Loss of income

In section 5.2, estimated income at risk for the community of Little Anse was determined (table 5.9). The same estimations are used as damages for loss of income to the community.

Safety

While there is no relevant data for Little Anse with respect to storm impacts on vulnerable population members (over 60 and under 14 years of age), for the purpose of this research, these same assets at risk values estimated at subsection 5.2 are used as damages.

Table 5.15 below is based on estimations presented in tables 5.2 to 5.14 and summarises the total assets, assets at risk and damage comparisons for all pillars of the study. Except of safety indicators all values are in dollars. Storm Scenarios II, III, IV and VI have been interpolated and extrapolated based on Storms Scenarios I and V corresponding to the 1m and 2m maximum observed water levels. Total asset values (TA) are provided in table 5.2.

Table 5.15. Summary of assets at risk, damages and new asset state for all indicators

Storm Scenario Community Indicator	I	II	III	IV	V	VI
Houses						
Asset at risk (AR)	**666,750**	793,750	920,750	1,016,000	**1,143,000**	1,270,000
Damages	**84,000**	125,000	174,000	224,000	**288,000**	360,000
New asset state (TA-D (ρ AR))	**3,091,000**	3,075,000	3,059,000	3.047,000	**3,031,000**	3,015,000
Buildings						
Asset at risk (AR)	**64,000**	64,000	64,000	64,000	**64,000**	64,000
Damages	**8,000**	12,000	16,000	24,000	**28,000**	32,000
New asset state (TA-D (ρ AR))	**56,000**	52,000	48,000	40,000	**36,000**	32,000
Roads						
Asset at risk (AR)	**605988**	704814	803640	902466	**1002378**	1101204
Damages	**147312**	203786	269360	344034	**428272**	521196
New asset state (TA-D (ρ AR))	**2125686**	2069212	2003638	1928964	**1844726**	1751802
Wharf						
Asset at risk (AR)	25,000	25,000	25,000	25,000	25,000	25,000

Damages	**5000**	5625	6250	6875	**7500**	8125
New asset state (TA-D (ρ AR))	**20000**	19,375	18,750	18,125	**17,500**	16,875
Wells						
Asset at risk (AR)	**95,000**	114,000	133,000	152,000	**171,000**	190,000
Damages	**5100**	6120	7140	8160	**9180**	10200
New asset state (TA-D (ρ AR))	**422,400**	421,380	420,360	419,340	**418,320**	417,300
Residential Land						
Asset at risk (AR)	**266,916**	331,668	396,420	461,172	**525,912**	590,664
Damages	**16,015**	19,900	23,785	27,670	**31,555**	35,440
New asset state (TA-D (ρ AR))	**1,848,917**	1,845,032	1,841,147	1,837,262	**1,833,377**	1,829,492
Water Bodies						
Asset at risk (AR)	**19,221**	19,221	19,221	19,221	**19,221**	19,221
Damages	**961**	1,922	2,883	3,844	**4,805**	5,766
New asset state (TA-D (ρ AR))	**18,260**	17,299	16,338	15,377	**14,416**	13,455
Trees						
Asset at risk (AR)	**548**	664	781	897	**1,014**	1,130

Damages	**55**	133	234	359	**507**	678
New asset state (TA-D (ρ AR))	**54,745**	54,667	54,566	54,441	**54,293**	54,122
Community Center	Not impacted	Not impacted	Not impacted	Not impacted	Not impacted	Not impacted
Church Grounds						
Asset at risk (AR)	**800,000**	800,000	800,000	800,000	**800,000**	800,000
Damages	**80,000**	120,000	160,000	200,000	**240,000**	280,000
New asset state (TA-D (ρ AR))	**720,000**	680,000	640,000	600,000	**560,000**	480,000
Income						
Asset at risk (AR)	**13,660**	20,490	27,320	34,150	**40,980**	47,810
Damages	**13,660**	20,490	27,320	34,150	**40,980**	47,810
New asset state (TA-D (ρ AR))	**3,483,340**	3,476,510	3,469,680	4,462,850	**3,456,020**	3,449,190
Safety (people over 60)						
Asset at risk (AR)	**21%**	24%	27%	30%	**36%**	40%
Damages	**-**	-	-	-	**-**	-
New asset state (TA-D (ρ AR))	**79%**	76%	73%	70%	**64%**	60%
Safety (People under 14)						

Asset at risk (AR)	**21%**	24%	27%	30%	**36%**	42%
Damages	-	-	-	-	-	-
New asset state (TA-D (ρ AR))	**79%**	76%	73%	70%	**64%**	58%

At the end of this section table 5.16 is presented which summarises the sum of At Risk and Damage values per pillar and per Storm Scenario. These values do not include non monetary estimations, i.e. safety at risk.

Table 5.16. Sum of At Risk and Damage values per pillar

Storm Scenario / Pillar	**I**		**II**		**III**		**IV**		**V**		**VI**	
	At Risk	**Damages**	**At Risk**	**Damages**	**At Risk**	**Damages**	**At Risk**	**Damages**	**At Risk**	**Damages**	**At Risk**	**Damages**
Economic	$1,456,738	$249,412	$1,701,564	$352,531	$1,946,390	$472,750	$2,159,466	$607,069	$2,405,378	$760,952	$2,650,204	$931,521
Environment	$286,685	$17,031	$351,553	$21,955	$416,422	$26,902	$481,290	$31,873	$546,147	$36,867	$611,015	$41,884
Social	$13,660	$13,660	$20,490	$20,490	$27,320	$27,320	$34,150	$34,150	$40,980	$40,980	$47,810	$47,810
Cultural	$800,000	$80,000	$800,000	$120,000	$800,000	$160,000	$800,000	$200,000	$800,000	$240,000	$800,000	$280,000
Total	$2,557,083	$360,103	$2,873,607	$514,976	$3,190,132	$686,972	$3,474,906	$873,092	$3,792,505	$1,078,799	$4,109,029	$1,301,215

It is noted from Table 5.16 that the Economic pillar has the highest At Risk and Damage values in comparison to the other Community Profile pillar values.

5.4. Adaptation strategies

The next step in the development and analysis of adaptation strategies is to consider adaptation options designed to mediate the impacts of severe storms. For the case of Little Anse a set of adaptation strategies are introduced and analyzed in this section. First, an introduction to the current state of Little Anse breakwater is provided. The current state of Little Anse breakwater, new breakwater strategies and their cost estimations have been studied by Baird and Associates (2010). This thesis acknowledges the use of the Baird coastal engineering feasibility study information on the Little Anse breakwater including the development and analysis of alternative breakwater options for the community and the estimated capital costs. These values are indispensible in the evaluation and comparison of these breakwater adaptation options.

The existing breakwater structure was constructed between 1946 and 1948 with an initial 10 tonne of concrete blocks. At a later unknown date, concrete blocks were reinforced with a poured-in-place slab and covered entirely with armour stones (Baird and Associates, 2010). In despite of these reinforcements, in 2011 the existing structure is in a state of disrepair and is no longer providing the desired protection to the community of Little Anse that regularly experiences flooding from storms (The Reporter 2011).

The existing structure allows significant wave energy to pass over, around and through it, resulting in undesirable wave agitation in boat mooring areas and allowing wave and debris damage on the low lying road in lee of the breakwater (Baird and Associates, 2010). The latest reports from the community indicates that not much have been done to change the state of the breakwater or propose any other alternative to the community of Little Anse (The Reporter 2011; The Hawk 2010). Some of the technical deficiencies of the existing breakwater are discussed below.

The orientation of the existing breakwater is in such way that it exposes the harbour entrance to major storm events. Moreover, the armour stones have been displaced throughout time and therefore are no longer providing the desired protection (Baird and Associates, 2010). Because of such displacements the concrete block and slab core is exposed and subject to regular wave attack. This allows waves to propagate over and through this section of the structure. Displacement of armour stones have been attributed to poor stone quality, inadequate stone size and poured-in-place concrete slab (modern designs use filter layers for better wave pressure dissipation) - (Baird and Associates, 2010).

Another reason behind the current state of the breakwater is the lack of maintenance. Because of the high cost of mobilizing equipment and materials (such as armour stones) to the site, coastal structures such as the Little Anse breakwater tend to receive maintenance only when there is a need for substantial overhaul. Maintenance is an important factor in maintaining the integrity and functional capacity of coastal structures. However, there is no evidence of such activity on Little Anse breakwater over the past years (Baird and Associates, 2010).

Dominant wave directions relevant to the location of this study have a major impact on suggested adaptation options. The dominant wave directions are from the east to the south. These are the dominant directions in terms of frequency of occurrence and magnitude. Although large waves originating from the north do occur, they are less frequent (Baird and Associates, 2010).

Current research is considering the net impacts of storm events on the community's assets. With this consideration the frequency of storms from different directions are not considered. This implies that regardless of their origin, if such storms occurred, what damages would they cause? And, if such adaptation strategies were in place at the time, what would be their impacts?

Based on the discussion in Chapter 2 (subsection 2.3.2), adaptation options can be in various forms (e.g., protection of the coastal zone from storms, accommodation of the coastal zone due to storms, and retreat from coastal storms). For this thesis, three such strategies are considered:

1) "Protection" - improved engineered breakwater systems that 'attack' the potential damage impacts of severe storms in order to mitigate the damages.
2) "Accommodation" - building up a new road that directly addresses the impacts of the breakwater failure in order to circumvent these damages;
3) "Retreat" - move a portion of Little Anse households that have been known to be impacted by severe storms in order to eliminate the risk of storm damage; and

The set of specific “engineering” options considered for Little Anse breakwater are discussed below based on the analysis of Baird and Associates (2010). Figures 5.7 to 5.12 depict these alternatives. Based on discussions in section 3.1, and the evaluations presented in subsections 5.2 and 5.3 above, each engineering alternative is introduced along with its potential impact on “assets at risk” and damage estimations as presented in Table 5.14.

Protection 1. Rehabilitation of the existing breakwater: With this alternative the existing breakwater will remain at its current location but will be overhauled to an up to date engineering state (Figure 5.7).

Figure 5.7: Rehabilitating the existing breakwater

Source: Baird and Associates (2010)

In this option, there are cost savings from the possibility of constructing the core breakwater area with the intact material from the existing structure. Table 5.17 summarises the cost estimations for this option.

Table 5.17. Cost estimations for rehabilitation of the existing breakwater

Source: Baird and Associates (2010)

Description	Range	Capital Cost ($, millions)	Soft Cost ($, millions)	Total Cost ($, millions)	Maintenance ($, thousands)
Rehabilitation of the existing BW	Lower Bound	1.1	0.3	1.4	35
	Upper Bound	1.6	0.4	2.0	50
Average				1.7	42.5

The upper bound prices are used to reflect the availability of contactors, fuel costs, competition for stones and weather delays. Lower bound values represent a more ideal condition. “Soft costs” are estimated as following percentages of the capital cost:

- Mobilization and demobilisation: 10%
- Engineering costs: 5%
- Contingency costs: 10%
- Annualized maintenance allowance is estimated at 2.5% per year.

Although the improved breakwater is probably more efficient in containing the waves originating from the east, the south and north opening are still open and therefore it’s likely that those assets exposed to such events still get flooded (Figure 5.8 and 5.9). From these calculations we can see that we do not expect much of a reduced storm impact from deployment of this rehabilitation strategy. The fact that the north and south sides are open makes the impact of such a strategy ineffective.

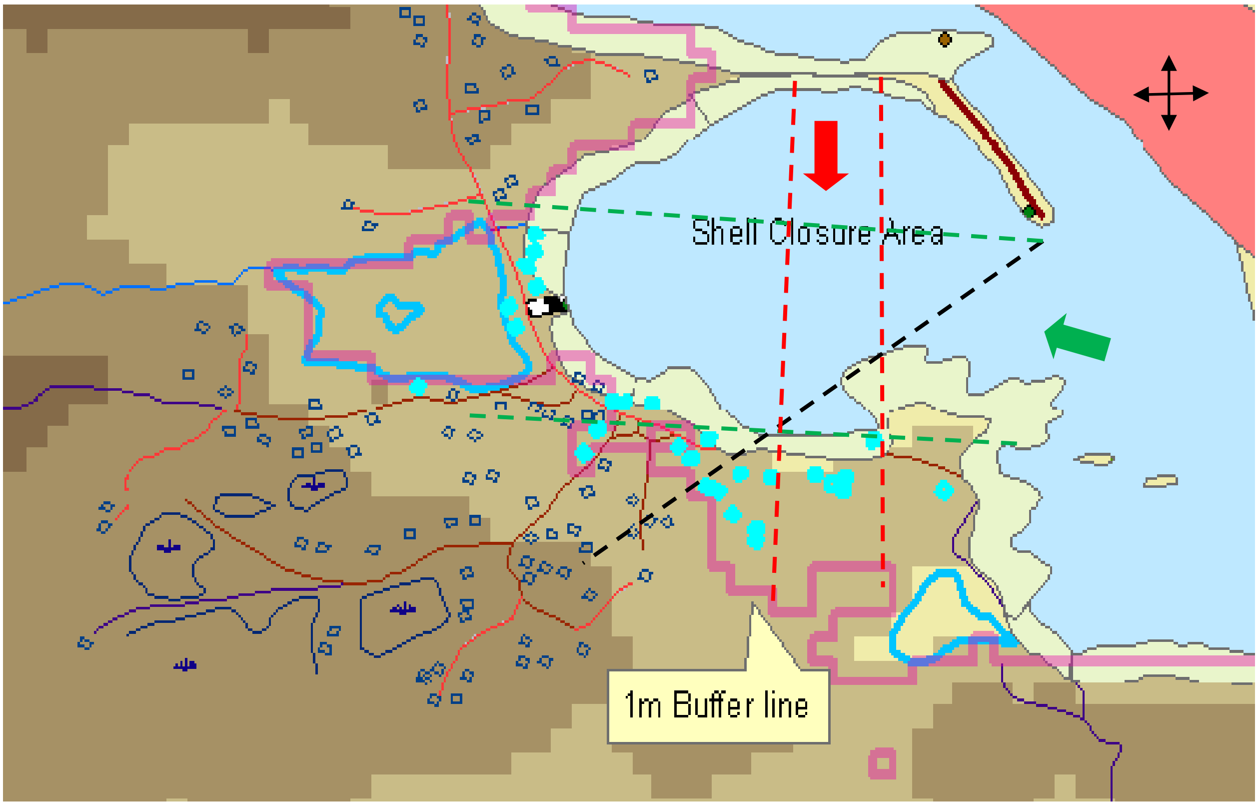


Figure 5.8. Exposed / covered areas as the result of rehabilitating the existing breakwater (1 meter water level)

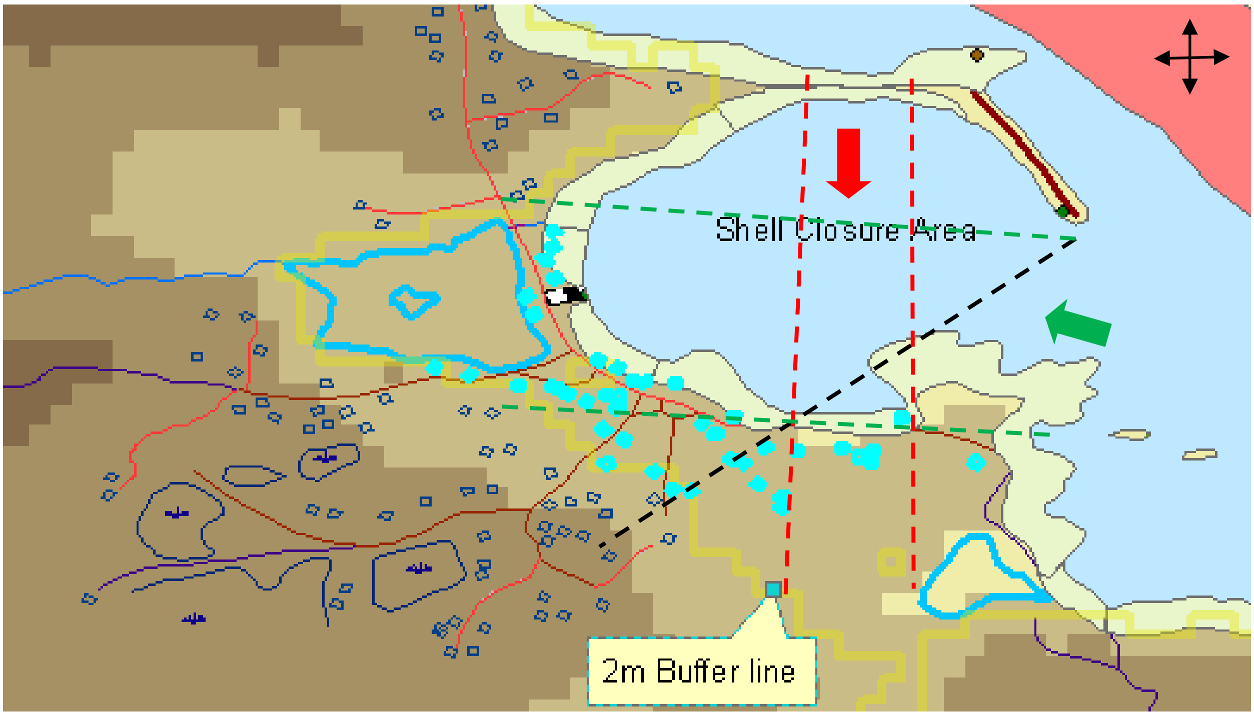


Figure 5.9. Exposed / covered areas as the result of rehabilitating the existing breakwater (2 meter water level)

Overall we expect the following impacts as the result of this strategy:

- Only a few houses will experience diminished flooding, therefore we do not expect a substantial change on the dependant indicators such as impacts on: residential land, wells and safety at risk.
- No changes on the number of projected flooded out buildings since they reside very close to the shoreline. It's assumed that due to the existence of the rehabilitated structure, the initial damage to Buildings of $1,000 is reduced to $800.
- Since the south gap is still open, the Wharf is expected to be 100% flooded, as before. However it is assumed that the initial damage of 20% of capital cost is reduced to 15%.
- The main road is still substantially flooded and therefore the community will not be able to access the road. This leads to the same loss of income as before.
- The impact on environmental resources (water bodies and trees) is less evident and is assumed to be 40% and 5% of total exposed area respectively. A small value is chosen for trees since most of the damages to trees are due to wind and therefore the rehabilitated breakwater does not have much of an impact.
- In the case of church grounds, the impact of the rehabilitation strategy is less evident and assumed to decrease the initial damage to 8%.

Based on estimations in subsections 5.2 and 5.3 and discussions above, Table 5.18 is constructed to record the expected changes after rehabilitating the breakwater compared with total assets, assets at risk and damages. Scenarios II, III, IV and VI have been interpolated and extrapolated based on scenarios I and V. The total asset values (TA) can be accessed from table 5.2.

Table 5.18. Expected changes and comparison between total assets, assets at risk and damages after rehabilitating the existing breakwater

Adaptation cost	**Storm Scenario I**	**Storm Scenario II**	**Storm Scenario III**	**Storm Scenario IV**	**Storm Scenario V**	**Storm Scenario VI**
Before	0	0	0	0	0	0
After	1,700,000	1,700,000	1,700,000	1,700,000	1,700,000	1,700,000
Houses	**Storm Scenario I**	**Storm Scenario II**	**Storm Scenario III**	**Storm Scenario IV**	**Storm Scenario V**	**Storm Scenario VI**
Before	**21**	25	29	32	**36**	40
After	**15**	18	21	24	**29**	33
Asset at risk (AR)	**476,250**	571,500	666,750	762,000	**920,750**	1,047,750
Damages	**60,000**	90,000	126,000	168,000	**232,000**	297,000
New asset state (TA-D (ρ AR))	**3,115,000**	3,085,000	3,049,000	3,007,000	**2,943,000**	2,878,000
Buildings	**Storm Scenario I**	**Storm Scenario II**	**Storm Scenario III**	**Storm Scenario IV**	**Storm Scenario V**	**Storm Scenario VI**
Before	**8**	8	8	8	**8**	8

After	**8**	8	8	8	**8**	8
Asset at risk (AR)	**64,000**	64,000	64,000	64,000	**64,000**	64,000
Damages	**6,400**	10,400	14,400	18,400	**22,400**	26,400
New asset state (TA-D (ρ AR))	**57,600**	53,600	49,600	45,600	**41,600**	37,600
Roads – No Change	**Storm Scenario I**	**Storm Scenario II**	**Storm Scenario III**	**Storm Scenario IV**	**Storm Scenario V**	**Storm Scenario VI**
Before	**558m**	649m	740m	831m	**923m**	1014m
After	**558m**	649m	740m	831m	**923m**	1014m
Wharf	**Storm Scenario I**	**Storm Scenario II**	**Storm Scenario III**	**Storm Scenario IV**	**Storm Scenario V**	**Storm Scenario VI**
Before	100% flooded	100% flooded	100% flooded	100% flooded	100% flooded	100% flooded
After	100% flooded	100% flooded	100% flooded	100% flooded	100% flooded	100% flooded
Asset at risk (AR)	25,000	25,000	25,000	25,000	25,000	25,000
Damages	**3750**	4375	5000	5625	**6250**	6875
New asset state (TA-D (ρ AR))	**21,250**	20,625	20,000	19,375	**18,750**	18,125
Wells	**Storm**	**Storm**	**Storm**	**Storm**	**Storm**	**Storm**

	Scenario I	Scenario II	Scenario III	Scenario IV	Scenario V	Scenario VI
Before	**10**	12	14	16	**18**	20
After	**7**	8	10	12	**14**	16
Asset at risk (AR)	**66500**	76000	95000	114000	**133000**	152000
Damages	**3570**	4080	5100	6120	**7140**	8160
New asset state (TA-D (ρ AR))	**423930**	423420	422400	421380	**420360**	419340
Residential Land	**Storm Scenario I**	**Storm Scenario II**	**Storm Scenario III**	**Storm Scenario IV**	**Storm Scenario V**	**Storm Scenario VI**
Before	**22243 (SQM)**	27639 **(SQM)**	33035 **(SQM)**	38431 **(SQM)**	**43826 (SQM)**	49222 **(SQM)**
After	**20186**	25083	29980	34876	**37785**	42437
Asset at risk (AR)	**242232**	300996	359760	418512	**453420**	509244
Damages	**14534**	18060	21586	25111	**27206**	30555
New asset state (TA-D (ρ AR))	**1850398**	1846872	1843346	1839821	**1837726**	1834377
Water Bodies	**Storm Scenario I**	**Storm Scenario II**	**Storm Scenario III**	**Storm Scenario IV**	**Storm Scenario V**	**Storm Scenario VI**
Before	19221 (SQM)	19221 (SQM)	19221 (SQM)	19221 (SQM)	19221 (SQM)	19221 (SQM)

After	11533	11533	11533	11533	11533	11533
Asset at risk (AR)	11,533	11,533	11,533	11,533	11,533	11,533
Damages	577	1,153	1,730	2,307	2,883	4,037
New asset state (TA-D (ρ AR))	18,644	18,068	17,491	16,914	16,338	15,184
Trees	**Storm Scenario I**	**Storm Scenario II**	**Storm Scenario III**	**Storm Scenario IV**	**Storm Scenario V**	**Storm Scenario VI**
Before	**2000 (SQM)**	2425 (SQM)	2850 (SQM)	3275 (SQM)	**3700** (SQM)	4125 (SQM)
After	**1900**	2303.75	2707.5	3111.25	**3515**	3918.75
Asset at risk (AR)	**521**	631	742	852	**963**	1,074
Damages	**52**	126	223	341	**482**	644
New asset state (TA-D (ρ AR))	**54,748**	54,674	54,577	54,459	**54,318**	54,156
Community Centre	**Storm Scenario I**	**Storm Scenario II**	**Storm Scenario III**	**Storm Scenario IV**	**Storm Scenario V**	**Storm Scenario VI**
	Not Impacted	Not Impacted	Not Impacted	Not Impacted	Not Impacted	Not Impacted
Church Grounds	**Storm Scenario I**	**Storm Scenario II**	**Storm Scenario III**	**Storm Scenario IV**	**Storm Scenario V**	**Storm Scenario VI**

Before	1	1	1	1	1	1
After	1	1	1	1	1	1
Asset at risk (AR)	800,000	800,000	800,000	800,000	800,000	800,000
Damages	64,000	104,000	144,000	184,000	224,000	304,000
New asset state (TA-D (ρ AR))	736,000	696,000	656,000	616,000	576,000	496,000
Income – No Change	**Storm Scenario I**	**Storm Scenario II**	**Storm Scenario III**	**Storm Scenario IV**	**Storm Scenario V**	**Storm Scenario VI**
Before	**13,660**	20,490	27,320	34,150	**40,980**	47,810
After	**13,660**	20,490	27,320	34,150	**40,980**	47,810
Safety (people over 60)	**Storm Scenario I**	**Storm Scenario II**	**Storm Scenario III**	**Storm Scenario IV**	**Storm Scenario V**	**Storm Scenario VI**
Before	**14**	16	18	20	**24**	27
After	**10**	12	14	16	**19**	21
Asset at risk (AR)	**15%**	18%	21%	24%	**28%**	31%
Damages	**-**	-	-	-	**-**	-
New asset state (TA-D (ρ AR))	**85%**	82%	79%	76%	**72%**	69%

Safety (People under 14)	**Storm Scenario I**	**Storm Scenario II**	**Storm Scenario III**	**Storm Scenario IV**	**Storm Scenario V**	**Storm Scenario VI**
Before	**7**	8	9	10	**12**	14
After	**5**	6	7	8	**10**	12
Asset at risk (AR)	**15%**	18%	21%	24%	**30%**	36%
Damages	-	-	-	-	-	-
New asset state (TA-D (ρ AR))	**85%**	82%	79%	76%	**70%**	64%

Protection 2. Close the existing opening and create a new north facing opening: With this option the current state of the existing breakwater is improved by closing the south facing gap, and open a new north faced causeway (Figure 5.10). This option has the potential to protect the community's assets exposed to events originated from east and south. However, it is likely that those assets facing the causeway still get impacted as the result of events originated from the north.

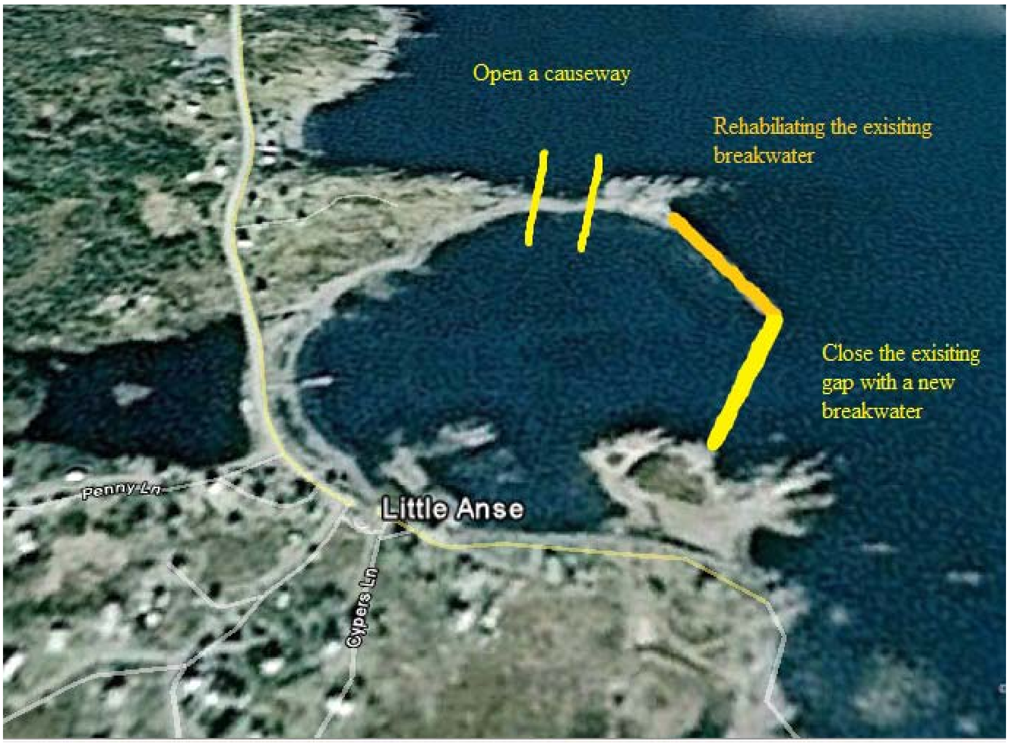


Figure 5.10: Close the existing opening and create a new north facing opening

Source: Baird and Associates (2010)

Cost estimations for this strategy are presented in Table 5.19.

Table 5.19. Cost estimations for closing the existing opening and create a north facing causeway

Source: Baird and Associates (2010)

Description	Range	Capital Cost ($, millions)	Soft Cost ($, millions)	Total Cost ($, millions)	Maintenance ($, thousands)
Rehab of existing BW, Closing the gap and opening a causeway	Lower Bound	3.1	0.8	3.9	97.5
	Upper Bound	4.2	1.1	5.3	132.5
Average				4.6	115

Although this strategy is probably more efficient in containing the waves originating from east and south, the north side is still open. Although large waves originated from the north are less frequent, it's likely that those assets exposed to the north side still get flooded (Figures 5.11 and 5.12). It's noteworthy that the current research considers the net impacts of storm events on the community's assets. With this consideration, the probability of storms from different directions is not considered. This implies that if such storms occurred, what damages would they cause? And, if such adaptation strategies were in place at the time, what would be their impacts?

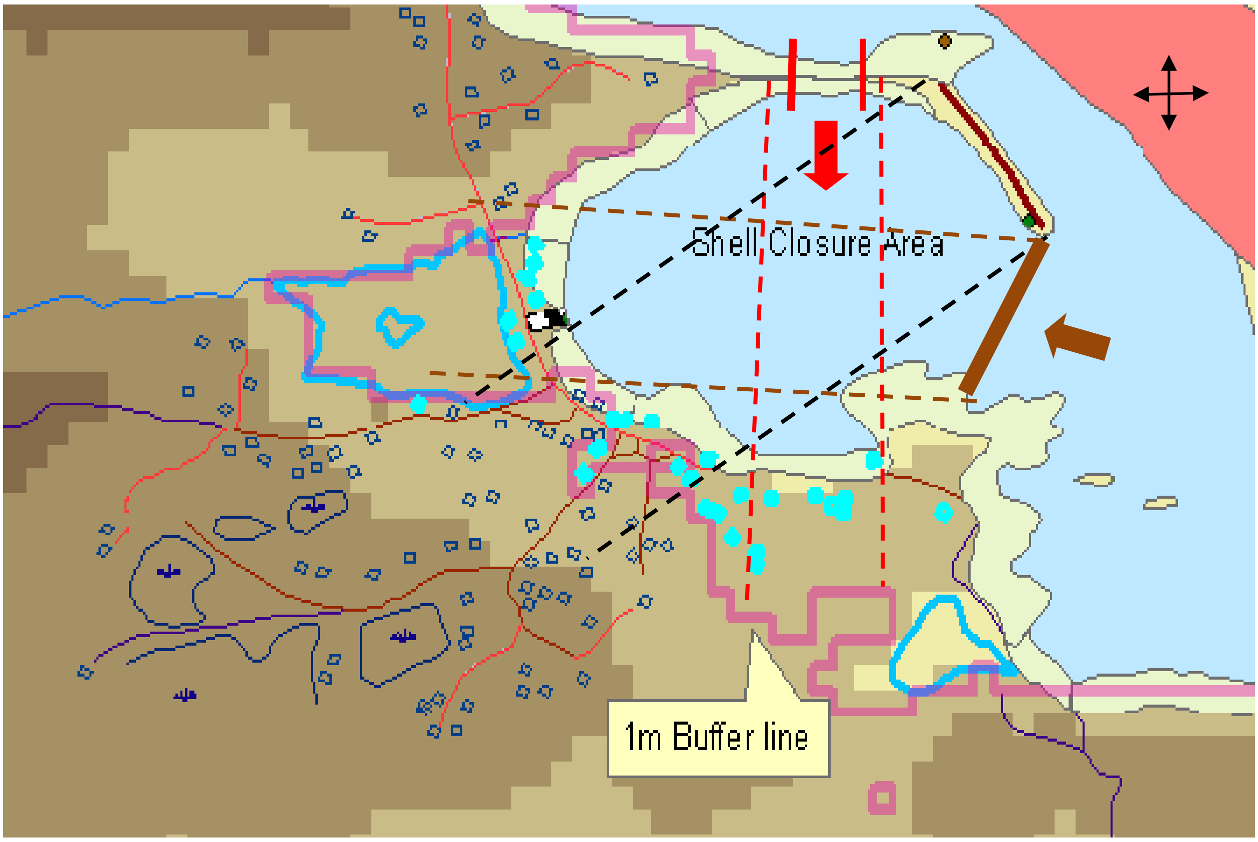


Figure 5.11. Exposed / covered areas as the result of closing the existing opening and creating a new north facing causeway (1 meter water level)

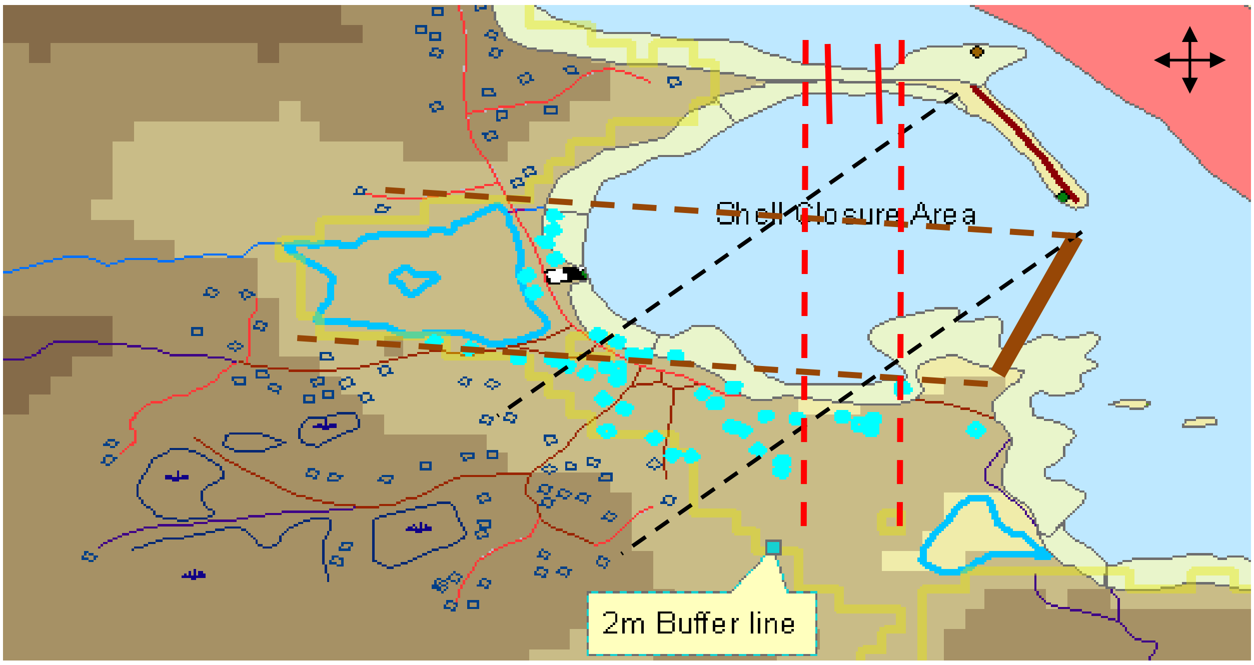


Figure 5.12. Exposed / covered areas as the result of closing the existing opening and creating a new north facing causeway (1 meter water level)

From the above figures, the previous strategy (i.e., only rehabilitating the existing breakwater), this alternative provides more protection to the community. Overall the following changes are expected as the result of this strategy:

- Due to the increased improvement of this strategy over rehabilitation, fewer houses will be flooded. This improvement reflects on the dependant storm impact indicators, i.e., wells, residential land and safety.
- No changes to the number of flooded buildings since they reside very close to the shoreline. However, it is assumed that due to the existence of this structure initial damage of $1,000 are reduced to $600 dollars.
- The wharf is again expected to be 100% flooded since it resides very close to the shoreline. However it is assumed that the initial damage of 20% of capital cost is reduced to 10%.
- Due to the placement of the new breakwater, it is not expected that there will be a major impact on the road - it is assumed that the initial damage of $264 per meter is reduced to $200 per meter. Therefore, it’s very unlikely that the community gets isolated during the storm under this option. Nevertheless we expect a minor impact on community’s income due to the fact that some people may stay home for safety reasons.
- The impact on natural resources (water bodies and trees) is less evident and is assumed to be 65% and 7% of total exposed area respectively. A small value is chosen for trees since most of the damages to trees are due to wind, therefore, a breakwater probably does not have much of an impact.
- In the case of church grounds, the impact of the strategy is less evident and it’s assumed to decrease the initial damage to 6%.

Based on the discussion above, and cost estimations in subsections 5.2 and 5.3, Table 5.20 is constructed for expected changes from this strategy and the comparison between total assets, assets at risk and damages. Storm Scenarios II, III, IV and VI have been interpolated and extrapolated based on Storm Scenarios I and V. The total asset values (TA) are from Table 5.2.

Table 5.20. Expected changes and comparison between total assets, assets at risk and damages after closing the gap and opening a new north facing causeway

Adaptation cost	**Storm Scenario I**	**Storm Scenario II**	**Storm Scenario III**	**Storm Scenario IV**	**Storm Scenario V**	**Storm Scenario VI**
Before	0	0	0	0	0	0
After	4,600,000	4,600,000	4,600,000	4,600,000	4,600,000	4,600,000
Houses	**Storm Scenario I**	**Storm Scenario II**	**Storm Scenario III**	**Storm Scenario IV**	**Storm Scenario V**	**Storm Scenario VI**
Before	**21**	25	29	32	**36**	40
After	**14**	16	18	20	**24**	27
Asset at risk (AR)	**444500**	508000	571500	635000	**762000**	857250
Damages	**56,000**	80,000	108,000	140,000	**192,000**	243,000
New asset state (TA-D (ρ AR))	**3119000**	3095000	3067000	3035000	**2983000**	2932000
Buildings	**Storm Scenario I**	**Storm Scenario II**	**Storm Scenario III**	**Storm Scenario IV**	**Storm Scenario V**	**Storm Scenario VI**
Before	**8**	8	8	8	**8**	8

After	**8**	8	8	8	**8**	8
Asset at risk (AR)	**64,000**	64,000	64,000	64,000	**64,000**	64,000
Damages	**4,800**	8,800	12,800	16,800	**20,800**	24,800
New asset state (TA-D (ρ AR))	**59,200**	55,200	51,200	47,200	**43,200**	39,200
Roads	**Storm Scenario I**	**Storm Scenario II**	**Storm Scenario III**	**Storm Scenario IV**	**Storm Scenario V**	**Storm Scenario VI**
Before	**558m**	649m	740m	831m	**923m**	1014m
After	**558**	649	740	831	**923**	1014
Asset at risk (AR)	**605988**	704814	803640	902466	**1002378**	1101204
Damages	**111600**	162250	269360	290850	**428272**	456300
New asset state (TA-D (ρ AR))	**2161398**	2110748	2003638	1982148	**1844726**	1816698
Wharf	**Storm Scenario I**	**Storm Scenario II**	**Storm Scenario III**	**Storm Scenario IV**	**Storm Scenario V**	**Storm Scenario VI**
Before	100% flooded	100% flooded	100% flooded	100% flooded	100% flooded	100% flooded
After	100% flooded	100% flooded	100% flooded	100% flooded	100% flooded	100% flooded
Asset at risk (AR)	**25000**	25000	25000	25000	**25000**	25000

Damages	**2500**	3125	3750	4375	**5000**	5625
New asset state (TA-D (ρ AR))	**22,500**	21,875	21,250	20,625	**20,000**	19,375
Wells	**Storm Scenario I**	**Storm Scenario II**	**Storm Scenario III**	**Storm Scenario IV**	**Storm Scenario V**	**Storm Scenario VI**
Before	**10**	12	14	16	**18**	20
After	**7**	8	9	10	**12**	13
Asset at risk (AR)	**66500**	76000	85500	95000	**114000**	123500
Damages	**3570**	4080	4590	5100	**6120**	6630
New asset state (TA-D (ρ AR))	**423930**	423420	422910	422400	**421380**	420870
Residential Land	**Storm Scenario I**	**Storm Scenario II**	**Storm Scenario III**	**Storm Scenario IV**	**Storm Scenario V**	**Storm Scenario VI**
Before	**22243 (SQM)**	27639 (SQM)	33035 (SQM)	38431 (SQM)	**43826 (SQM)**	49222 (SQM)
After	**19216**	22351	25486	28621	**31758**	34893
Asset at risk (AR)	**230592**	268212	305832	343452	**381096**	418716
Damages	**13836**	16093	18350	20608	**22866**	25123
New asset state (TA-D (ρ AR))	**1851096**	1848839	1846582	1844324	**1842066**	1839809

Water Bodies	**Storm Scenario I**	**Storm Scenario II**	**Storm Scenario III**	**Storm Scenario IV**	**Storm Scenario V**	**Storm Scenario VI**
Before	19221 (SQM)	19221 (SQM)	19221 (SQM)	19221 (SQM)	19221 (SQM)	19221 (SQM)
After	**6727**	6727	6727	6727	**6727**	6727
Asset at risk (AR)	**6,727**	6,727	6,727	6,727	**6,727**	6,727
Damages	**336**	673	1,009	1,345	**1,682**	2,354
New asset state (TA-D (ρ AR))	**18,885**	18,548	18,212	17,876	**17,539**	16,867
Trees	**Storm Scenario I**	**Storm Scenario II**	**Storm Scenario III**	**Storm Scenario IV**	**Storm Scenario V**	**Storm Scenario VI**
Before	**2000** (SQM)	2425 (SQM)	2850 (SQM)	3275 (SQM)	**3700** (SQM)	4125 (SQM)
After	**1860**	2255.25	2650.5	3045.75	**3441**	3836.25
Asset at risk (AR)	**510**	618	726	835	**943**	1,051
Damages	**51**	124	218	334	**471**	631
New asset state (TA-D (ρ AR))	**54,749**	54,676	54,582	54,466	**54,329**	54,169
Community Centre	**Storm Scenario I**	**Storm Scenario II**	**Storm Scenario III**	**Storm Scenario IV**	**Storm Scenario V**	**Storm Scenario VI**

	Not Impacted	Not Impacted	Not Impacted	Not Impacted	Not Impacted	Not Impacted
Church Grounds	**Storm Scenario I**	**Storm Scenario II**	**Storm Scenario III**	**Storm Scenario IV**	**Storm Scenario V**	**Storm Scenario VI**
Before	1	1	1	1	1	1
After	1	1	1	1	1	1
Asset at risk (AR)	800,000	800,000	800,000	800,000	800,000	800,000
Damages	**48,000**	88,000	128,000	168,000	**208,000**	288,000
New asset state (TA-D (ρ AR))	**752,000**	712,000	672,000	632,000	**592,000**	512,000
Income	**Storm Scenario I**	**Storm Scenario II**	**Storm Scenario III**	**Storm Scenario IV**	**Storm Scenario V**	**Storm Scenario VI**
Before	All the community					
After	**14**	16	18	20	**24**	27
Asset at risk (AR)	**1918**	3288	4932	6850	**9864**	12947
Damages	**1918**	3288	4932	6850	**9864**	12947
New asset state (TA-D (ρ AR))	**3495082**	3493712	3492068	3490150	**3487136**	3484053
Safety (people over 60)	**Storm**	**Storm**	**Storm**	**Storm**	**Storm**	**Storm**

	Scenario I	**Scenario II**	**Scenario III**	**Scenario IV**	**Scenario V**	**Scenario VI**
Before	**14**	16	18	20	**24**	27
After	**9**	11	12	13	**16**	18
Asset at risk (AR)	**13%**	16%	18%	19%	**24%**	27%
Damages	**-**	-	-	-	**-**	-
New asset state (TA-D (ρ AR))	**87%**	84%	82%	81%	**76%**	73%
Safety (People under 14)	**Storm Scenario I**	**Storm Scenario II**	**Storm Scenario III**	**Storm Scenario IV**	**Storm Scenario V**	**Storm Scenario VI**
Before	**7**	8	9	10	**12**	14
After	**5**	5	6	7	**8**	9
Asset at risk (AR)	**15%**	15%	18%	21%	**24%**	27%
Damages	-	-	-	-	-	-
New asset state (TA-D (ρ AR))	**85%**	85%	82%	79%	**76%**	73%

Protection 3 - Create a modified opening with a new breakwater arm extending from the south: This option narrows the current opening in a way that waves would go through a significant energy reduction before they reach the inner harbour area (Figure 5.13). This alternative would also require the rehabilitation of the existing breakwater as well as the new arm.

Figure 5.12: A modified opening with a new breakwater arm extending from the south

Source: Baird and Associates (2010)

Cost estimations for this option are presented in table 5.21.

Table 5.21. Cost estimations for a modified opening with a new breakwater arm extending from the south

Source: Baird and Associates (2010)

Description	Range	Capital Cost ($, millions)	Soft Cost ($, millions)	Total Cost ($, millions)	Maintenance ($, thousands)
modified opening with a new BW arm extending from the south	Lower Bound	3.5	0.9	4.3	107.5
	Upper Bound	4.6	1.2	5.8	145
Average				5.05	126.25

This option can significantly mitigate the surge events originating from the south and east. With the staggered structure in place, waves will be further contained before reaching the shoreline. Therefore we can expect that among all other options this strategy can provide the best protection to community from flooding. However this option is also the most expensive capital cost strategy among all other breakwater engineering alternatives.

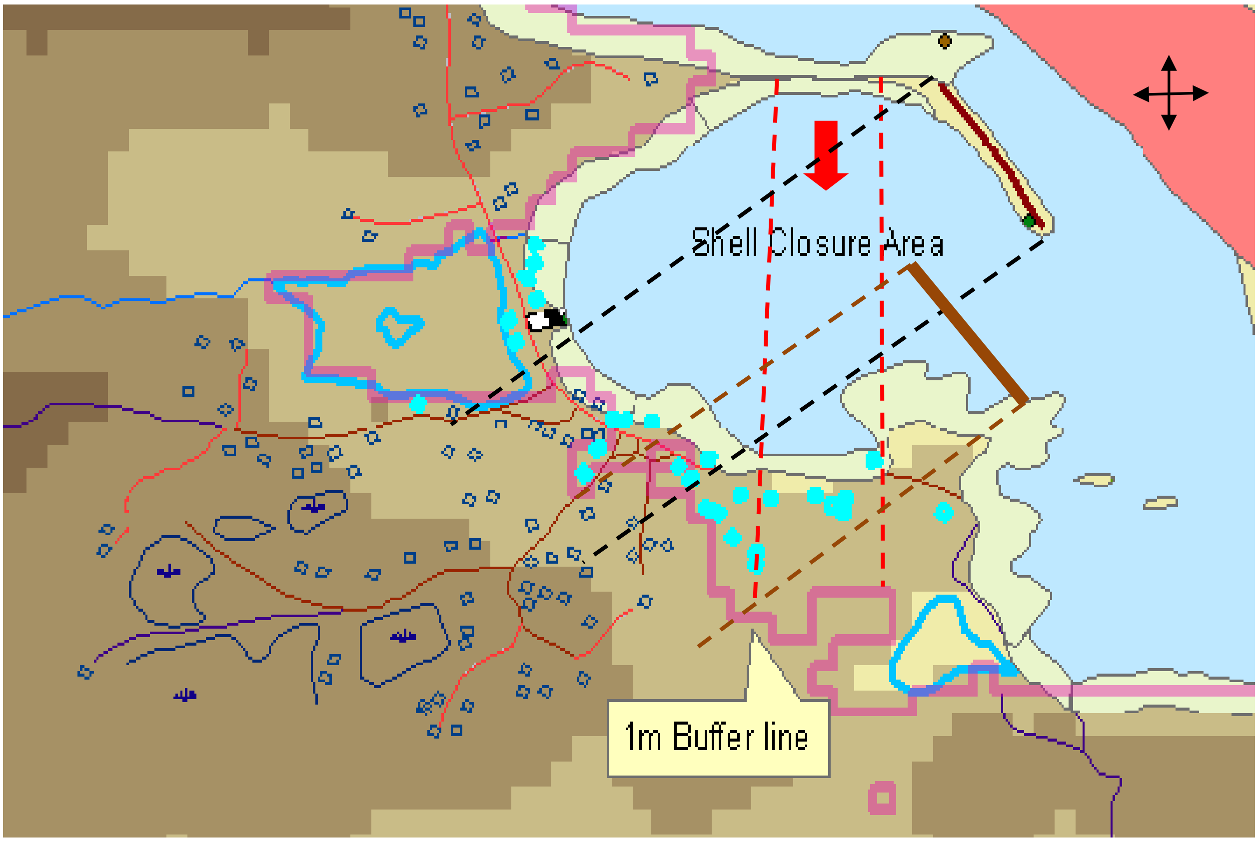


Figure 5.13. Exposed / covered areas as the result of modified opening with a new breakwater arm extending from the south (1 meter water level)

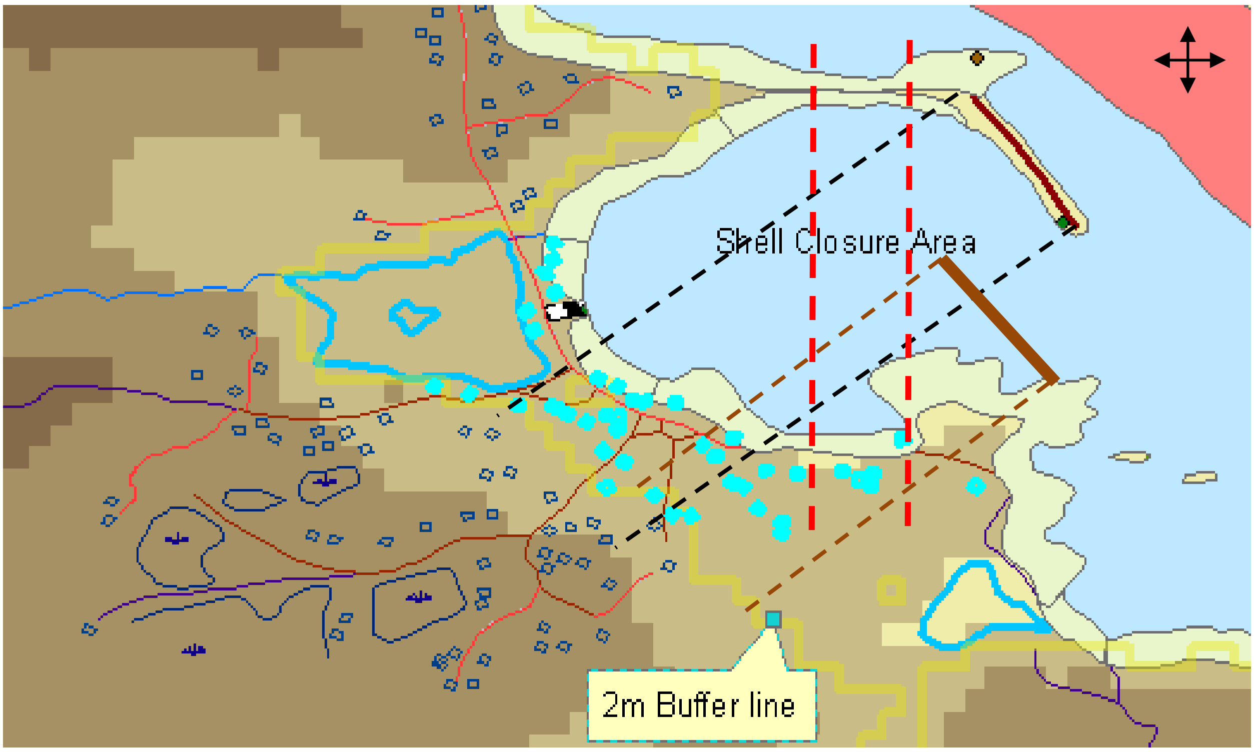


Figure 5.14. Exposed / covered areas as the result of modified opening with a new breakwater arm extending from the south (2 meter water level)

Based on Figure 5.13 and 5.14 for 1 m and 2 m maximum water level surges, the following changes are expected as the result of this strategy:

- Minimum houses flooded. This reflects on the dependant storm indicators, i.e., wells, residential land values, and safety.
- Due to the existence of the dual staggered breakwater structure, the road is expected to gain maximum protection (compared to all other engineering alternatives) from flooding.
- No changes to the number of flooded buildings since they reside very close to the shoreline. However, it is assumed that due to the existence of this structure, initial damage of $1,000 is reduced to $400 per flooded building as indicated by the revised buffer lines of Figures 5.13 and 5.14.
- The Little Anse wharf is still expected to be 100% flooded since it resides very close to the shoreline. However it is assumed that the initial damage of 20% of capital cost is reduced to 5%.
- Moreover, due to the placement of the new breakwater, a maximum protection on the road is expected (assuming that the initial damage of $264 per meter is reduced to $80 per meter). Therefore, it is very unlikely that the community will be isolated during severe storms. Nevertheless, a minor impact on community's income is expected due to the fact that some people may stay home for safety reasons.
- The impact on natural resources (water bodies and trees) is less evident, and is assumed to be 80% and 10% of total exposed area, respectively. A small value is chosen for trees since most of the damages to trees are due to wind and therefore a breakwater probably does not have much of an impact.
- In the case of church grounds, the impact of this strategy is assumed to decrease the initial damage to 3%.

Based on the discussion above, and cost estimations in subsections 5.2 and 5.3, Table 5.22 is constructed for expected changes after this strategy and the comparison between total assets, assets at risk and damages. Storm Scenarios II, III, IV and VI have been interpolated and extrapolated based on the estimates for Storm Scenarios I and V. The total asset values (TA) are found in Table 5.2.

Table 5.22. Expected changes and comparison between total assets, assets at risk and damages after creating a modified opening with a new breakwater arm.

Adaptation cost	**Storm Scenario I**	**Storm Scenario II**	**Storm Scenario III**	**Storm Scenario IV**	**Storm Scenario V**	**Storm Scenario VI**
Before	0	0	0	0	0	0
After	5,050,000	5,050,000	5,050,000	5,050,000	5,050,000	5,050,000
Houses	**Storm Scenario I**	**Storm Scenario II**	**Storm Scenario III**	**Storm Scenario IV**	**Storm Scenario V**	**Storm Scenario VI**
Before	**21**	25	29	32	**36**	40
After	**13**	14	15	17	**19**	20
Asset at risk (AR)	**412750**	444500	476250	539750	**603250**	635000
Damages	**52,000**	70,000	90,000	119,000	**152,000**	180,000
New asset state (TA-D (ρ AR))	**3123000**	3105000	3085000	3056000	**3023000**	2995000
Buildings	**Storm Scenario I**	**Storm Scenario II**	**Storm Scenario III**	**Storm Scenario IV**	**Storm Scenario V**	**Storm Scenario VI**
Before	**8**	8	8	8	**8**	8

After	**8**	8	8	8	**8**	8
Asset at risk (AR)	**64,000**	64,000	64,000	64,000	**64,000**	64,000
Damages	**3,200**	7,200	11,200	15,200	**19,200**	23,200
New asset state (TA-D (ρ AR))	**60,800**	56,800	52,800	48,800	**44,800**	40,800
Roads	**Storm Scenario I**	**Storm Scenario II**	**Storm Scenario III**	**Storm Scenario IV**	**Storm Scenario V**	**Storm Scenario VI**
Before	**558m**	649m	740m	831m	**923m**	1014m
After	**558m**	649m	740m	831m	**923m**	1014m
Asset at risk (AR)	**605988**	704814	803640	902466	**1002378**	1101204
Damages	**44640**	84370	133200	191130	**258440**	334620
New asset state (TA-D (ρ AR))	**2228358**	2188628	2139798	2081868	**2014558**	1938378
Wharf	**Storm Scenario I**	**Storm Scenario II**	**Storm Scenario III**	**Storm Scenario IV**	**Storm Scenario V**	**Storm Scenario VI**
Before	100% flooded	100% flooded	100% flooded	100% flooded	100% flooded	100% flooded
After	100% flooded	100% flooded	100% flooded	100% flooded	100% flooded	100% flooded
Asset at risk (AR)	**25000**	25000	25000	25000	**25000**	25000

Damages	**1250**	1875	2500	3125	**3750**	4375
New asset state (TA-D (ρ AR))	**23,750**	23,125	22,500	21,875	**21,250**	20,625
Wells	**Storm Scenario I**	**Storm Scenario II**	**Storm Scenario III**	**Storm Scenario IV**	**Storm Scenario V**	**Storm Scenario VI**
Before	**10**	12	14	16	**18**	20
After	**6**	7	7	8	**9**	10
Asset at risk (AR)	**57000**	66500	66500	76000	**85500**	95000
Damages	**3060**	3570	3570	4080	**4590**	5100
New asset state (TA-D (ρ AR))	**424440**	423930	423930	423420	**422910**	422400
Residential Land	**Storm Scenario I**	**Storm Scenario II**	**Storm Scenario III**	**Storm Scenario IV**	**Storm Scenario V**	**Storm Scenario VI**
Before	**22243 (SQM)**	27639 (SQM)	33035 (SQM)	38431 (SQM)	**43826 (SQM)**	49222 (SQM)
After	**17495 (SQM)**	19744 (SQM)	21993 (SQM)	24242 (SQM)	**26492 (SQM)**	28741 (SQM)
Asset at risk (AR)	**209940**	236928	263916	290904	**317904**	344892
Damages	**12597**	14216	15835	17455	**19075**	20694
New asset state (TA-D (ρ AR))	**1852335**	1850716	1849097	1847477	**1845857**	1844238

Water Bodies	**Storm Scenario I**	**Storm Scenario II**	**Storm Scenario III**	**Storm Scenario IV**	**Storm Scenario V**	**Storm Scenario VI**
Before	**19221 (SQM)**	19221 (SQM)	19221 (SQM)	19221 (SQM)	**19221 (SQM)**	19221 (SQM)
After	**3844**	3844	3844	3844	**3844**	3844
Asset at risk (AR)	**3,844**	3,844	3,844	3,844	**3,844**	3,844
Damages	**192**	384	577	769	**961**	1,345
New asset state (TA-D (ρ AR))	**19,029**	18,837	18,644	18,452	**18,260**	17,876
Trees	**Storm Scenario I**	**Storm Scenario II**	**Storm Scenario III**	**Storm Scenario IV**	**Storm Scenario V**	**Storm Scenario VI**
Before	**2000 (SQM)**	2425 (SQM)	2850 (SQM)	3275 (SQM)	**3700 (SQM)**	4125 (SQM)
After	**1800**	2182.5	2565	2947.5	**3330**	**3712.5**
Asset at risk (AR)	**493**	598	703	808	**912**	1,017
Damages	**49**	120	211	323	**456**	610
New asset state (TA-D (ρ AR))	**54,751**	54,680	54,589	54,477	**54,344**	54,190
Community Centre	**Storm Scenario I**	**Storm Scenario II**	**Storm Scenario III**	**Storm Scenario IV**	**Storm Scenario V**	**Storm Scenario VI**

	Not Impacted	Not Impacted	Not Impacted	Not Impacted	Not Impacted	Not Impacted
Church Grounds	**Storm Scenario I**	**Storm Scenario II**	**Storm Scenario III**	**Storm Scenario IV**	**Storm Scenario V**	**Storm Scenario VI**
Before	1	1	1	1	1	1
After	1	1	1	1	1	1
Asset at risk (AR)	800,000	800,000	800,000	800,000	800,000	800,000
Damages	**24,000**	64,000	104,000	144,000	**184,000**	264,000
New asset state (TA-D (ρ AR))	**776,000**	736,000	696,000	656,000	**616,000**	536,000
Income	**Storm Scenario I**	**Storm Scenario II**	**Storm Scenario III**	**Storm Scenario IV**	**Storm Scenario V**	**Storm Scenario VI**
Before	All the community					
After	**13**	14	15	17	**19**	20
Asset at risk (AR)	**1781**	2877	4110	5823	**7809**	9590
Damages	**1781**	2877	4110	5823	**7809**	9590
New asset state (TA-D (ρ AR))	**3495219**	**3494123**	**3492890**	**3491177**	**3489191**	**3487410**
Safety (people over 60)	**Scenario I**	**Scenario II**	**Scenario III**	**Scenario IV**	**Scenario V**	**Scenario VI**

Before	**14**	16	18	20	**24**	27
After	**9**	9	10	11	**13**	13
Asset at risk (AR)	**13%**	13%	15%	16%	**19%**	19%
Damages	**-**	-	-	-	**-**	-
New asset state (TA-D (ρ AR))	**87%**	87%	85%	84%	**81%**	81%
Safety (People under 14)	**Scenario I**	**Scenario II**	**Scenario III**	**Scenario IV**	**Scenario V**	**Scenario VI**
Before	**7**	8	9	10	**12**	14
After	**4**	5	5	6	**6**	7
Asset at risk (AR)	**12%**	15%	15%	18%	**18%**	21%
Damages	**-**	-	-	-	**-**	-
New asset state (TA-D (ρ AR))	**88%**	85%	85%	82%	**82%**	79%

Accommodation - Road Build Up: For this strategy, building up a new road further from the shoreline is considered. The merit behind the best location for such a road is basically an engineering question and it is not addressed here, but like other strategies discussed in previous paragraphs, the cost estimations and potential impacts on damages are determined. It is assumed that the new road is required to be 1400 meter in length. It is also assumed that, in the presence of this new road, that the current road is no longer needed.

Before discussing the impacts of this strategy on potential damages of the six storm scenarios, the costs of this strategy are presented. The cost includes: capital cost of the road build up (material and labour) - estimated in subsection 5.2, mobilization cost (machinery costs) – assumed to be 10% of capital cost and engineering cost (engineers consulting fees) – assumed to be 5% of capital cost. These estimations are shown in Table 5.23.

Table 5.23. Cost of building a new road

Description	**Value**
Capital cost (materials and labour)	$1,520,400
Mobilization cost	$152,040
Engineering cost	$76,020
Total cost	$1,748,460

As can be expected, a new road has only an impact on few indicators, namely, the road itself (the current road will no longer be in use), income and safety. Other indicators will be intact. These limited impacts make justification of choosing such a strategy difficult. The main reason for such a proposition is that sensitivity of the community toward the current road is high. Moreover, considering that the current road is the only access route to Little Anse with the outside, building a new road which is more immune to storm surge impacts seems to be a long term and potentially justifiable option.

Based on the discussion above, and the cost estimations in subsections 5.2 and 5.3, Table 5.24 for expected changes of this strategy is constructed, and the comparison between total assets, assets at risk and damages is presented. Storm Scenarios II, III, IV and VI have been interpolated and extrapolated based on Storm Scenarios I and V. The total asset values (TA) are found in Table 5.2.

Table 5.24. Expected changes and comparison between total assets, assets at risk and damages after building up the new road

Adaptation cost	**Storm Scenario I**	**Storm Scenario II**	**Storm Scenario III**	**Storm Scenario IV**	**Storm Scenario V**	**Storm Scenario VI**
Before	0	0	0	0	0	0
After	1,748,460	1,748,460	1,748,460	1,748,460	1,748,460	1,748,460
Road	**Storm Scenario I**	**Storm Scenario II**	**Storm Scenario III**	**Storm Scenario IV**	**Storm Scenario V**	**Storm Scenario VI**
Before	**558m**	649m	740m	831m	**923m**	1014m
After	**0**	0	0	0	**0**	0
Asset at risk (AR)	**0**	0	0	0	**0**	0
Damages	**0**	0	0	0	**0**	0
New asset state (TA-D (ρ AR))	**2,272,998**	2,272,998	2,272,998	2,272,998	**2,272,998**	2,272,998
Income	**Storm Scenario I**	**Storm Scenario II**	**Storm Scenario III**	**Storm Scenario IV**	**Storm Scenario V**	**Storm Scenario VI**
Before	All the community					
After	**21**	25	29	32	**36**	40

Asset at risk (AR)	**2877**	5138	7946	10960	**14796**	19180
Damages	**2877**	5138	7946	10960	**14796**	19180
New asset state (TA-D (ρ AR))	**3494123**	**3491862**	**3489054**	**3486040**	**3482204**	**3477820**
Safety (people over 60)	**Storm Scenario I**	**Storm Scenario II**	**Storm Scenario III**	**Storm Scenario IV**	**Storm Scenario V**	**Storm Scenario VI**
Before	**14**	16	18	20	**24**	27
After	**10**	12	14	16	**19**	22
Asset at risk (AR)	**15%**	18%	21%	24%	**28%**	33%
New asset state (TA-D (ρ AR))	**85%**	82%	79%	76%	**72%**	67%
Safety (People under 14)	**Storm Scenario I**	**Storm Scenario II**	**Storm Scenario III**	**Storm Scenario IV**	**Storm Scenario V**	**Storm Scenario VI**
Before	**7**	8	9	10	**12**	14
After	**3**	4	5	7	**9**	12
Asset at risk (AR)	**9%**	12%	15%	21%	**27%**	36%
New asset state (TA-D (ρ AR))	**91%**	88%	85%	79%	**73%**	64%

Retreat: For this strategy, moving a portion of houses out of the community and away from the coastline to somewhere safer from flooding is developed. Although the choice of relocation of the retreating houses is not considered, the cost estimations and potential impacts on damages are discussed.

Consider the 29 houses (Storm Scenario III impact) as the number of houses to be moved from the flood zones. As can be expected, this strategy does not have the potential to protect all impacted assets. It will only influence houses along with its dependent indicators: buildings, wells, residential land, income and safety.

The cost of the retreat strategy include: compensation for the houses, private buildings and land plus mobilization cost (uncompensated cost of relocating a household to a new location). These estimations are shown in Table 5.25.

Table 5.25. Cost of relocating the houses of Little Anse

Description	Houses	Per value	Total Cost
Houses	29	$31,750	$920,750
Buildings	8	$8000	$64,000
Residential Land	75400 sq m	$12	$918,864
Mobilization cost	29 households	$15,000	$435,000
Total Cost of relocation			$2,338,614

Based discussion above and cost estimations in subsections 5.2 and 5.3, Table 5.26 is constructed for expected changes of this strategy and its comparison between total assets, assets at risk and damages. Storm Scenarios II, III, IV and VI have been interpolated and extrapolated based on Storm Scenarios I and V. The total asset values (TA) are found in Table 5.2.

Table 5.26. Expected changes and comparison between total assets, assets at risk and damages after retreating the houses

Adaptation cost	**Storm Scenario I**	**Storm Scenario II**	**Storm Scenario III**	**Storm Scenario IV**	**Storm Scenario V**	**Storm Scenario VI**
Before	0	0	0	0	0	0
After	2,401,614	2,401,614	2,401,614	2,401,614	2,401,614	2,401,614
Houses	**Storm Scenario I**	**Storm Scenario II**	**Storm Scenario III**	**Storm Scenario IV**	**Storm Scenario V**	**Storm Scenario VI**
Before	**21**	25	29	32	**36**	40
After	**0**	0	0	3	**7**	11
Asset at risk (AR)	**0**	0	0	95,250	**222,250**	349,250
Damages	**0**	0	0	21,000	**56,000**	99,000
New asset state (TA-D (ρ AR))	**3,175,000**	3,175,000	3,175,000	3,154,000	**3,119,000**	3,076,000
Buildings	**Storm Scenario I**	**Storm Scenario II**	**Storm Scenario III**	**Storm Scenario IV**	**Storm Scenario V**	**Storm Scenario VI**
Before	**8**	8	8	8	**8**	8
After	**0**	0	0	0	**0**	0

Asset at risk (AR)	**0**	0	0	0	**0**	0
Damages	**0**	0	0	0	**0**	0
New asset state (TA-D (ρ AR))	**64,000**	**64,000**	**64,000**	**64,000**	**64,000**	**64,000**
Wells	**Storm Scenario I**	**Storm Scenario II**	**Storm Scenario III**	**Storm Scenario IV**	**Storm Scenario V**	**Storm Scenario VI**
Before	**10**	12	14	16	**18**	20
After	**0**	0	0	1	**3**	5
Asset at risk (AR)	**0**	0	0	9,500	**28,500**	47,500
Damages	**0**	0	0	510	**1,530**	2,550
New asset state (TA-D (ρ AR))	**427,500**	427,500	427,500	426,990	**425,970**	424,950
Residential Land	**Storm Scenario I**	**Storm Scenario II**	**Storm Scenario III**	**Storm Scenario IV**	**Storm Scenario V**	**Storm Scenario VI**
Before	**22,243 (SQM)**	27,639 (SQM)	33,035 (SQM)	38,431 (SQM)	**43,826 (SQM)**	49,222 (SQM)
After	**0**	0	0	4,050	**9,450**	14,850
Asset at risk (AR)	**0**	0	0	48,600	**113,400**	178,200
Damages	**0**	0	0	2,916	**6,804**	10,692

New asset state (TA-D (ρ AR))	**1,864,932**	1,864,932	1,864,932	1,862,016	**1,858,128**	1,854,240
Income	**Storm Scenario I**	**Storm Scenario II**	**Storm Scenario III**	**Storm Scenario IV**	**Storm Scenario V**	**Storm Scenario VI**
Before	All the community					
After	**71**	71	71	71	**71**	71
Asset at risk (AR)	**9,727**	14,591	19,454	24,318	**29,181**	34,045
Damages	**9,727**	14,591	19,454	24,318	**29,181**	34,045
New asset state (TA-D (ρ AR))	**3,487,273**	3,482,409	3,477,546	3,472,682	**3,467,819**	3,462,955
Safety (people over 60)	**Storm Scenario I**	**Storm Scenario II**	**Storm Scenario III**	**Storm Scenario IV**	**Storm Scenario V**	**Storm Scenario VI**
Before	**14**	16	18	20	**24**	27
After	**1**	1	1	2	**3**	5
Asset at risk (AR)	**1%**	1%	1%	3%	**4%**	7%
Damages	**-**	**-**	**-**	**-**	**-**	**-**
New asset state (TA-D (ρ AR))	**99%**	**99%**	**99%**	**97%**	**96%**	**93%**
Safety (People under 14)	**Storm**	**Storm**	**Storm**	**Storm**	**Storm**	**Storm**

	Scenario I	**Scenario II**	**Scenario III**	**Scenario IV**	**Scenario V**	**Scenario VI**
Before	**7**	8	9	10	**12**	14
After	**1**	1	1	1	**2**	3
Asset at risk (AR)	**3%**	3%	3%	3%	**6%**	9%
Damages	**-**	-	-	-	**-**	-
New asset state (TA-D (ρ AR))	**97%**	97%	97%	97%	**94%**	91%

5.5. Utilities

Based on the methodology associated with valuing the indicator values of storms (subsections 3.1, 5.2 and 5.3), this section constructs the indicator utility functions in order to compare decision makers' valuations of the changing community status under storms and no storms. In subsection 3.1, the general utility function and the basis for determining the upper and lower bound of this function were discussed. The "Ideal State" or (SQ^*) was introduced as the basis for upper bound of the utility function. It was also discussed that this "Ideal State" is highly subjective and there is also a need for community involvement in determining this state.

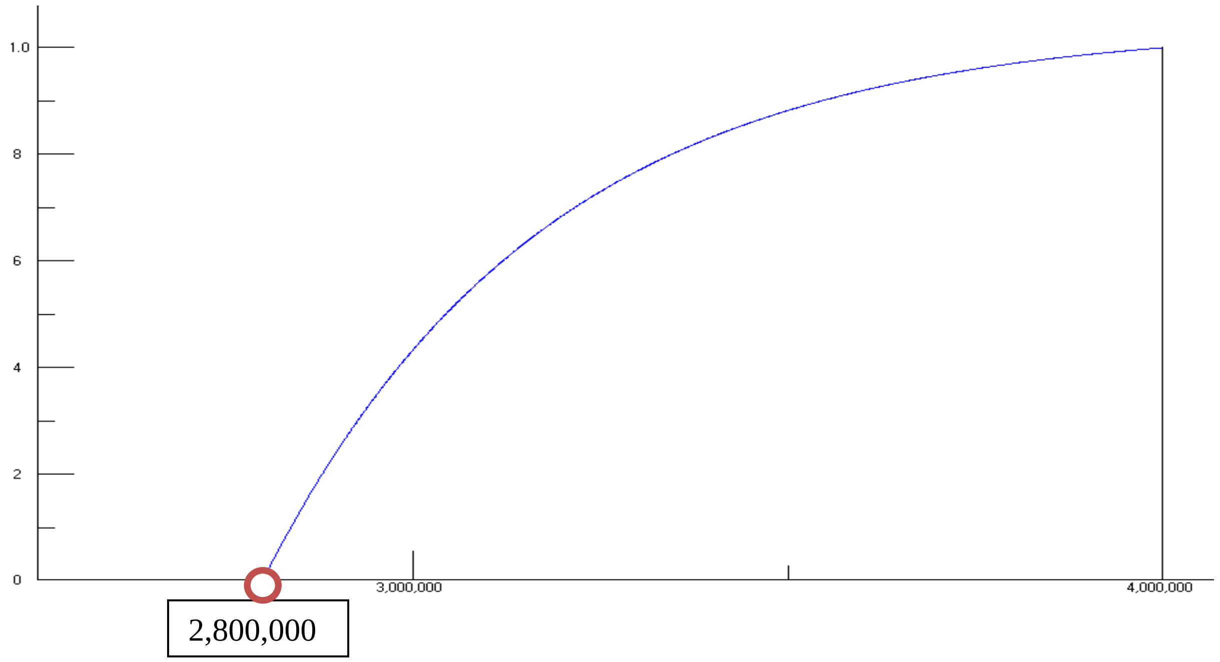
It was also discussed in section 3.1 that the worst outcome to the community's assets is equivalent to the damages of most intense storm scenario (In storm scenario VI). This outcome (new asset state after subtraction of maximum damages) is the basis for determining the lower bound of the utility function. However, even a more severe case is imaginable since there is always a chance to have a more severe impact than the most intense storm scenario. This can be due to many reasons such as future sea level rise that has the potential to make storm surge events more severe. Therefore, in this section adjustments have been made to reflect this possibility. The same reasoning was applied for the case of Isle Madame in Chapter 4.

All the proposed values for upper and lower bound of utility functions have been made subjectively on part of this researcher.

Houses

Based on table 5.2 the total asset value of houses and buildings before a storm (TA) is $3,175,000 and based on table 5.14 new asset state after Storm Scenario VI impact is $ 3,015,000. The utility function is presented in figures 5.15. These values are readjusted to $4,000,000 and $2,800,000 respectively.

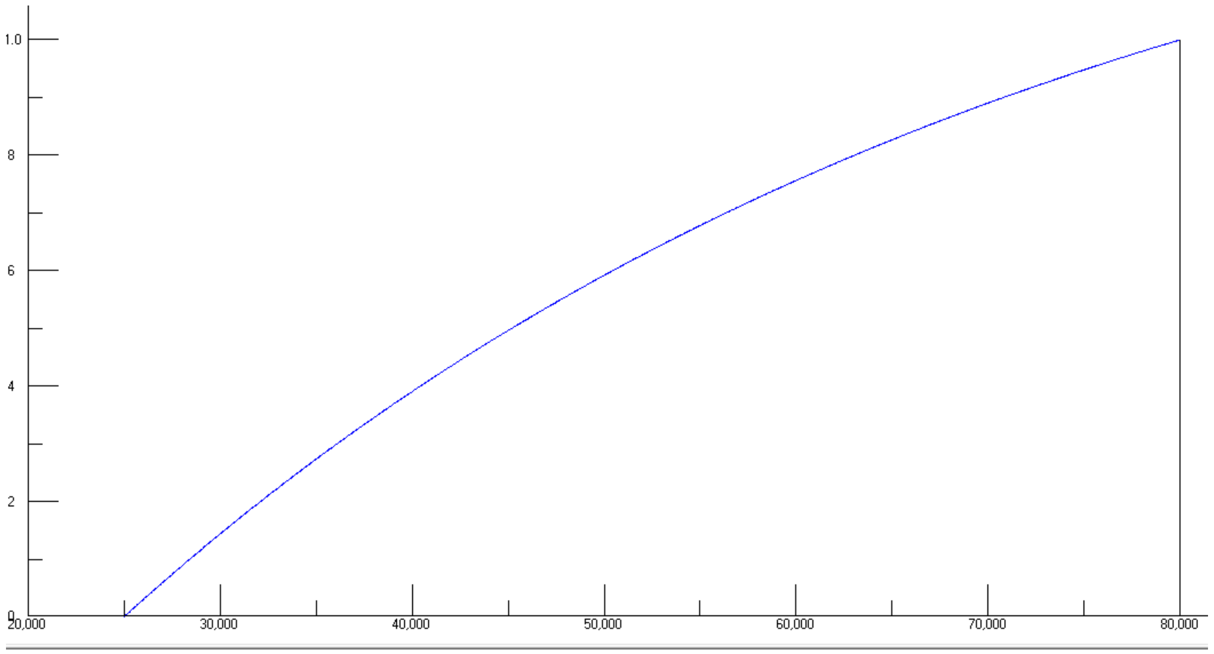
Figure 5.15. Utility function of houses



Buildings

Based on table 5.2 the total asset value of buildings before a storm (TA) is $64,000 and based on table 5.14 new asset state value after Storm Scenario VI impact is $32,000. The utility function is presented in figure 5.16. These values are readjusted to $80,000 and $25,000 respectively.

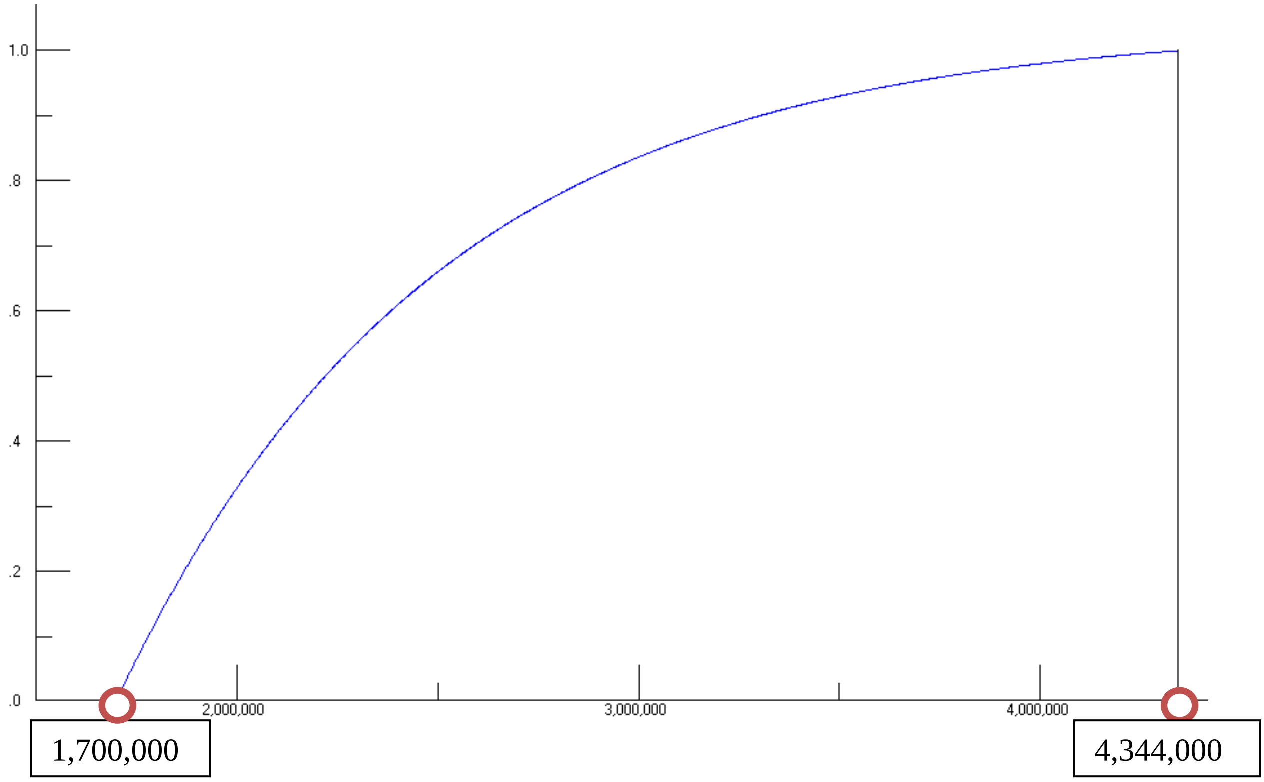
Figure 5.16. Utility function of buildings



Roads

Based on table 5.2 the total asset value of road before a storm (TA) is $2,272,998 and based on table 5.14 new asset state after Storm Scenario VI impact is $1,751,802. The utility function is presented in figure 5.17. These values are readjusted to $4,344,000 and $1,700,000 respectively.

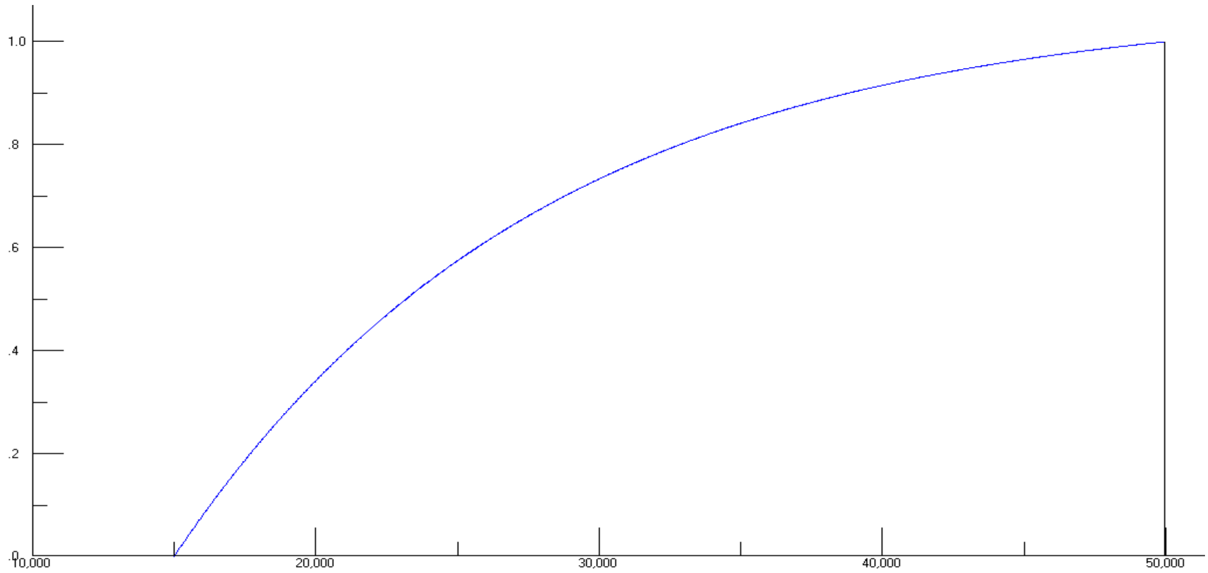
Figure 5.17. Utility function of roads



Wharf

Based on table 5.2 the total asset value of wharf before a storm (TA) is $25,000 and based on table 5.14 new asset state after Storm Scenario VI impact is $16,875. The utility function is presented in figure 5.18. These values are readjusted to $50,000 and $15,000 respectively.

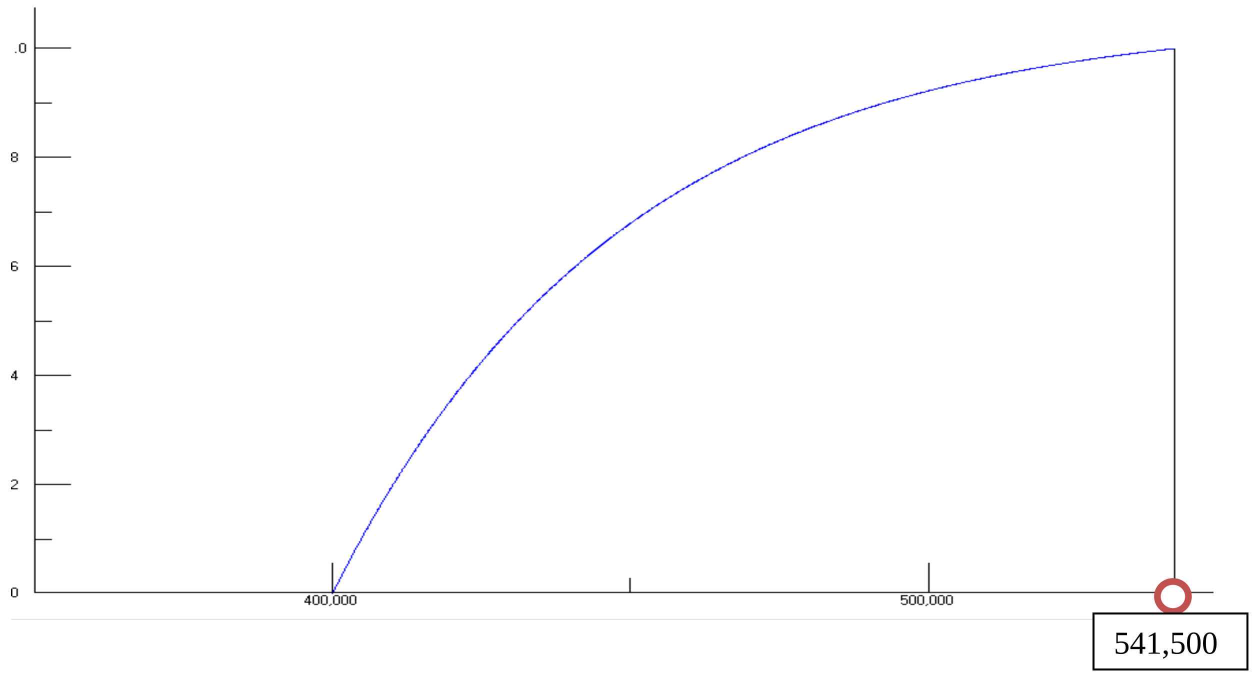
Figure 5.18. Utility function of wharf



Wells

Based on table 5.2 the total asset value of wells before a storm (TA) is $427,500 and based on table 5.14 new asset state after Storm Scenario VI impact is $417,300. The utility function is presented in figure 5.19. These values are readjusted to $541,500 and $400,000 respectively.

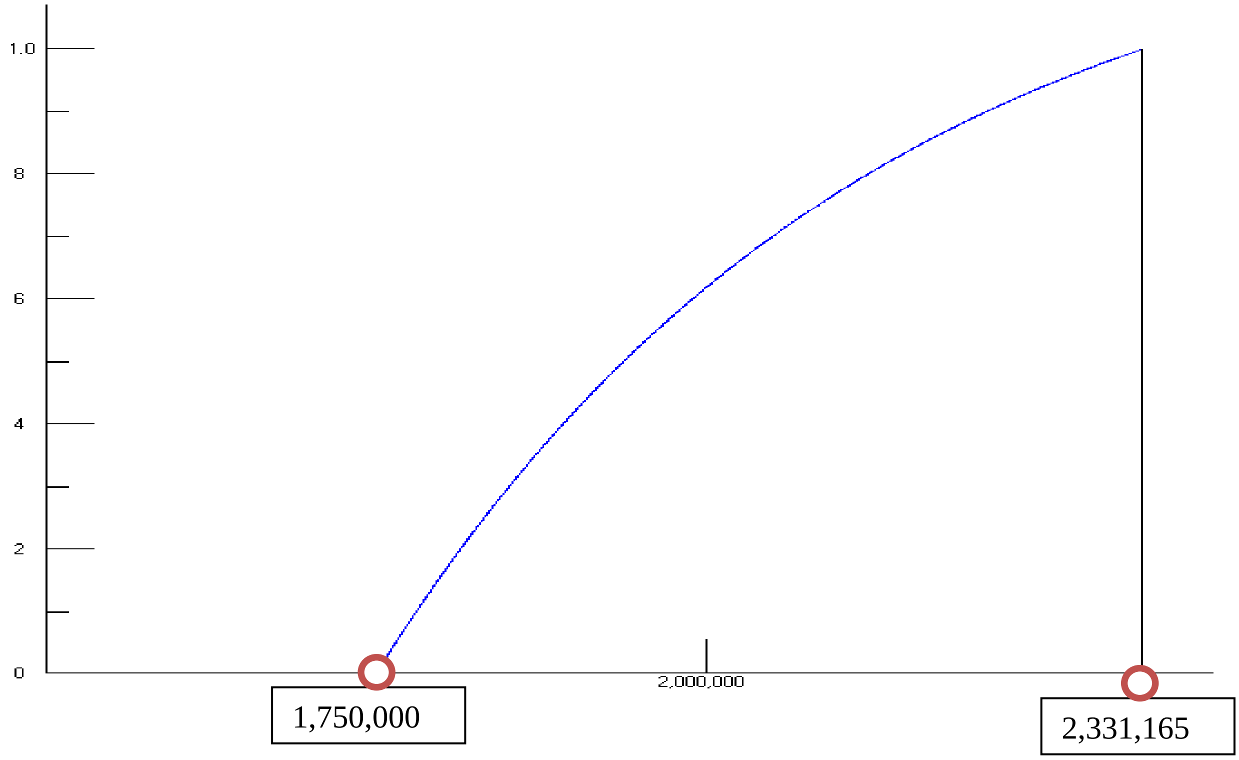
Figure 5.19. Utility function of wells



Residential land

Based on table 5.2 the total asset value of residential land before a storm (TA) is $1,864,932 and based on table 5.14 new asset state after Storm Scenario VI impact is $1,829,492. The utility function is presented in figures 5.20. These values are readjusted to $2,331,165 and $1,750,000 respectively.

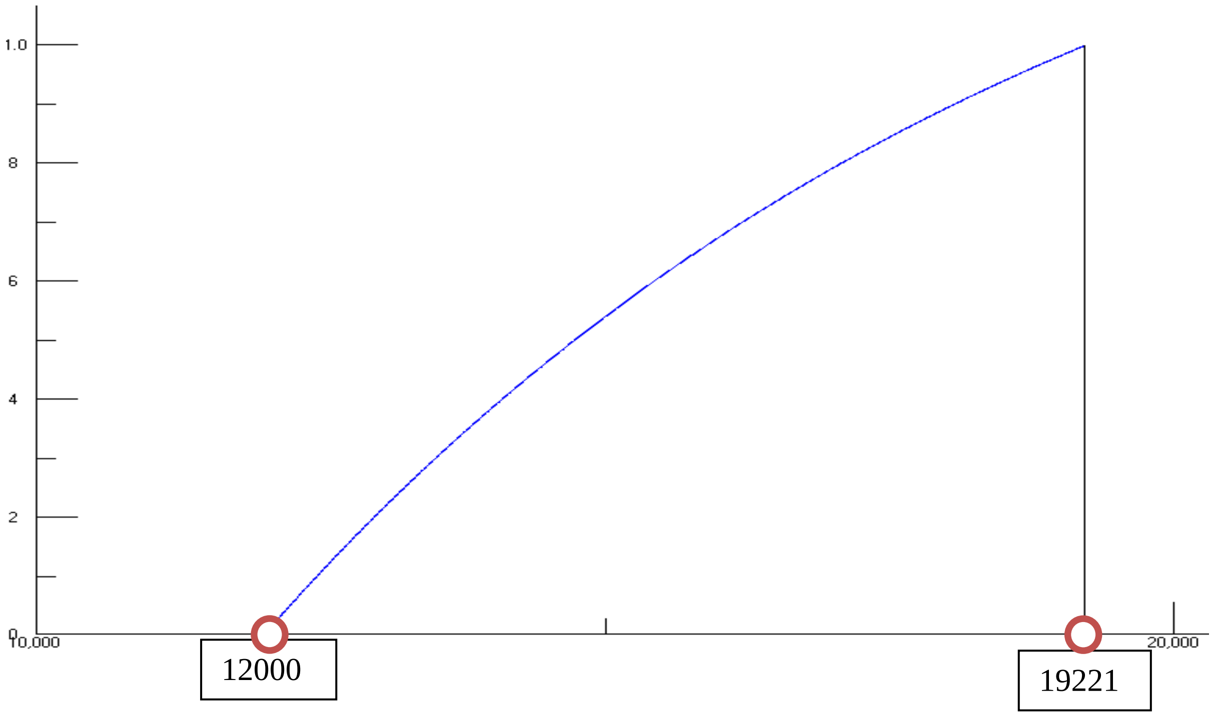
Figure 5.20. Utility function of residential land



Water Bodies

Based on table 5.2 the total asset value of water bodies before a storm (TA) is $19221 and based on table 5.14 new asset state after Storm Scenario VI impact is $12000. The utility function is presented in figure 5.21.

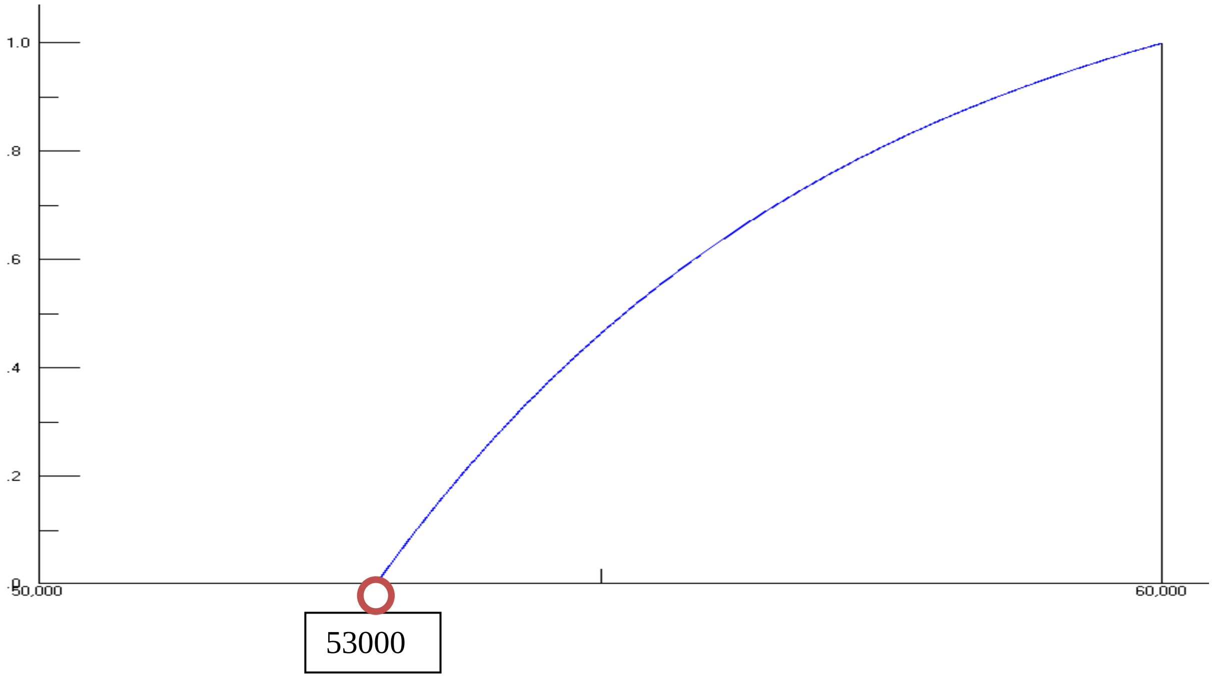
Figure 5.21. Utility function of water bodies



Trees

Based on table 5.2 the total asset value of trees before a storm (TA) is $54800 and based on table 5.14 new asset state after Storm Scenario VI impact is $54122. The utility function is presented in figure 5.22. These values are readjusted to $60,000 and $53,000 respectively.

Figure 5.22. Utility function of trees

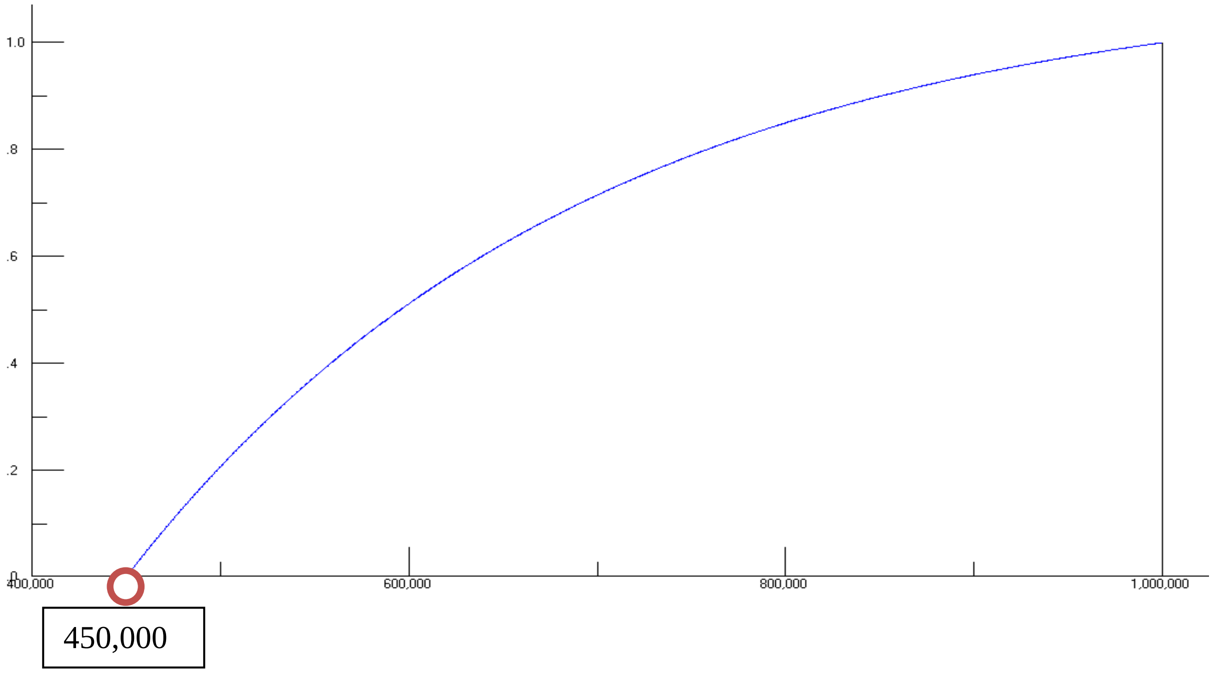


Community center is not impacted therefore its utility value is always one.

Church grounds

Based on table 5.2 the total asset value of the church before a storm (TA) is $800,000 and based on table 5.14 new asset state after Storm Scenario VI impact is $480,000. The utility function is presented in figure 5.23. These values are readjusted to $1,000,000 and $450,000 respectively.

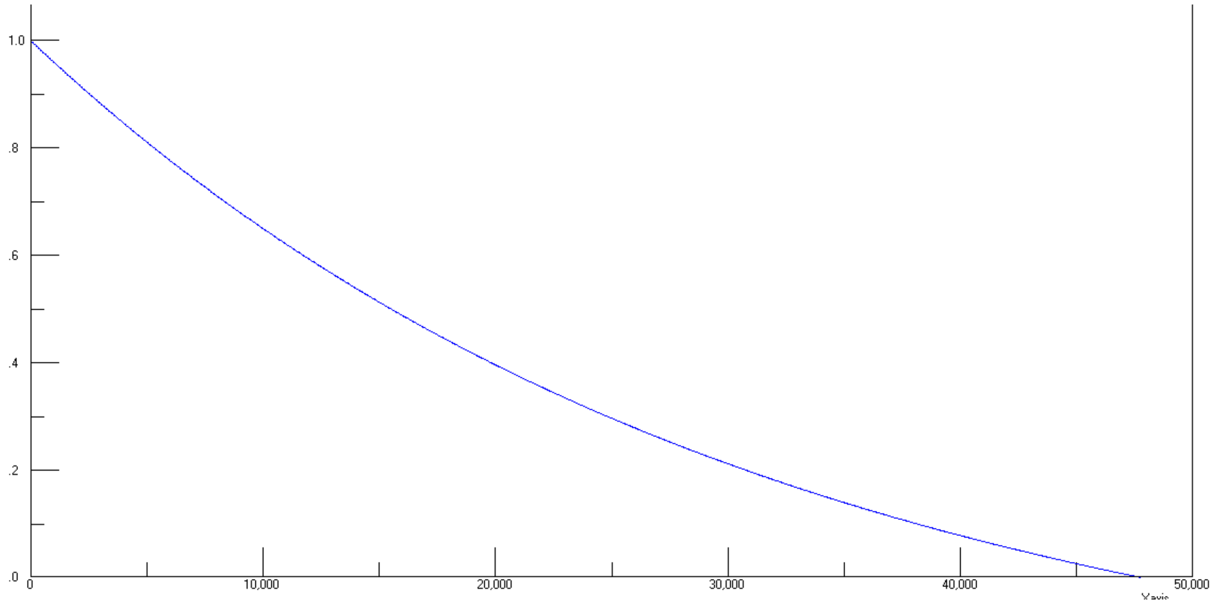
Figure 5.23. Utility function of church grounds



Income

In the case of income we are going to use a different approach. The reason for that is total asset values (TA) have been estimated based on annual income of the community whereas damages have been estimated based on daily income of the community. This gives us a new asset value which is very close to initial asset value (TA). In order to avoid this problem we have considered the upper limit of the utility function to be the maximum income that can be lost, i.e. $47,810 (Storm Scenario VI). The lower limit is zero which indicates the situation where no income is lost. The utility function has the decreasing form (figure 5.24).

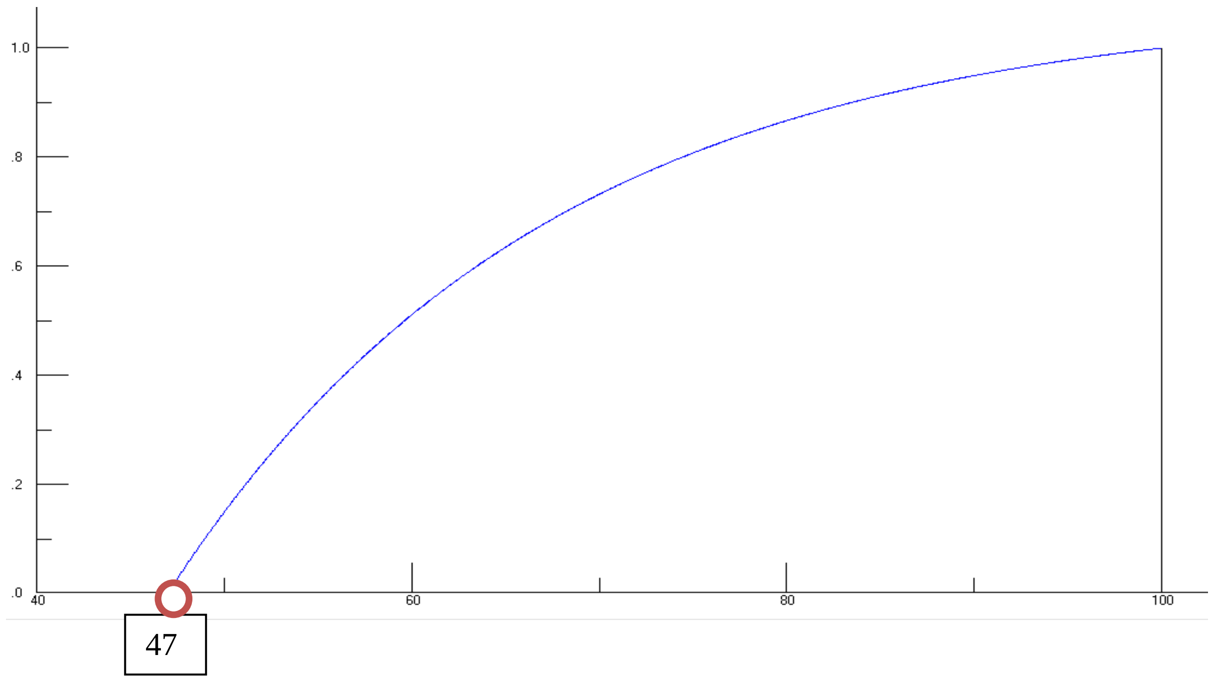
Figure 5.24. Utility function of income loss



Safety (people over 60)

Based on table 5.2 the total asset value of this indicator before a storm (TA) is 100% and based on table 5.14 new asset state after Storm Scenario VI impact is 60%. This value has been readjusted to 47%. The utility function is presented in figure 5.25.

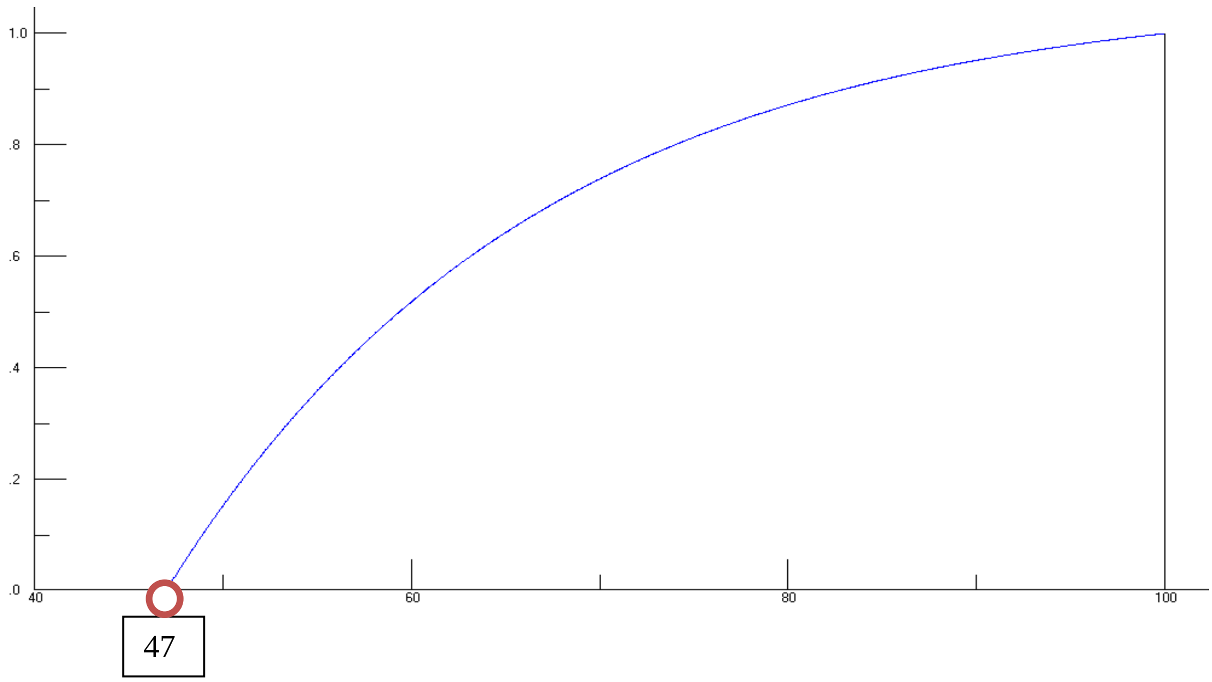
Figure 5.25. Utility function of safety (people over 60)



Safety (people under 14)

Based on table 5.2 the total asset value of this indicator before a storm (TA) is 100% and based on table 5.14 new asset value after Storm Scenario VI impact is 60%. This value has been readjusted to 47%. The utility function is presented in figure 5.26.

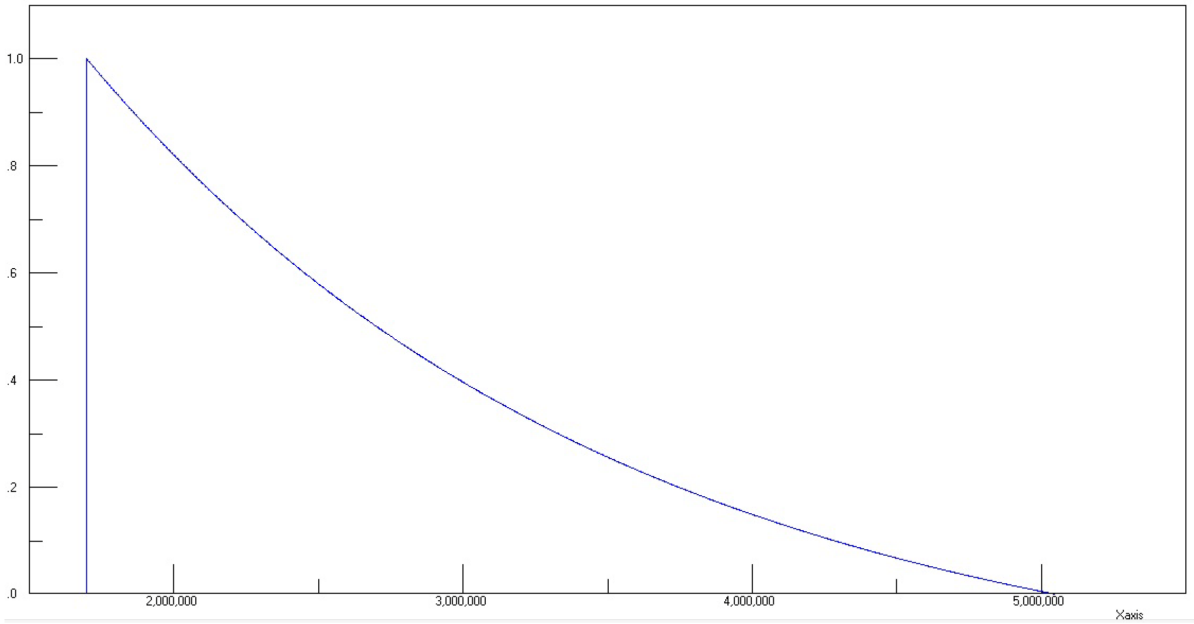
Figure 5.26. Utility function of safety (people under 14)



Cost of adaptation

In section 5.4 we discussed adaptation options along with their costs. Cost has a decreasing utility function - less cost is more favourable. Therefore the utility function of adaptation costs does not pertain to water level scenarios. The utility function depends on the type of adaptation considered. Utility wise these adaptation options have been compared to themselves and therefore the upper limit value corresponds to the most expensive option (5.05 million) and the lower limit value corresponds to the least expensive option (1.7 million). Figure 5.27 depicts the cost of adaptation utility function.

Figure 5.27. Utility function for cost of adaptation



5.6. Analysis and discussion

As noted in Chapters 2 and 3 of thesis, AHP methodology and Expert Choice software as a decision making support tool have been utilized to aid us analysing the tradeoffs between our various adaptation strategies. In section 2.1.4, the AHP methodology and in section 3.3, the Expert Choice environment were discussed. Throughout sections 5.2 to 5.5 the necessary data for such analyses were presented. The merits of an adaptation option can be different from various perspectives and therefore the group version of the AHP model was introduced (section 2.1.5).

5.6.1. Introducing stakeholders and the pair-wise comparison

The stakeholders and pairwise comparison weights considered here for Little Anse are identical to those illustrated for the case of Isle Madame (Subsection 4.1).

5.6.2. Combined analysis of "No Storm" scenario with six scenarios impacts.

The combined version of AHP methodology was discussed in subsection 2.1.5 to assist us with group decision making. Moreover, it was depicted in subsection 4.1 that each stakeholder holds a unique perspective toward the various vulnerability indicators and therefore weights them differently than other stakeholders. Combined AHP assists us to take into consideration these discrepancies and at the same time realizing the tradeoffs among different options.

In this section, the "No Storm" scenario is compared with all the six Storm Scenarios impacts. This comparison is to show that as Storm Scenarios get more severe, the more damaging the impacts become (Figures 5.28 to 5.33). All values provide below have been acquired using the AHP based software Expert Choice version 2000 (Expert Choice, 2000).

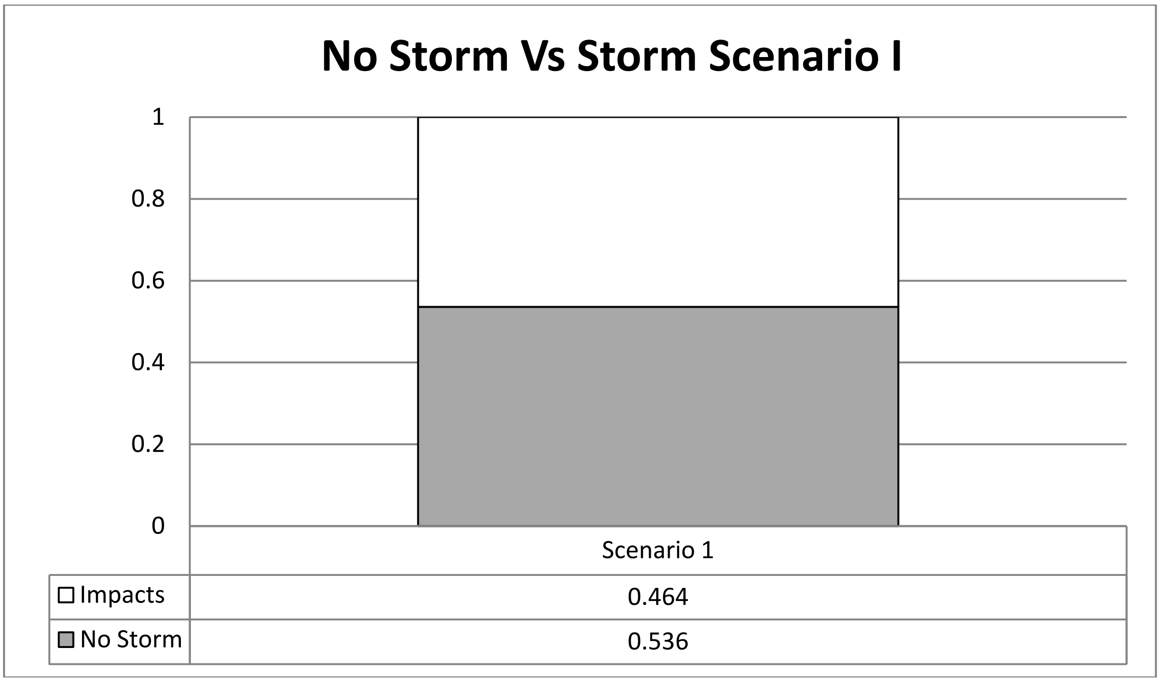


Figure 5.28. Comparison of "No Storm" scenario and Storm Scenario I impacts

Due to the relatively low damages expected of a Storm Scenario I, the final scores of the "No Storm" and the Storm Scenario I indicators are not far apart. The vulnerability measure is $V^I(u)$ =0.536-0.464=0.072.

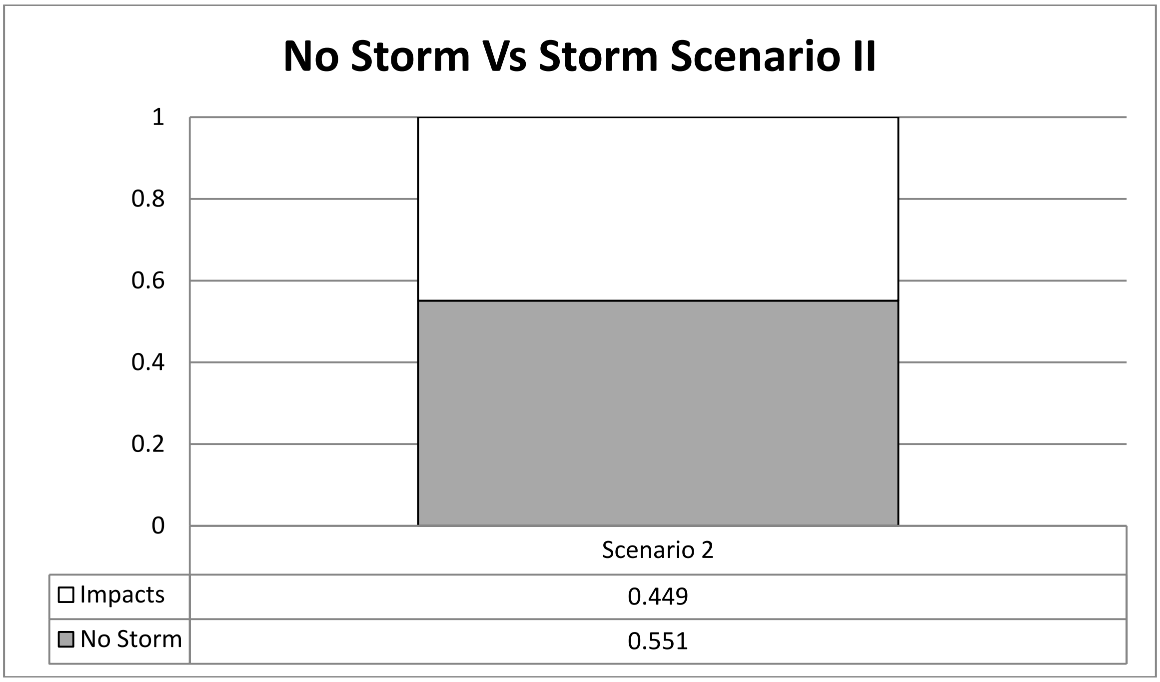


Figure 5.29. Comparison of "No Storm" scenario and Storm Scenario II impacts

Estimated damages from Storm Scenario II are more significant than Storm Scenario I. The vulnerability measure is $V^{II}(u)$ =0.551-0.449=0.102.

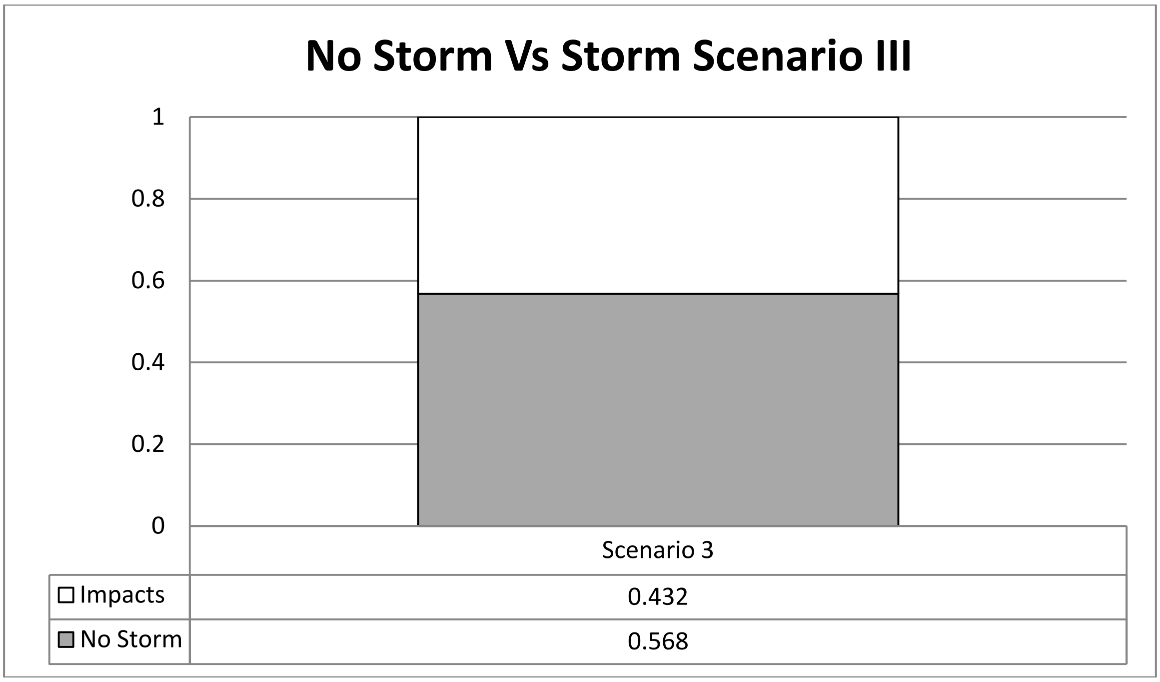


Figure 5.30. Comparison of "No Storm" scenario and Storm Scenario III impacts

Estimated damages from this more severe storm become more significant as reflected in the differences in scores of these two scenarios. The vulnerability measure is $V^{III}(u)$ =0.568-0.432=0.136.

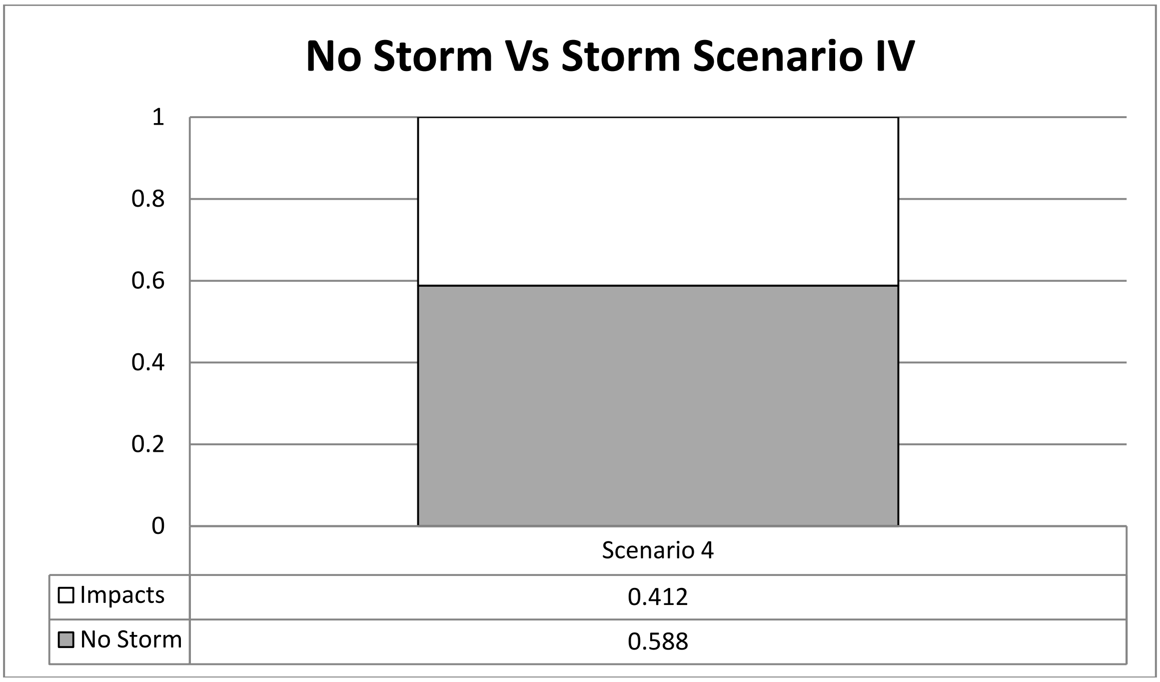


Figure 5.31. Comparison of "No Storm" scenario and Storm Scenario IV impacts

Similar to previous graph, as the severity of Storm Scenario increases, estimated damages become more significant and are reflected in the differences in scores of these two scenarios. The vulnerability measure is $V^{IV}(u)$ =0.588-0.412=0.176.

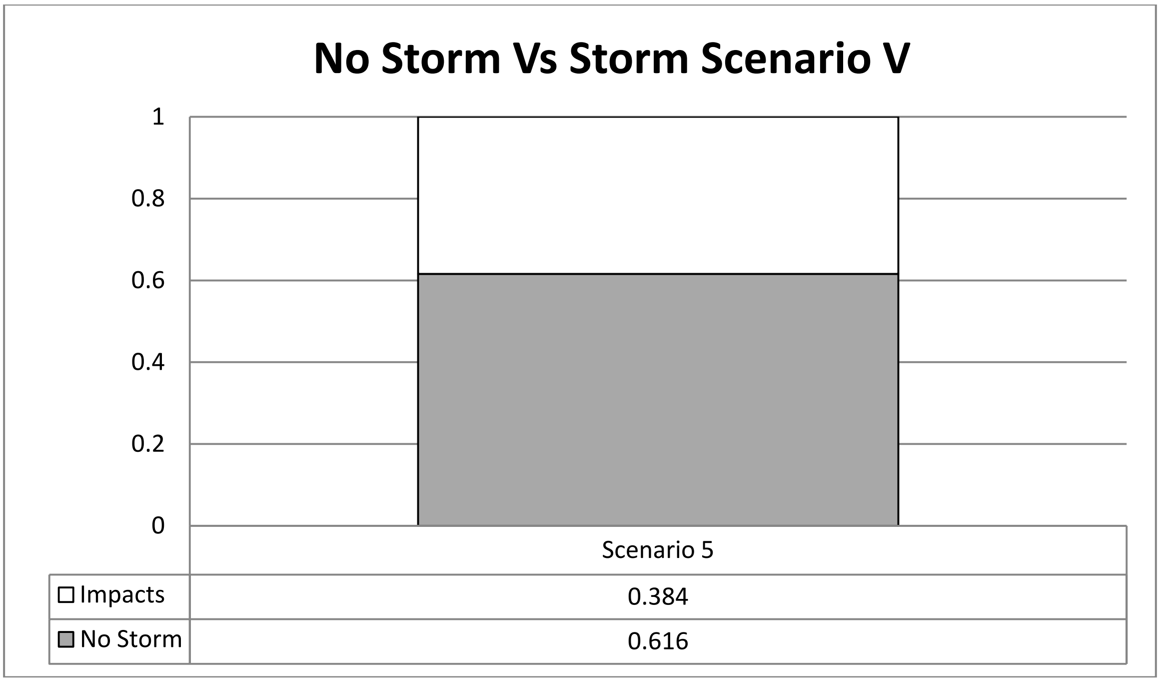


Figure 5.32. Comparison of "No Storm" scenario and Storm Scenario V impacts

Similar to previous graph, the severity of Storm Scenario V results in higher estimated damages and a widing difference between scores of these two scenarios. The vulnerability measure is $V^{V}(u)$ =0.616-0.384=0.232.

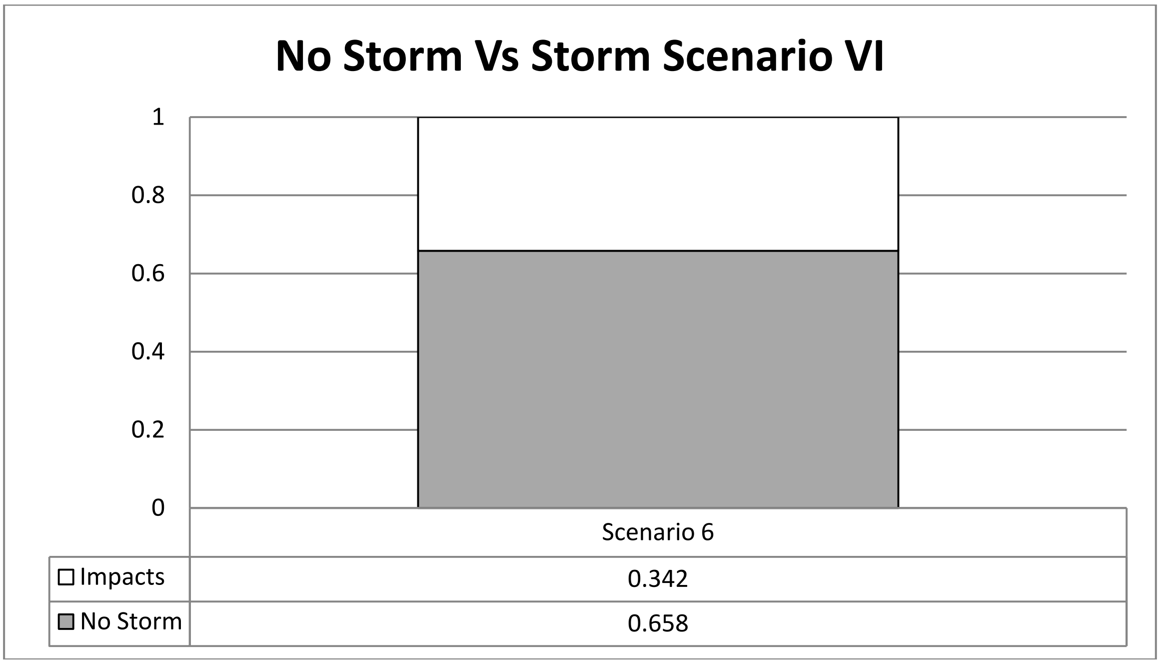


Figure 5.33. Comparison of "No Storm" scenario and Storm Scenario VI impacts

Maximum estimated damage is caused by Storm Scenario VI and therefore the largest difference between scores of these two scenarios. Storm Scenario VI is the least favourable scenario among all other Storm Scenarios. The vulnerability measure is $V^{VI}(u)$ =0.658-0.342=0.316.

It is evident from figures above that by moving from Storm Scenario I to Storm Scenario VI – when compared with the "No Storm" scenario - the scores get smaller and the vulnerability measure increases. Changes in scores indicate that changes in impacts and estimated damages provide the basis for considering adaptation options to address these shifts.

5.6.3. Combined comparison between three different breakwater strategies

In this section the three different breakwater strategies discussed in section 5.3 are compared from the combined participants AHP perspective (Chapter 2 and 3). The best engineering breakwater strategy can be compared with the remaining alternatives (i.e., retreat and road build up) as a means of overall analysis of the general adaptation set of "protect", "accommodate", and "retreat" versus doing nothing.

Figures 5.34 to 5.39 depict the scores of these strategies for each Storm Scenario as acquired by Expert Choice Software (Expert Choice, 2000). What is presented here is a combined perspective of scores. For different stakeholder's scores per Storm Scenario refer to Appendix D - Stakeholder's ranking on adaptation strategies for each scenario.

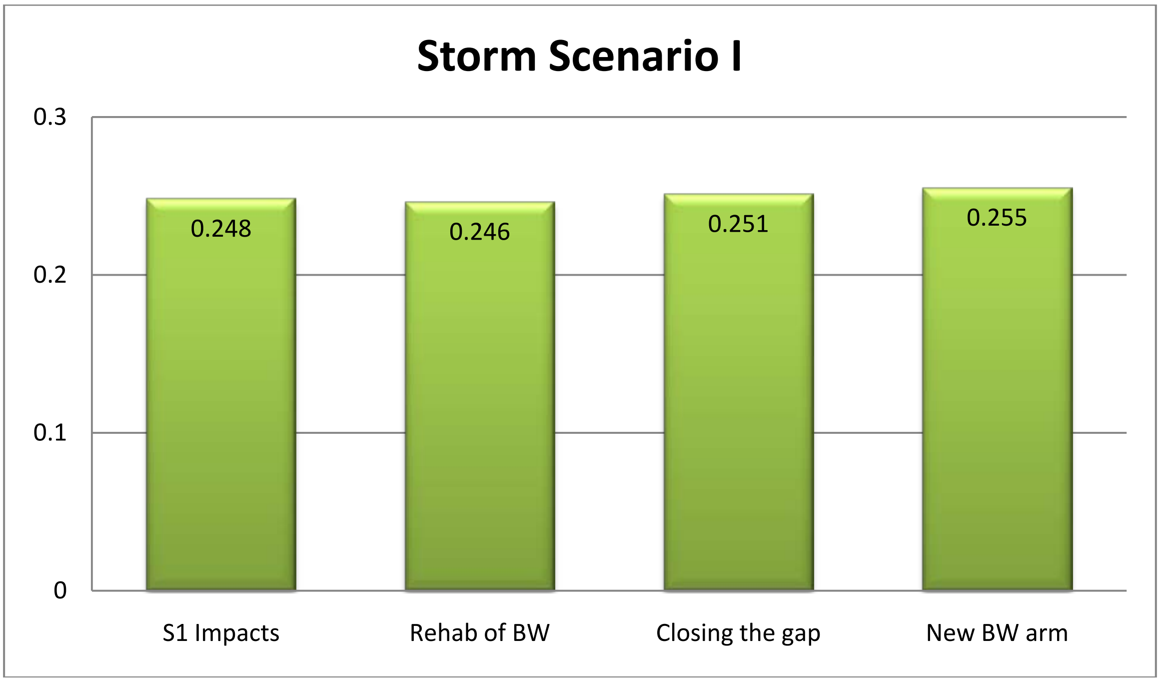


Figure 5.34. Comparison of all breakwater strategies on Storm Scenario I impacts

"New Breakwater arm" stands out among other options however all strategies are close to status quo and therefore "Do Nothing" ("S1 Impacts") is likely the perferred option for this least damaging severe storm.

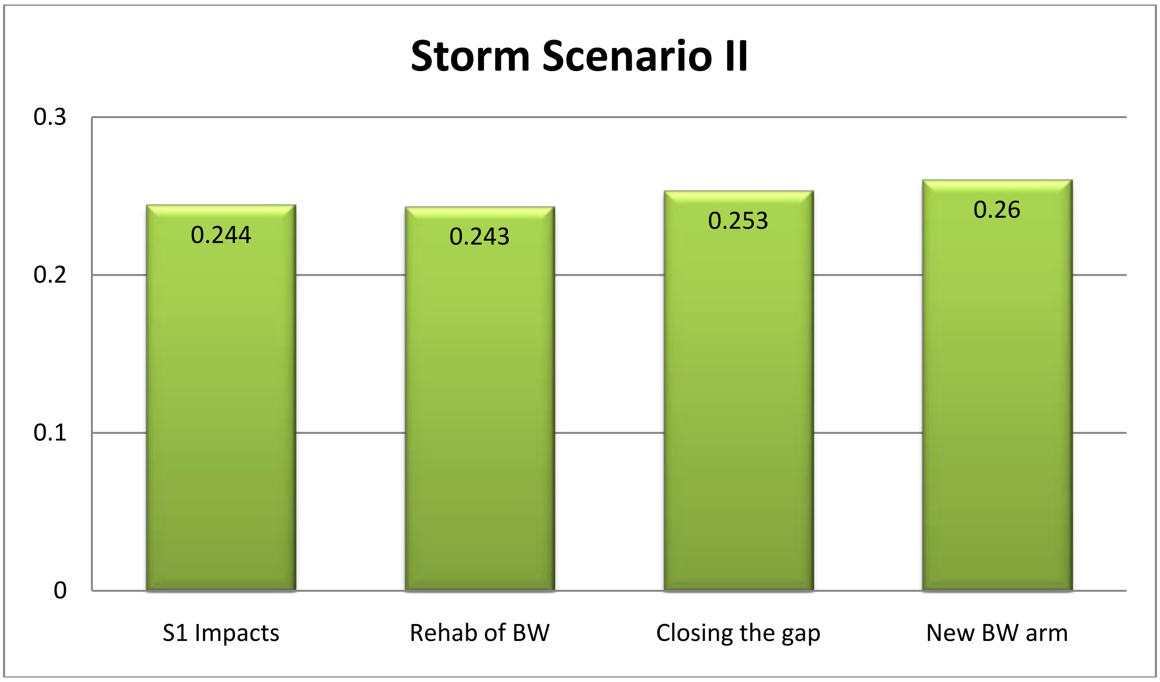


Figure 5.35. Comparison of all breakwater strategies on Storm Scenario II impacts

“New Breakwater arm” stands out among other options and begins to emerge as the preferred engineering option.

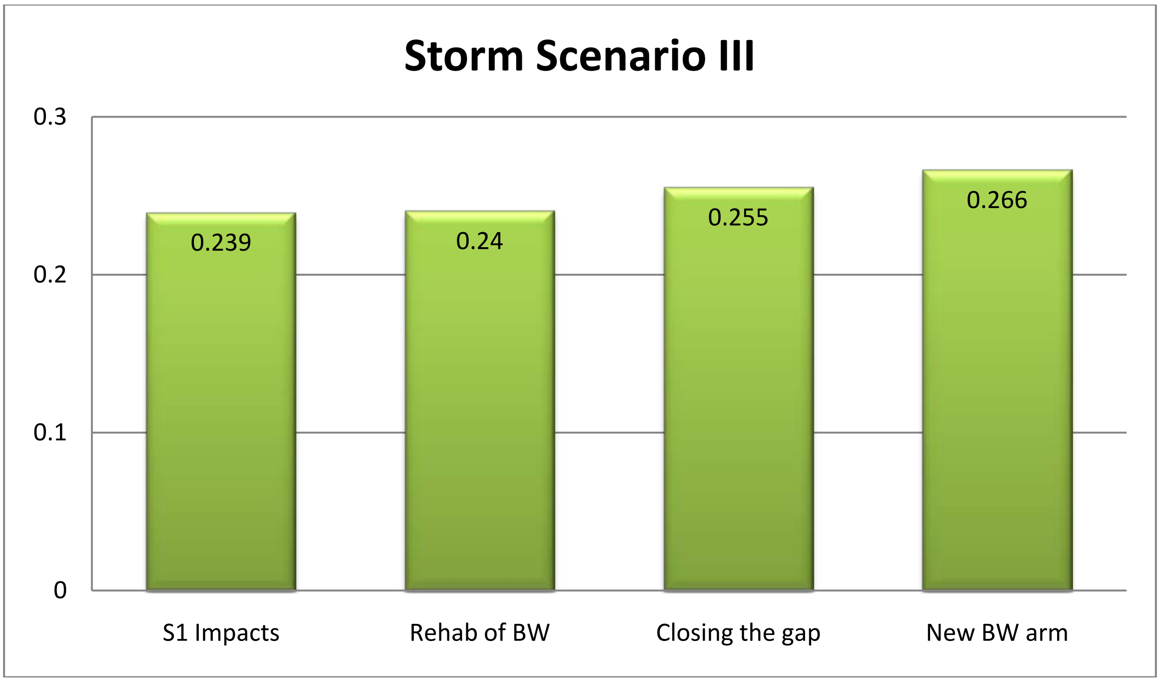


Figure 5.36. Comparison of all breakwater strategies on Storm Scenario III impacts

“New Breakwater arm” stands out among other options and therefore is notably the preferred option among all engineering options for the breakwater at this storm severity.

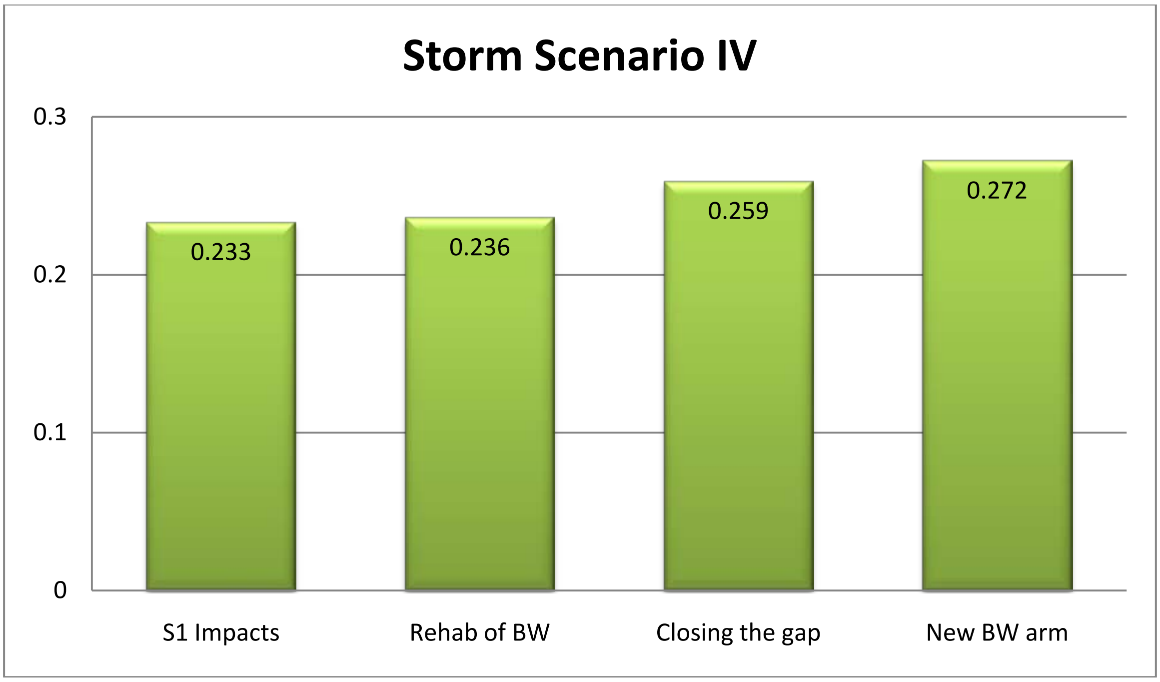


Figure 5.37. Comparison of all breakwater strategies on Storm Scenario IV impacts

“New Breakwater arm” stands out among other options and therefore it continues to be the most preferred option as the storm severity increases.

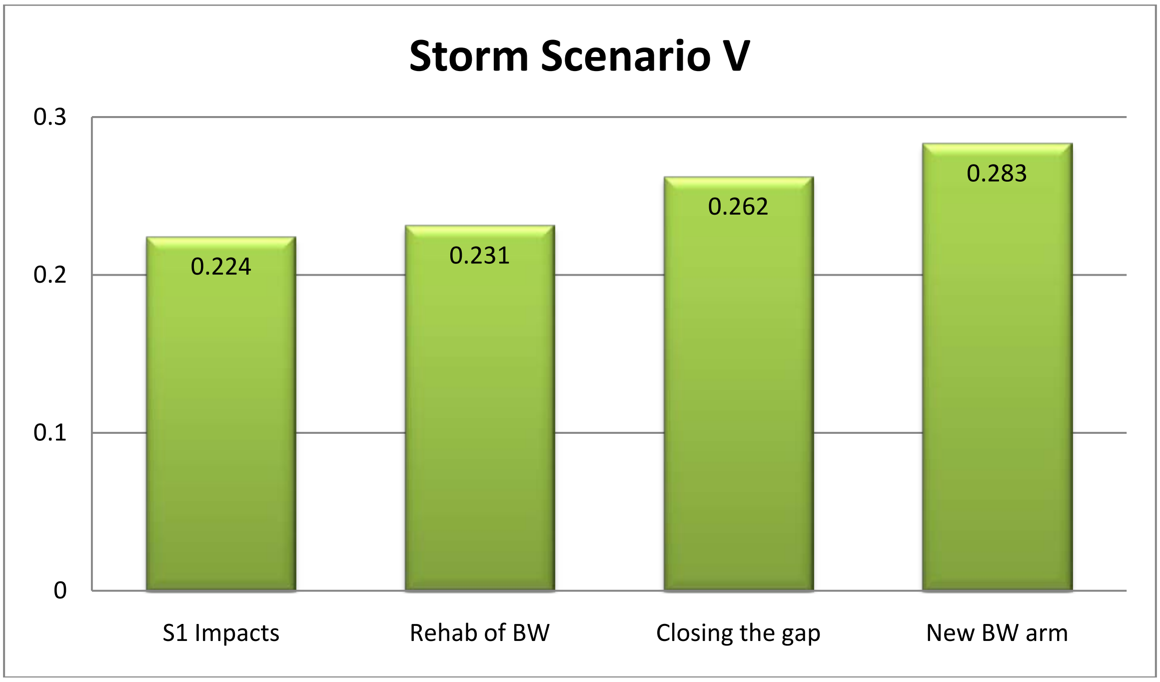


Figure 5.38. Comparison of all breakwater strategies on Storm Scenario V impacts

“New Breakwater arm” stands out among other options and therefore is the best option.

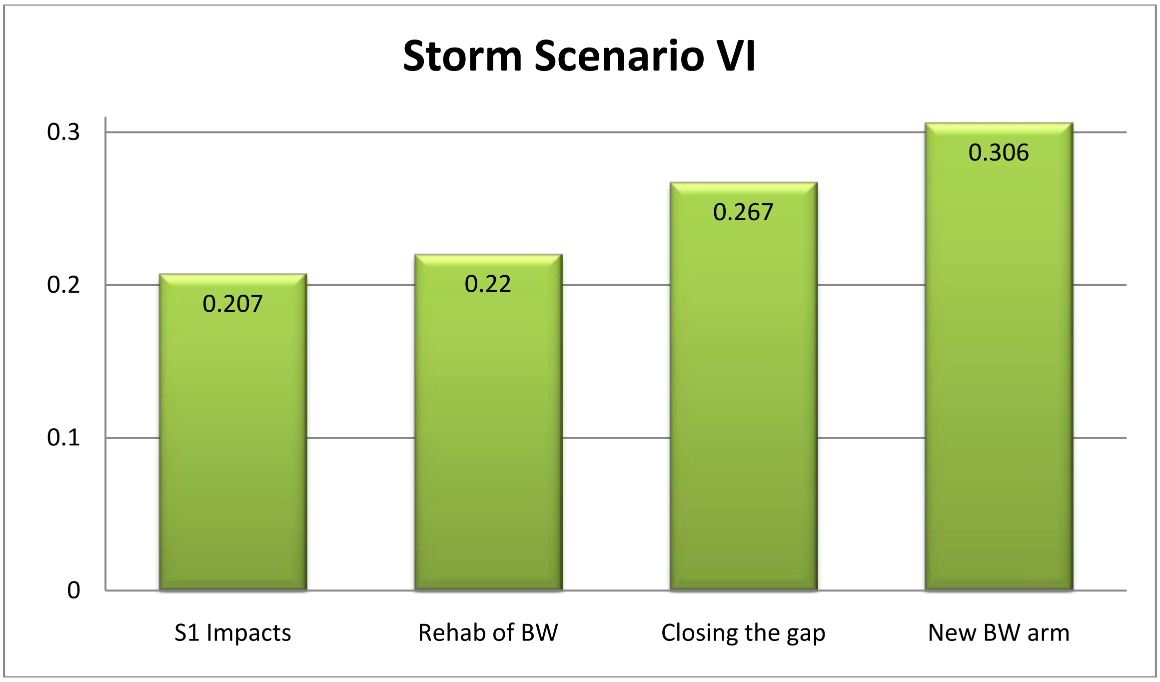


Figure 5.39. Comparison of all breakwater strategies on Storm Scenario VI impacts

As before, the “New Breakwater arm” significantly distances itself from other options and therefore is the best option as the storms become more severe.

It is evident from figures above that in case of Storm Scenario I, it is better to do nothing (Status Quo) rather than spending the resources of the community on suggested strategies that effectively do not yield a Community Profile indicator set that is preferable to the status quo, and do nothing option. As the severity of Storm Scenarios increase, however, contributions of these strategies become more significant with the apparent capability of the “new breakwater arm” to dominate clearly. The “New breakwater arm” strategy is therefore chosen as the best engineering candidate strategy for the inclusion in the analysis conducted in the next section which considers the “protect”, “accommodation”, “retreat” and “do nothing” options as the suite of adaptation strategies for comparison and analysis.

5.6.4. Comparison between "Retreat", "New Road Build Up" and "New Breakwater Arm" alternatives.

In this section three remaining alternatives along with the candidate from previous section – "New Breakwater Arm" are compared directly in the AHP model. Throughout figures 5.40 to 5.45 the final scores acquired by Expert Choice software (Expert Choice, 2000) are presented. What is presented here is a combined perspective of scores for the suite of adaptive strategies. For different stakeholder's scores per Storm Scenario refer also to Appendix D - Stakeholder's ranking on adaptation strategies for each scenario.

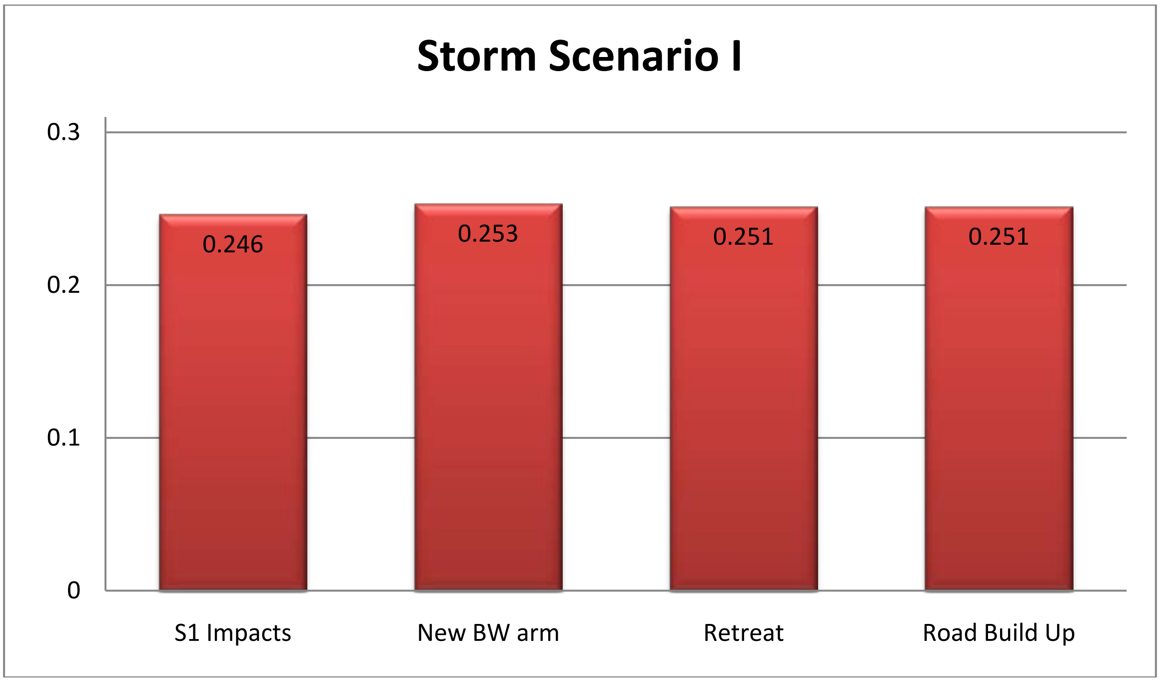


Figure 5.40. Comparison of "Retreat", "Road Build Up" and "New breakwater arm" strategies on Storm Scenario I impacts

All options are close to each other with "New breakwater arm" slightly better than others. Also, for this least severe storm scenario all options appear marginally better than the Status Quo (do nothing – "S1 Impacts") option.

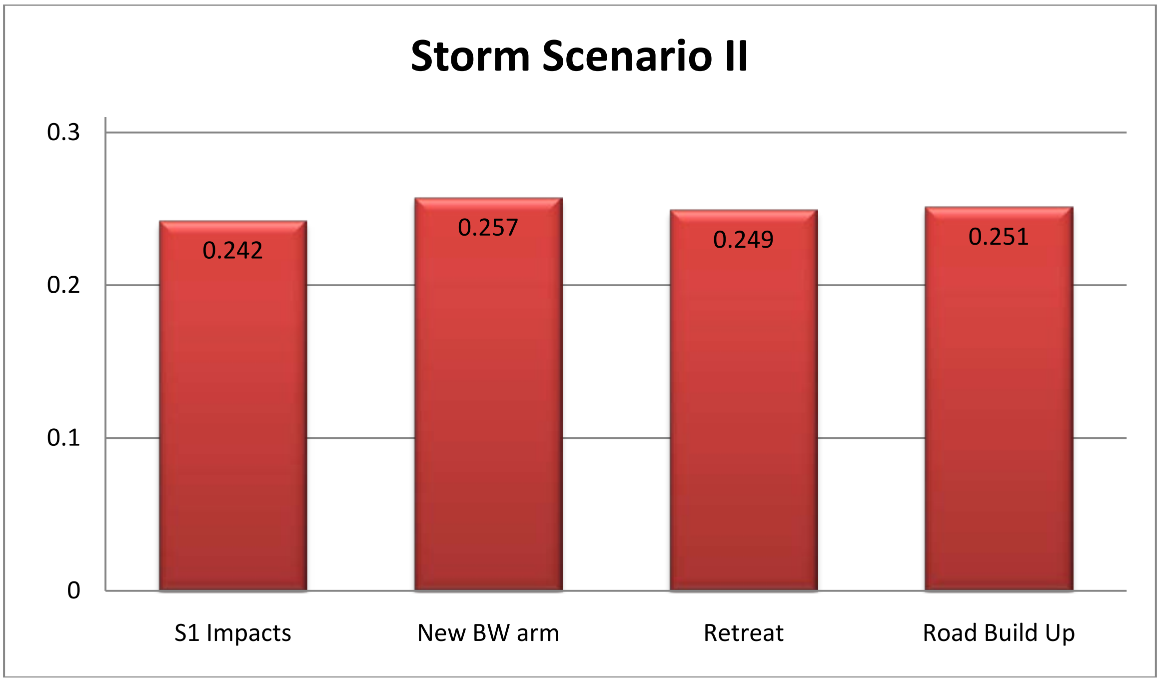


Figure 5.41. Comparison of "Retreat", "Road Build Up" and "New breakwater arm" strategies on Storm Scenario II impacts

All options are close to each other with "New breakwater arm" better than others. "Road build up" option is slightly better than the "Retreat" option with the Status Quo option diminishing in comparison to its valuation at the lower storm scenario (Figure 5.43).

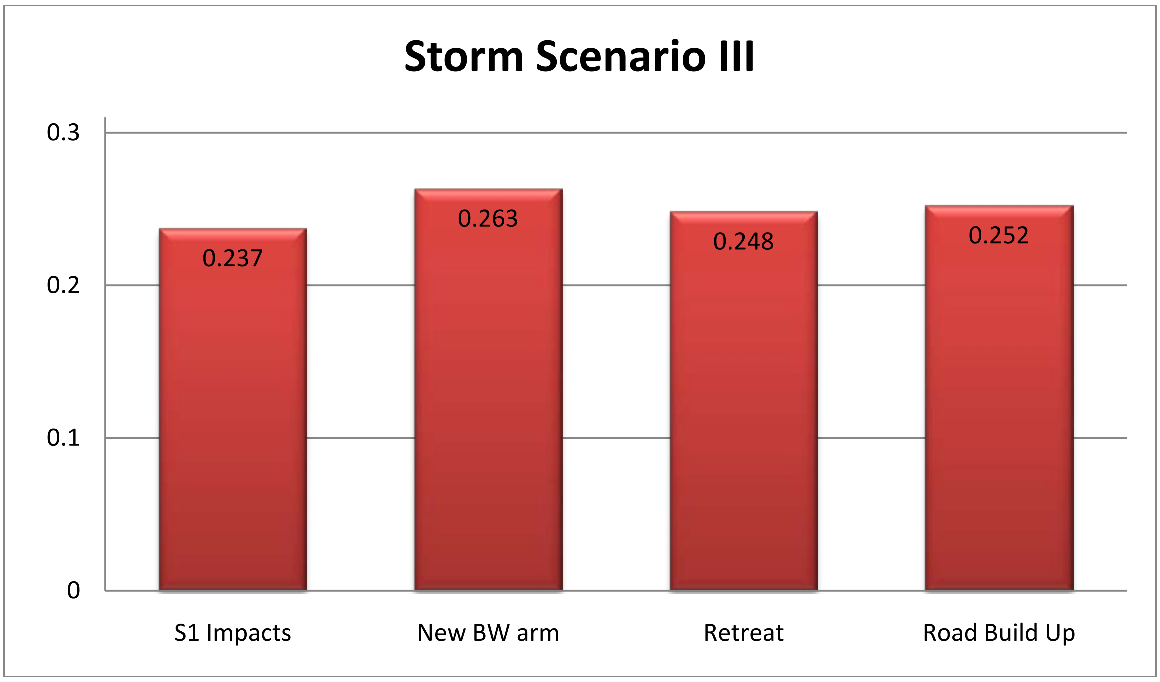


Figure 5.42. Comparison of "Retreat", "Road Build Up" and "New breakwater arm" strategies on Storm Scenario III impacts

"New breakwater arm" stands out among others. "Road build up" option is slightly better than "Retreat" option, and the Status Quo option is further reduced in comparison.

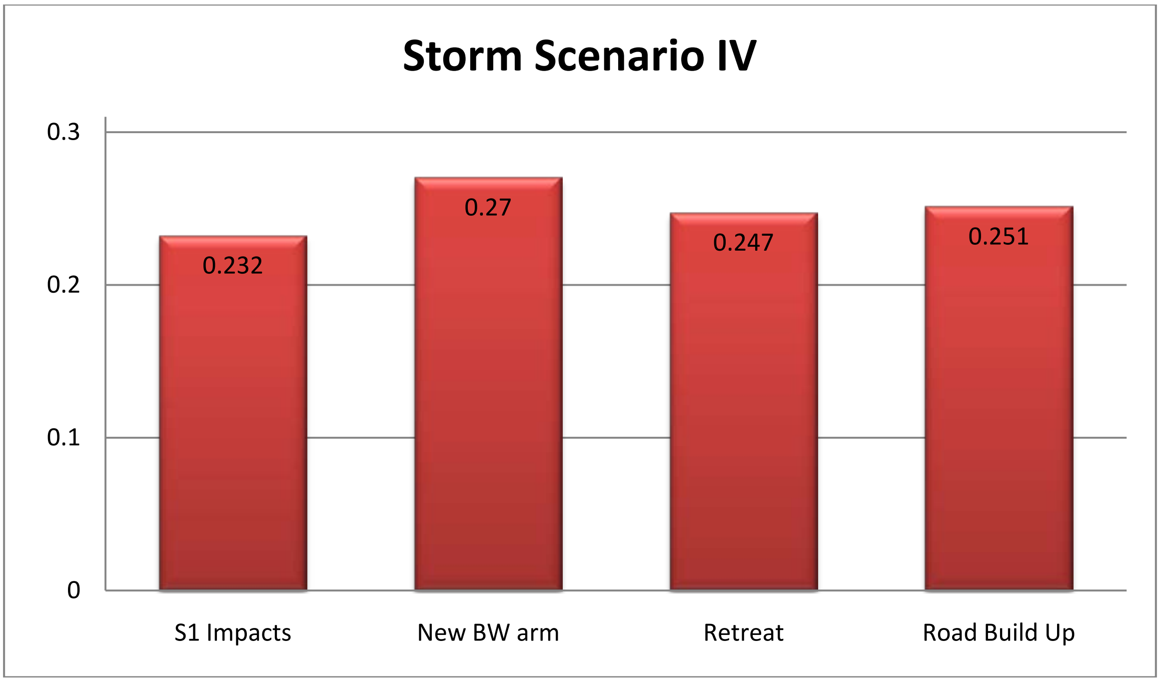


Figure 5.43. Comparison of "Retreat", "Road Build Up" and "New breakwater arm" strategies on Storm Scenario IV impacts

"New breakwater arm" stands out among others at this storm scenario level. "Road build up" option is marginally better than "Retreat" option.

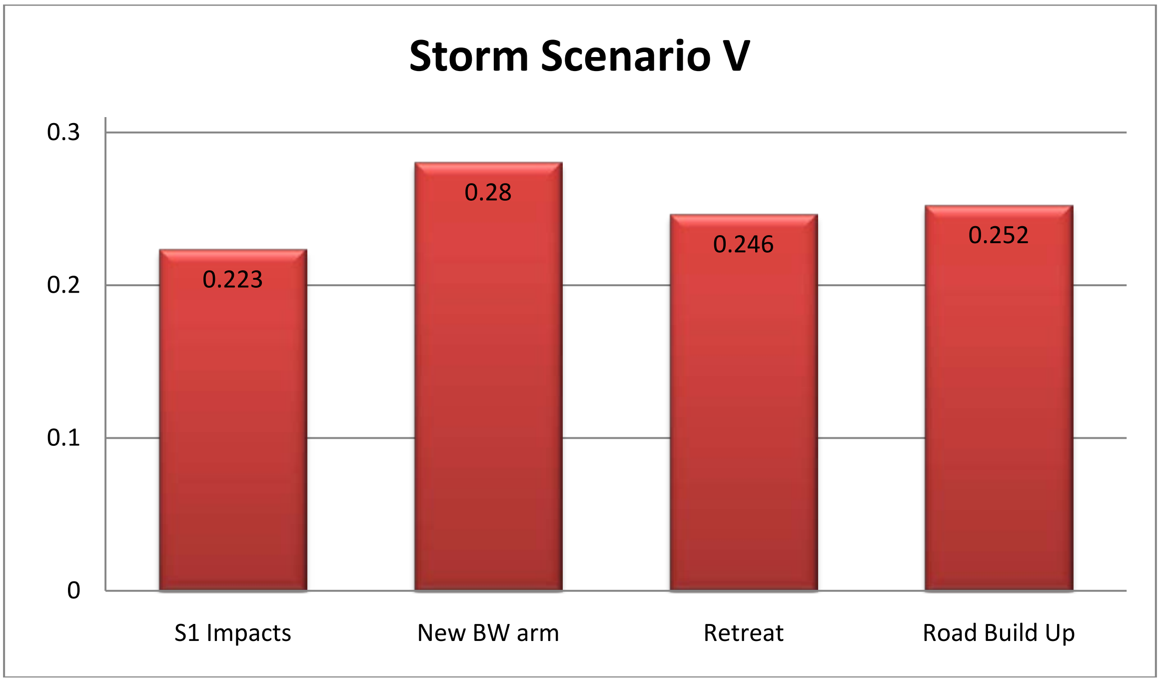


Figure 5.44. Comparison of “Retreat”, “Road Build Up” and “New breakwater arm” strategies on Storm Scenario V impacts

“New breakwater arm” stands out among others. “Road build up” option is better than “retreat” option.

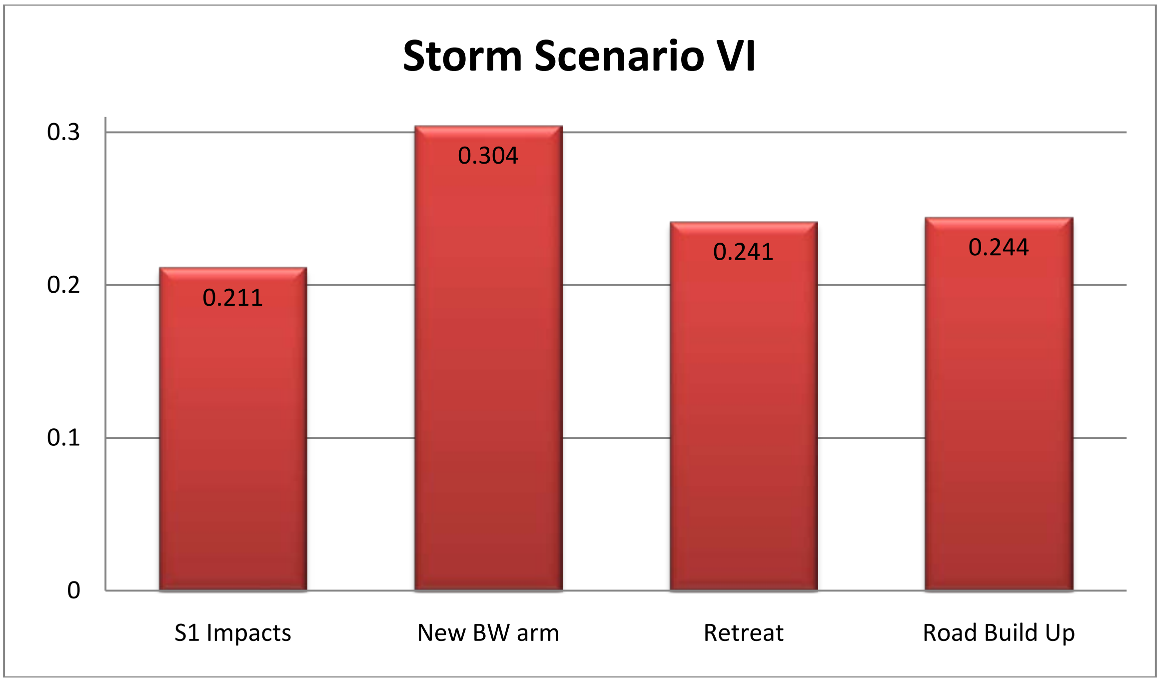


Figure 5.45. Comparison of "Retreat", "Road Build Up" and "New breakwater arm" strategies on Storm Scenario VI impacts

From above figures it is evident that "New breakwater arm" strategy stays dominant from Storm Scenario II to VI. Among all other alternatives this strategy makes the most significant contribution to mitigate the impacts of Storm Scenarios. "Road build up" strategy is slightly better than the "Retreat" option in all Storm Scenarios due principally to its low relative cost. Although compared to "Road build up", the "Retreat" strategy makes more contribution on indicators overall (houses, buildings, income, well and safety versus only road and safety in the case of "road build up" strategy) but the higher cost of "retreat" and the significance of the road (in terms of pair-wise comparison weights in the hierarchy) makes the "road build up" alternative superior to the "retreat" strategy.

By taking intangible costs into consideration (e.g., reluctance to abandon your house), the "Retreat" strategy can become even more inferior to other strategies.

Based on the discussion presented in Chapter 2 (subsection 2.1.5 and 2.1.4), group decision making analysis can be conducted from both input and output perspective. What is presented above is from the input perspective – Geometric mean method - which is the default method of Expert Choice software (Expert Choice, 2000). The same analysis is conducted from an output ("averaging") perspective and compared to the previous results. These are reported in summary form in Table 5.27.

Table 5.27. Comparison of results of input (combined) vs. output (average of rankings) perspectives

Storm Scenario I	Local Government	Business/Industry	Community	Professional	Average(output Perspective)	Combined(input perspective)
Status Quo	0.247	0.267	0.252	0.254	**0.255**	0.246
New BW Arm	0.251	0.236	0.248	0.245	0.245	**0.253**
Retreat	0.249	0.247	0.249	0.252	0.24925	0.251
road build up	0.253	0.25	0.251	0.249	0.25075	0.251
Storm Scenario II	Local Government	Business/Industry	Community	Professional	Average(output Perspective)	Combined(input perspective)
Status Quo	0.242	0.264	0.248	0.254	**0.252**	0.242
New BW Arm	0.257	0.24	0.253	0.245	0.24875	**0.257**
Retreat	0.247	0.246	0.248	0.252	0.24825	0.249
road build up	0.254	0.251	0.251	0.249	0.25125	0.251
Storm Scenario III	Local Government	Business/Industry	Community	Professional	Average(output Perspective)	Combined(input perspective)
Status Quo	0.237	0.26	0.244	0.247	0.247	0.237
New BW Arm	0.263	0.244	0.258	0.256	**0.25525**	**0.263**
Retreat	0.245	0.245	0.246	0.249	0.24625	0.248
road build up	0.255	0.251	0.251	0.248	0.25125	0.252
Storm Scenario IV	Local Government	Business/Industry	Community	Professional	Average(output Perspective)	Combined(input perspective)
Status Quo	0.231	0.256	0.239	0.242	0.242	0.232
New BW Arm	0.271	0.249	0.265	0.263	**0.262**	**0.27**

Retreat	0.244	0.244	0.245	0.248	0.24525	0.247
road build up	0.254	0.251	0.25	0.247	0.2505	0.251
Storm Scenario V	Local Government	Business/Industry	Community	Professional	Average(output Perspective)	Combined(input perspective)
Status Quo	0.221	0.25	0.232	0.236	0.23475	0.223
New BW Arm	0.282	0.256	0.274	0.272	**0.271**	**0.28**
Retreat	0.244	0.242	0.244	0.246	0.244	0.246
road build up	0.253	0.252	0.25	0.246	0.25025	0.252
Storm Scenario VI	Local Government	Business/Industry	Community	Professional	Average(output Perspective)	Combined(input perspective)
Status Quo	0.208	0.242	0.222	0.229	0.22525	0.211
New BW Arm	0.307	0.273	0.299	0.293	**0.293**	**0.304**
Retreat	0.24	0.236	0.238	0.239	0.23825	0.241
road build up	0.245	0.249	0.242	0.238	0.2435	0.244

The only discrepancy observed between these two methods is in Storm Scenarios I and II where the combined method (input perspective) suggests the option “New breakwater arm” and average method (output perspective) suggests “Status Quo” as the preferred alternative. For all other Storm Scenarios, the results are consistent among these two methods – “New breakwater arm” being the preferred alternative especially as storm severity increases. Superiority of the “Status Quo” (“do nothing”) strategy for these two Storm Scenarios suggests that considering the high costs of adaptation and small damages of Storm Scenarios I and II, it may not worth it to invest in any capital intensive adaptation strategies. However, it can be concluded that overall “New breakwater arm” is the most preferred adaptation alternative among others and that the “Retreat” is the least preferred among active adaptation options as analysed here for the case of the Little Anse breakwater.

Similar to the case of Isle Madame (Chapter 4), the vulnerability of the Little Anse community is evaluated based on the discussions in Chapter 3. Figure 5.46 illustrates the comparison of "No Storm" scenario with "Ideal" scenario along with other six Storm Scenarios. Figure 5.47 illustrates the comparison of "Ideal" scenario with "No Storm" scenario along with all other six Storm Scenarios.

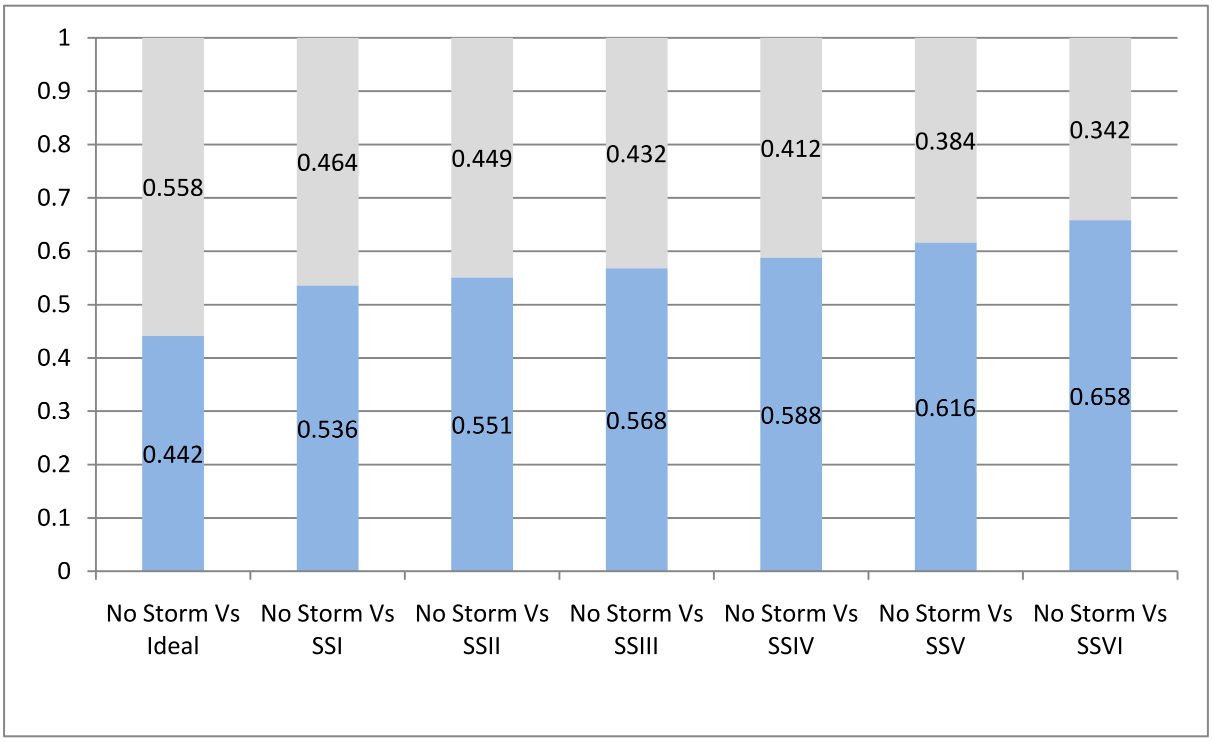


Figure 5.46. Comparison of "No Storm" scenario with "Ideal" and all six scenarios impacts

In Chapter 3 the concept of vulnerability was defined as the difference between the pre-storm and post-storm Community Profile states in terms of the weighted utility values of the indicators.

Based on this definition the vulnerability of the community can be evaluated with respect to each Storm Scenario. The difference between "No Storm" and each scenario's final score determines the vulnerability of the community with respect to that scenario. By moving from Storm Scenario I to VI the difference between the weighted utility values – "No Storm" and corresponding scenario – increase; therefore we can conclude that the community gets more vulnerable as the intensity of scenarios increase.

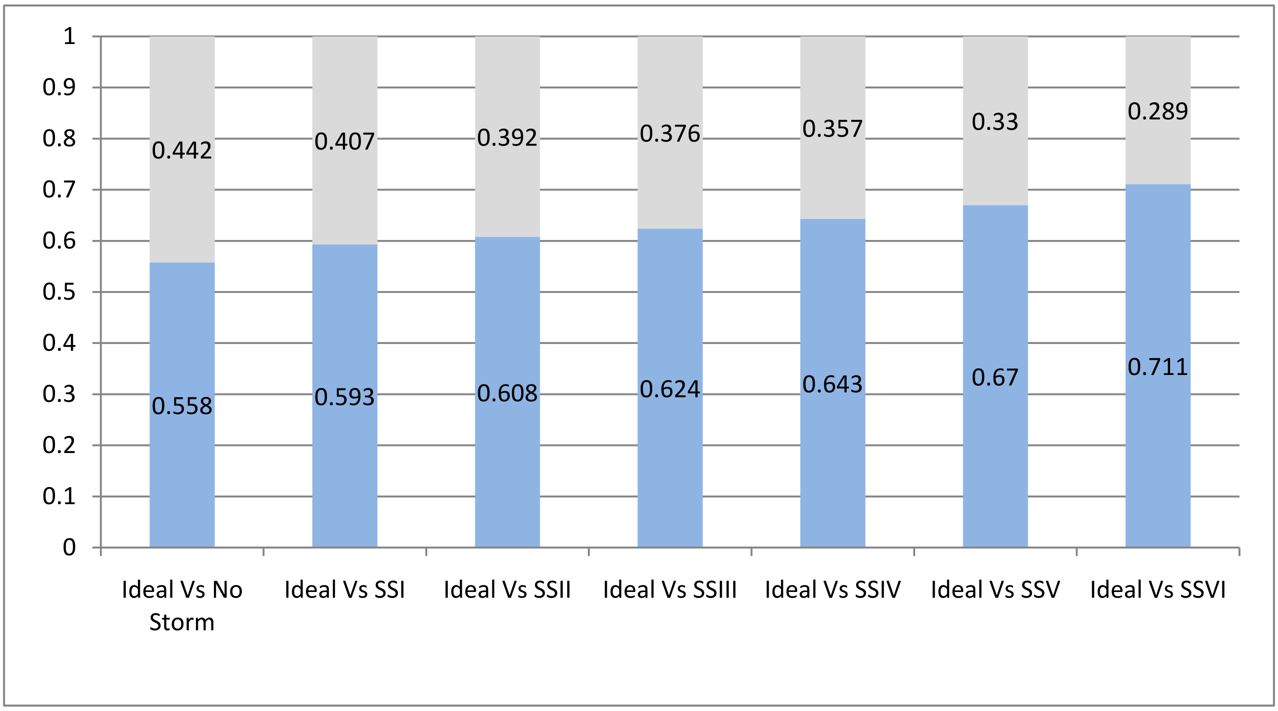


Figure 5.47. Comparison of "Ideal" scenario with "No Storm" and all six scenarios impacts

If vulnerability is analyzed as the difference between "Ideal" state and each Storm Scenario weighted utility values then such comparison results in a larger difference between these two values - compared to "No Storm" and each scenario – and therefore suggest a higher vulnerability of the community. However the trend is the same as discussed in the previous paragraph, in a sense that as the scenario's intensity increase the community gets more vulnerable.

Based on the discussion in Chapter 3, the concept of resilience is analyzed with respect to the contribution of adaptation strategies. "New Breakwater Arm" option is chosen for this part due to its superiority to other options. The impact of this strategy is compared with each of the six Storm Scenarios (Figure 5.48). In the figure below "NBA" has been used as an abbreviation for "New Breakwater Arm".

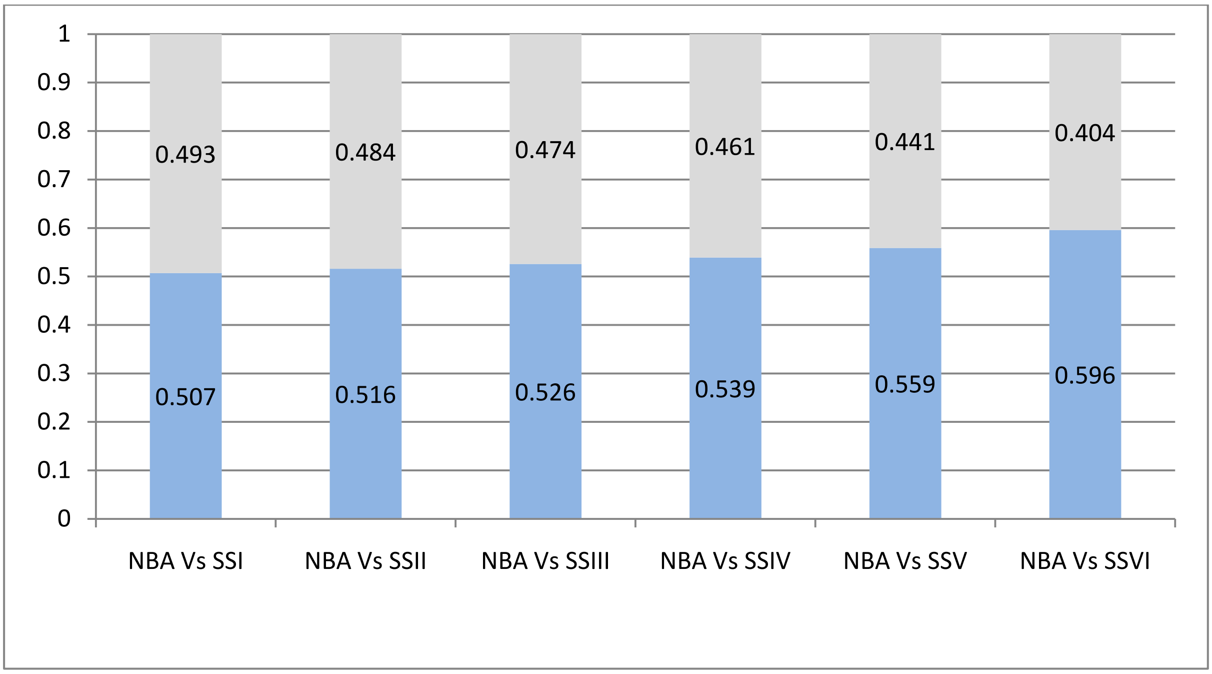


Figure 5.48. Comparison of "New Breakwater Arm" adaptation strategy with all the six Storm Scenarios' impacts

It is evident from figure above that the difference between the weighted utility values of "New Breakwater Arm" and each Storm Scenario increases as the Storm Scenarios become more severe. The lower differential weighted utility values are an indication of lower contribution of the adaptation strategy to the resilience of the community and vice versa. As the Storm Scenarios become more severe the contribution of this adaptation becomes more significant, therefore adding more toward the resilient of the community.

6. Conclusion and recommendation for future study

This chapter presents a summary of the thesis research including a reconciliation of the research results with the research objectives (Chapter 1) and a discussion of areas identified for future research. The first section of this chapter provides the thesis summary results with respect to the defined objectives. The latter section discusses recommendations for future research.

6.1. Summary of thesis results

The reader is reminded of the research objectives stated in Chapter 1. In the section below, these objectives are discussed. The thesis Objectives are as follows:

1) *To define a set of indicators in order to determine the extent of vulnerability of coastal communities to various climate change scenarios.* In order to answer this question an extensive literature review was conducted and presented in Chapter 2. These studies helped understand the meaning of vulnerability and its indicators. Vulnerability was examined from both social and physical perspective and concluded that a proper vulnerability framework should be an integration of both. Literature on vulnerability indicators was also examined and in Chapter 5 – where the case on Little Anse breakwater was presented – a set of vulnerability indicators for that community was suggested.

   Apart from identifying the vulnerability indicators, a model to suggest future Storm Scenarios relevant to our communities was also discussed. The case of Charlottetown as an example for modeling water level scenarios (Chapter 2 and Chapter 3) was analysed for this purpose. The methodology was applied to conduct the same analysis for Isle Madame's Storm Scenarios and its applicability for Little Anse community. Equipped with this knowledge we were ready to estimate the impacts of these Storm Scenarios on each vulnerability indicators.

2) *To identify social, economical, environmental and cultural impacts of environmental change scenarios.* The case of Isle Madame (Chapter 4) and the case of Little Anse breakwater (Chapter 5) was presented and the impacts of various Storm Scenarios on

economics, environmental, social and cultural indicators were analyzed for these communities. In Chapter 3, water level scenarios applicable to these communities were analyzed and by using ArcGIS the damages on communities' assets were analyzed (Chapter 4 and 5).

3) *To identify adaptation strategies and engage multiple community stakeholders to evaluate the desirability of such adaptation options.* In Chapter 5, adaptation strategies were suggested for the Little Anse community. The potential of mitigating the impacts of each Storm Scenario as the result of introducing these strategies were also analyzed.

Moreover, based on the AHP methodology a framework to evaluate preference of each adaptation strategy was introduced. With the knowledge that such measures should be analyzed from a group perspective, relevant stakeholders were introduced and a procedure to combine their different perspective suggested (Chapters 3, 4 and 5). This procedure was further applied to the case of Little Anse where the desirability of different adaptation options per Storm Scenario and from the perspective of each stakeholder was evaluated (Chapter 5).

In summary this research has developed a framework to evaluate and support decisions regarding adapting to environmental change impacts on coastal communities, where multiple participants and criteria exist.

This work applied to the cases discussed in the thesis has been designed so that it can be adopted by other communities within the C-Change project.

6.2. Recommendations for future research

A critical review of the thesis leads to further related research. The extension of the research stems from the efforts and difficulties associated with the current work. These extensions are itemized below.

1) Data

Information on various vulnerability aspects of small coastal communities is virtually nonexistent. In Chapter 3 the lack of historical data on storms relevant to coastal communities was discussed. An important component of future research would be in the development of a procedure to collect and categorize such information in a local community Storm Impacts Databases. Availability of detailed information with respect to Storm Scenarios can lead to the development of more accurate scenarios, better storm damage estimates and a clearer picture of where preparedness would be most significant. The existence of such information combined with a high resolution digital elevation maps (DEM) such as LIDAR can bring much improved accuracy to GIS based results.

2) Storm Damage Estimates

Much effort has been put through this research to derive a procedure to estimate damages and "at risk" values with respect to each community's asset. Future research is needed to emphasize a common procedure for storm damage accounting where a set of guidelines can be provided in order to report on damages on various community's asset.

Although the most significant storm related impact - storm surge and flooding is considered for this research, there are other storm related stresses such as direct damage from wind and precipitation. Adding these stresses will make the storm impact analysis more complete.

3) Extension of the Evaluation Framework to Other Communities

Coastal communities located in Canada – Isle Madame and Little Anse – were considered for applying the vulnerability and adaptive strategy evaluation framework. Applying this framework to other coastal communities will add to the applicability and generalization of our framework. This is particularly relevant to the C-Change ICURA project that includes communities throughput Canada's coastal zone as well as communities in the Caribbean. Note that every community is different and will require different indicators and valuations. Vulnerability indicators considered for Isle Madame were unique to that community (Chapter 4) as well as Little Anse which has its own set of indicators (Chapter 5).

4) Deterministic Analysis:

This research assumes a deterministic approach toward storm events and as a result, damage and "at risk" estimations are also deterministic. With the light of more data on historical storms, future research can expand this deterministic approach toward including probabilities in such estimations.

5) Sensitivity Analysis

AHP sensitivity analysis can be conducted to examine the impacts of altered weights, changes in utility and alternative approaches to multi-participant information. In future research, sensitivity analysis can be provided to reflect the robustness of such study with respect to AHP model parameters. By altering weights for example it can be determined that how sensitive are tradeoffs of each stakeholder with respect to vulnerability indicators of AHP hierarchy. Such analysis can be aided by tools provided in Expert Choice (Expert Choice 2000) environment such as various Sensitivity Graphs.

Future study can also focus on an appropriate implementation procedure and possible obstacles of recommended adaptation strategies in this research.

6) Exploration of Other Decision Methods

Analytical Hierarchy Process (AHP) was utilized as the decision support tool for this study. In Chapter 1, evidence from the literature about the appropriateness of this method to our study was examined. However a possible extension can be to utilize a different MCDM method to conduct such a study and compare the results with this AHP based research.

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Appendix A: Community Data Profile – Template

The SSHRC-IDRC ICURA project "Community Profile Metadata set" has been developed as part of the C-Change program. The elements of the Community Profile are currently being applied to the description of all Canadian C-Change communities. This work has been presented in Hartt (2011), Pakdel (2011), and in C-Change Working Paper No, 2, Hartt et al (2011) available in draft form from the C-Change website at www.coastalchange.ca. The dimensions, categories and indicators of the Community Profile are shown in the table below. Selected and relevant indicators from the Commuity Data Profile provided below are used in the this thesis in the construction of the multicriteria decision support system developed here and applied in the problem settings in Isle Madame and the Little Anse breakwater.

No.	Main Dimensions	#	Level 1 Categories	No.	Indicators
1	Environmental	A	Topography	I	Land Area
				II	Mean Elevation
				III	Lowest Point
				IV	Highest Point
				V	Slope
		B	Hydrology	I	Watershed Boundaries
				II	Lakes, Rivers, Streams
		C	Coastal Geomorphology	I	Length
				II	Physical Composition
				III	Bathymetry
				IV	Ports and Harbours
				V	Wave Climate

				VI	Sedimentation and Erosion
		D	Habitat and Species	I	Terrestrial
				II	Fresh and salt water wetlands
				III	Aquatic
				IV	Migratory species and routes
				V	Rare/Endangered
		E	Land Cover	I	Forests
				II	Wetlands
				III	Barrens
				IV	Grasslands and Pastures
				V	Flood Plains and Hazard Lands
		F	Land Use	I	Town Centers
				II	Industrial
				III	Commercial
				IV	Residential
				V	Agriculture
				VI	Forestry
				VII	Mineral extraction
				VIII	Transportation and utilities
				IX	Energy production
				X	Parks and open space
				XI	Beaches

				XII	Protected Areas
				XIII	Scenic/historical/cultural areas
				XIV	Tourism
		G	Marine Use	I	Aquaculture
				II	Marine Benthic
				III	Recreational Fishing
				IV	Commercial Fishing
				V	Recreational Boating
				VI	Transportation routes
				VII	Tourism
				VIII	Protected areas
				IX	Scenic/historical/cultural areas
		I	Climate	I	Mean temperatures
				II	Mean precipitation
				III	Prevailing winds and wind speed
				IV	Storm events
				V	High tides and storm surges
2	Economic	A	Industry by Type	I	Agriculture and other resourced based occupations
				II	Constructions
				III	Manufacturing
				IV	Wholesale trade

				V	Retail
				VI	Finance and real estate
				VII	Heath care and social services educational services
				VIII	Other services
		B	Industry Revenues	I	Natural resources
				II	Tourism
				III	Commercial
				IV	Industrial
		C	Built Environment	I	Private dwellings
				II	Industrial structures
				III	Commercial structures
				IV	Retail structures
				V	Coastal structures
				VI	Fuel storage
		D	Public Works	I	Government buildings
				II	Fire fighting
				III	Policing
				IV	Hospitals
				V	Solid waste management systems
				VI	Municipal wastewater systems
				VII	Storm water collection and disposal systems

				VIII	Potable water source, treatment and supply systems
				IX	Energy generation and supply systems
				X	Transportation systems
		E	Real-Estate Values	I	Residential property
				II	Coastal residential property
				III	Coastal tourism property
				IV	Commercial property value
				V	Industrial property value
				VI	Municipal tax base
				VII	Average value of owned dwellings
3	Social	A	Population Statistics	I	Population in 2006
				II	Population in 2001
				III	Population density per sq. Km
				IV	Median age of the population
				V	Population change (%)
				VI	Aboriginal population
				VII	Population less than 14 years of age
				VIII	Population 15 – 59 years of age
				IX	Population over 60 years of age
		B	Education	I	School

				II	No certificate, diploma, degree
				III	High school certificate
				IV	College or non-university certificate
				V	University diploma below Bachelors
				VI	University certificate, diploma, degree
		C	Health Status	I	Morbidity rates
				II	Mortality rates/average age
				III	# of hospitals/clinics/hospices/other health care centers per capita
				IV	Number of residences without family doctor
				V	How does the community perceive their health/happiness
				VI	Recreation Places (sport field, shooting range…)
				VII	Hospitals/clinics…
		D	Occupation by Type	I	Management
				II	Business, finance, or administration
				III	Natural/applied sciences
				IV	Social science, education, government, religion

				V	Sales and service
				VI	Trades, transport, and equipment
				VII	Unique to primary industry
				VIII	Processing, manufacturing, or utilities
		E	Employment and Earnings	I	Total population (over age 15) in labor force
				II	Employment/unemployment rate
				III	Median income (all census families)
				IV	Median income (all private households)
				V	Median earnings (age 15 and over)
4	Cultural	A	Governance Systems	I	Government agencies (federal, provincial, municipal, EMR, other)
				II	First Nations, aboriginal, Métis
				III	Other non-government organizations (co-management, advisory boards)
				IV	Enabling legislation (Planning Acts, Municipal By-laws, Environmental Protection Acts)
				V	Decision-making processes

		B	Community Dynamics	I	Community leaders
				II	Business leaders
				III	Important Families
				IV	Other traditional/significant people
		C	Community Groupings	I	Religious
				II	Language
				III	Family organization
				IV	Traditions/heritage
		D	Communications Resources	I	Community newspapers, other print media/news
				II	Local access cable TV Channel
				III	Local radio stations
				IV	Television (homes with television)
				V	Telephones (homes with, cell phone users)
				VI	Internet Access (homes with, schools with, public access)
		E	Language	I	English only
				II	French only
				III	French and English
				IV	No French or English
		F	Places of	I	Sacred sites

			Significance	II	Historical sites
				III	Museum
				IV	Church and Cemetery
				V	library
				VI	Historic site
				VII	Archaeological and anthropological Sites
		G	Cultural Events		

Table A.1: Dimensions, Level 1 Categories and Indicators of the C-Change Community Data Profile Template

Appendix B - HURDAT files of Charlottetown's related storms (Best tracks)

Tables H.1 to H.9 present historical storms related to Charlottetown with details like date, speed, wind, pressure and type of the storm. In these tables the highlighted row indicates the variables used for Charlottetown. Figures H1 to H8 illustrate storms tracks of Charlottetown's historical storms.

Table H1: Charlottetown's historical storm (Hanna)

Source: NOAA (2010)

Storm Name	Month	Day	Hour	Lat.	Long.	Dir.	Speed	Wind	Pressure	-------Type-------
Hanna 2008										
	September	3	0 UTC	20.4N	72.6W	125 deg	5 kph	100 kph	988 mb	Tropical Storm
	September	3	6 UTC	20.2N	72.4W	135 deg	3 kph	95 kph	991 mb	Tropical Storm
	September	3	12 UTC	20.6N	71.9W	50 deg	11 kph	85 kph	996 mb	Tropical Storm
	September	3	18 UTC	21.6N	71.8W	5 deg	18 kph	95 kph	994 mb	Tropical Storm
	September	4	0 UTC	22.7N	71.8W	0 deg	20 kph	100 kph	989 mb	Tropical Storm
	September	4	6 UTC	23.4N	72.4W	320 deg	14 kph	110 kph	990 mb	Tropical Storm
	September	4	12 UTC	24.1N	73.2W	315 deg	18 kph	100 kph	989 mb	Tropical Storm
	September	4	18 UTC	25.1N	74.3W	315 deg	25 kph	100 kph	989 mb	Tropical Storm
	September	5	0 UTC	26.1N	75.8W	305 deg	29 kph	100 kph	987 mb	Tropical Storm

	September	5	6 UTC	27.2N	77.3W	310 deg	31 kph	100 kph	984 mb	Tropical Storm
	September	5	12 UTC	28.2N	78.5W	315 deg	25 kph	100 kph	980 mb	Tropical Storm
	September	5	18 UTC	29.9N	78.7W	355 deg	31 kph	110 kph	980 mb	Tropical Storm
	September	6	0 UTC	31.5N	79.3W	340 deg	29 kph	110 kph	980 mb	Tropical Storm
	September	6	6 UTC	33.8N	78.7W	10 deg	42 kph	110 kph	981 mb	Tropical Storm
	September	6	12 UTC	35.7N	78.1W	15 deg	35 kph	85 kph	985 mb	Tropical Storm
	September	6	18 UTC	37.8N	76.7W	30 deg	42 kph	85 kph	993 mb	Tropical Storm
	September	7	0 UTC	40.0N	74.5W	40 deg	50 kph	85 kph	994 mb	Tropical Storm
	September	7	6 UTC	41.9N	71.7W	50 deg	51 kph	85 kph	995 mb	Extratropical Storm
	September	7	12 UTC	43.8N	68.0W	55 deg	61 kph	85 kph	995 mb	Extratropical Storm
	September	7	18 UTC	45.7N	63.7W	60 deg	64 kph	85 kph	995 mb	Extratropical Storm
	September	8	0 UTC	47.0N	59.1W	70 deg	63 kph	75 kph	996 mb	Extratropical Storm
	September	8	6 UTC	47.5N	55.4W	80 deg	46 kph	75 kph	996 mb	Extratropical Storm

Table H2: Charlottetown's historical storm (Juan)

Source: NOAA (2010)

Juan 2003										
	September	27	0 UTC	33.3N	62.0W	0 deg	12 kph	140 kph	984 mb	Hurricane - Category 1
	September	27	6 UTC	34.4N	62.2W	350 deg	20 kph	140 kph	981 mb	Hurricane - Category 1
	September	27	12 UTC	35.2N	62.8W	330 deg	16 kph	140 kph	979 mb	Hurricane - Category 1
	September	27	18 UTC	35.5N	63.2W	315 deg	7 kph	165 kph	969 mb	Hurricane - Category 2
	September	28	0 UTC	36.3N	63.6W	340 deg	14 kph	165 kph	970 mb	Hurricane - Category 2
	September	28	6 UTC	37.1N	64.0W	340 deg	14 kph	165 kph	970 mb	Hurricane - Category 2
	September	28	12 UTC	38.5N	64.1W	355 deg	25 kph	165 kph	970 mb	Hurricane - Category 2
	September	28	18 UTC	40.2N	64.1W	0 deg	31 kph	165 kph	970 mb	Hurricane - Category 2
	September	29	0 UTC	42.8N	63.9W	5 deg	48 kph	160 kph	972 mb	Hurricane - Category 2
	September	29	6 UTC	46.0N	63.8W	0 deg	59 kph	120 kph	982 mb	Hurricane - Category 1
	September	29	12 UTC	49.8N	62.4W	15 deg	72 kph	85 kph	995 mb	Tropical Storm

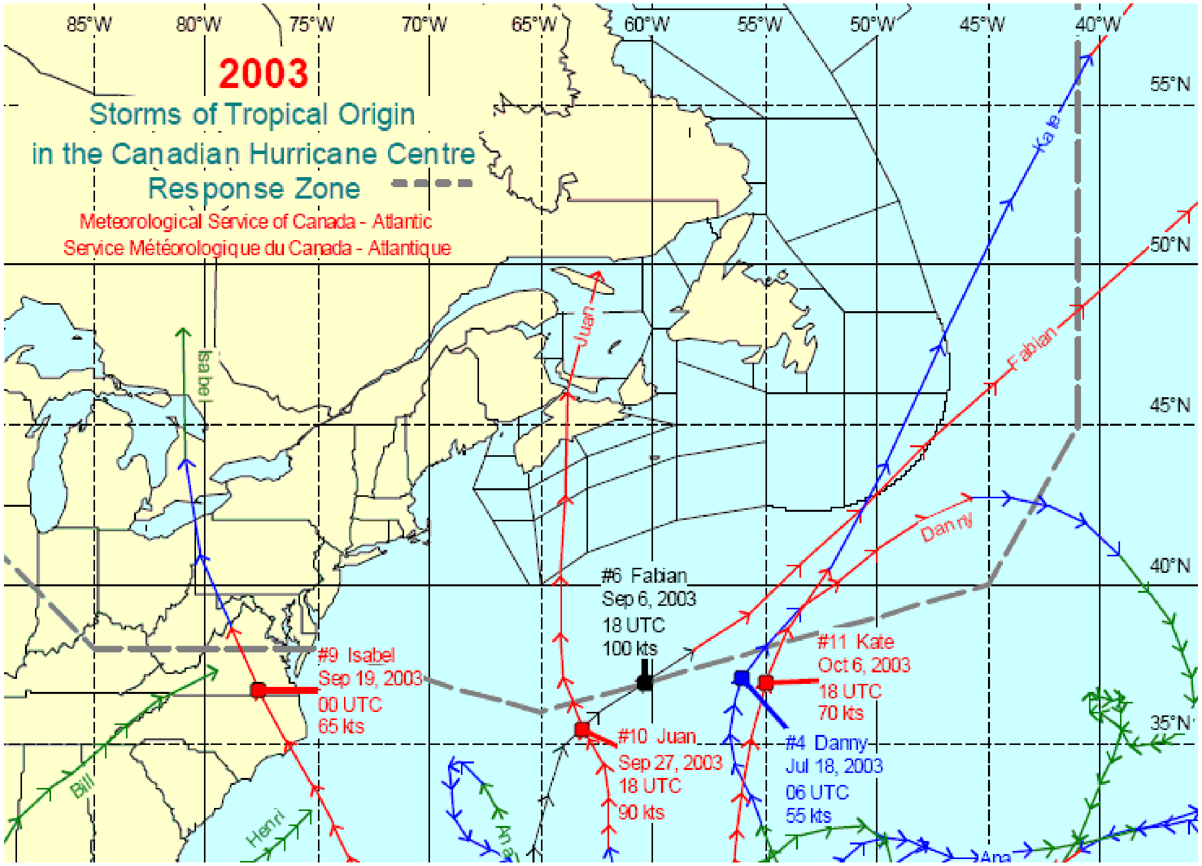


Figure H1: Hurricane Juan's best track

Source: Environment Canada (2010)

Table H3: Charlottetown's historical storm (Gustav)

Source: NOAA (2010)

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

	September	13	12 UTC	54.5N	51.4W	20 deg	38 kph	85 kph	972 mb	Extratropical Storm
	September	13	18 UTC	56.0N	49.5W	35 deg	33 kph	85 kph	976 mb	Extratropical Storm
	September	14	0 UTC	57.0N	51.5W	310 deg	25 kph	75 kph	982 mb	Extratropical Storm

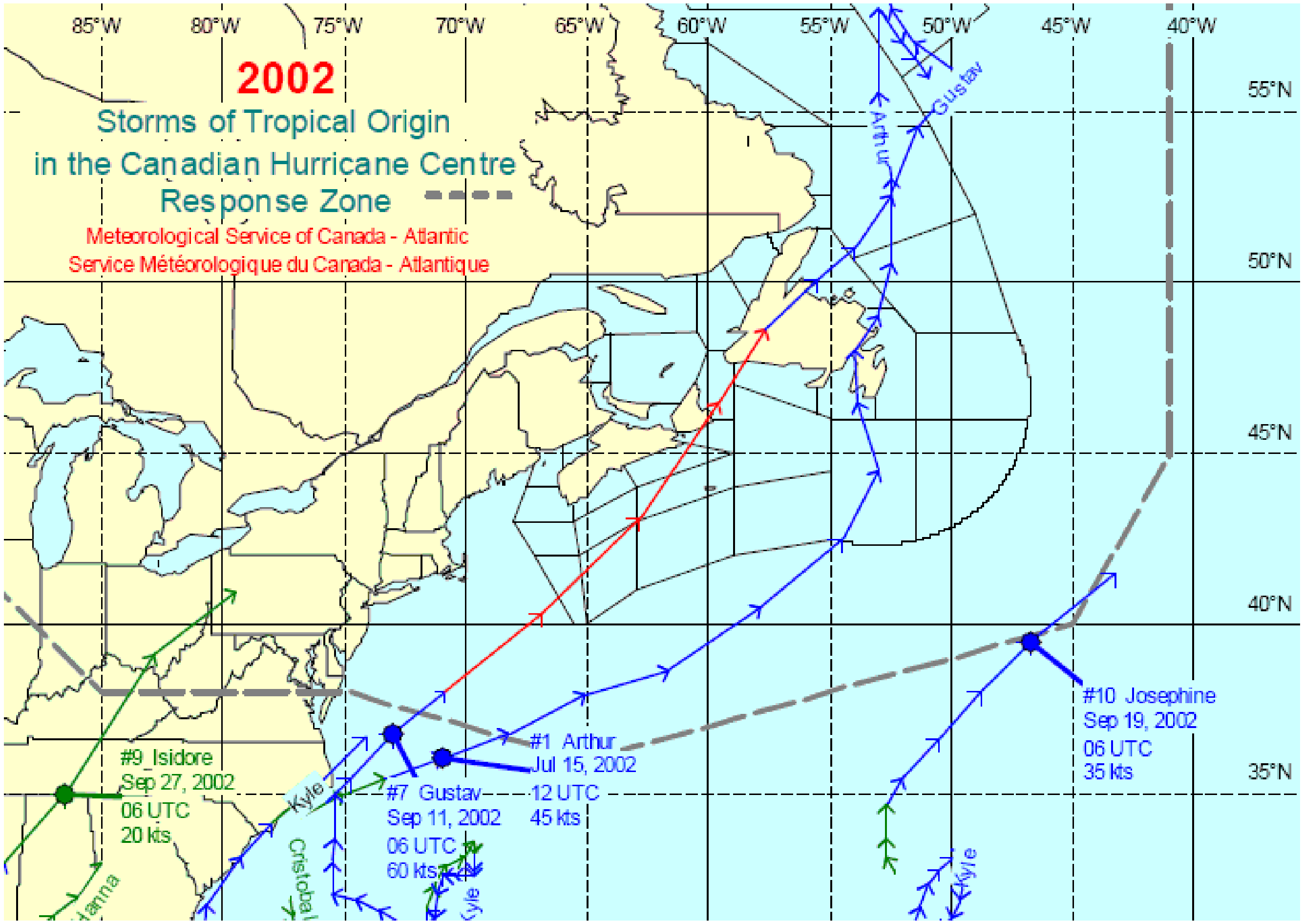


Figure H2: Hurricane Gustav's best track

Source: Environment Canada (2010)

Table H4: Charlottetown's historical storm (Subtrop)

Source: NOAA (2010)

Subtrop 2000										
	October	27	0 UTC	29.2N	72.5W	340 deg	16 kph	95 kph	997 mb	Subtropical Storm
	October	27	6 UTC	30.0N	72.6W	355 deg	14 kph	95 kph	997 mb	Subtropical Storm
	October	27	12 UTC	30.9N	72.5W	5 deg	16 kph	95 kph	997 mb	Subtropical Storm
	October	27	18 UTC	32.6N	71.6W	25 deg	33 kph	95 kph	996 mb	Subtropical Storm
	October	28	0 UTC	34.2N	70.7W	25 deg	31 kph	95 kph	994 mb	Subtropical Storm
	October	28	6 UTC	35.7N	69.9W	25 deg	29 kph	95 kph	992 mb	Subtropical Storm
	October	28	12 UTC	36.5N	68.1W	60 deg	29 kph	95 kph	990 mb	Subtropical Storm
	October	28	18 UTC	38.0N	65.5W	55 deg	46 kph	100 kph	984 mb	Subtropical Storm
	October	29	0 UTC	40.5N	62.6W	40 deg	61 kph	100 kph	978 mb	Subtropical Storm
	October	29	6 UTC	44.0N	60.0W	30 deg	72 kph	95 kph	980 mb	Extratropical Storm
	October	29	12 UTC	46.0N	59.5W	10 deg	37 kph	85 kph	992 mb	Extratropical Storm

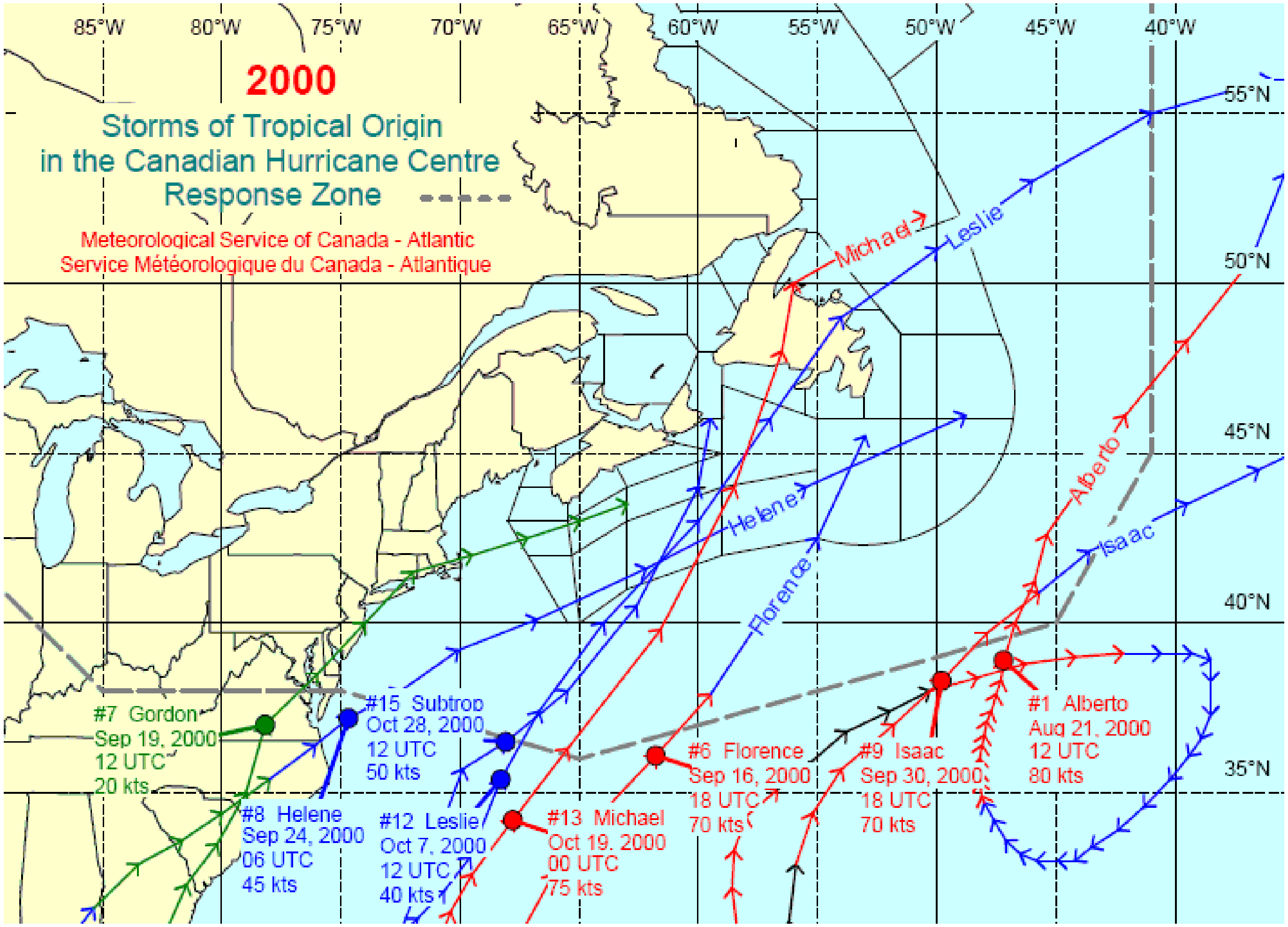


Figure H3: Subtrop's best track

Source: Environment Canada (2010)

Table H5: Charlottetown's historical storm (Hortense)

Source: NOAA (2010)

Hortense 1996										
	September	12	6 UTC	23.0N	71.4W	340 deg	12 kph	195 kph	962 mb	Major Hurricane - Category 3
	September	12	12 UTC	23.9N	71.8W	340 deg	16 kph	215 kph	959 mb	Major Hurricane - Category 4
	September	12	18 UTC	24.7N	71.8W	0 deg	14 kph	215 kph	946 mb	Major Hurricane - Category 4
	September	13	0 UTC	25.9N	71.5W	15 deg	22 kph	220 kph	935 mb	Major Hurricane - Category 4
	September	13	6 UTC	27.2N	71.4W	5 deg	24 kph	215 kph	942 mb	Major Hurricane - Category 4
	September	13	12 UTC	29.0N	70.9W	15 deg	33 kph	185 kph	948 mb	Major Hurricane - Category 3
	September	13	18 UTC	31.0N	70.3W	15 deg	37 kph	185 kph	948 mb	Major Hurricane - Category 3
	September	14	0 UTC	33.3N	69.5W	15 deg	42 kph	165 kph	948 mb	Hurricane - Category 2
	September	14	6 UTC	35.9N	68.4W	20 deg	50 kph	165 kph	955 mb	Hurricane - Category 2
	September	14	12 UTC	38.5N	67.1W	20 deg	50 kph	160 kph	960 mb	Hurricane - Category 2
	September	14	18 UTC	42.0N	65.2W	25 deg	68 kph	140 kph	960 mb	Hurricane - Category 1
	September	15	0 UTC	44.3N	63.3W	30 deg	48 kph	130 kph	970 mb	Hurricane - Category 1
	September	15	6 UTC	45.5N	61.5W	45 deg	31 kph	120 kph	980 mb	Hurricane - Category 1
	September	15	12 UTC	46.3N	59.1W	65 deg	33 kph	110 kph	982 mb	Tropical Storm

	September	15	18 UTC	46.0N	55.0W	95 deg	51 kph	75 kph	996 mb	Extratropical Storm
	September	16	0 UTC	46.0N	54.0W	90 deg	11 kph	75 kph	998 mb	Extratropical Storm
	September	16	6 UTC	45.0N	50.0W	110 deg	53 kph	65 kph	999 mb	Extratropical Storm

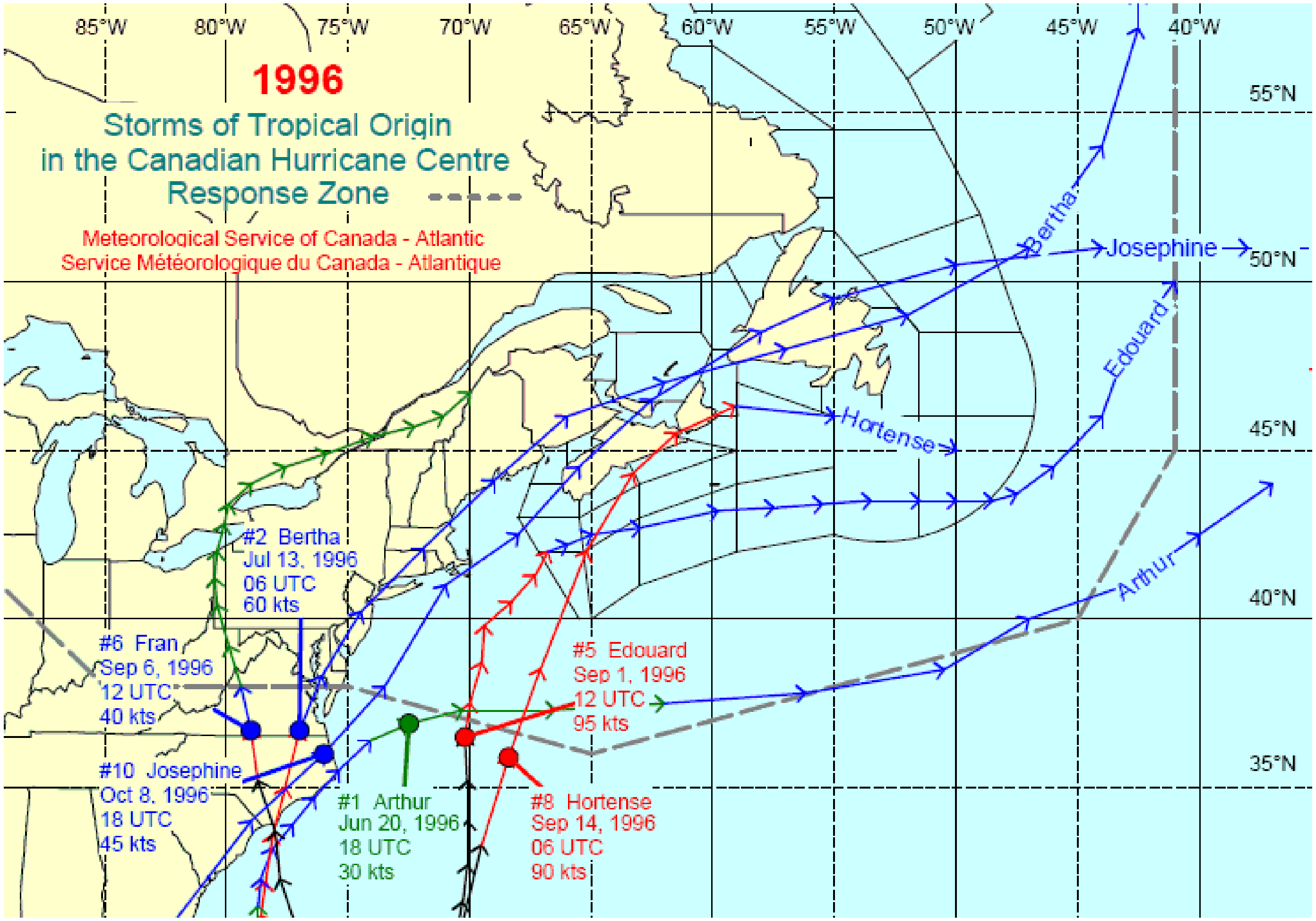


Figure H4: Hortense's best track

Source: Environment Canada (2010)

Table H6: Charlottetown's historical storm (Blanche)

Source: NOAA (2010)

Blanche 1975										
	July	26	0 UTC	31.0N	75.0W	355 deg	20 kph	55 kph	1005 mb	Tropical Depression
	July	26	6 UTC	32.2N	74.6W	15 deg	22 kph	65 kph	1004 mb	Tropical Storm
	July	26	12 UTC	33.4N	73.5W	40 deg	27 kph	65 kph	1003 mb	Tropical Storm
	July	26	18 UTC	34.2N	72.2W	55 deg	24 kph	95 kph	998 mb	Tropical Storm
	July	27	0 UTC	35.0N	71.0W	50 deg	22 kph	110 kph	992 mb	Tropical Storm
	July	27	6 UTC	35.9N	70.0W	40 deg	22 kph	120 kph	987 mb	Hurricane - Category 1
	July	27	12 UTC	36.9N	69.0W	40 deg	22 kph	130 kph	984 mb	Hurricane - Category 1
	July	27	18 UTC	37.9N	68.0W	40 deg	22 kph	140 kph	981 mb	Hurricane - Category 1
	July	28	0 UTC	39.3N	67.2W	25 deg	27 kph	140 kph	980 mb	Hurricane - Category 1
	July	28	6 UTC	41.2N	66.4W	20 deg	35 kph	130 kph	980 mb	Hurricane - Category 1
	July	28	12 UTC	44.0N	65.2W	20 deg	53 kph	110 kph	988 mb	Extratropical Storm
	July	28	18 UTC	47.2N	62.4W	30 deg	68 kph	110 kph	992 mb	Extratropical Storm

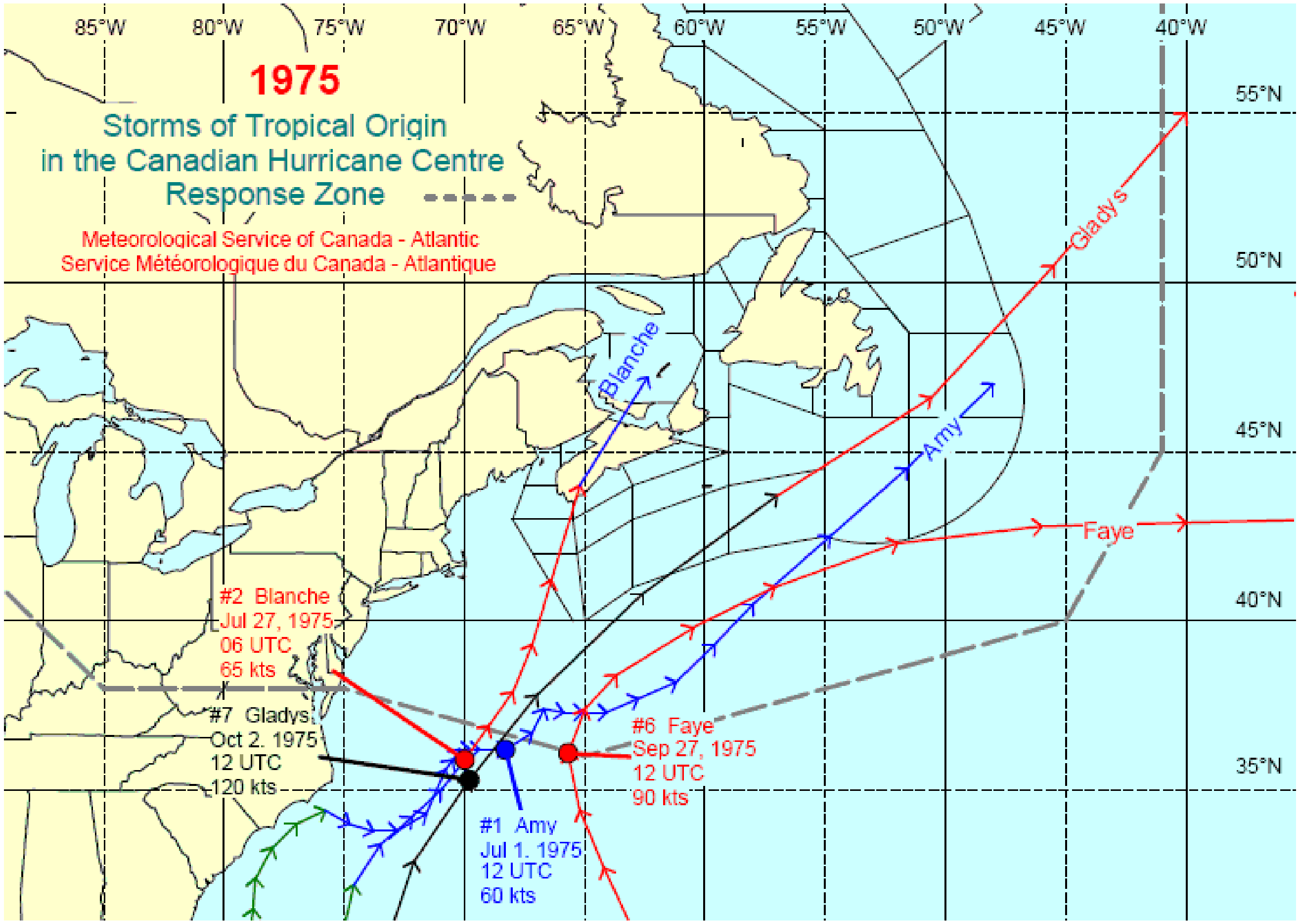


Figure H5: Blanche's best track

Source: Environment Canada (2010)

Table H7: Charlottetown's historical storm (Genny)

Source: NOAA (2010)

Genny 1963										
	October	26	0 UTC	32.4N	78.1W	70 deg	14 kph	160 kph	-- mb	Hurricane - Category 2
	October	26	6 UTC	33.2N	77.3W	40 deg	18 kph	150 kph	988 mb	Hurricane - Category 1
	October	26	12 UTC	33.2N	76.9W	90 deg	5 kph	150 kph	986 mb	Hurricane - Category 1
	October	26	18 UTC	32.9N	76.5W	130 deg	7 kph	140 kph	978 mb	Hurricane - Category 1
	October	27	0 UTC	33.0N	76.0W	75 deg	7 kph	130 kph	979 mb	Hurricane - Category 1
	October	27	6 UTC	32.9N	75.9W	140 deg	1 kph	130 kph	980 mb	Hurricane - Category 1
	October	27	12 UTC	32.9N	75.3W	90 deg	9 kph	130 kph	972 mb	Hurricane - Category 1
	October	27	18 UTC	32.7N	74.6W	110 deg	11 kph	140 kph	975 mb	Hurricane - Category 1
	October	28	0 UTC	32.6N	73.4W	95 deg	18 kph	140 kph	-- mb	Hurricane - Category 1
	October	28	6 UTC	33.2N	72.9W	35 deg	12 kph	150 kph	-- mb	Hurricane - Category 1
	October	28	12 UTC	33.9N	72.3W	35 deg	14 kph	150 kph	968 mb	Hurricane - Category 1
	October	28	18 UTC	35.1N	71.5W	30 deg	24 kph	160 kph	963 mb	Hurricane - Category 2
	October	29	0 UTC	36.3N	70.3W	40 deg	27 kph	175 kph	-- mb	Hurricane - Category 2
	October	29	6 UTC	37.8N	68.8W	40 deg	35 kph	175 kph	-- mb	Hurricane - Category 2

	October	29	12 UTC	40.8N	67.2W	20 deg	59 kph	175 kph	958 mb	Hurricane - Category 2
	October	29	18 UTC	44.0N	66.0W	15 deg	61 kph	165 kph	-- mb	Extratropical Storm
	October	30	0 UTC	47.0N	64.0W	25 deg	61 kph	150 kph	-- mb	Extratropical Storm
	October	30	6 UTC	49.0N	63.0W	20 deg	38 kph	150 kph	-- mb	Extratropical Storm

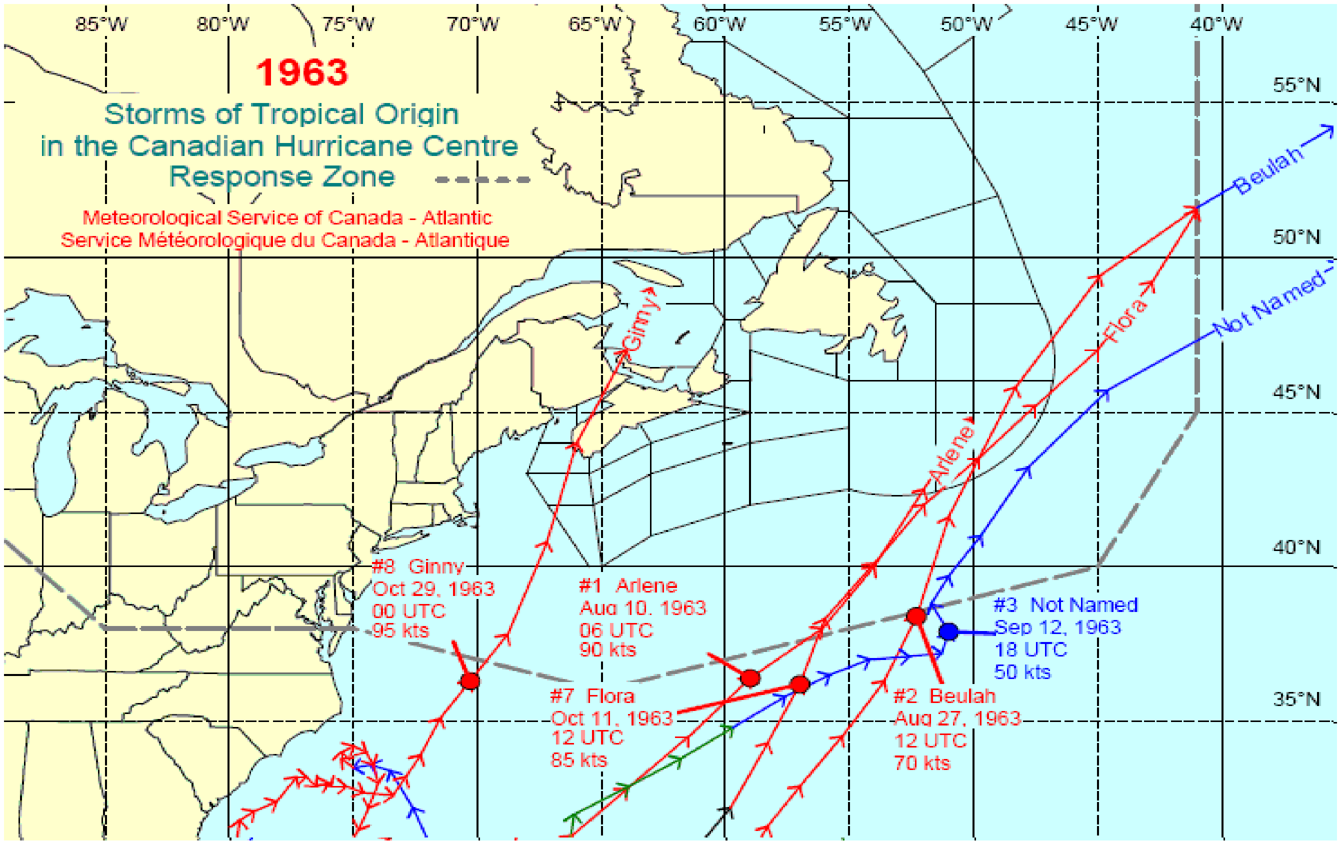


Figure H6: Ginny's best track

Source: Environment Canada (2010)

Table H8: Charlottetown's historical storm (Carol)

Source: NOAA (2010)

Carol 1953										
	September	5	0 UTC	26.3N	65.1W	330 deg	25 kph	220 kph	-- mb	Major Hurricane - Category 4
	September	5	6 UTC	27.8N	66.1W	330 deg	31 kph	215 kph	-- mb	Major Hurricane - Category 4
	September	5	12 UTC	29.2N	67.1W	330 deg	29 kph	195 kph	-- mb	Major Hurricane - Category 3
	September	5	18 UTC	29.9N	67.6W	330 deg	14 kph	185 kph	-- mb	Major Hurricane - Category 3
	September	6	0 UTC	30.5N	68.0W	330 deg	11 kph	175 kph	-- mb	Hurricane - Category 2
	September	6	6 UTC	31.6N	68.8W	330 deg	22 kph	165 kph	-- mb	Hurricane - Category 2
	September	6	12 UTC	33.0N	69.6W	335 deg	27 kph	160 kph	-- mb	Hurricane - Category 2
	September	6	18 UTC	35.0N	70.6W	335 deg	38 kph	150 kph	-- mb	Hurricane - Category 1
	September	7	0 UTC	37.2N	70.8W	355 deg	40 kph	150 kph	-- mb	Hurricane - Category 1
	September	7	6 UTC	38.6N	70.3W	15 deg	25 kph	140 kph	-- mb	Hurricane - Category 1
	September	7	12 UTC	40.3N	69.3W	25 deg	33 kph	130 kph	-- mb	Hurricane - Category 1
	September	7	18 UTC	43.3N	67.3W	25 deg	61 kph	120 kph	-- mb	Hurricane - Category 1
	September	8	0 UTC	46.4N	65.2W	25 deg	63 kph	110 kph	-- mb	Extratropical Storm
	September	8	6 UTC	49.1N	63.0W	30 deg	55 kph	100 kph	-- mb	Extratropical Storm
	September	8	12 UTC	51.8N	60.8W	25 deg	55 kph	95 kph	-- mb	Extratropical Storm

	September	8	18 UTC	54.5N	58.4W	30 deg	55 kph	95 kph	-- mb	Extratropical Storm
	September	9	0 UTC	57.0N	56.2W	25 deg	50 kph	85 kph	-- mb	Extratropical Storm
	September	9	6 UTC	59.5N	54.1W	25 deg	50 kph	85 kph	-- mb	Extratropical Storm
	September	9	12 UTC	61.8N	52.0W	25 deg	46 kph	85 kph	-- mb	Extratropical Storm

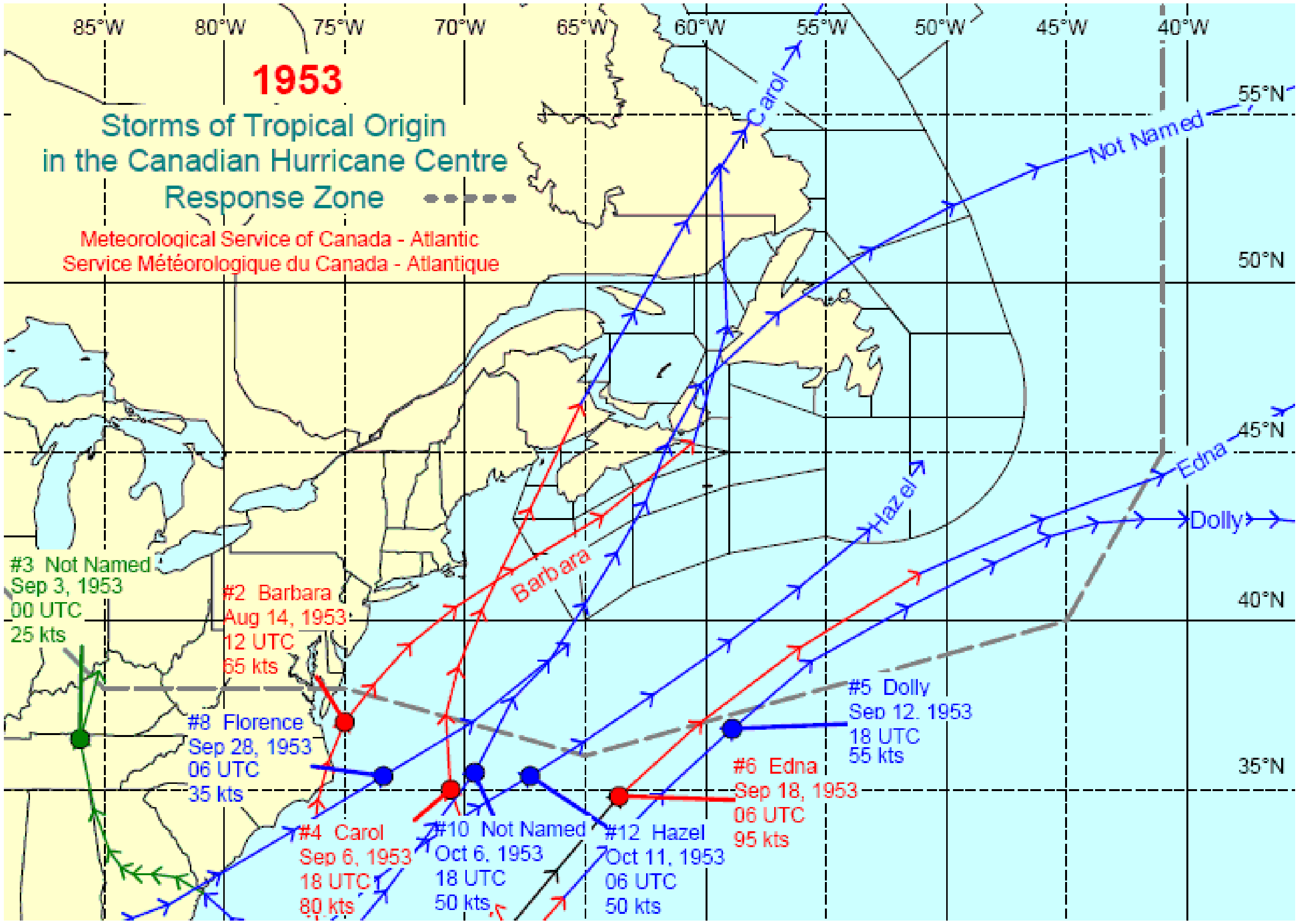


Figure H7: Carol's best track

Source: Environment Canada (2010)

Table H9: Charlottetown's historical storm (Able)

Source: NOAA (2010)

Able 1950										
	August	16	0 UTC	25.7N	68.3W	290 deg	9 kph	160 kph	-- mb	Hurricane - Category 2
	August	16	6 UTC	25.8N	68.8W	285 deg	7 kph	165 kph	-- mb	Hurricane - Category 2
	August	16	12 UTC	25.7N	69.2W	255 deg	5 kph	165 kph	-- mb	Hurricane - Category 2
	August	16	18 UTC	25.6N	69.7W	255 deg	7 kph	175 kph	-- mb	Hurricane - Category 2
	August	17	0 UTC	25.4N	70.4W	250 deg	11 kph	185 kph	-- mb	Major Hurricane - Category 3
	August	17	6 UTC	25.3N	71.4W	265 deg	16 kph	195 kph	-- mb	Major Hurricane - Category 3
	August	17	12 UTC	25.3N	72.4W	270 deg	16 kph	205 kph	-- mb	Major Hurricane - Category 3
	August	17	18 UTC	25.5N	73.2W	285 deg	12 kph	215 kph	-- mb	Major Hurricane - Category 4
	August	18	0 UTC	26.1N	73.8W	320 deg	14 kph	220 kph	-- mb	Major Hurricane - Category 4
	August	18	6 UTC	26.8N	74.4W	325 deg	14 kph	220 kph	-- mb	Major Hurricane - Category 4
	August	18	12 UTC	27.5N	74.9W	330 deg	14 kph	220 kph	-- mb	Major Hurricane - Category 4
	August	18	18 UTC	28.2N	75.4W	330 deg	14 kph	220 kph	-- mb	Major Hurricane - Category 4
	August	19	0 UTC	28.9N	75.8W	335 deg	12 kph	220 kph	-- mb	Major Hurricane - Category 4
	August	19	6 UTC	29.9N	76.1W	345 deg	18 kph	220 kph	-- mb	Major Hurricane - Category 4

	August	19	12 UTC	31.0N	76.2W	355 deg	20 kph	220 kph	-- mb	Major Hurricane - Category 4
	August	19	18 UTC	31.9N	76.0W	10 deg	16 kph	220 kph	-- mb	Major Hurricane - Category 4
	August	20	0 UTC	32.8N	75.7W	15 deg	16 kph	220 kph	-- mb	Major Hurricane - Category 4
	August	20	6 UTC	34.5N	74.8W	25 deg	33 kph	215 kph	-- mb	Major Hurricane - Category 4
	August	20	12 UTC	36.5N	72.9W	40 deg	46 kph	205 kph	-- mb	Major Hurricane - Category 3
	August	20	18 UTC	37.9N	71.4W	40 deg	33 kph	195 kph	-- mb	Major Hurricane - Category 3
	August	21	0 UTC	39.4N	69.5W	45 deg	38 kph	165 kph	-- mb	Hurricane - Category 2
	August	21	6 UTC	41.8N	67.0W	40 deg	55 kph	120 kph	-- mb	Hurricane - Category 1
	August	21	12 UTC	44.2N	64.3W	40 deg	57 kph	65 kph	-- mb	Tropical Storm
	August	21	18 UTC	46.0N	62.0W	40 deg	44 kph	55 kph	-- mb	Tropical Depression
	August	22	0 UTC	47.9N	59.6W	40 deg	46 kph	55 kph	-- mb	Tropical Depression
	August	22	6 UTC	49.8N	56.8W	45 deg	48 kph	45 kph	-- mb	Tropical Depression
	August	22	12 UTC	51.8N	54.0W	40 deg	48 kph	45 kph	-- mb	Tropical Depression
	August	22	18 UTC	53.6N	50.7W	50 deg	48 kph	45 kph	-- mb	Tropical Depression

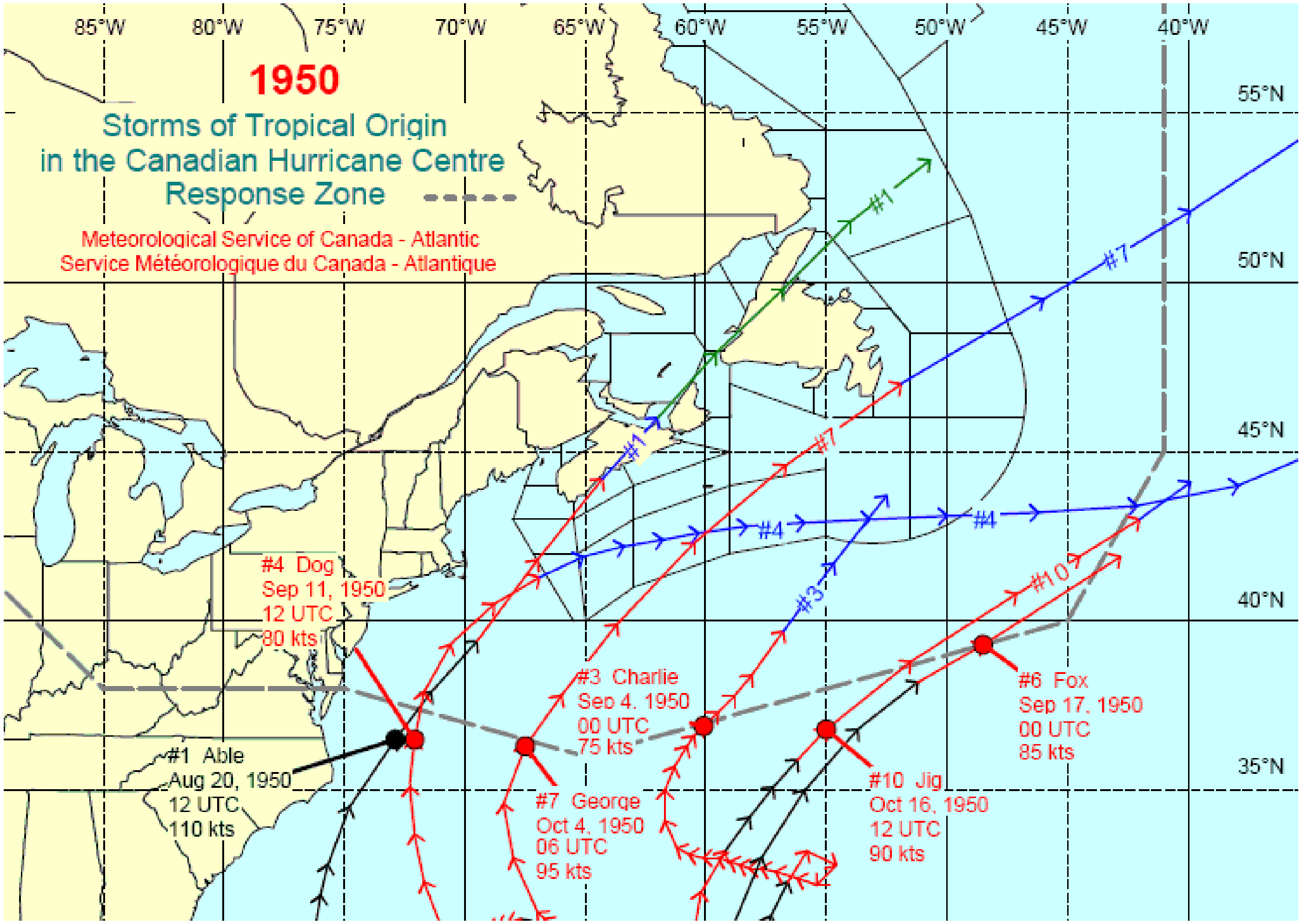


Figure H8: Able's best track

Source: Environment Canada (2010)

Appendix C - HURDAT files of Isle Madame related storms (Best Tracks)

Tables G1 to G16 present historical storms in Isle Madame including details like date, speed, wind, pressure and type of the storm, in this table the highlighted row in each tables illustrates the data used for this thesis. Moreover, Figures G1 to G12 illustrate storms tracks of Isle Madame's historical storms (Pakdel, 2011).

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

	August	24	6 UTC	48.0N	53.0W	65 deg	68 kph	110 kph	980 mb	Tropical Storm
	August	24	12 UTC	49.2N	47.2W	75 deg	74 kph	110 kph	980 mb	Extratropical Storm
	August	24	18 UTC	50.0N	41.2W	80 deg	72 kph	110 kph	980 mb	Extratropical Storm
	August	25	0 UTC	50.3N	35.4W	85 deg	68 kph	110 kph	980 mb	Extratropical Storm
	August	25	6 UTC	50.7N	29.6W	85 deg	68 kph	110 kph	980 mb	Extratropical Storm
	August	25	12 UTC	51.2N	23.8W	80 deg	66 kph	110 kph	980 mb	Extratropical Storm
	August	25	18 UTC	52.0N	18.0W	75 deg	66 kph	95 kph	982 mb	Extratropical Storm

Table G1: Isle Madame's historical storms

Source: NOAA 2010

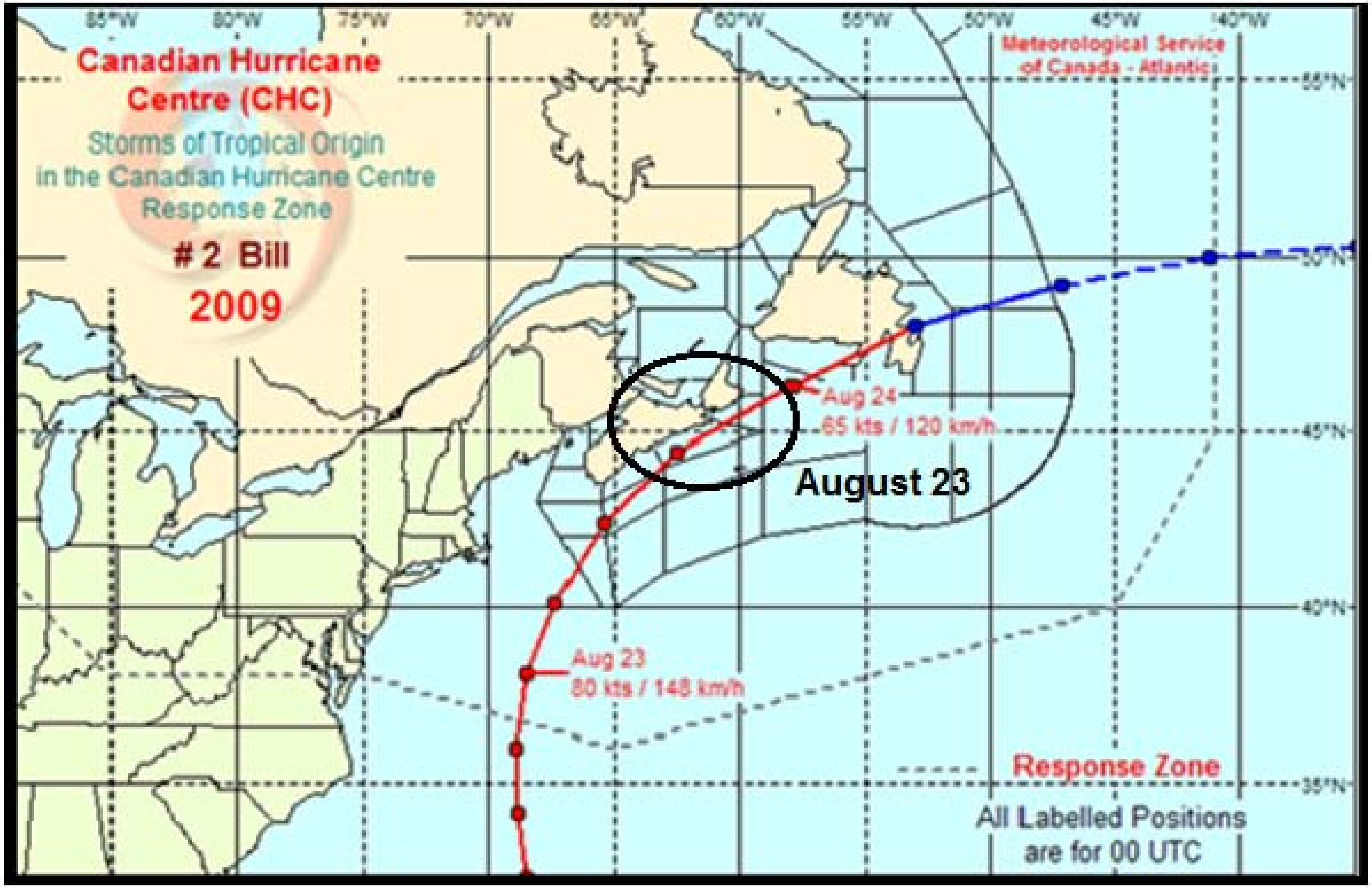


Figure G1: Storm tracks of Isle Madame's historical storms

Source: Environment Canada (2010)

Storm Name	Month	Day	Hour	Lat.	Long.	Dir.	Speed	Wind	Pressure	-------Type-------
NOT NAMED 2006										
	July	17	0 UTC	38.3N	67.6W	40 deg	12 kph	55 kph	1009 mb	Extratropical Storm
	July	17	6 UTC	39.1N	66.4W	50 deg	22 kph	55 kph	1008 mb	Tropical Depression
	July	17	12 UTC	40.0N	65.1W	50 deg	24 kph	75 kph	1003 mb	Tropical Storm
	July	17	18 UTC	41.1N	63.7W	45 deg	27 kph	85 kph	998 mb	Tropical Storm
	July	18	0 UTC	42.4N	62.1W	45 deg	31 kph	75 kph	999 mb	Tropical Storm
	July	18	6 UTC	43.7N	60.1W	50 deg	35 kph	65 kph	1004 mb	Tropical Storm
	July	18	12 UTC	45.5N	58.0W	40 deg	42 kph	55 kph	1007 mb	Tropical Storm
	July	18	18 UTC	47.1N	55.8W	45 deg	40 kph	45 kph	1009 mb	Tropical Storm
	July	19	0 UTC	48.6N	52.9W	50 deg	44 kph	45 kph	1012 mb	Tropical Storm
	July	19	6 UTC	49.2N	49.4W	75 deg	42 kph	45 kph	1012 mb	Tropical Storm
	July	19	12 UTC	49.8N	46.1W	75 deg	40 kph	45 kph	1014 mb	Tropical Storm

Table G2: Isle Madame's historical storms

Source: NOAA (2010)

Storm Name	Month	Day	Hour	Lat.	Long.	Dir.	Speed	Wind	Pressure	-------Type-------
ALBERTO 2006										
	June	14	0 UTC	31.3N	82.8W	30 deg	20 kph	65 kph	1001 mb	Tropical Storm
	June	14	6 UTC	32.8N	81.9W	25 deg	29 kph	55 kph	1003 mb	Tropical Depression
	June	14	12 UTC	34.3N	80.7W	35 deg	33 kph	65 kph	1003 mb	Extratropical Storm
	June	14	18 UTC	35.5N	77.5W	65 deg	51 kph	65 kph	1002 mb	Extratropical Storm
	June	15	0 UTC	37.0N	73.0W	70 deg	72 kph	85 kph	999 mb	Extratropical Storm
	June	15	6 UTC	38.8N	69.9W	55 deg	55 kph	85 kph	990 mb	Extratropical Storm
	June	15	12 UTC	40.9N	66.8W	50 deg	57 kph	95 kph	979 mb	Extratropical Storm
	June	15	18 UTC	42.6N	64.2W	50 deg	46 kph	100 kph	971 mb	Extratropical Storm
	June	16	0 UTC	44.0N	62.0W	50 deg	38 kph	100 kph	969 mb	Extratropical Storm

	June	16	6 UTC	46.0N	58.5W	50 deg	57 kph	95 kph	972 mb	Extratropical Storm
	June	16	12 UTC	47.4N	55.0W	60 deg	50 kph	85 kph	985 mb	Extratropical Storm
	June	16	18 UTC	49.3N	51.5W	50 deg	55 kph	75 kph	990 mb	Extratropical Storm
	June	17	0 UTC	50.8N	45.2W	70 deg	79 kph	75 kph	995 mb	Extratropical Storm
	June	17	6 UTC	51.5N	39.0W	80 deg	72 kph	75 kph	995 mb	Extratropical Storm
	June	17	12 UTC	53.0N	34.5W	60 deg	57 kph	75 kph	995 mb	Extratropical Storm
	June	17	18 UTC	54.0N	29.0W	75 deg	63 kph	65 kph	995 mb	Extratropical Storm

Table G3: Isle Madame's historical storms

Source: NOAA 2010

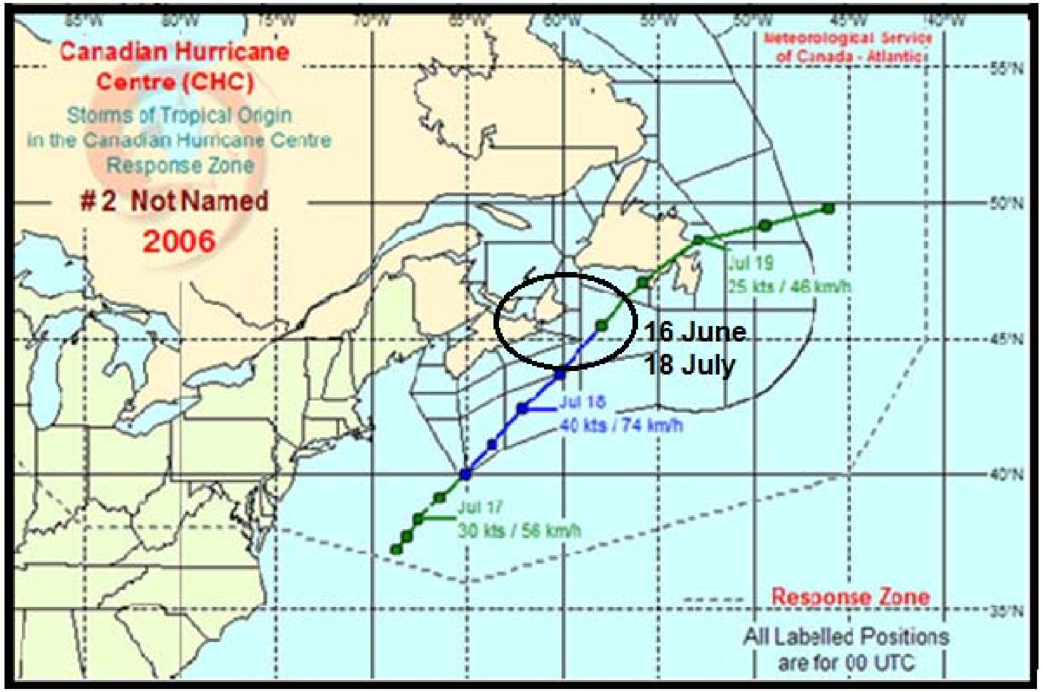


Figure G2: Storms tracks of Isle Madame's historical storms

Source: Environment Canada (2010)

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

2005										
	September	15	0 UTC	34.2N	76.9W	60 deg	9 kph	140 kph	979 mb	Hurricane - Category 1
	September	15	6 UTC	34.5N	76.3W	60 deg	9 kph	130 kph	982 mb	Hurricane - Category 1
	September	15	12 UTC	34.7N	75.8W	65 deg	7 kph	120 kph	984 mb	Hurricane - Category 1
	September	15	18 UTC	34.7N	75.6W	90 deg	1 kph	120 kph	986 mb	Hurricane - Category 1
	September	16	0 UTC	34.6N	75.1W	105 deg	7 kph	110 kph	987 mb	Tropical Storm
	September	16	6 UTC	34.7N	74.8W	70 deg	3 kph	100 kph	993 mb	Tropical Storm
	September	16	12 UTC	35.4N	74.4W	25 deg	12 kph	95 kph	995 mb	Tropical Storm
	September	16	18 UTC	36.4N	73.6W	35 deg	20 kph	100 kph	993 mb	Tropical Storm
	September	17	0 UTC	37.3N	72.7W	40 deg	20 kph	100 kph	995 mb	Tropical Storm
	September	17	6 UTC	38.7N	71.4W	35 deg	31 kph	95 kph	1000 mb	Tropical Storm
	September	17	12 UTC	40.0N	69.7W	45 deg	33 kph	95 kph	997 mb	Tropical Storm
	September	17	18	41.6N	67.3W	50 deg	44 kph	95 kph	995 mb	Tropical Storm

			UTC							
	September	18	0 UTC	43.2N	64.9W	50 deg	42 kph	85 kph	996 mb	Extratropical Storm
	September	18	6 UTC	44.8N	62.6W	45 deg	42 kph	85 kph	1000 mb	Extratropical Storm
	September	18	12 UTC	46.2N	59.9W	55 deg	42 kph	85 kph	1000 mb	Extratropical Storm
	September	18	18 UTC	47.4N	56.2W	65 deg	51 kph	85 kph	999 mb	Extratropical Storm
	September	19	0 UTC	48.4N	52.3W	70 deg	50 kph	85 kph	1000 mb	Extratropical Storm
	September	19	6 UTC	49.0N	48.8W	75 deg	42 kph	85 kph	1001 mb	Extratropical Storm
	September	19	12 UTC	49.5N	45.7W	75 deg	37 kph	85 kph	1000 mb	Extratropical Storm
	September	19	18 UTC	50.0N	42.1W	80 deg	42 kph	85 kph	999 mb	Extratropical Storm
	September	20	0 UTC	50.9N	38.5W	70 deg	44 kph	85 kph	998 mb	Extratropical Storm

Table G4: Isle Madame's historical storms

Source: NOAA 2010

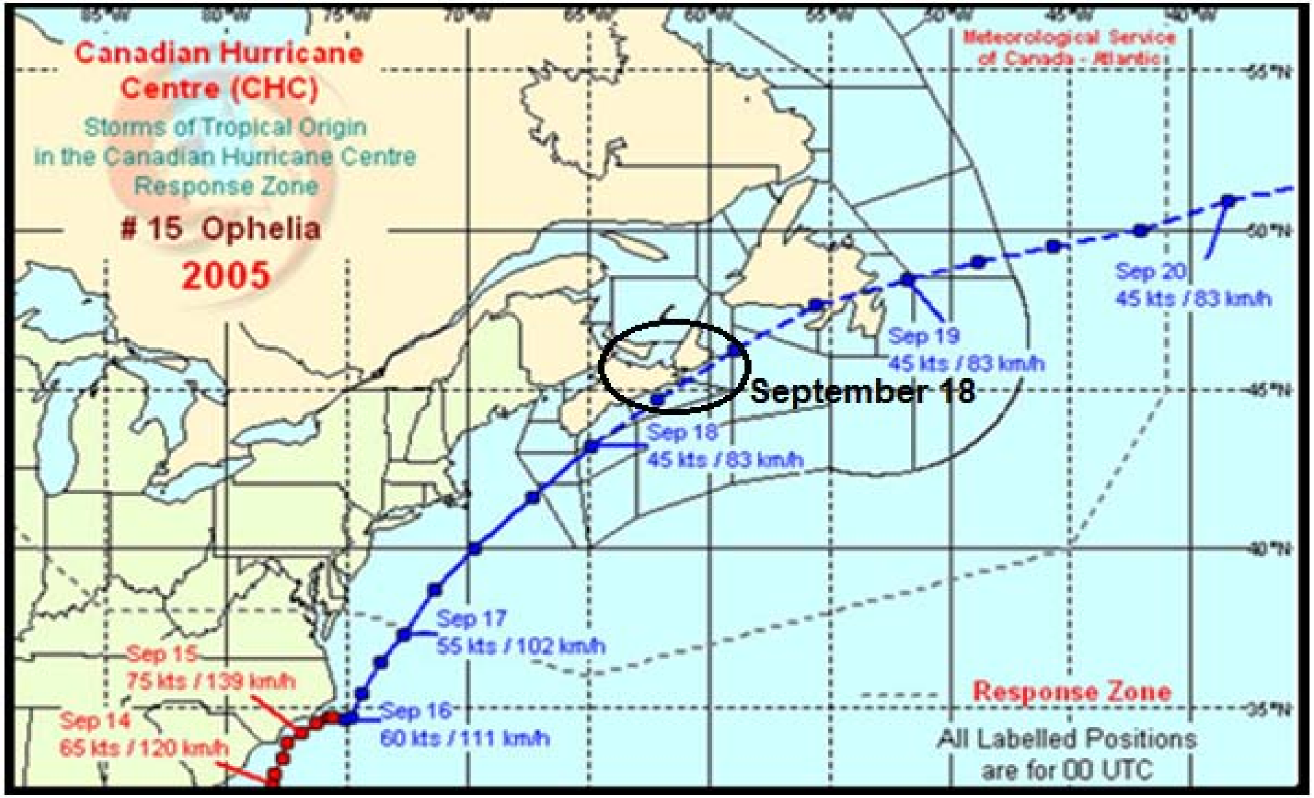


Figure G3: Storm tracks of Isle Madame's historical storms

Source: Environment Canada (2010)

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

	September	13	6 UTC	52.5N	52.5W	30 deg	31 kph	95 kph	968 mb	Extratropical Storm
	September	13	12 UTC	54.5N	51.4W	20 deg	38 kph	85 kph	972 mb	Extratropical Storm
	September	13	18 UTC	56.0N	49.5W	35 deg	33 kph	85 kph	976 mb	Extratropical Storm

Table G5: Isle Madame's historical storms

Source: NOAA 2010

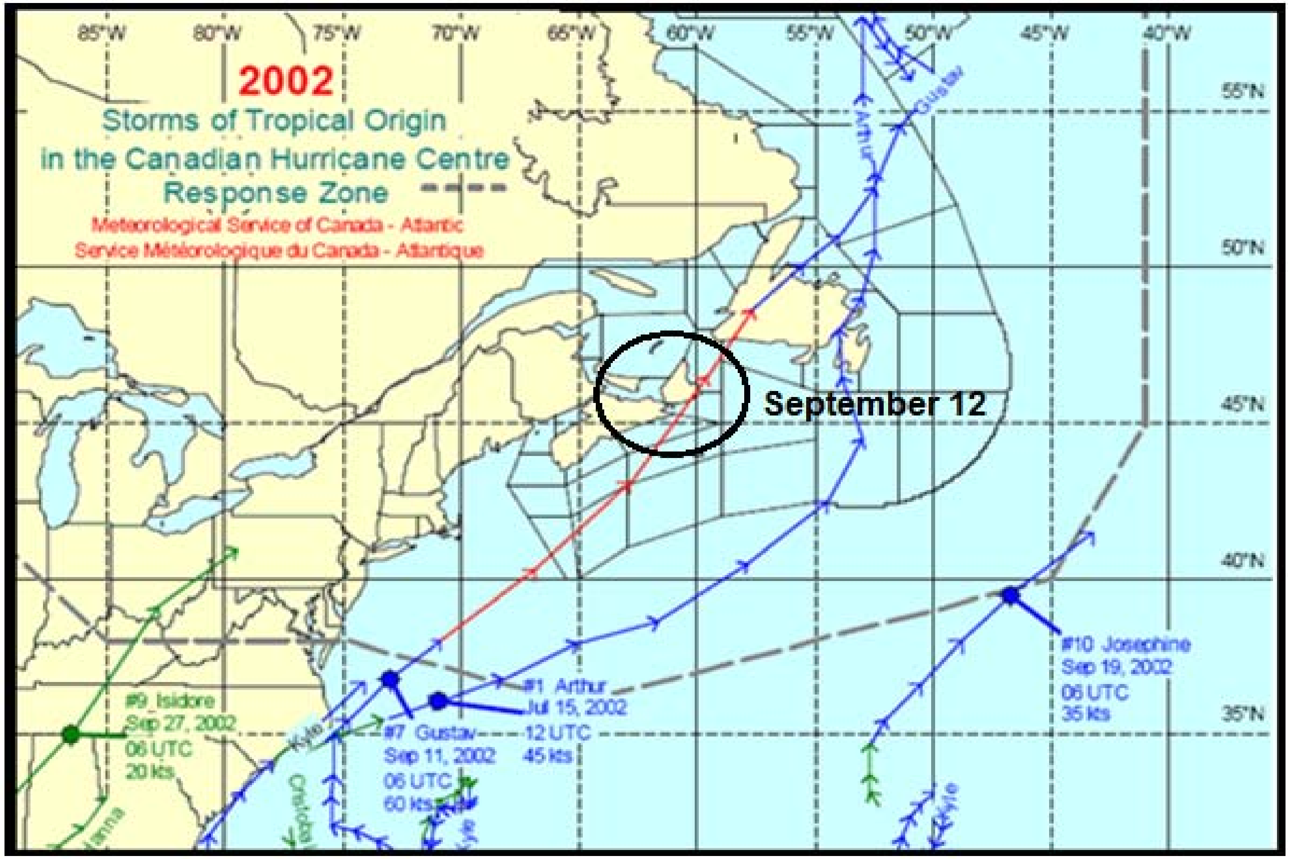


Figure G4: Storm tracks of Isle Madame's historical storms

Source: Environment Canada (2010)

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

Table G6: Isle Madame's historical storms

Source: NOAA (2010)

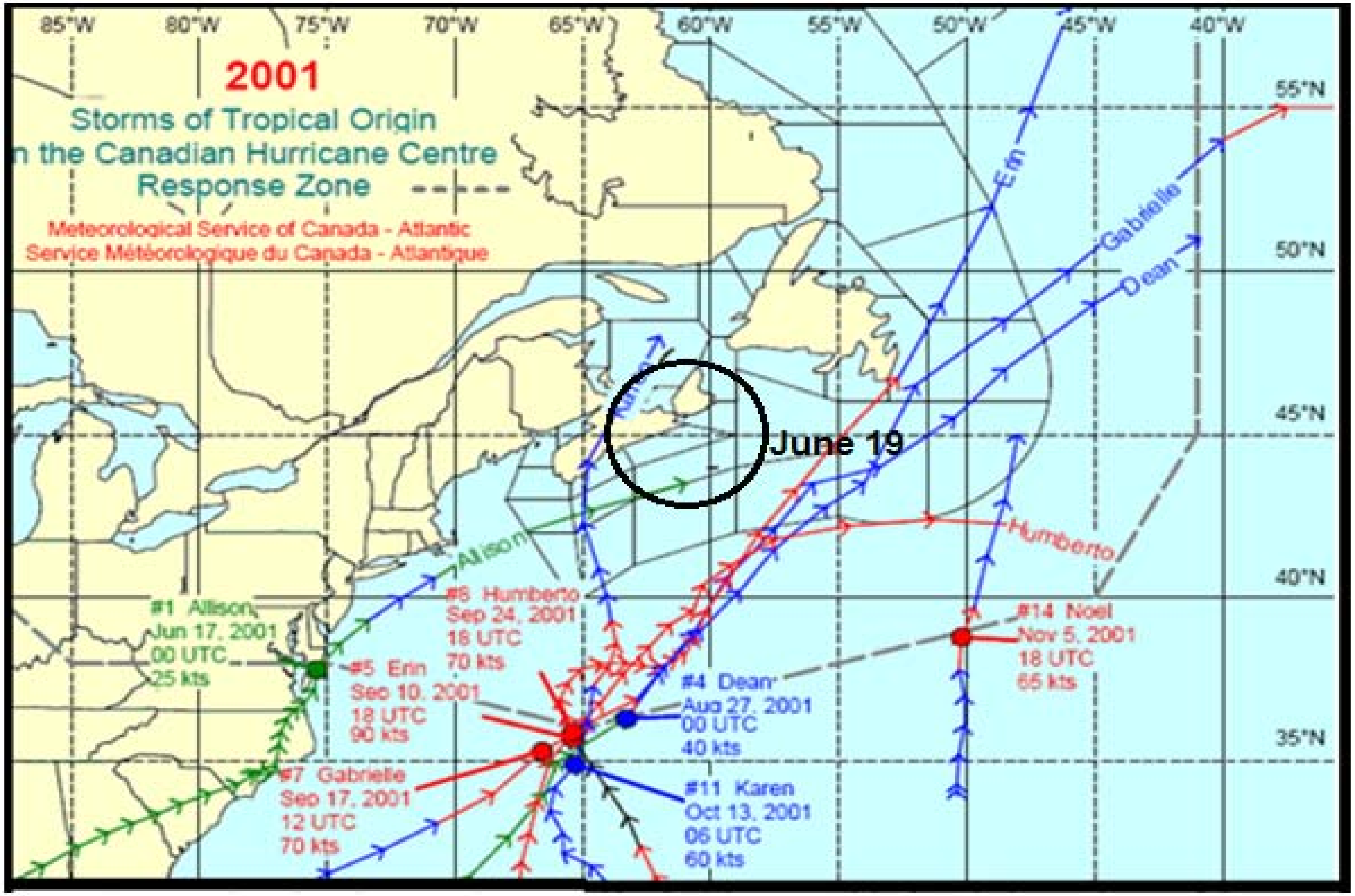


Figure G5: Storm tracks of Isle Madame's historical storms

Source: Environment Canada (2010)

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

	October	20	6 UTC	50.0N	56.0W	10 deg	37 kph	130 kph	966 mb	Extratropical Storm
	October	20	12 UTC	51.0N	53.5W	60 deg	33 kph	120 kph	968 mb	Extratropical Storm
	October	20	18 UTC	52.0N	50.5W	60 deg	38 kph	110 kph	970 mb	Extratropical Storm

Table G7: Isle Madame's historical storms

Source: NOAA (2010)

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

Table G8: Isle Madame's historical storms

Source: NOAA (2010)

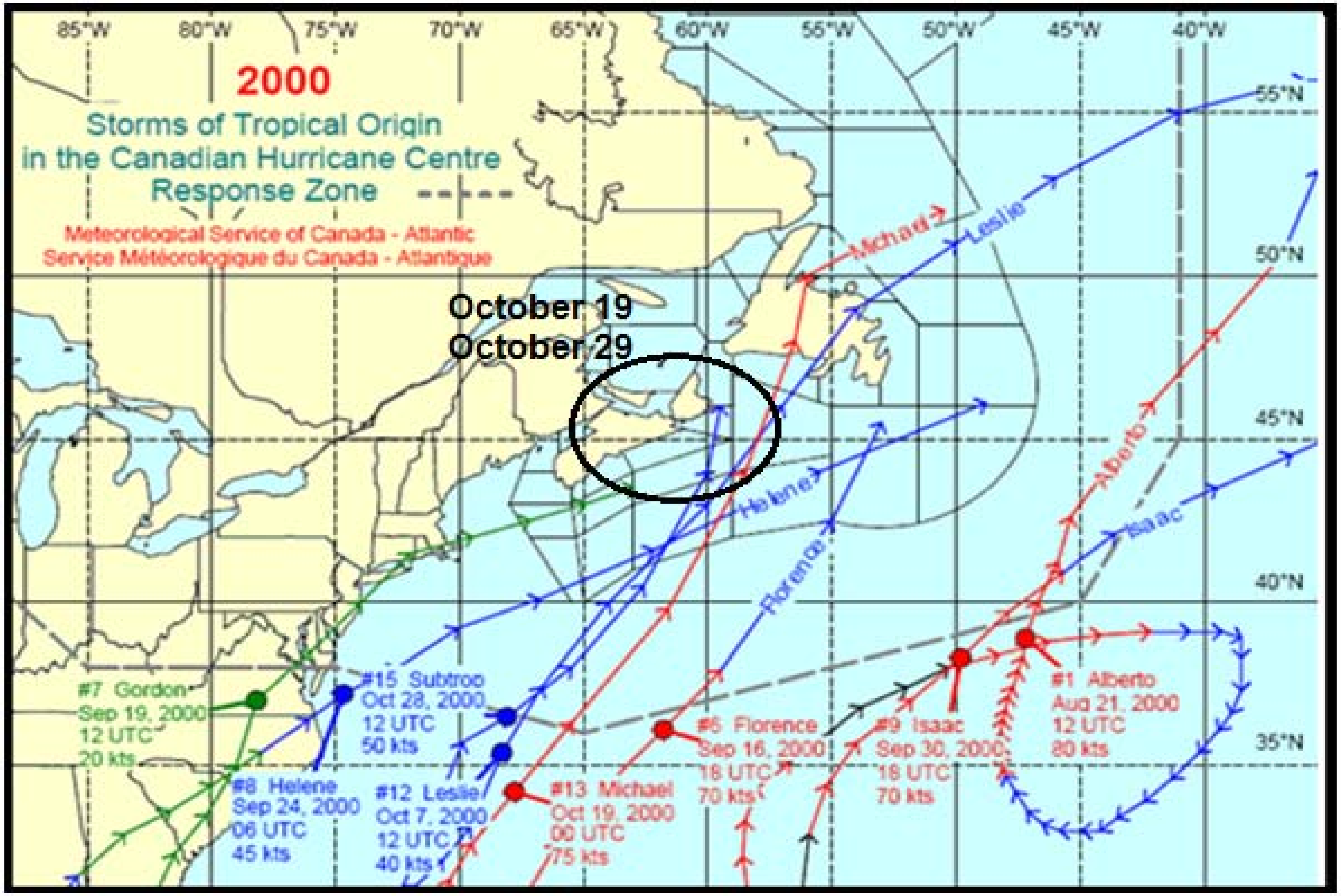


Figure G6: Storm tracks of Isle Madame's historical storms

Source: Environment Canada (2010)

Storm Name	Month	Day	Hour	Lat.	Long.	Dir.	Speed	Wind	Pressure	-------Type-------
HORTENSE 1996										
	September	13	0 UTC	25.9N	71.5W	15 deg	22 kph	220 kph	935 mb	Major Hurricane - Category 4
	September	13	6 UTC	27.2N	71.4W	5 deg	24 kph	215 kph	942 mb	Major Hurricane - Category 4
	September	13	12 UTC	29.0N	70.9W	15 deg	33 kph	185 kph	948 mb	Major Hurricane - Category 3
	September	13	18 UTC	31.0N	70.3W	15 deg	37 kph	185 kph	948 mb	Major Hurricane - Category 3
	September	14	0 UTC	33.3N	69.5W	15 deg	42 kph	165 kph	948 mb	Hurricane - Category 2
	September	14	6 UTC	35.9N	68.4W	20 deg	50 kph	165 kph	955 mb	Hurricane - Category 2
	September	14	12 UTC	38.5N	67.1W	20 deg	50 kph	160 kph	960 mb	Hurricane - Category 2
	September	14	18	42.0N	65.2W	25 deg	68 kph	140 kph	960 mb	Hurricane - Category 1

			UTC							
	September	15	0 UTC	44.3N	63.3W	30 deg	48 kph	130 kph	970 mb	Hurricane - Category 1
	September	15	6 UTC	45.5N	61.5W	45 deg	31 kph	120 kph	980 mb	Hurricane - Category 1
	September	15	12 UTC	46.3N	59.1W	65 deg	33 kph	110 kph	982 mb	Tropical Storm
	September	15	18 UTC	46.0N	55.0W	95 deg	51 kph	75 kph	996 mb	Extratropical Storm
	September	16	0 UTC	46.0N	54.0W	90 deg	11 kph	75 kph	998 mb	Extratropical Storm
	September	16	6 UTC	45.0N	50.0W	110 deg	53 kph	65 kph	999 mb	Extratropical Storm

Table G9: Isle Madame's historical storms

Source: NOAA (2010)

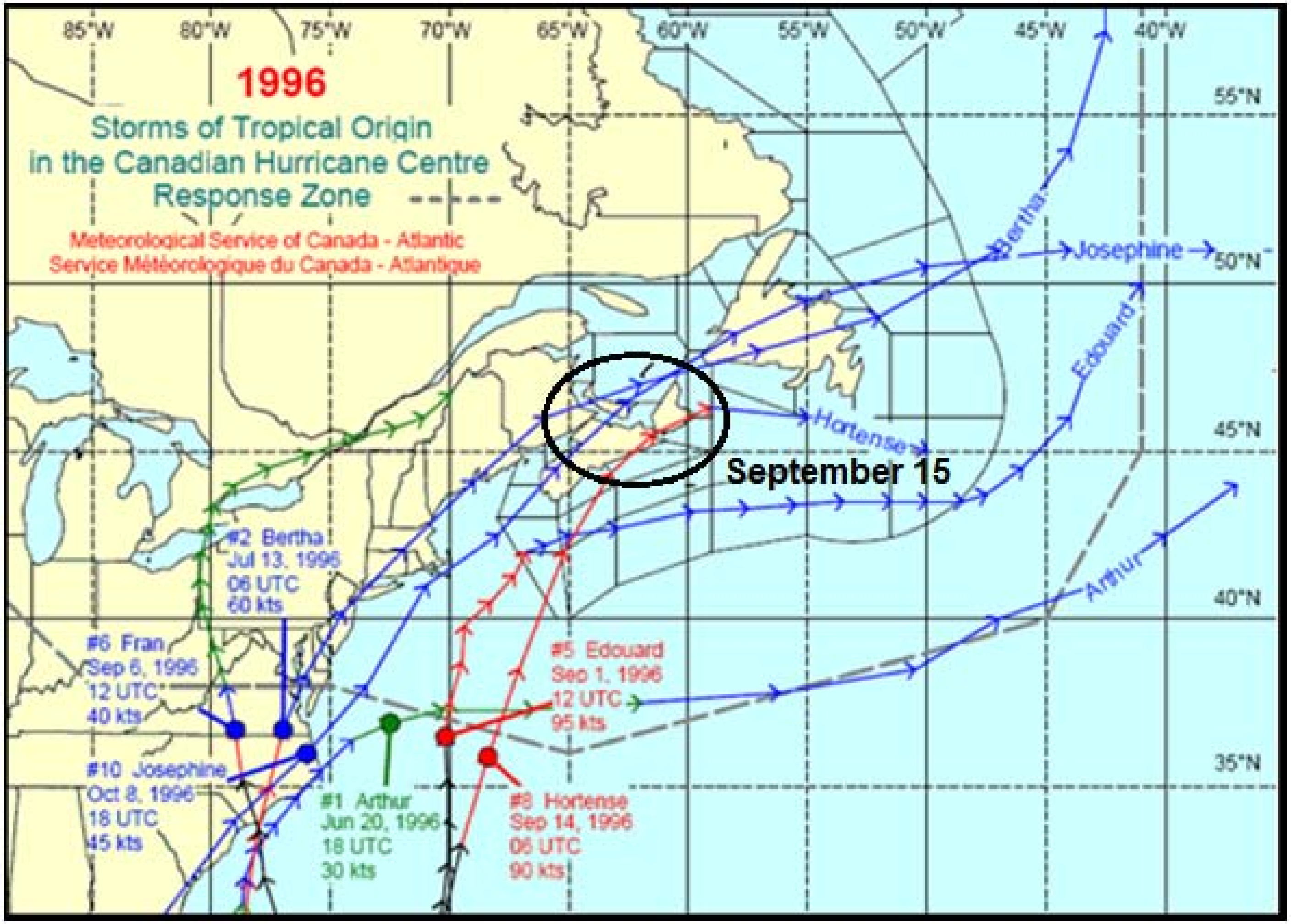

1996
Storms of Tropical Origin
in the Canadian Hurricane Centre
Response Zone
Meteorological Service of Canada - Atlantic
Service Météorologique du Canada - Atlantique
85°W
80°W
75°W
70°W
65°W
60°W
55°W
50°W
45°W
40°W
55°N
50°N
45°N
40°N
35°N
September 15
Bertha
Josephine
Edouard
Hortense
Arthur
#2 Bertha
Jul 13, 1996
06 UTC
60 kts
#6 Fran
Sep 6, 1996
12 UTC
40 kts
#10 Josephine
Oct 8, 1996
18 UTC
45 kts
#1 Arthur
Jun 20, 1996
18 UTC
30 kts
#5 Edouard
Sep 1, 1996
12 UTC
95 kts
#8 Hortense
Sep 14, 1996
06 UTC
90 kts

Figure G7: Storm tracks of Isle Madame's historical storms

Source: Environment Canada (2010)

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

Table G10: Isle Madame's historical storms

Source: NOAA (2010)

Storm Name	Month	Day	Hour	Lat.	Long.	Dir.	Speed	Wind	Pressure	-------Type-------
ALLISON 1995										
	June	6	0 UTC	31.8N	82.8W	40 deg	24 kph	55 kph	993 mb	Tropical Depression
	June	6	6 UTC	32.7N	81.5W	50 deg	25 kph	65 kph	994 mb	Extratropical Storm
	June	6	12 UTC	33.6N	80.0W	55 deg	27 kph	65 kph	995 mb	Extratropical Storm
	June	6	18 UTC	34.5N	78.1W	60 deg	33 kph	75 kph	995 mb	Extratropical Storm
	June	7	0 UTC	35.6N	75.9W	60 deg	38 kph	75 kph	992 mb	Extratropical Storm
	June	7	6 UTC	37.1N	73.6W	50 deg	42 kph	85 kph	990 mb	Extratropical Storm
	June	7	12 UTC	38.5N	71.0W	55 deg	44 kph	85 kph	988 mb	Extratropical Storm
	June	7	18 UTC	39.8N	69.2W	45 deg	35 kph	85 kph	984 mb	Extratropical Storm
	June	8	0 UTC	41.0N	67.7W	45 deg	29 kph	95 kph	982 mb	Extratropical Storm
	June	8	6 UTC	42.4N	66.0W	40 deg	33 kph	95 kph	984 mb	Extratropical Storm
	June	8	12 UTC	43.8N	63.7W	50 deg	38 kph	95 kph	989 mb	Extratropical Storm
	June	8	18 UTC	45.2N	61.2W	50 deg	40 kph	85 kph	993 mb	Extratropical Storm

	June	9	0 UTC	46.5N	58.5W	55 deg	40 kph	75 kph	995 mb	Extratropical Storm
	June	9	6 UTC	48.1N	55.9W	50 deg	42 kph	75 kph	996 mb	Extratropical Storm
	June	9	12 UTC	50.0N	53.0W	45 deg	48 kph	75 kph	997 mb	Extratropical Storm
	June	9	18 UTC	53.0N	52.0W	10 deg	55 kph	75 kph	1000 mb	Extratropical Storm
	June	10	0 UTC	57.0N	52.0W	0 deg	74 kph	75 kph	997 mb	Extratropical Storm
	June	10	6 UTC	60.0N	52.0W	0 deg	55 kph	75 kph	990 mb	Extratropical Storm
	June	10	12 UTC	62.0N	53.0W	345 deg	37 kph	75 kph	992 mb	Extratropical Storm
	June	10	18 UTC	64.0N	55.0W	335 deg	38 kph	65 kph	992 mb	Extratropical Storm
	June	11	0 UTC	65.0N	56.0W	335 deg	18 kph	65 kph	993 mb	Extratropical Storm

Table G11: Isle Madame's historical storms

Source: NOAA (2010)

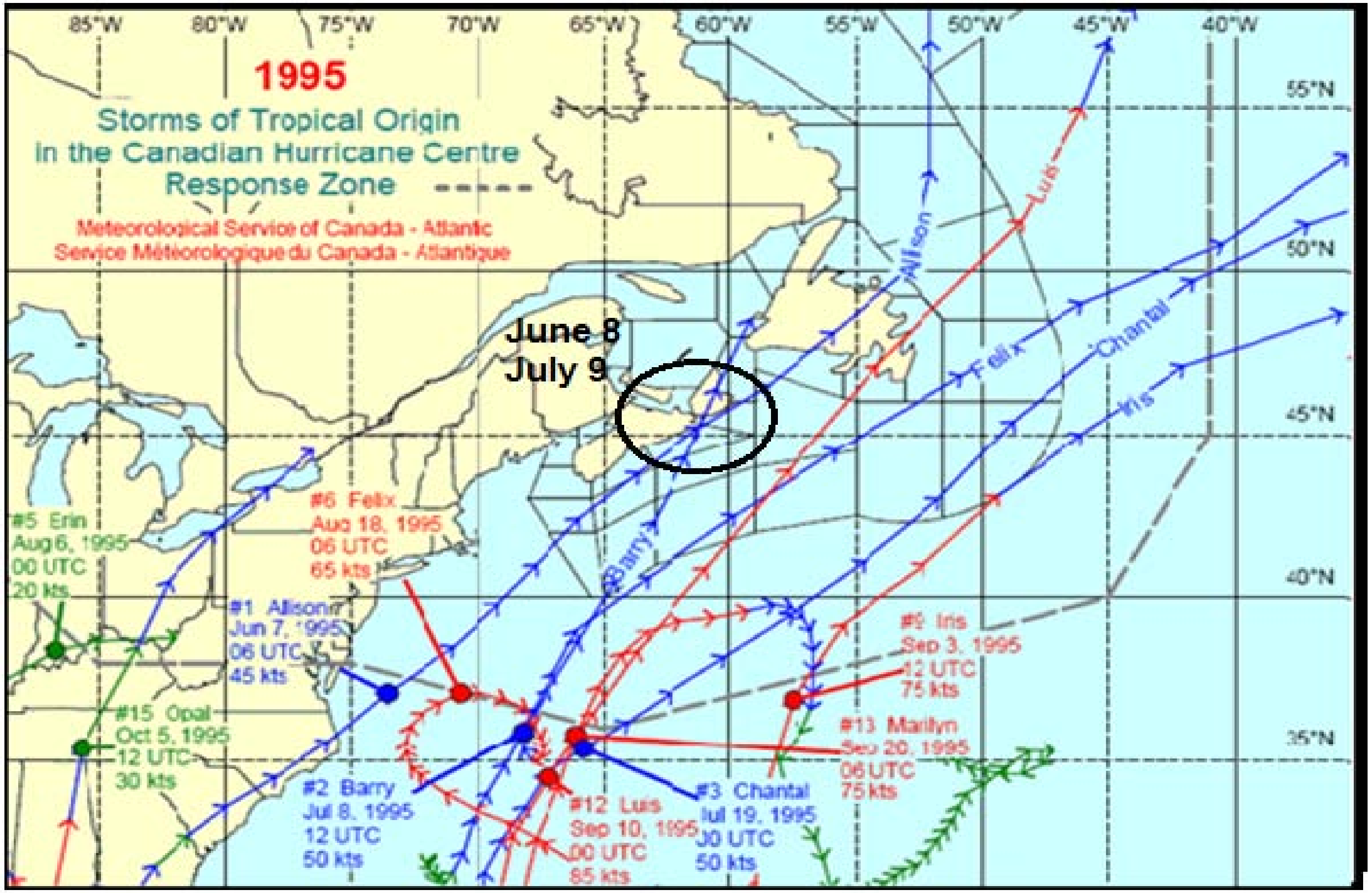


Figure G8: Storm tracks of Isle Madame's historical storms

Source: Environment Canada (2010)

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

Table G12: Isle Madame's historical storms

Source: NOAA (2010)

Storm Name	Month	Day	Hour	Lat.	Long.	Dir.	Speed	Wind	Pressure	-------Type-------
BERTHA 1990										
	July	29	0 UTC	30.2N	73.6W	40 deg	12 kph	120 kph	990 mb	Hurricane - Category 1
	July	29	6 UTC	30.8N	73.0W	40 deg	12 kph	120 kph	988 mb	Hurricane - Category 1
	July	29	12 UTC	31.3N	72.2W	55 deg	14 kph	120 kph	989 mb	Hurricane - Category 1
	July	29	18 UTC	31.9N	71.2W	55 deg	18 kph	110 kph	990 mb	Tropical Storm
	July	30	0 UTC	32.7N	70.2W	45 deg	20 kph	110 kph	989 mb	Tropical Storm
	July	30	6 UTC	33.7N	69.2W	40 deg	24 kph	110 kph	987 mb	Tropical Storm
	July	30	12 UTC	34.7N	68.3W	35 deg	22 kph	120 kph	985 mb	Hurricane - Category 1
	July	30	18 UTC	35.7N	67.5W	35 deg	20 kph	120 kph	979 mb	Hurricane - Category 1
	July	31	0 UTC	36.6N	67.0W	25 deg	16 kph	130 kph	974 mb	Hurricane - Category 1
	July	31	6 UTC	37.5N	66.5W	25 deg	16 kph	120 kph	975 mb	Hurricane - Category 1

	July	31	12 UTC	38.3N	65.9W	30 deg	16 kph	120 kph	976 mb	Hurricane - Category 1
	July	31	18 UTC	39.0N	65.3W	35 deg	14 kph	120 kph	977 mb	Hurricane - Category 1
	August	1	0 UTC	39.6N	64.5W	45 deg	14 kph	120 kph	977 mb	Hurricane - Category 1
	August	1	6 UTC	40.3N	63.7W	40 deg	16 kph	120 kph	977 mb	Hurricane - Category 1
	August	1	12 UTC	41.1N	62.7W	45 deg	20 kph	120 kph	977 mb	Hurricane - Category 1
	August	1	18 UTC	42.4N	61.5W	35 deg	27 kph	120 kph	975 mb	Hurricane - Category 1
	August	2	0 UTC	44.2N	60.5W	20 deg	35 kph	130 kph	973 mb	Hurricane - Category 1
	August	2	6 UTC	46.0N	60.0W	10 deg	33 kph	110 kph	978 mb	Extratropical Storm
	August	2	12 UTC	48.4N	60.0W	0 deg	44 kph	100 kph	982 mb	Extratropical Storm

Table G13: Isle Madame's historical storms

Source: NOAA (2010)

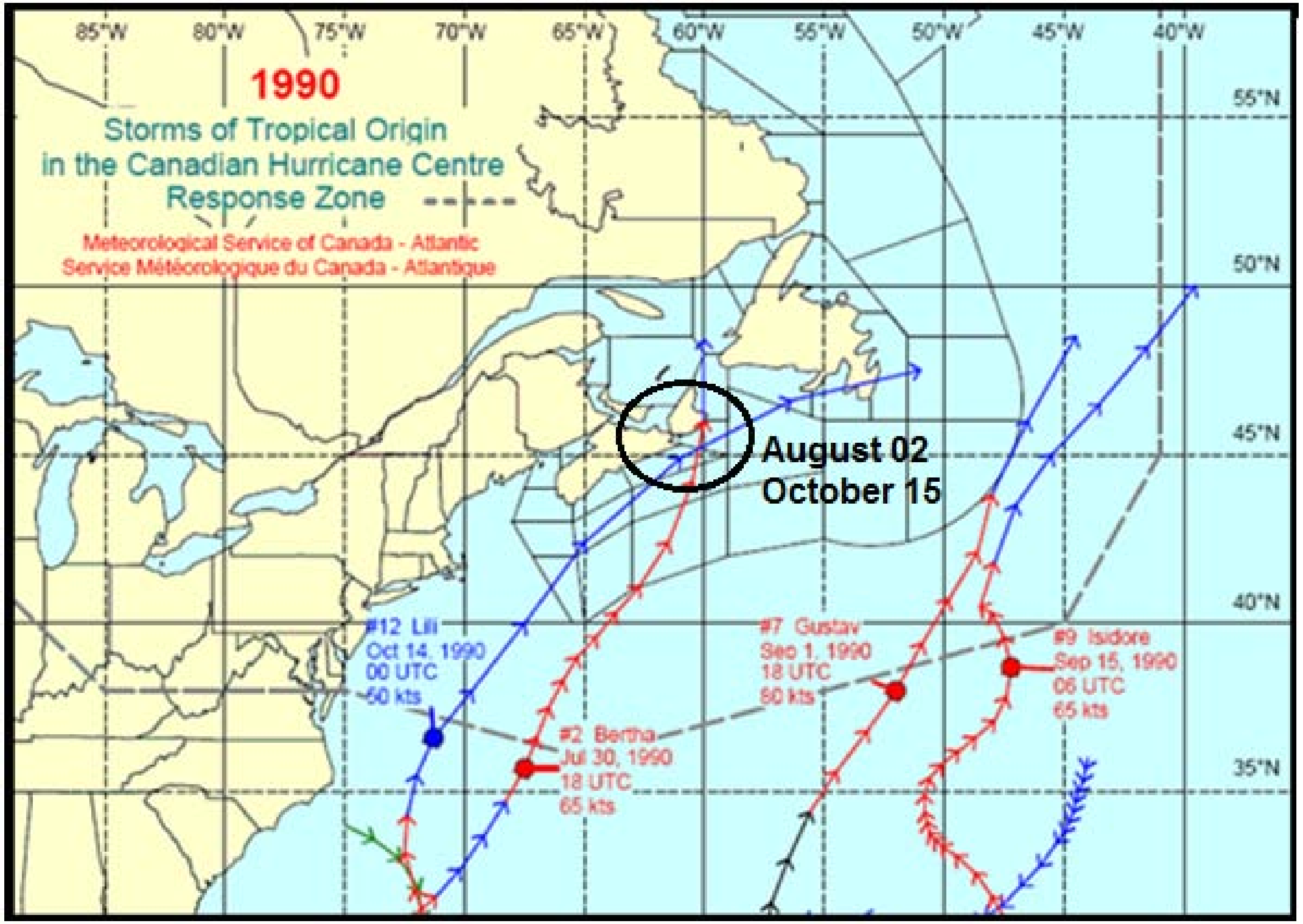


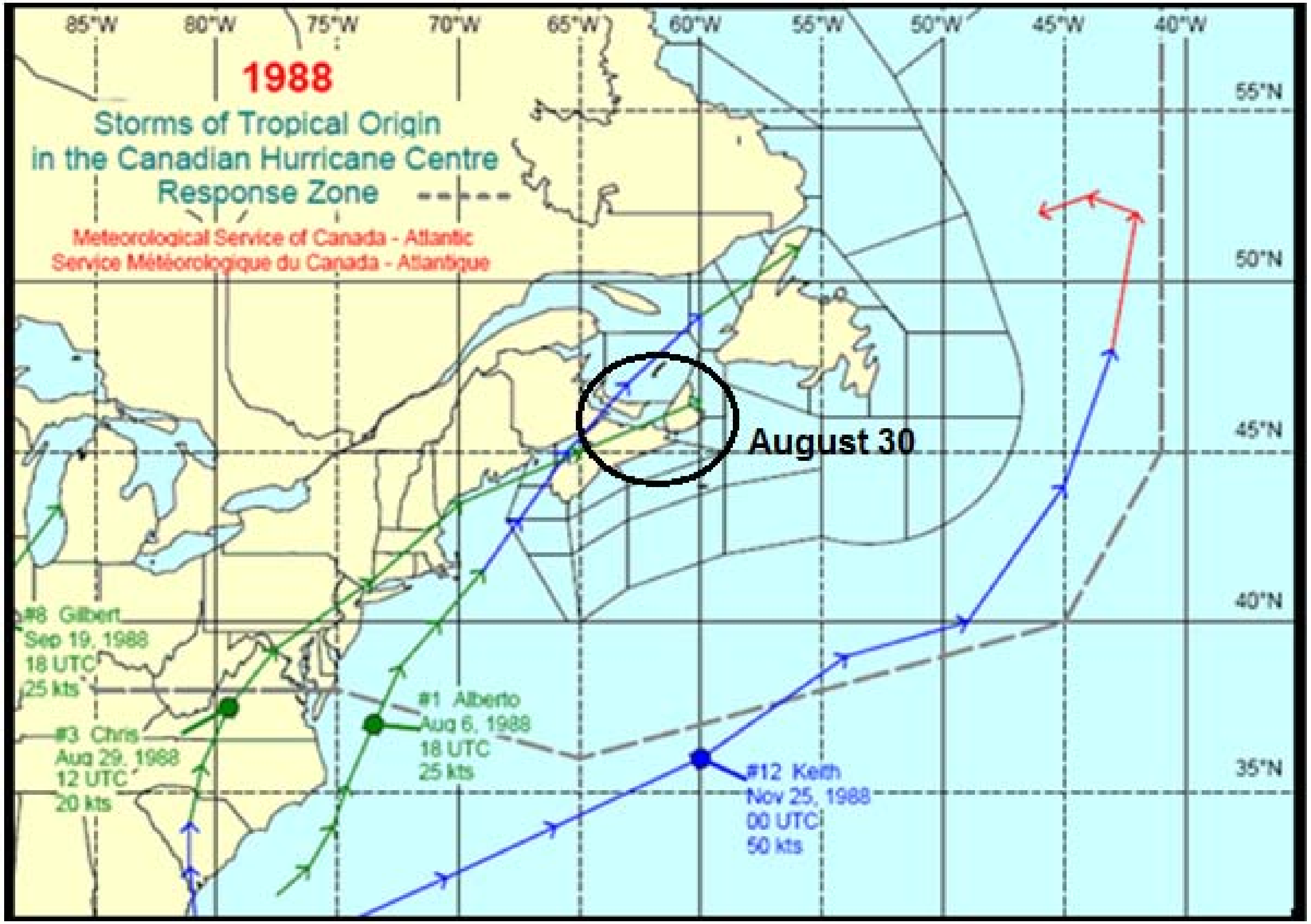
Figure G8: Storm tracks of Isle Madame's historical storms

Source: Environment Canada (2010)

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

Table G14: Isle Madame’s historical storms

Source: NOAA (2010)



85°W 80°W 75°W 70°W 65°W 60°W 55°W 50°W 45°W 40°W
55°N 50°N 45°N 40°N 35°N
1988
Storms of Tropical Origin
in the Canadian Hurricane Centre
Response Zone
Meteorological Service of Canada - Atlantic
Service Météorologique du Canada - Atlantique
August 30
#8 Gilbert
Sep 19, 1988
18 UTC
25 kts
#3 Chris
Aug 29, 1988
12 UTC
20 kts
#1 Alberto
Aug 6, 1988
18 UTC
25 kts
#12 Keith
Nov 25, 1988
00 UTC
50 kts

Figure G10: Storm tracks of Isle Madame's historical storms

Source: Environment Canada (2010)

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

Table G15: Isle Madame's historical storms

Source: NOAA (2010)

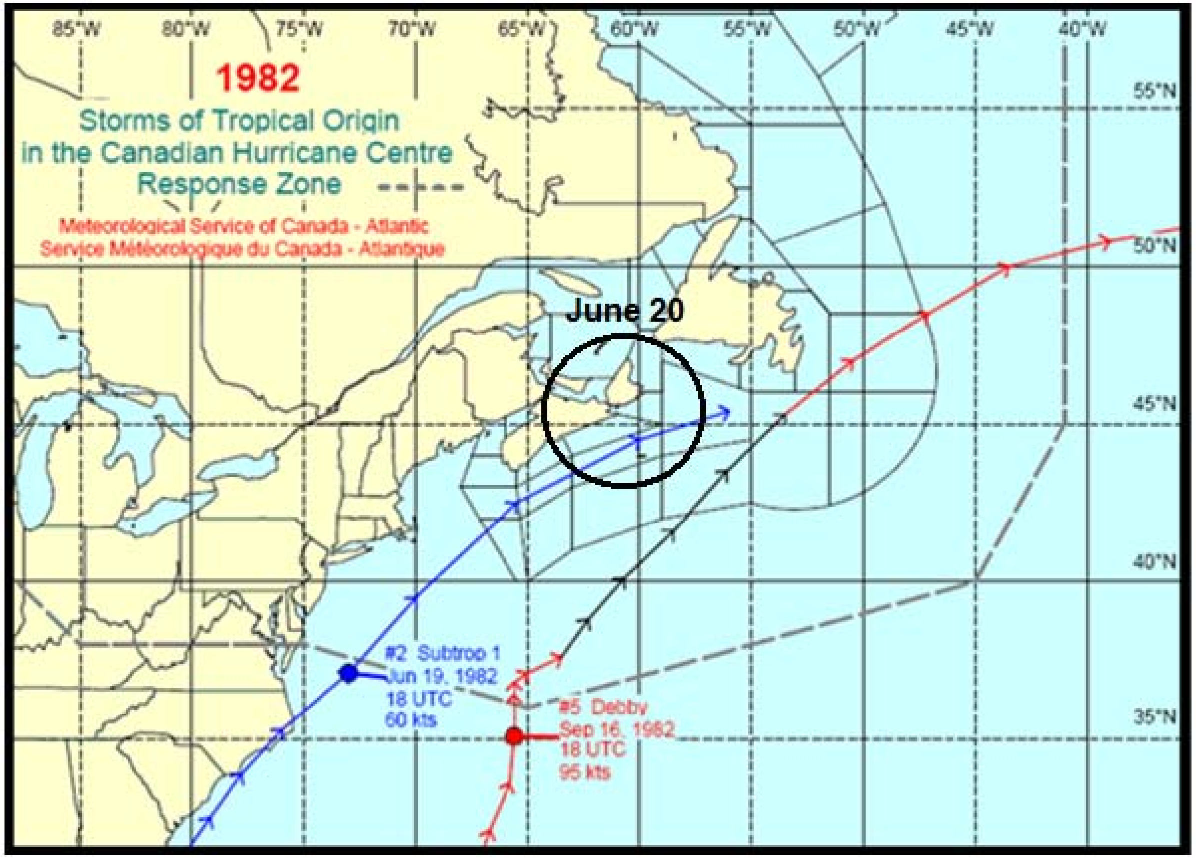


Figure G11: Storm tracks of Isle Madame's historical storms

Source: NOAA (2010)

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

Table G16: Isle Madame's historical storms

Source: NOAA (2010)

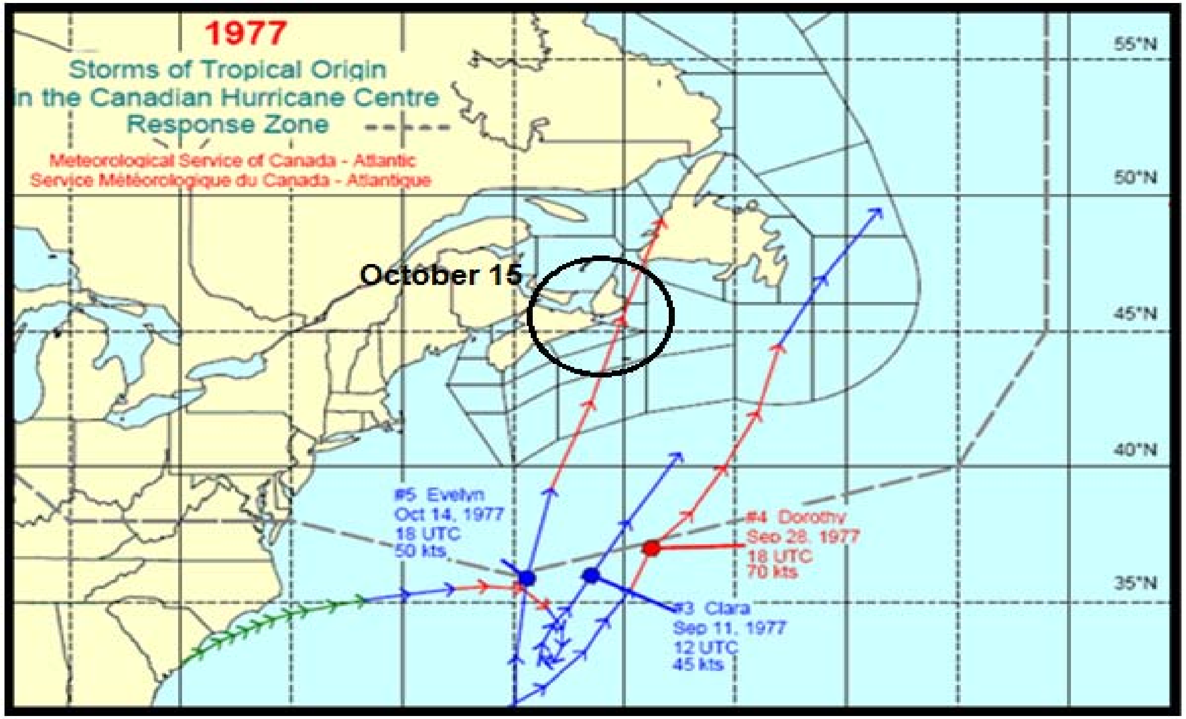


Figure G12: Storm tracks of Isle Madame's historical storms

Source: NOAA (2010)

Appendix D – Stakeholder's ranking on adaptation strategies for each scenario.

Figures below represent the rankings of adaptation options for each decision maker per scenario. The combined results are already presented and discussed in section 4.6. Figures J1 to J24 represent the rankings of our three breakwater options and figures J25 to J48 represent the rankings of "Retreat", "Road Build Up" and "New breakwater arm" from the perspective of each decision maker per scenario. Discussion is followed by each figure.

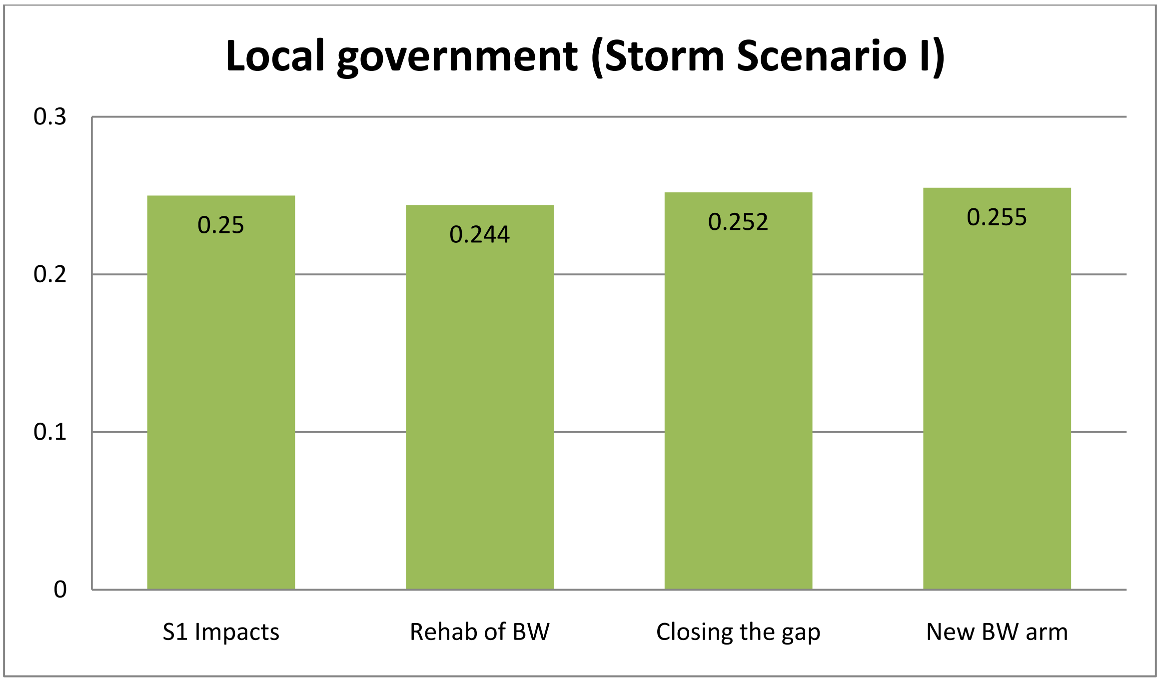


Figure J1: Breakwater strategies priorities from the perspective of Local Government for Storm Scenario I

From the perspective of local government for scenario I all breakwater options are slightly inferior or superior to "Status Quo" strategy. Implying that savings resulted from these set of options are not enough to justify their cost. We are better without adaptation (Status Quo).

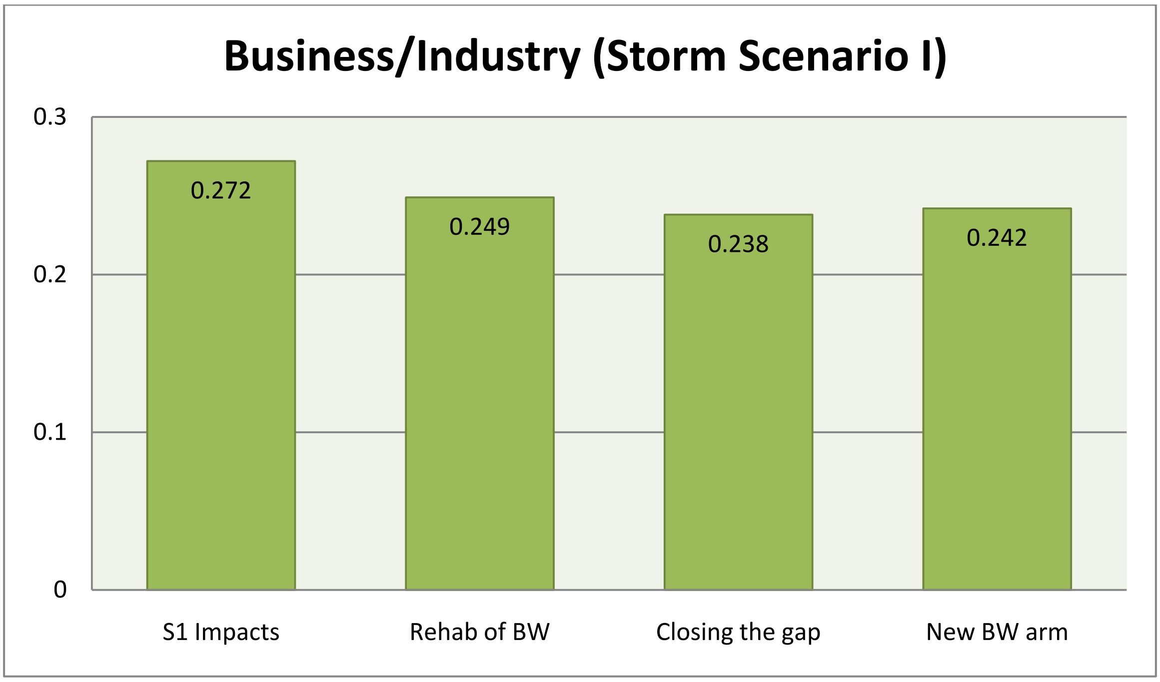


Figure J2: Breakwater strategies priorities from the perspective of Business/Industry for Storm Scenario I

From the perspective of Business/Industry- for storm scenario I- all breakwater options are inferior to "Status Quo" strategy. Implying that savings resulted from these set of options are not enough to justify their cost. We are better without adaptation (Status Quo).

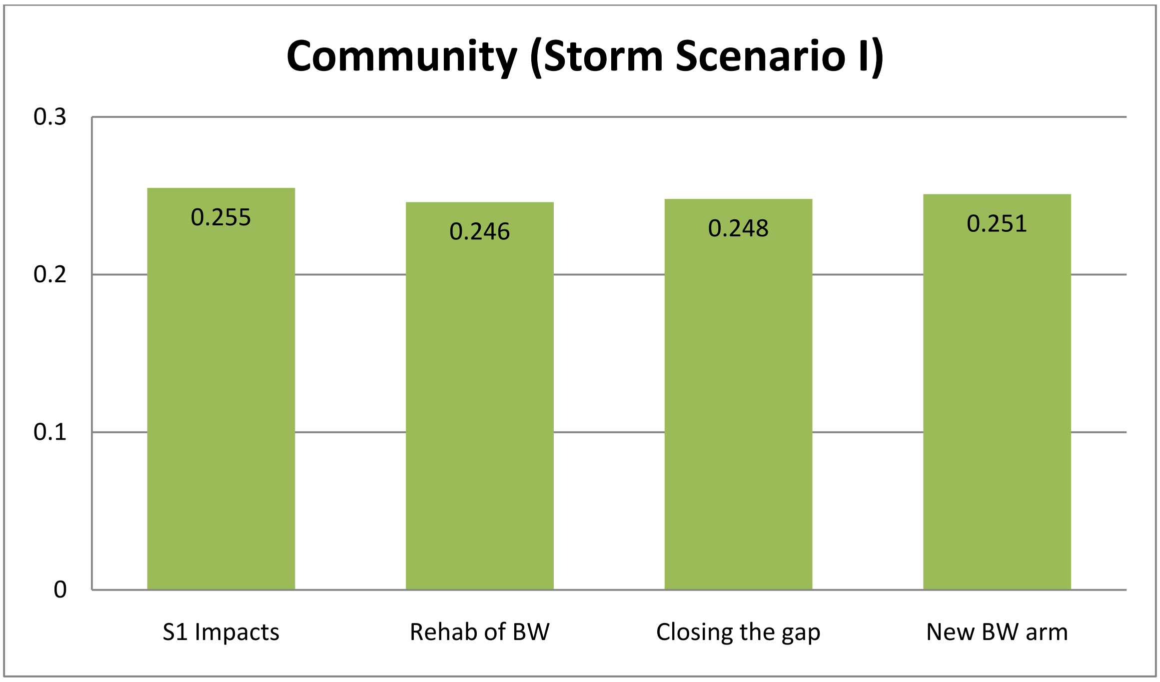


Figure J3: Breakwater strategies priorities from the perspective of Community for Storm Scenario I

From the perspective of Community - for storm scenario I- all breakwater options are slightly inferior to “Status Quo” strategy. Implying that savings resulted from these set of options are not enough to justify their cost. We are better without adaptation (Status Quo).

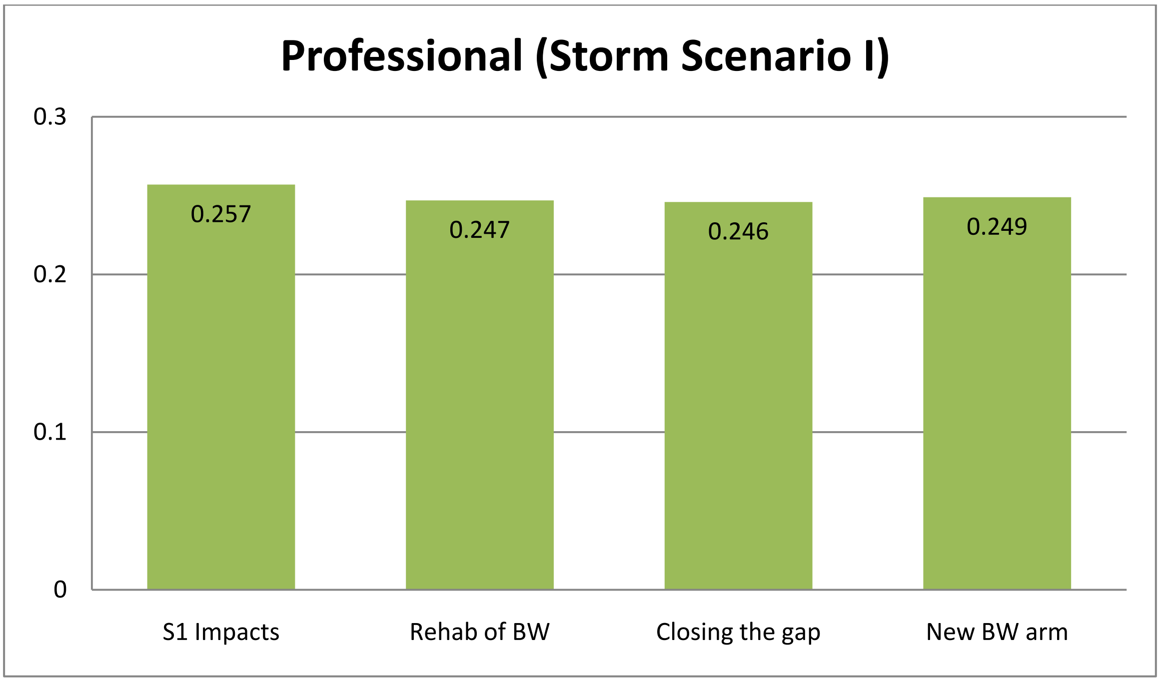


Figure J4: Breakwater strategies priorities from the perspective of Professionals for Storm Scenario I

From the perspective of Professionals - for storm scenario I- all breakwater options are slightly inferior to “Status Quo” strategy. Implying that savings resulted from these set of options are not enough to justify their cost. We are better without adaptation (Status Quo).

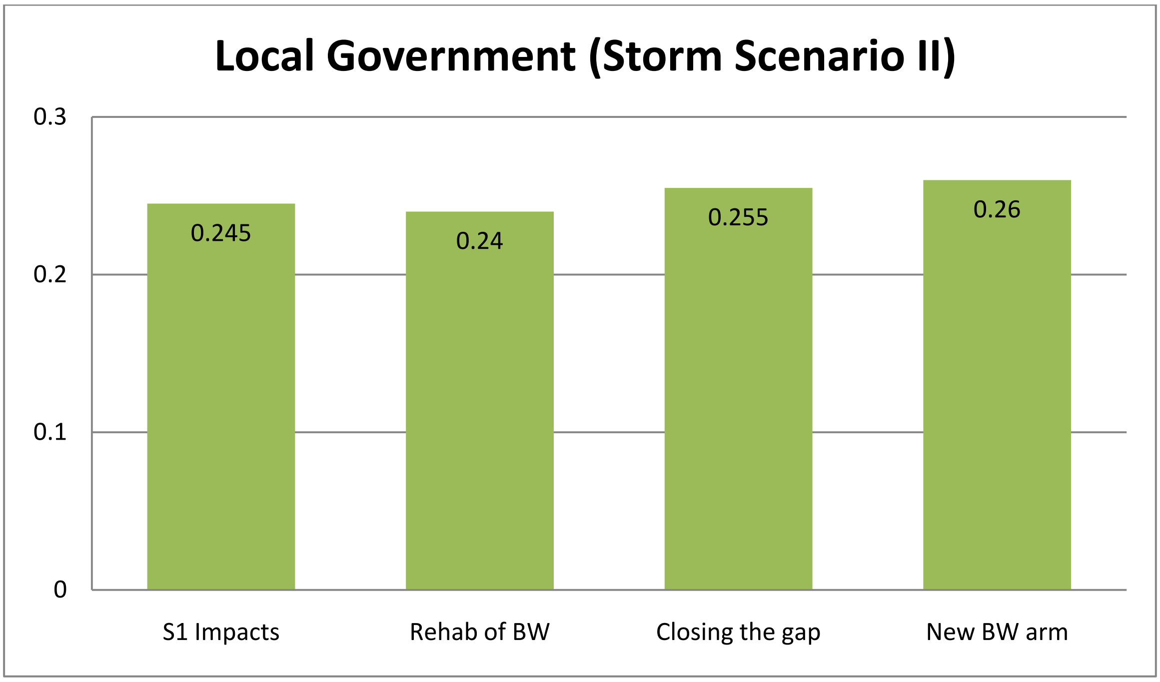


Figure J5: Breakwater strategies priorities from the perspective of Local Government for Storm Scenario II

From the perspective of Local Government- for storm scenario II- apart from "rehabilitation of existing breakwater" strategy all other alternatives are slightly superior to "Status Quo" alternative. New breakwater arm is the best option.

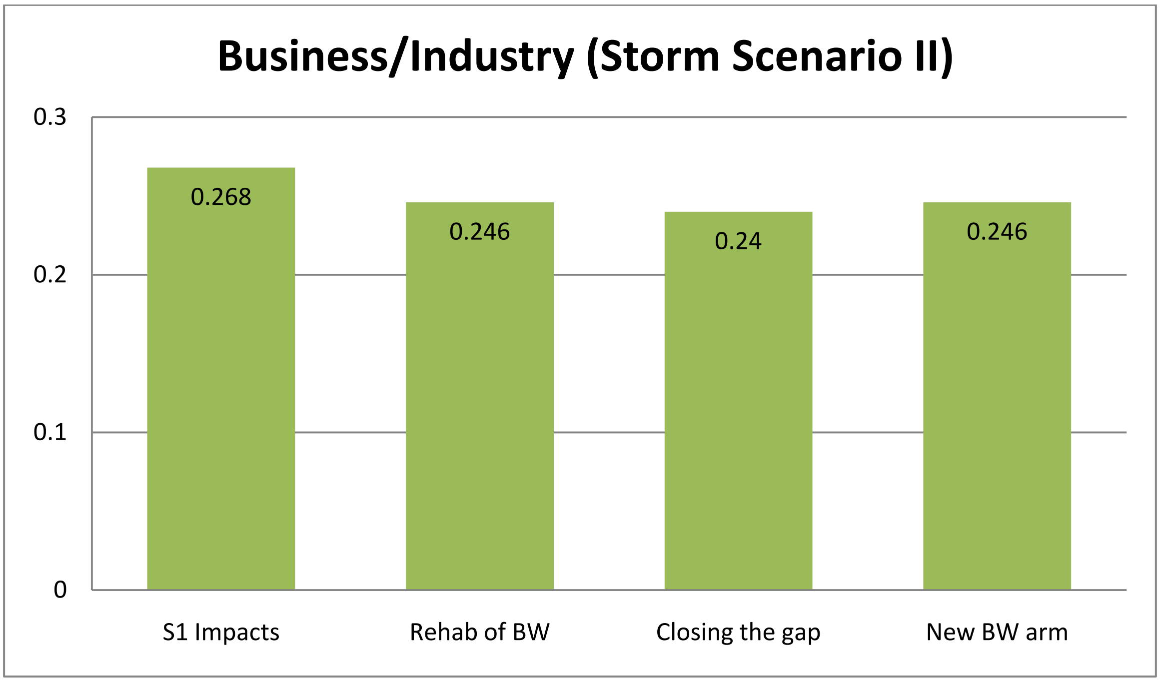


Figure J6: Breakwater strategies priorities from the perspective of Business/Industry for Storm Scenario II

From the perspective of Business/Industry- for storm scenario II- all breakwater options are inferior to "Status Quo" strategy. Implying that savings resulted from these set of options are not enough to justify their cost. We are better without adaptation (Status Quo).

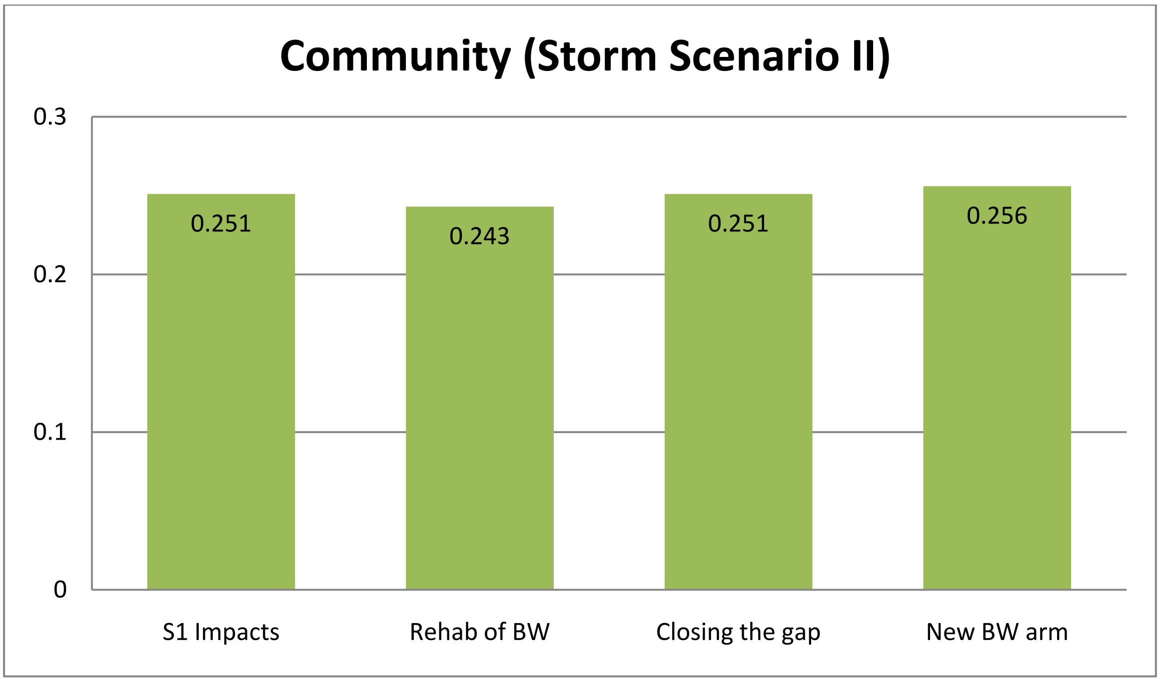


Figure J7: Breakwater strategies priorities from the perspective of Community for Storm Scenario II

From the perspective of Community- for storm scenario II- apart from "rehabilitation of existing breakwater" strategy all other alternatives are slightly superior to "Status Quo" alternative. New breakwater arm is the best option.

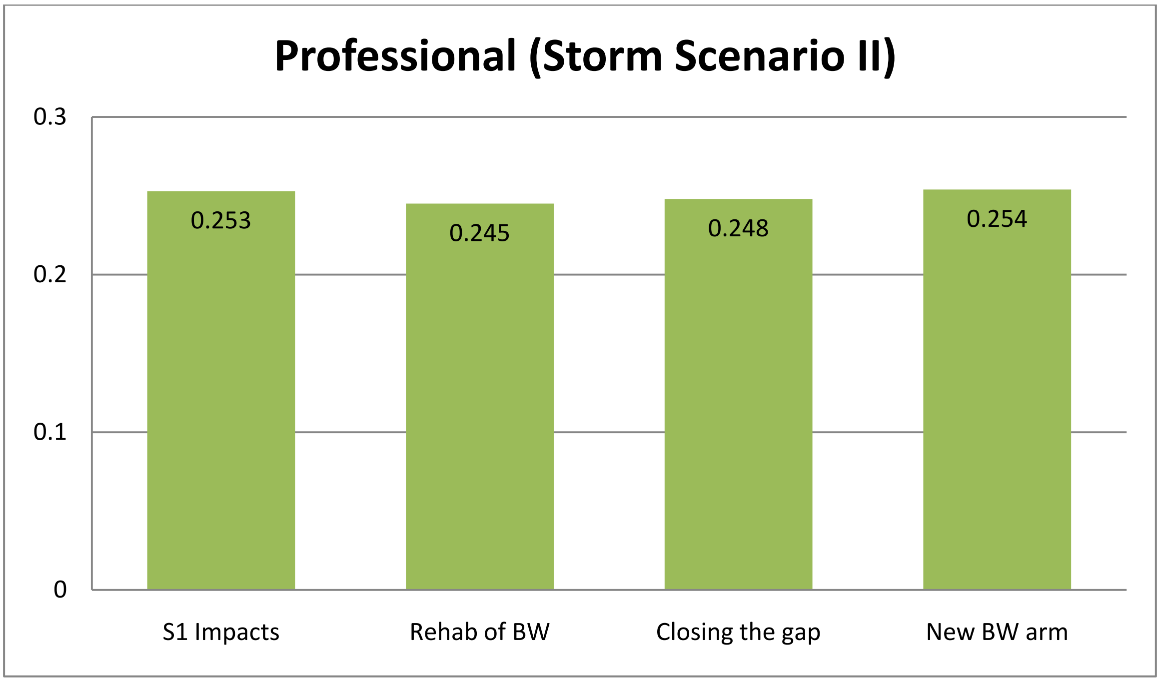


Figure J8: Breakwater strategies priorities from the perspective of professionals for Storm Scenario II

From the perspective of Professionals- for storm scenario II- apart from "New breakwater arm" strategy all other alternatives are slightly inferior to "Status Quo" alternative. New breakwater arm is the best option.

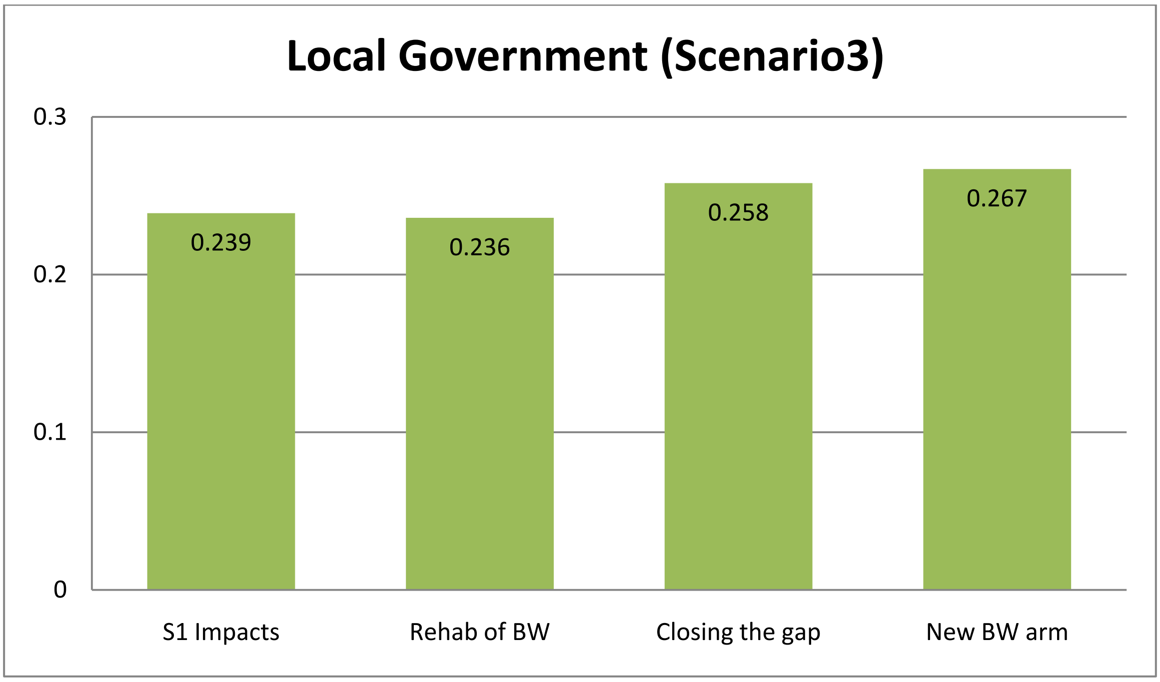


Figure J9: Breakwater strategies priorities from the perspective of Local Government for Storm Scenario III

From the perspective of Local Government- for storm scenario III- apart from “rehabilitation of existing breakwater” strategy all other alternatives are superior to “Status Quo” alternative. New breakwater arm is the best option.

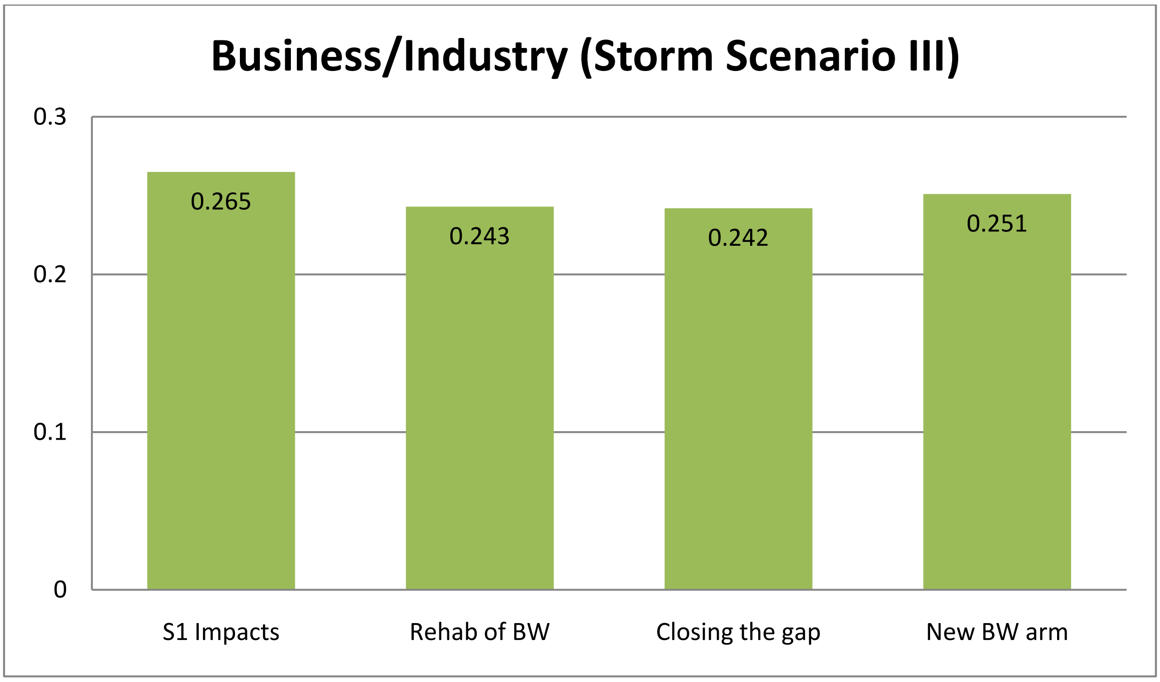


Figure J10: Breakwater strategies priorities from the perspective of Business/Industry for Storm Scenario III

From the perspective of Business/Industry- for storm scenario III- all breakwater options are inferior to “Status Quo” strategy. Implying that savings resulted from these set of options are not enough to justify their cost. We are better without adaptation (Status Quo).

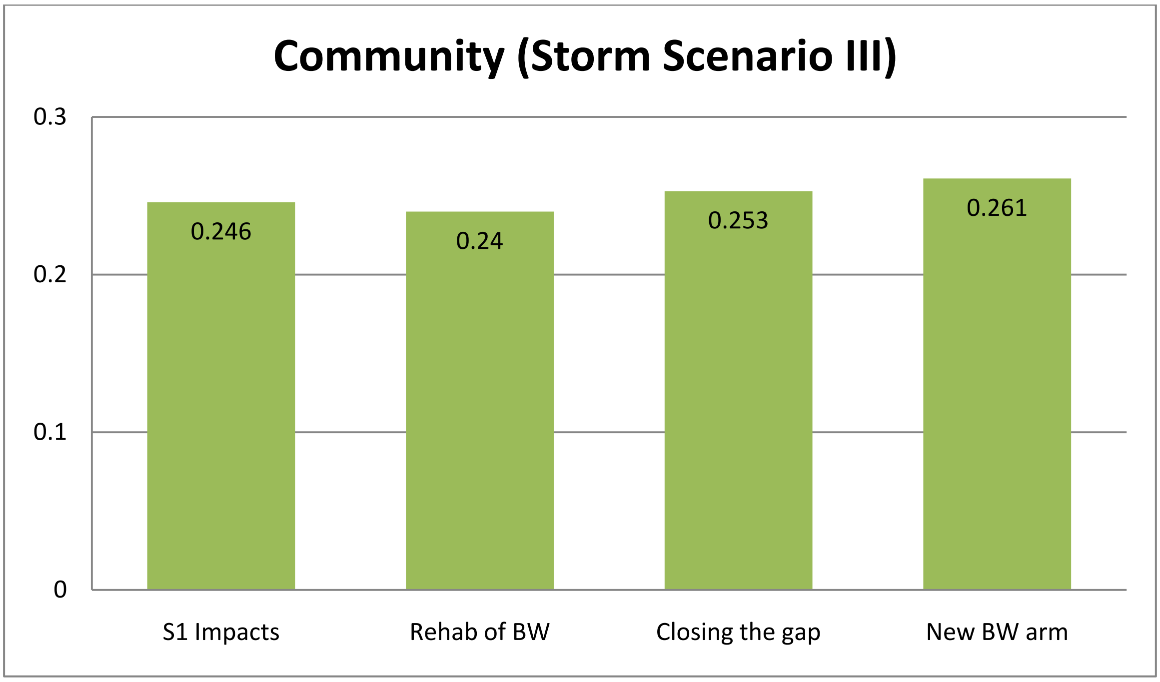


Figure J11: Breakwater strategies priorities from the perspective of Community for Storm Scenario III

From the perspective of Community- for storm scenario III- apart from “rehabilitation of existing breakwater” strategy all other alternatives are superior to “Status Quo” alternative. New breakwater arm is the best option.

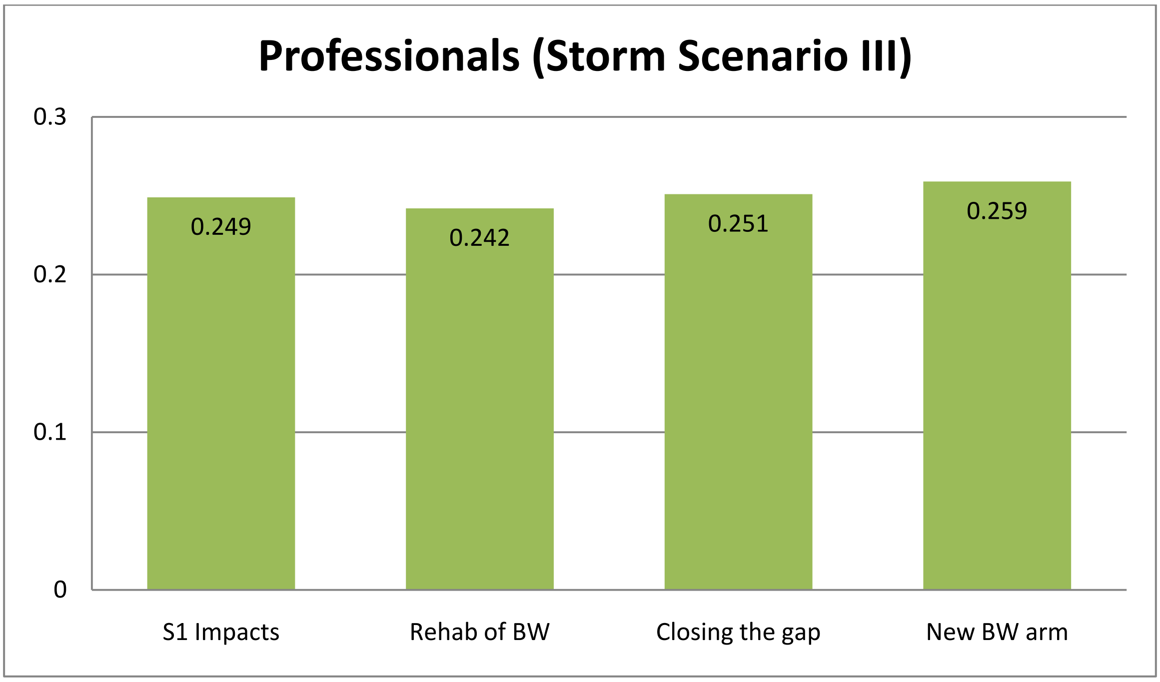


Figure J12: Breakwater strategies priorities from the perspective of Professionals for Storm Scenario III

From the perspective of Professionals- for storm scenario III- apart from “rehabilitation of existing breakwater” strategy all other alternatives are superior to “Status Quo” alternative. New breakwater arm is the best option.

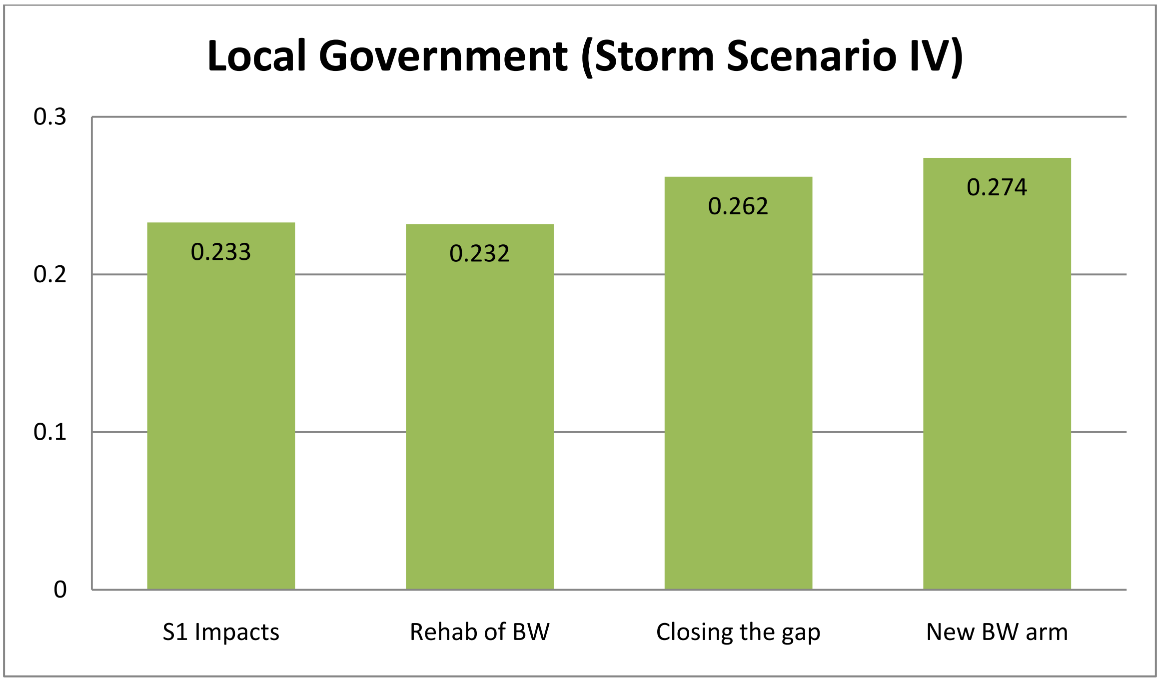


Figure J13: Breakwater strategies priorities from the perspective of Local Government for Storm Scenario IV

From the perspective of Local Government- for storm scenario IV- apart from “rehabilitation of existing breakwater” strategy all other alternatives are superior to “Status Quo” alternative. New breakwater arm is the best option.

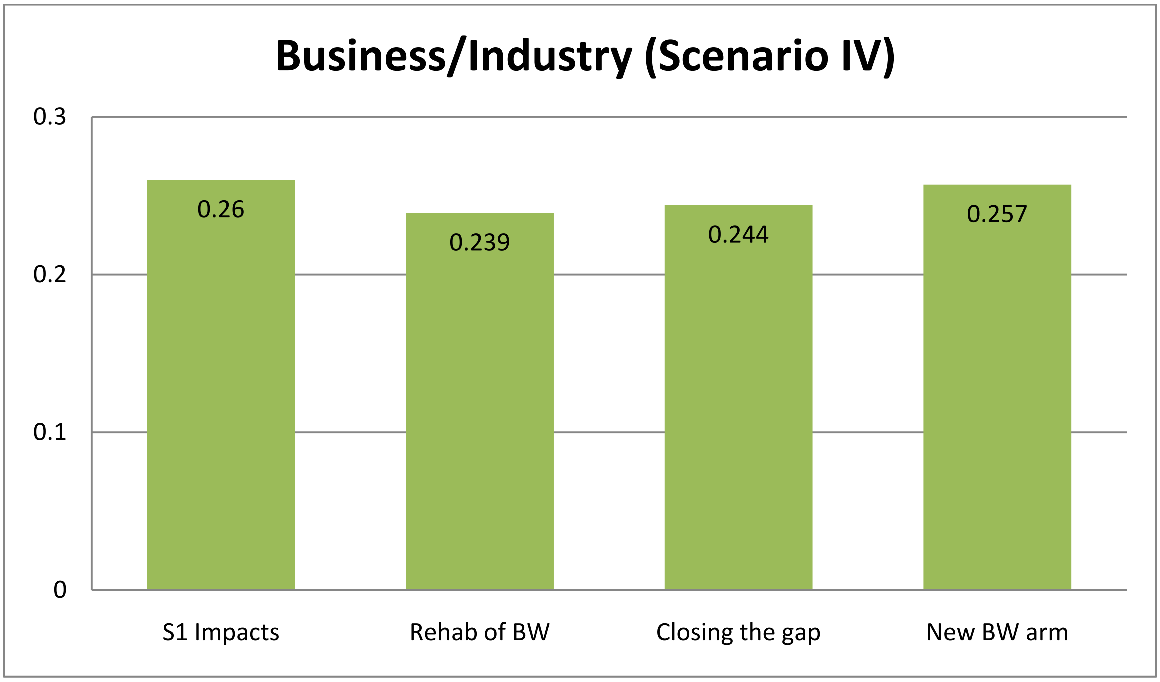


Figure J14: Breakwater strategies priorities from the perspective of Business/Industry for Storm Scenario IV

From the perspective of Business/Industry- for storm scenario IV- all breakwater options are inferior to "Status Quo" strategy. Implying that savings resulted from these set of options are not enough to justify their cost. We are better off without adaptation (Status Quo).

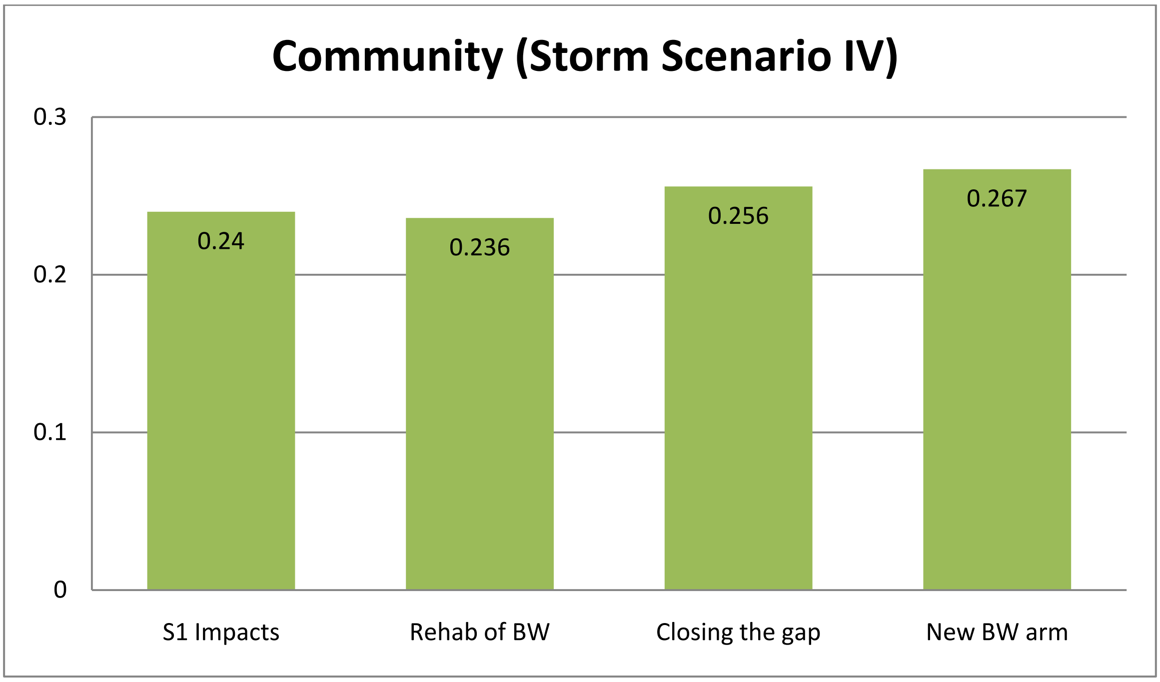


Figure J15: Breakwater strategies priorities from the perspective of Community for Storm Scenario IV

From the perspective of Community- for storm scenario IV- apart from “rehabilitation of existing breakwater” strategy all other alternatives are superior to “Status Quo” alternative. New breakwater arm is the best option.

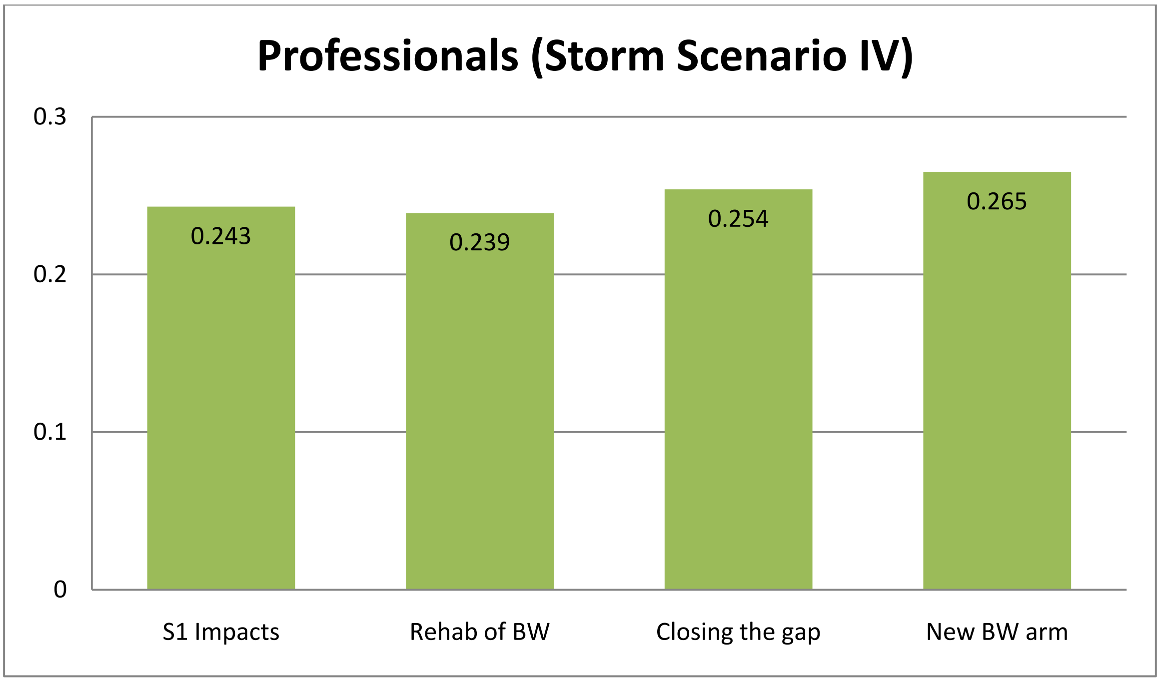


Figure J16: Breakwater strategies priorities from the perspective of Professionals for Storm Scenario IV

From the perspective of Professionals- for storm scenario IV - apart from “rehabilitation of existing breakwater” strategy all other alternatives are superior to “Status Quo” alternative. New breakwater arm is the best option.

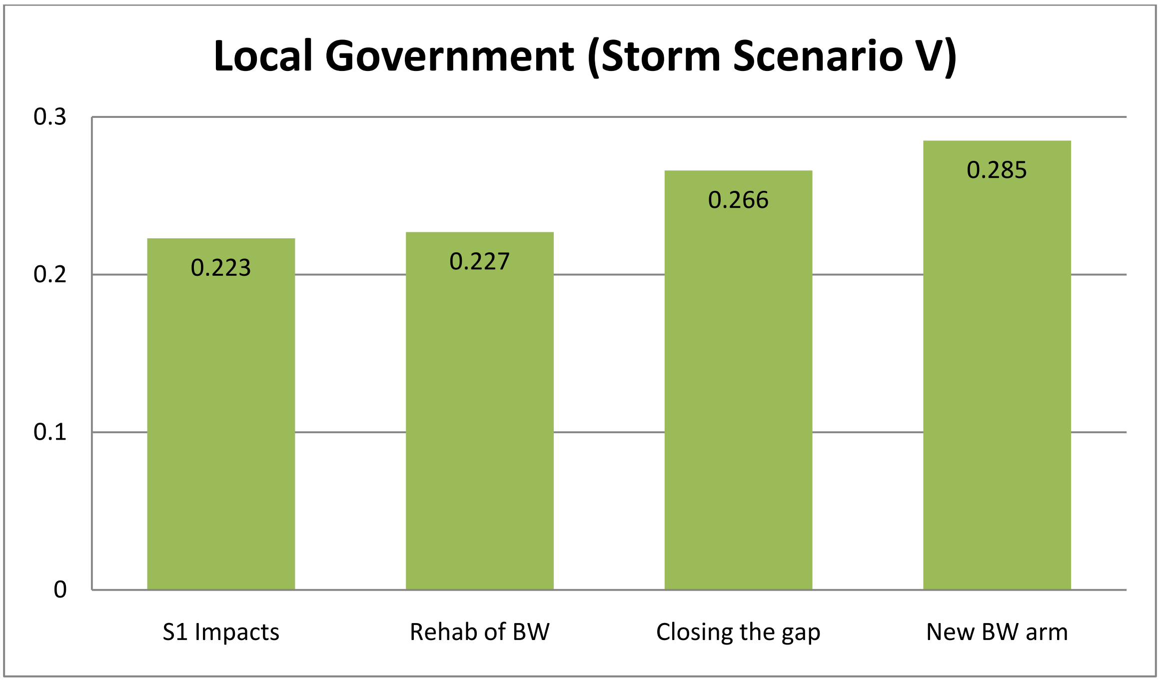


Figure J17: Breakwater strategies priorities from the perspective of Local Government for Storm Scenario V

From the perspective of Local Government- Storm Scenario V - all alternatives are superior to “Status Quo” alternative. New breakwater arm is the best option.

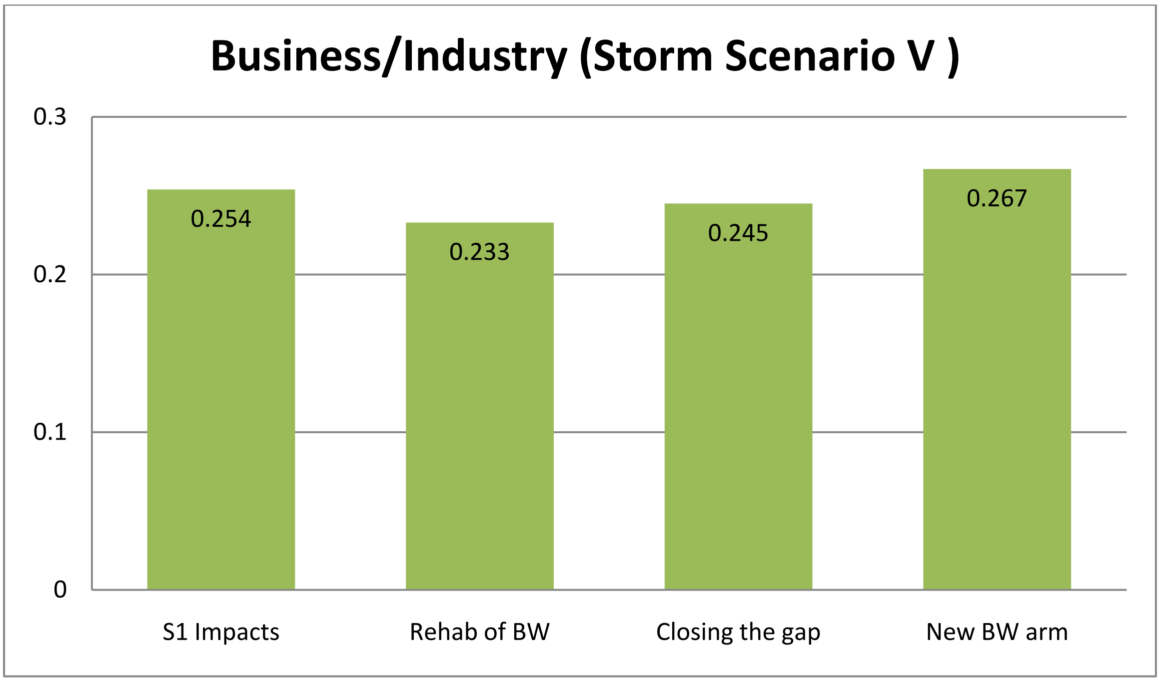


Figure J18: Breakwater strategies priorities from the perspective of Business/Industry for Storm Scenario V

From the perspective of Business/Industry- for Storm Scenario V - only “new breakwater arm” alternative is superior to “Status Quo” alternative and therefore is the best option.

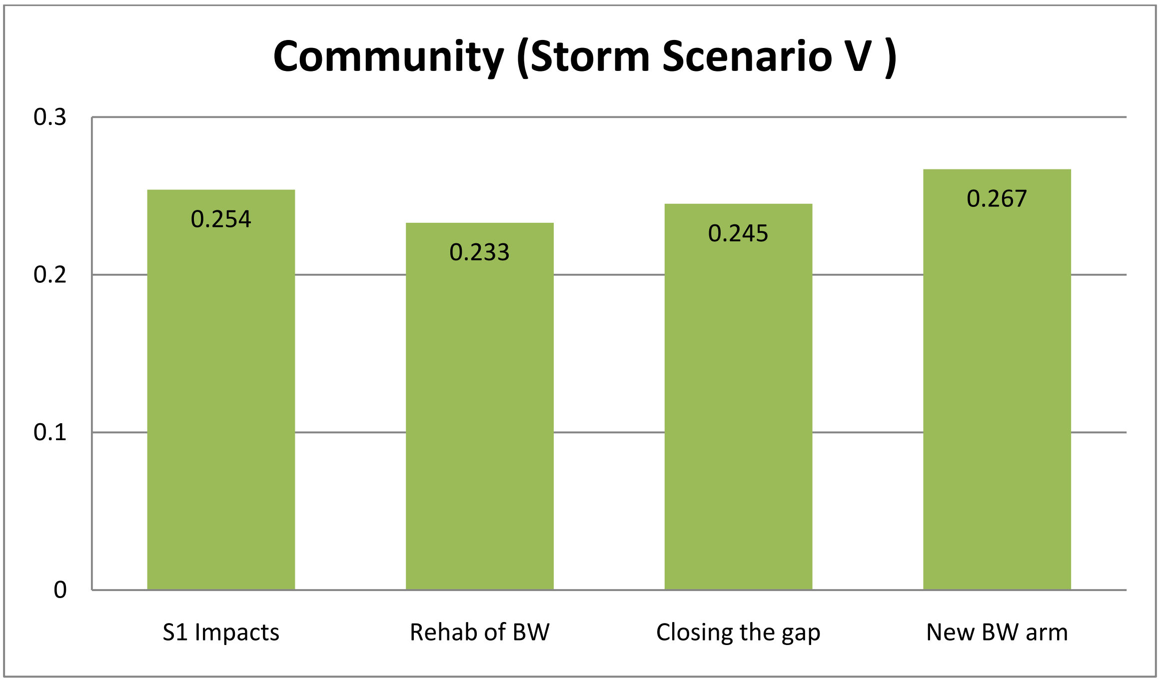


Figure J19: Breakwater strategies priorities from the perspective of Community for Storm Scenario V

From the perspective of Community- for storm scenario V- only “new breakwater arm” alternative is superior to “Status Quo” alternative and therefore is the best option.

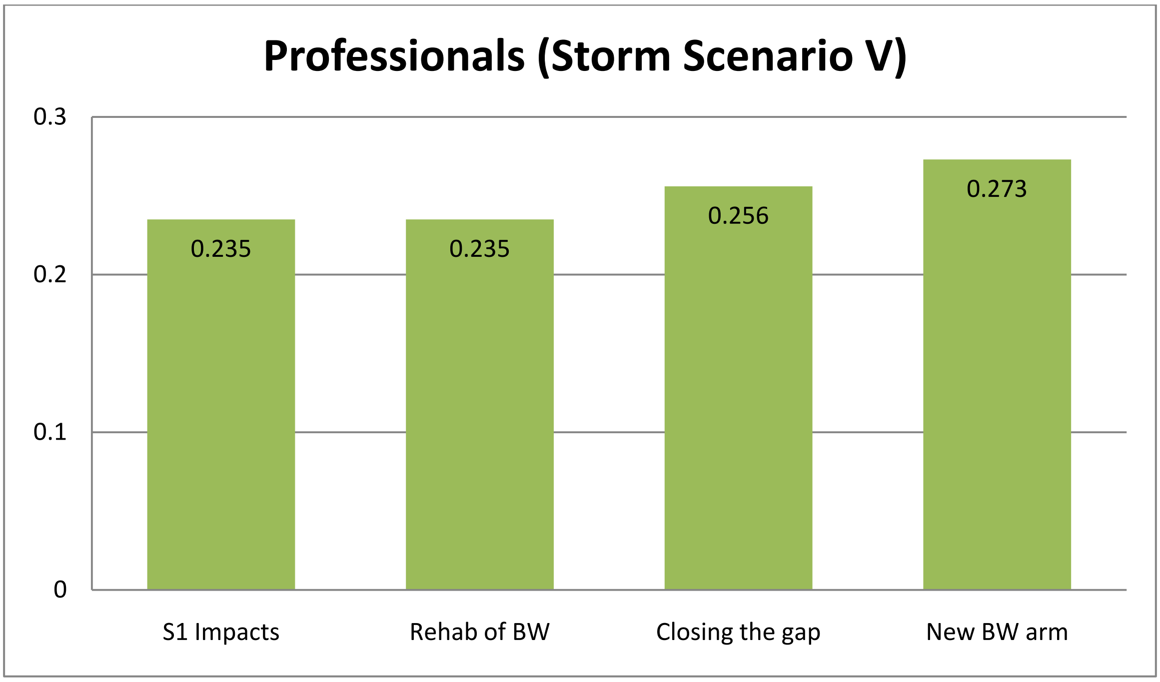


Figure J20: Breakwater strategies priorities from the perspective of Professionals for Storm Scenario V

From the perspective of Professionals- Storm Scenario V - all alternatives are superior to "Status Quo" alternative. New breakwater arm is the best option.

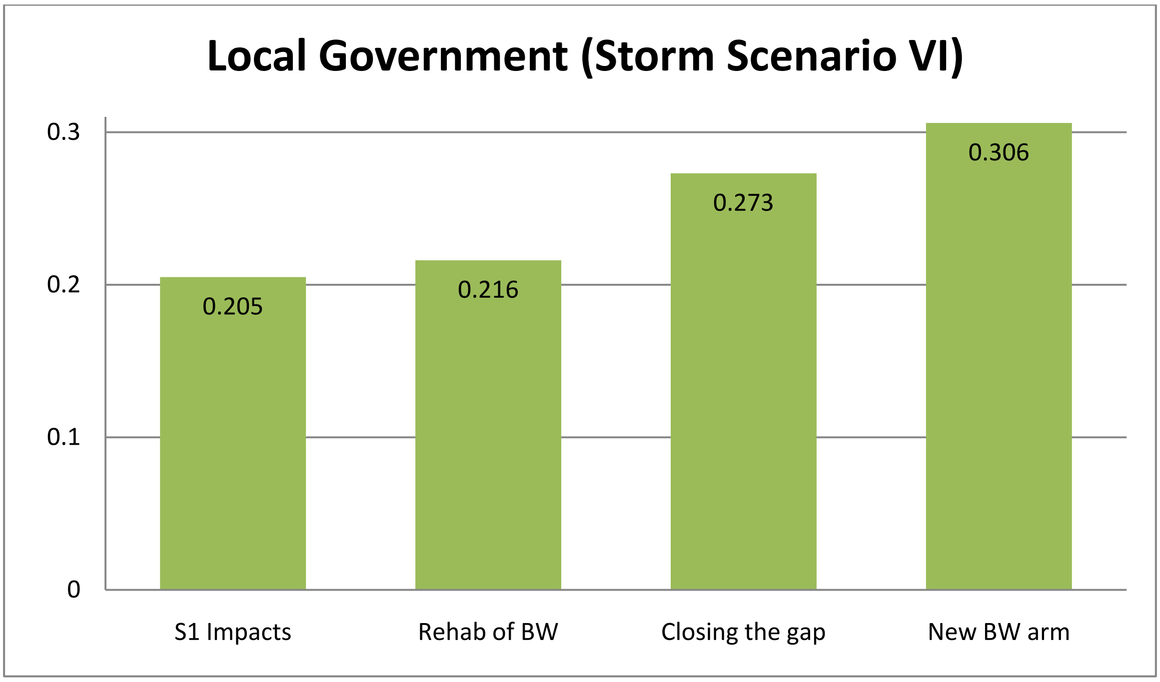


Figure J21: Breakwater strategies priorities from the perspective of Local Government for Storm Scenario VI

From the perspective of Local Government- for storm scenario VI- all alternatives are superior to “Status Quo” alternative. New breakwater arm is the best option.

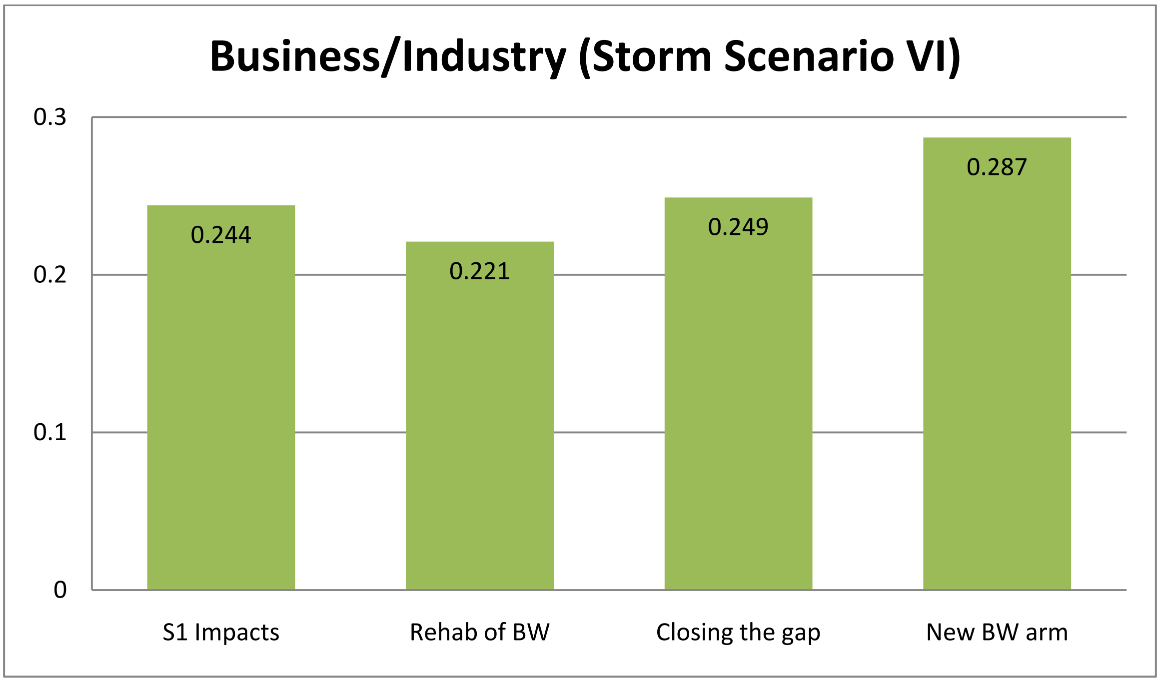


Figure J22: Breakwater strategies priorities from the perspective of Business/Industry for Storm Scenario VI

From the perspective of Business/Industry- for storm scenario VI - apart from “rehabilitation of the existing breakwater” all other alternatives are superior to “Status Quo” alternative. New breakwater arm is the best option.

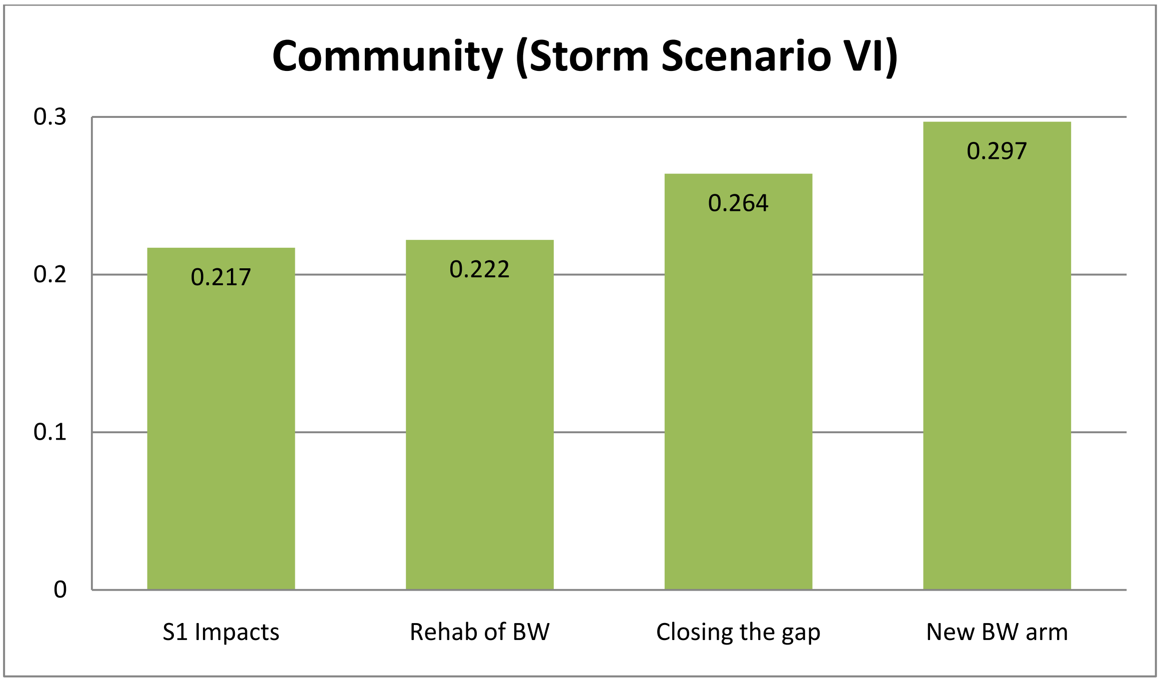


Figure J23: Breakwater strategies priorities from the perspective of Community for Storm Scenario VI

From the perspective of Community- for storm scenario VI - all alternatives are superior to "Status Quo" alternative. New breakwater arm is the best option.

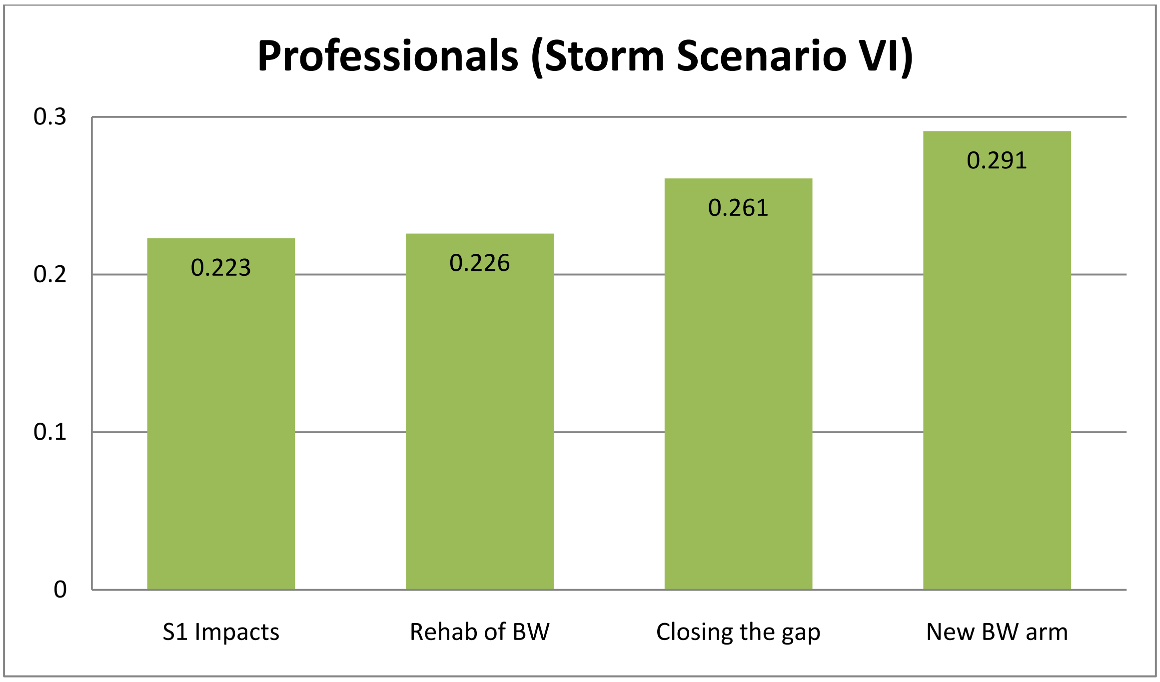


Figure J24: Breakwater strategies priorities from the perspective of Professionals for Storm Scenario VI

From the perspective of Professionals- for storm scenario VI- all alternatives are superior to “Status Quo” alternative. New breakwater arm is the best option.

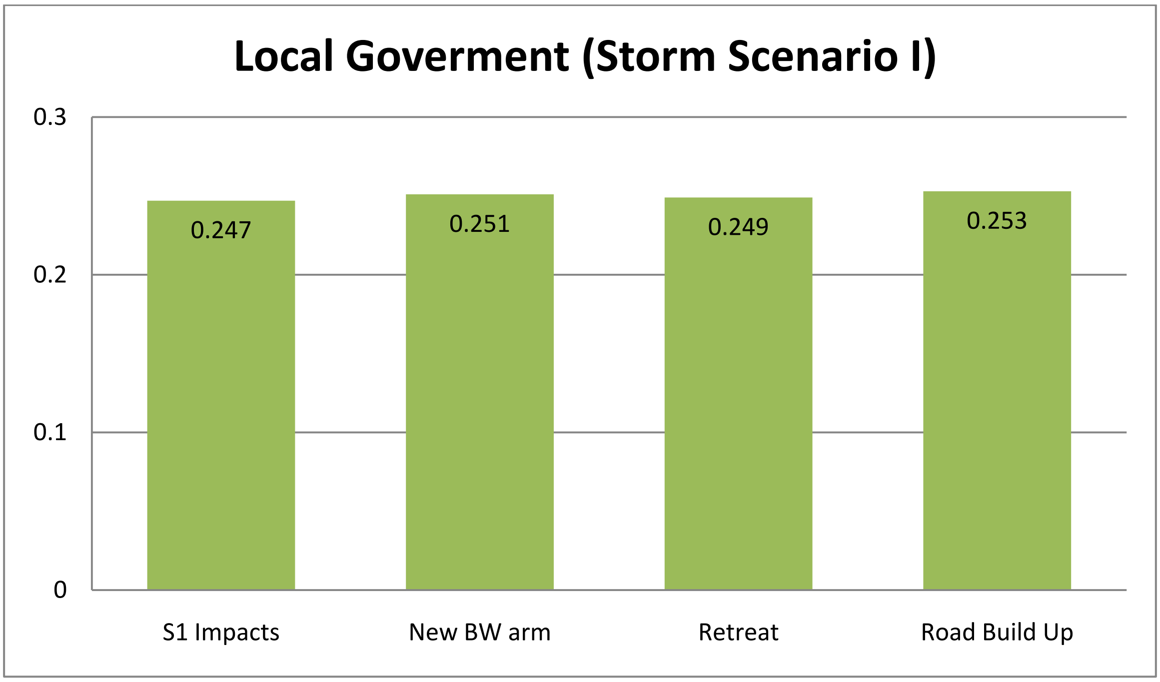


Figure J25: “Retreat”, “Road Build Up” and “New Breakwater arm” priorities from the perspective of Local Government for Storm Scenario I

From the perspective of Local Government- for storm scenario I- All strategies are slightly superior to “Status Quo” with “Road build up” alternative being slightly better than others.

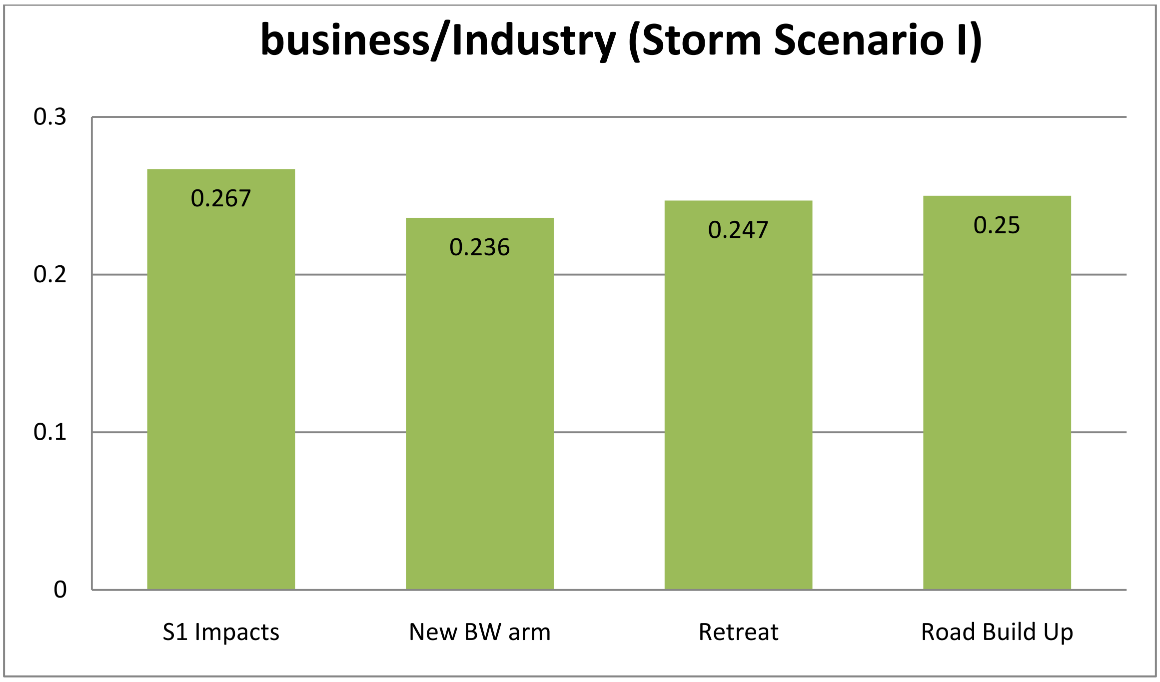


Figure J26: "Retreat", "Road Build Up" and "New Breakwater arm" priorities from the perspective of Business/Industry for Storm Scenario I

From the perspective of Business/Industry- for storm scenario I- all strategies are inferior to "Status Quo". We are better off doing nothing.

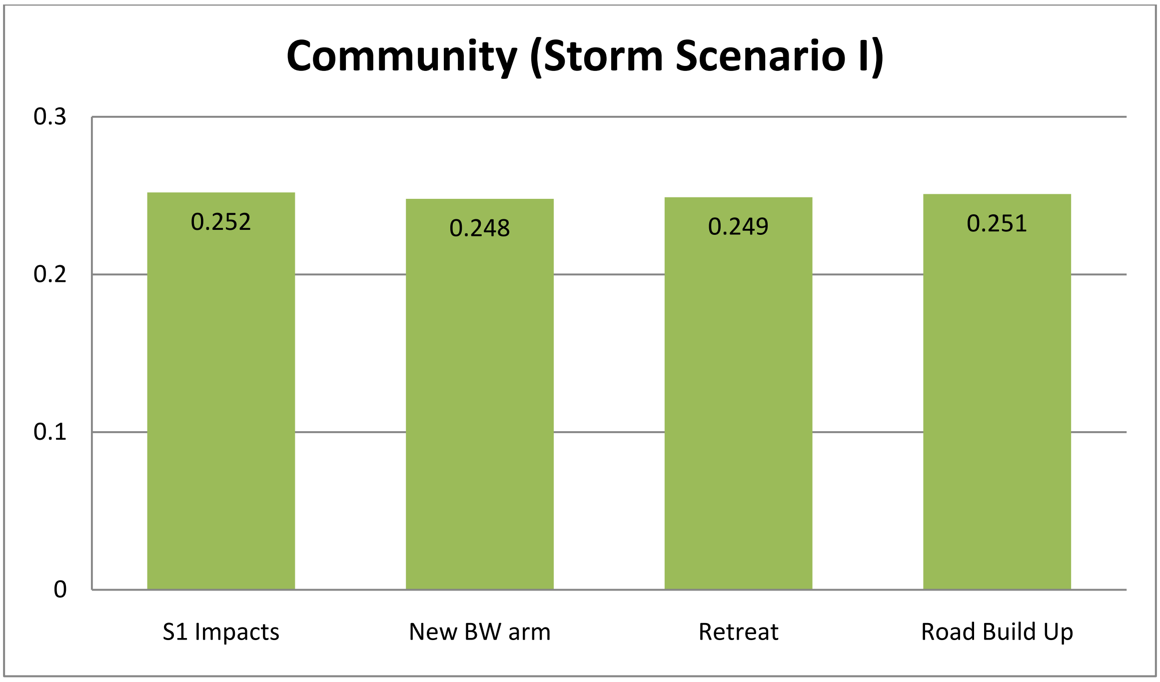


Figure J27: "Retreat", "Road Build Up" and "New Breakwater arm" priorities from the perspective of Community for Storm Scenario I

From the perspective of Community- for storm scenario I- all strategies are inferior to "Status Quo". We are better off doing nothing.

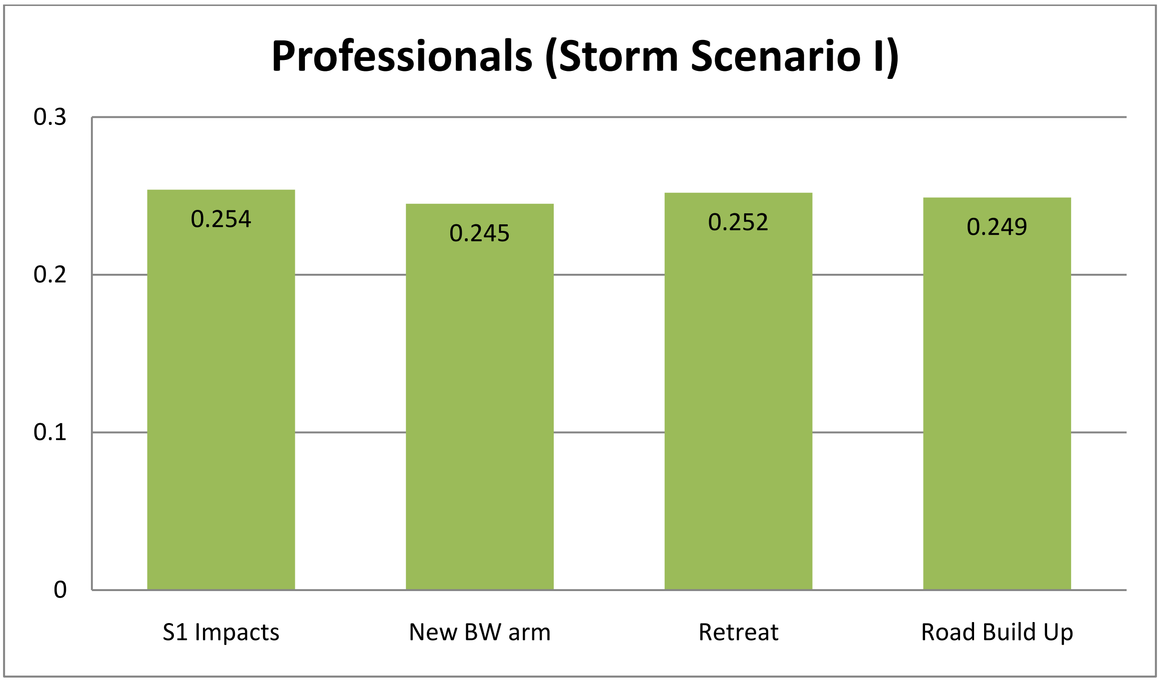


Figure J28: "Retreat", "Road Build Up" and "New Breakwater arm" priorities from the perspective of Professionals for Storm Scenario I

From the perspective of Professionals- for storm scenario I- all strategies are inferior to "Status Quo". We are better off doing nothing.

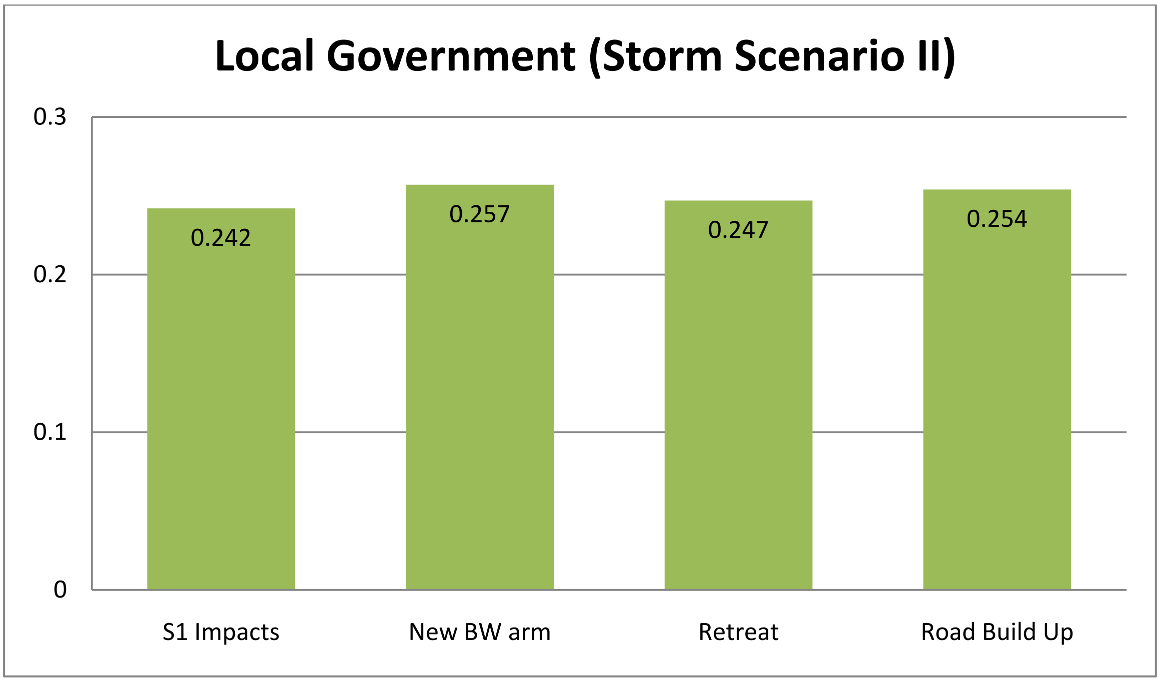


Figure J29: "Retreat", "Road Build Up" and "New Breakwater arm" priorities from the perspective of Local Government for Storm Scenario II

From the perspective of Local Government- for storm scenario II- All strategies are slightly superior to "Status Quo" with "New breakwater arm" alternative being better than others.

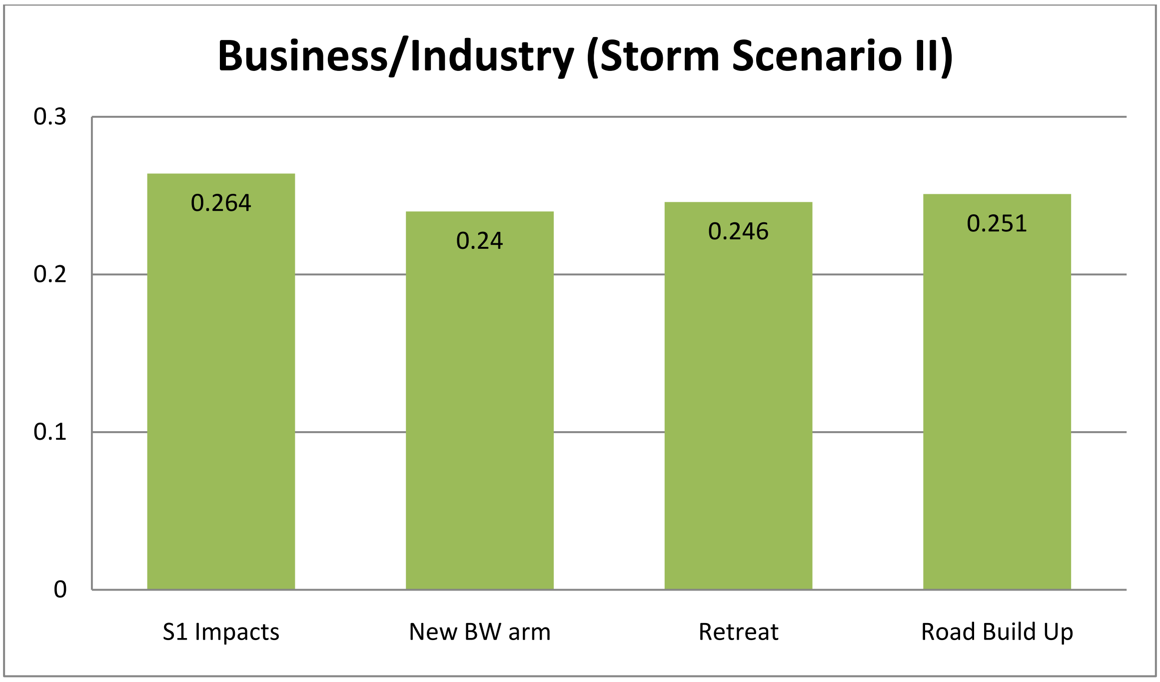


Figure J30: "Retreat", "Road Build Up" and "New Breakwater arm" priorities from the perspective of Local Government for Storm Scenario II

From the perspective of Business/Industry- for storm scenario II- all strategies are inferior to "Status Quo". We are better off doing nothing.

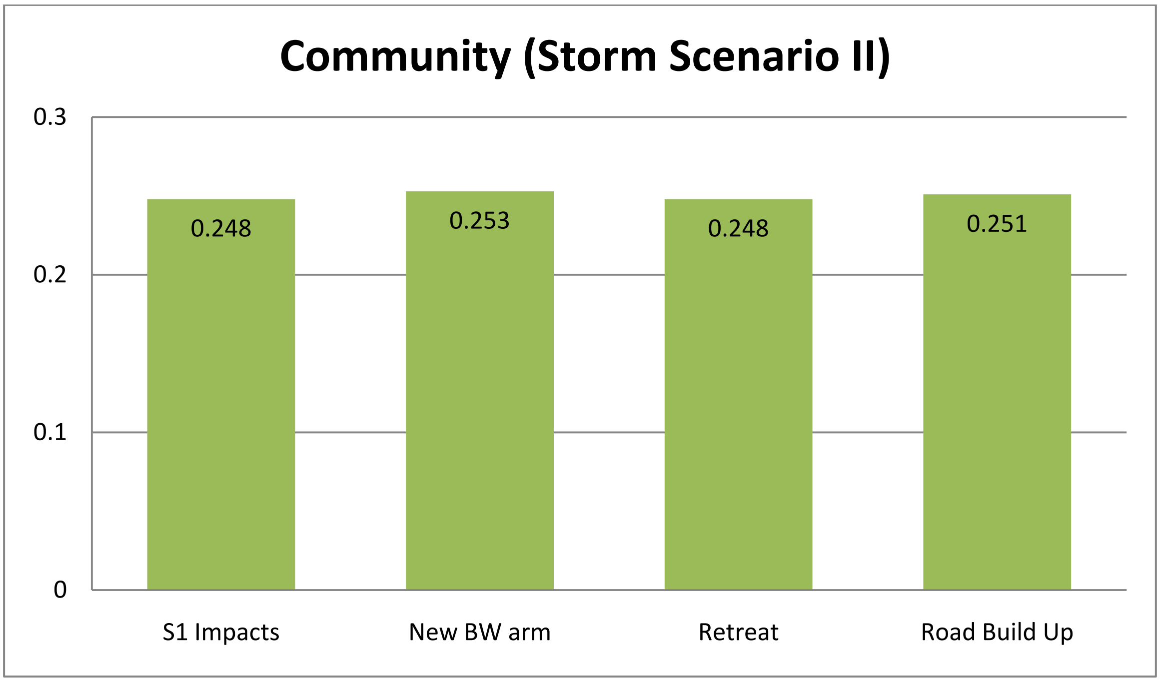


Figure J31: "Retreat", "Road Build Up" and "New Breakwater arm" priorities from the perspective of Community for Storm Scenario II

From the perspective of Community- for storm scenario II- All strategies are slightly superior to "Status Quo" with "New breakwater arm" alternative slightly better than others.

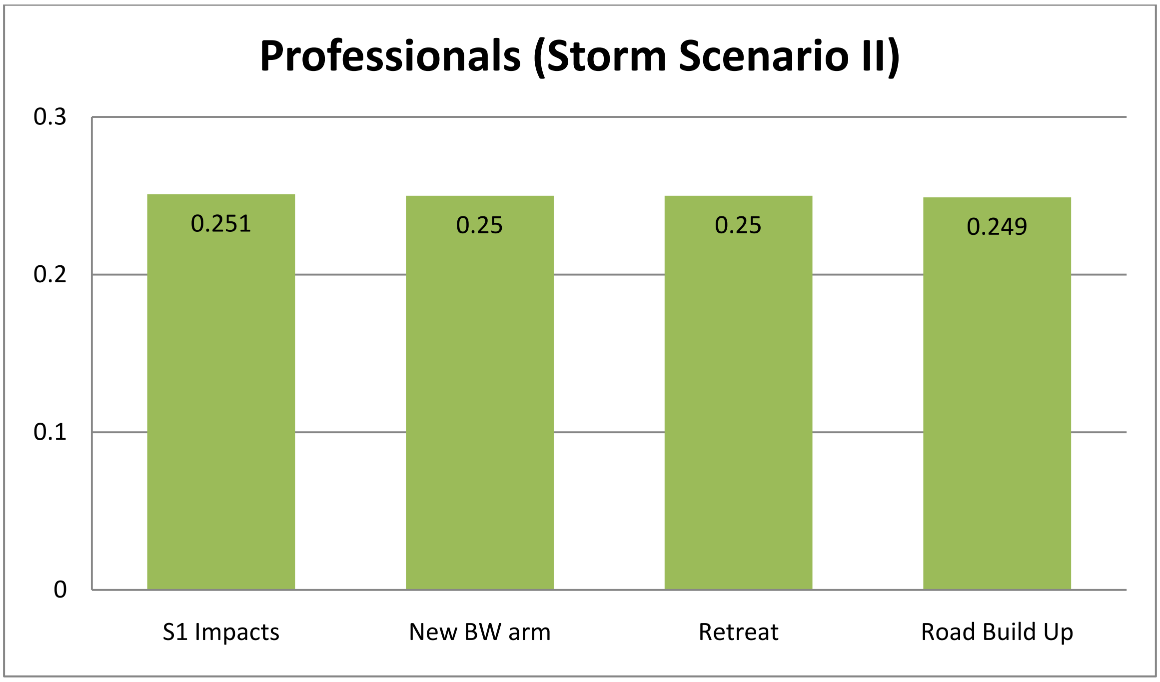


Figure J32: "Retreat", "Road Build Up" and "New Breakwater arm" priorities from the perspective of Professionals for Storm Scenario II

From the perspective of Professionals- for storm scenario II- all strategies are inferior to "Status Quo". We are better off doing nothing.

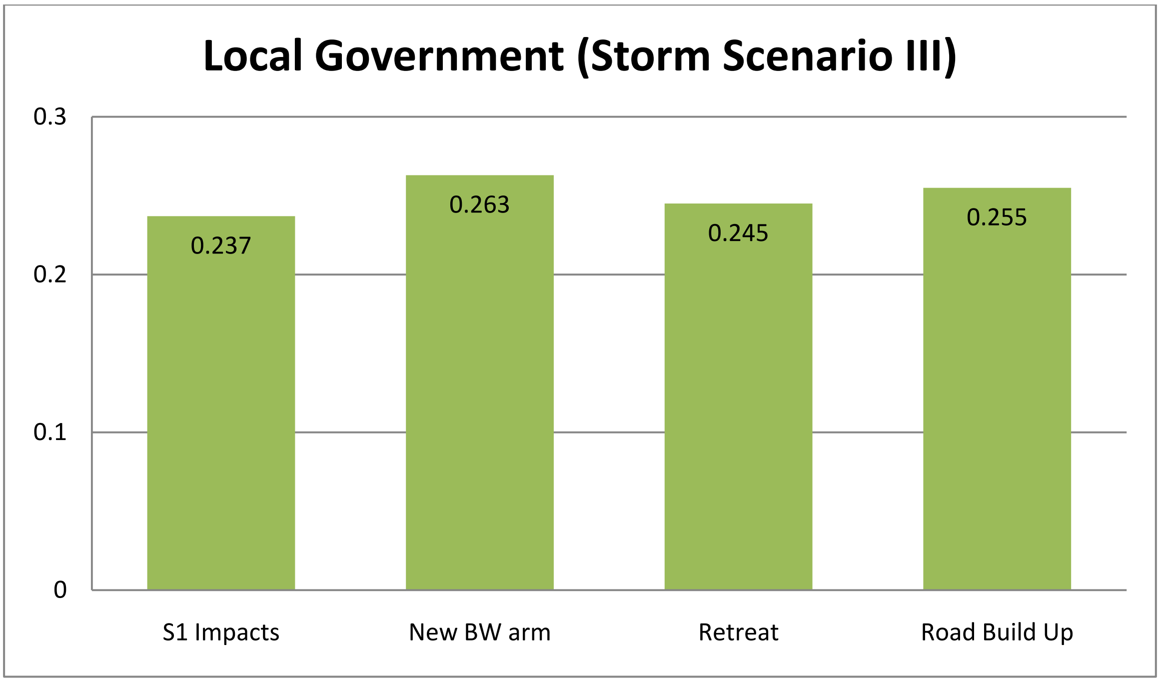


Figure J33: "Retreat", "Road Build Up" and "New Breakwater arm" priorities from the perspective of Local Government for Storm Scenario III

From the perspective of Local Government- for storm scenario III- All strategies are superior to "Status Quo" with "New breakwater arm" alternative being better than others.

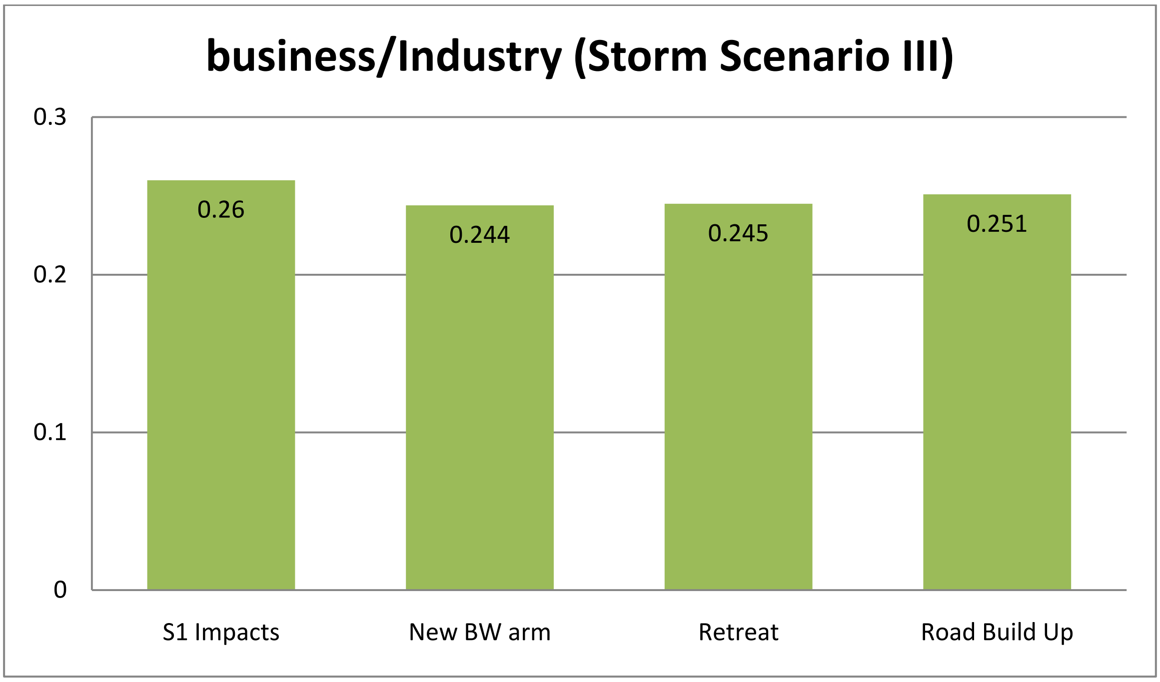


Figure J34: "Retreat", "Road Build Up" and "New Breakwater arm" priorities from the perspective of Business/Industry for Storm Scenario III

From the perspective of Business/Industry- for storm scenario III – all alternatives are inferior to "Status Quo" therefore we are better off doing nothing.

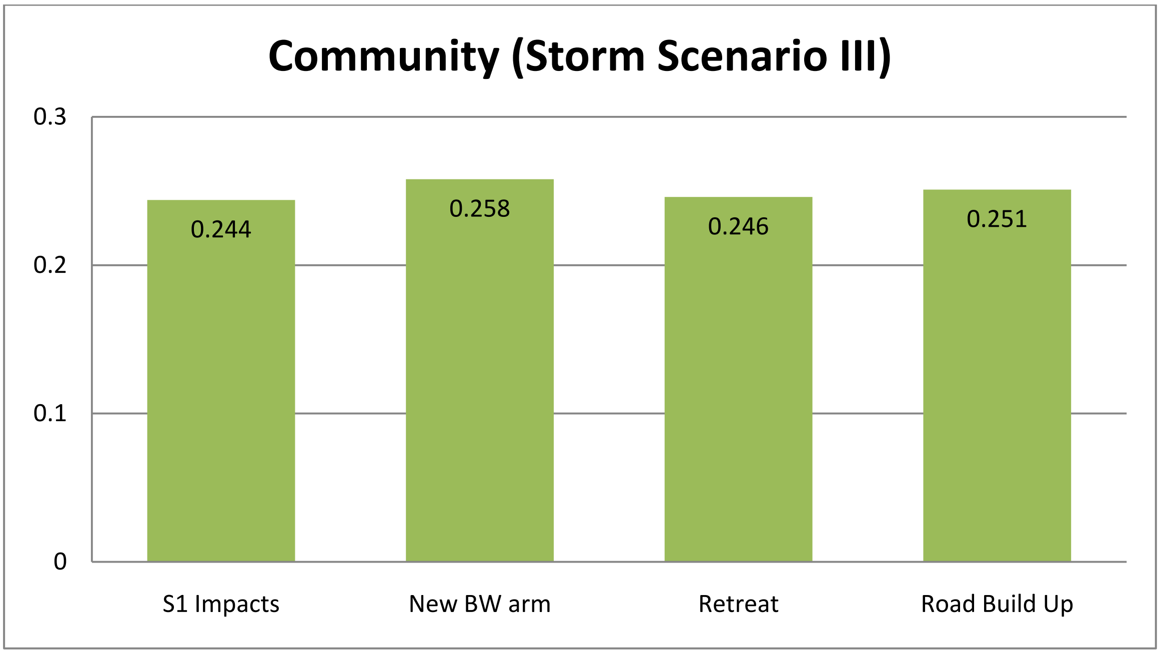


Figure J35: "Retreat", "Road Build Up" and "New Breakwater arm" priorities from the perspective of Community for Storm Scenario III

From the perspective of Community- for scenario III- All strategies are superior to "Status Quo" with "New breakwater arm" alternative being better than others.

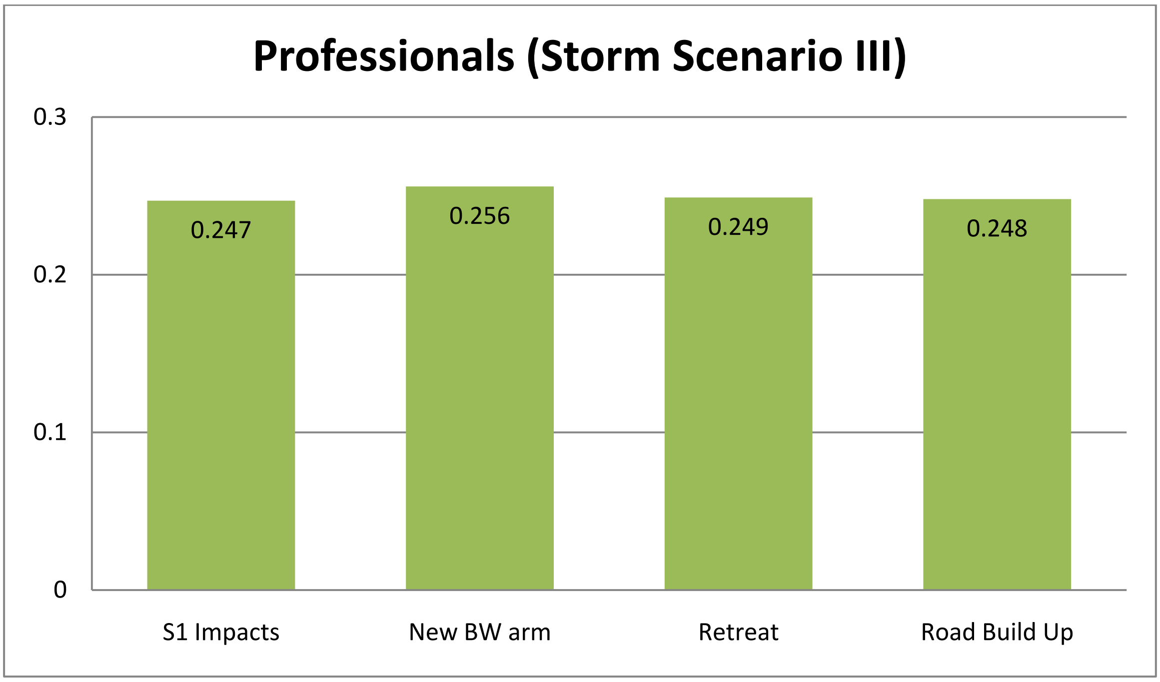


Figure J36: "Retreat", "Road Build Up" and "New Breakwater arm" priorities from the perspective of Professionals for Storm Scenario III

From the perspective of Professionals- for scenario III- all strategies are superior to "Status Quo" with "New breakwater arm" alternative being better than others.

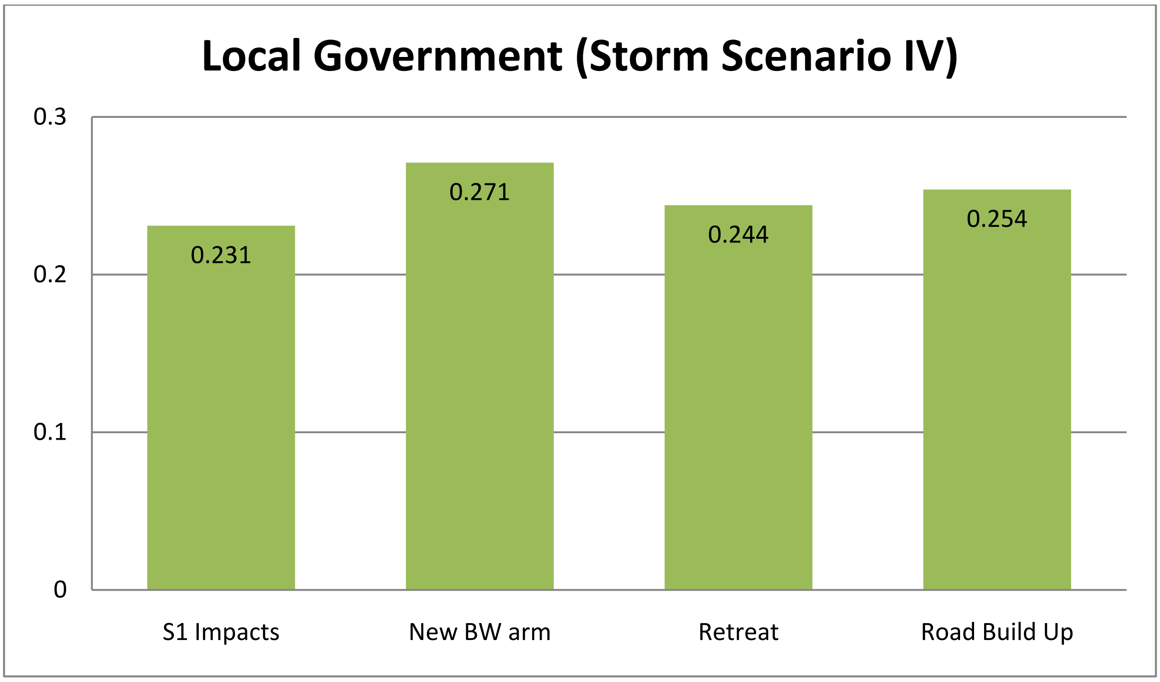


Figure J37: "Retreat", "Road Build Up" and "New Breakwater arm" priorities from the perspective of Local Government for Storm Scenario IV

From the perspective of Local Government- for scenario IV- all strategies are superior to "Status Quo" with "New breakwater arm" alternative being better than others.

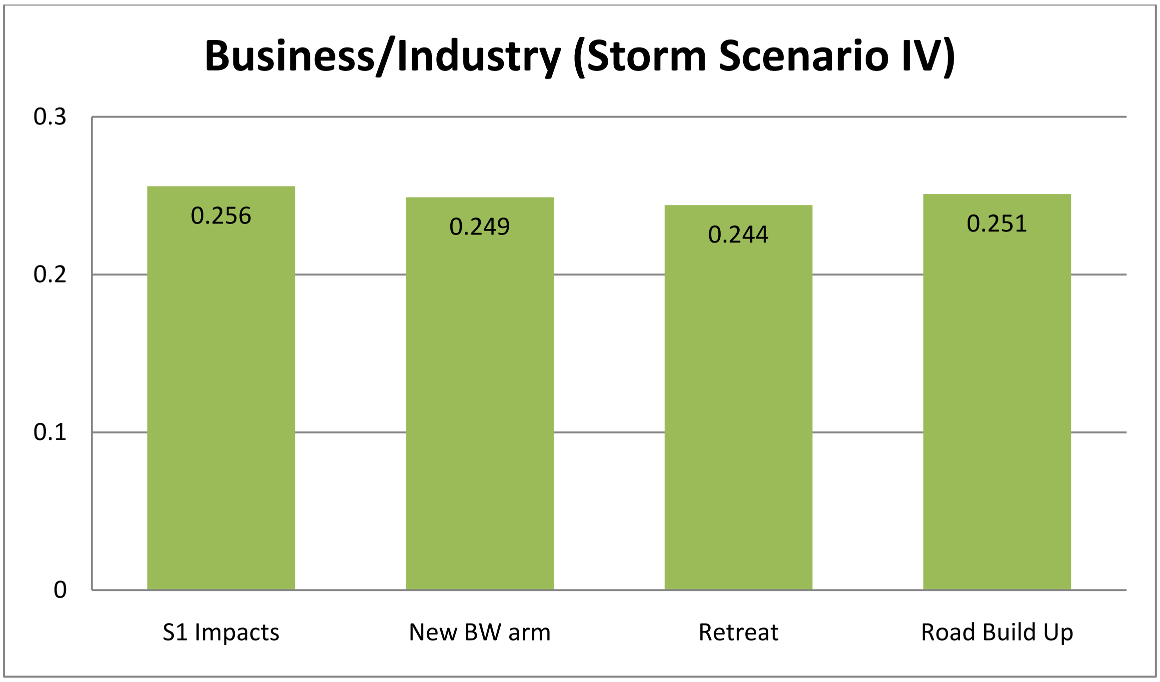


Figure J38: "Retreat", "Road Build Up" and "New Breakwater arm" priorities from the perspective of Business/Industry for Storm Scenario IV

From the perspective of Business/Industry- for scenario IV – all alternatives are inferior to "Status Quo" therefore we are better off doing nothing.

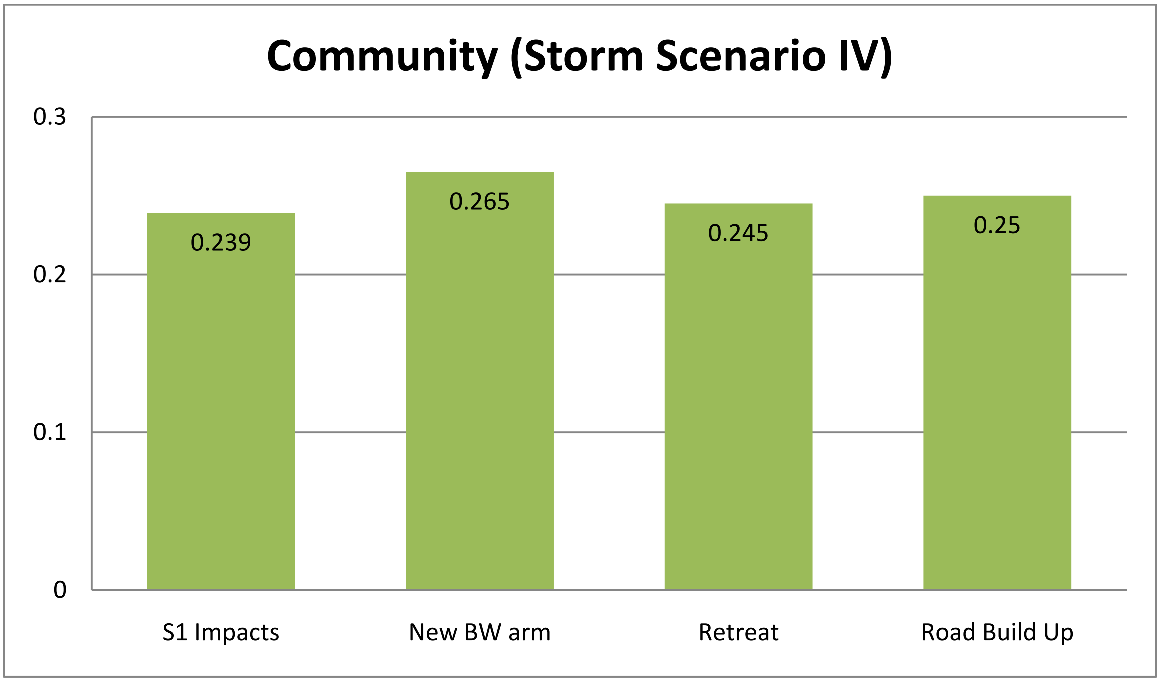


Figure J39: "Retreat", "Road Build Up" and "New Breakwater arm" priorities from the perspective of Community for Scenario Storm Scenario IV

From the perspective of Community- for scenario IV- all strategies are superior to "Status Quo" with "New breakwater arm" alternative being better than others.

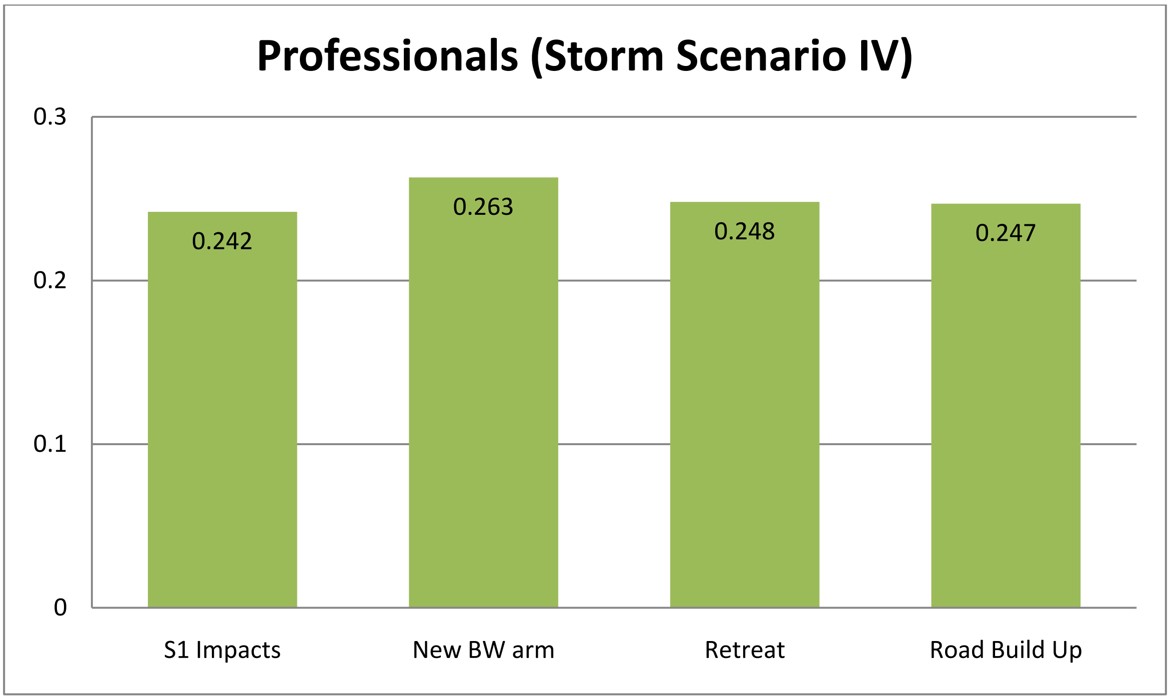


Figure J40: “Retreat”, “Road Build Up” and “New Breakwater arm” priorities from the perspective of Professionals for Scenario Storm Scenario IV

From the perspective of Professionals- for scenario IV- all strategies are superior to “Status Quo” with “New breakwater arm” alternative being better than others.

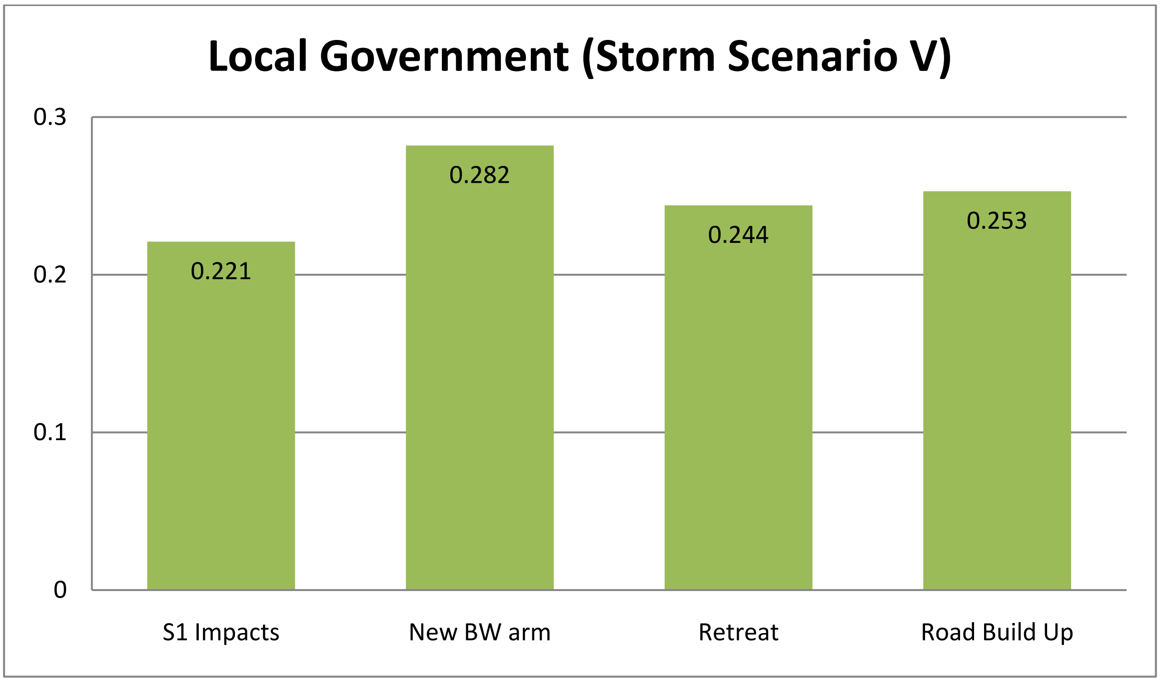


Figure J41: “Retreat”, “Road Build Up” and “New Breakwater arm” priorities from the perspective of Local Government for Storm Scenario V

From the perspective of Local Government- for scenario V- all strategies are superior to “Status Quo” with “New breakwater arm” alternative being better than others.

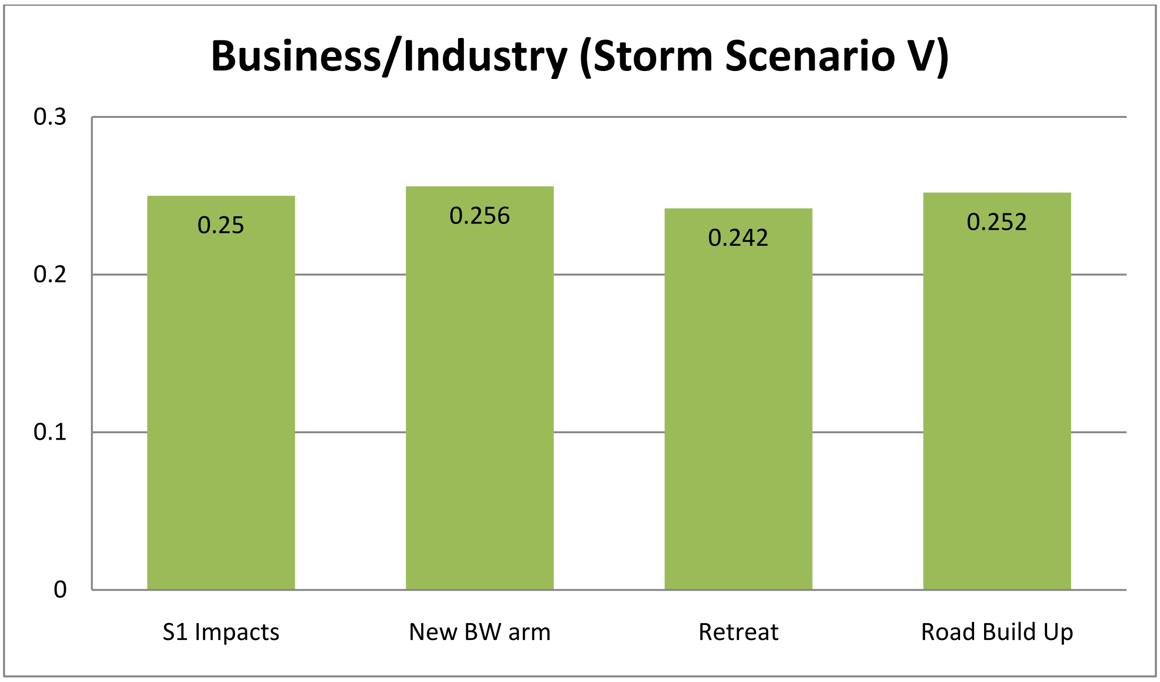


Figure J42: "Retreat", "Road Build Up" and "New Breakwater arm" priorities from the perspective of Business/Industry for Storm Scenario V

From the perspective of Business/Industry- for scenario V- apart from "retreat" all other strategies are superior to "Status Quo" with "New breakwater arm" alternative being better than others.

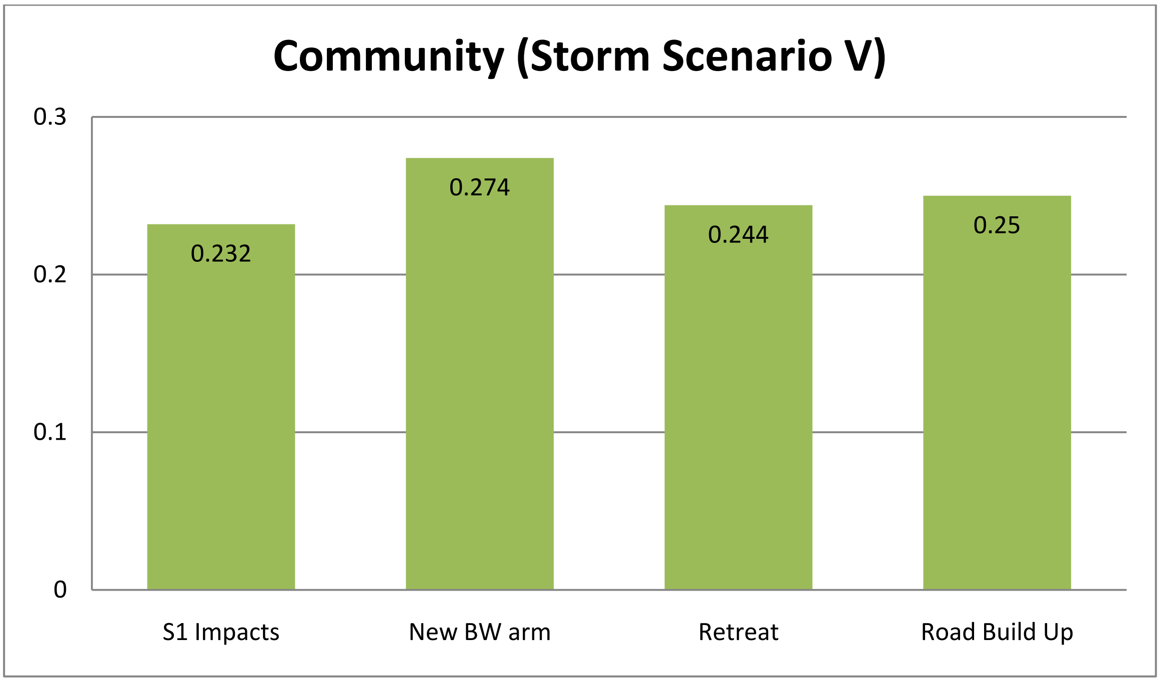


Figure J43: “Retreat”, “Road Build Up” and “New Breakwater arm” priorities from the perspective of Community for Storm Scenario V

From the perspective of Community- for scenario V- all strategies are superior to “Status Quo” with “New breakwater arm” alternative being better than others.

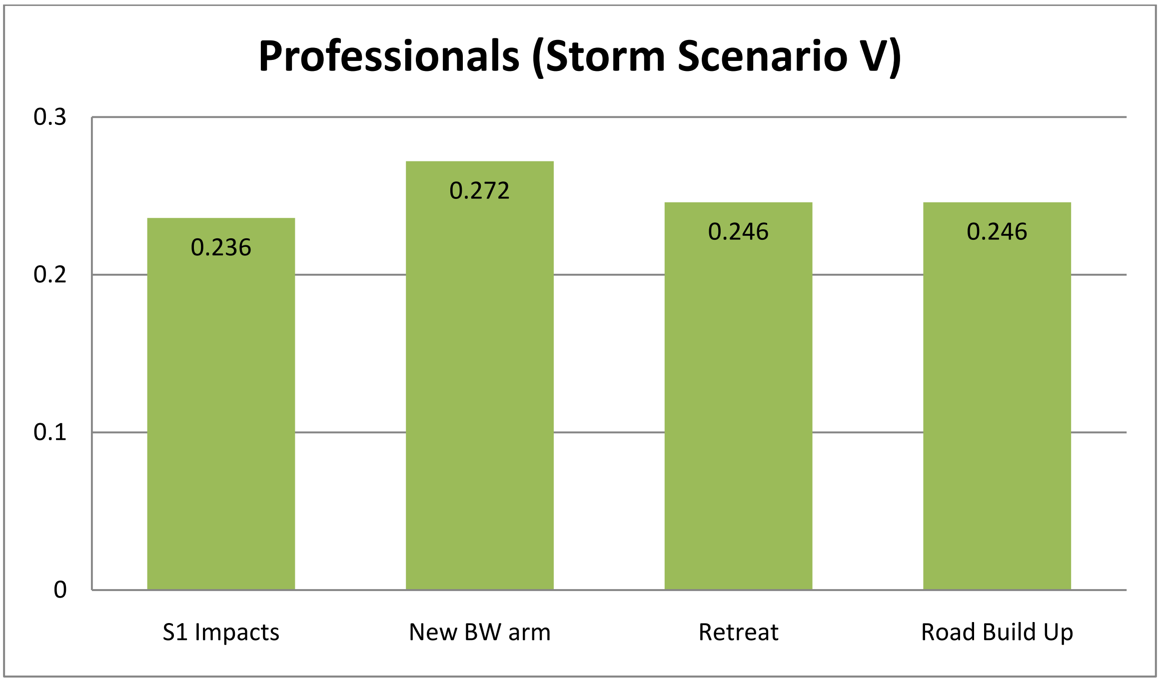


Figure J44: “Retreat”, “Road Build Up” and “New Breakwater arm” priorities from the perspective of Professionals for Storm Scenario V

From the perspective of Professionals- for scenario V- all strategies are superior to “Status Quo” with “New breakwater arm” alternative being better than others.

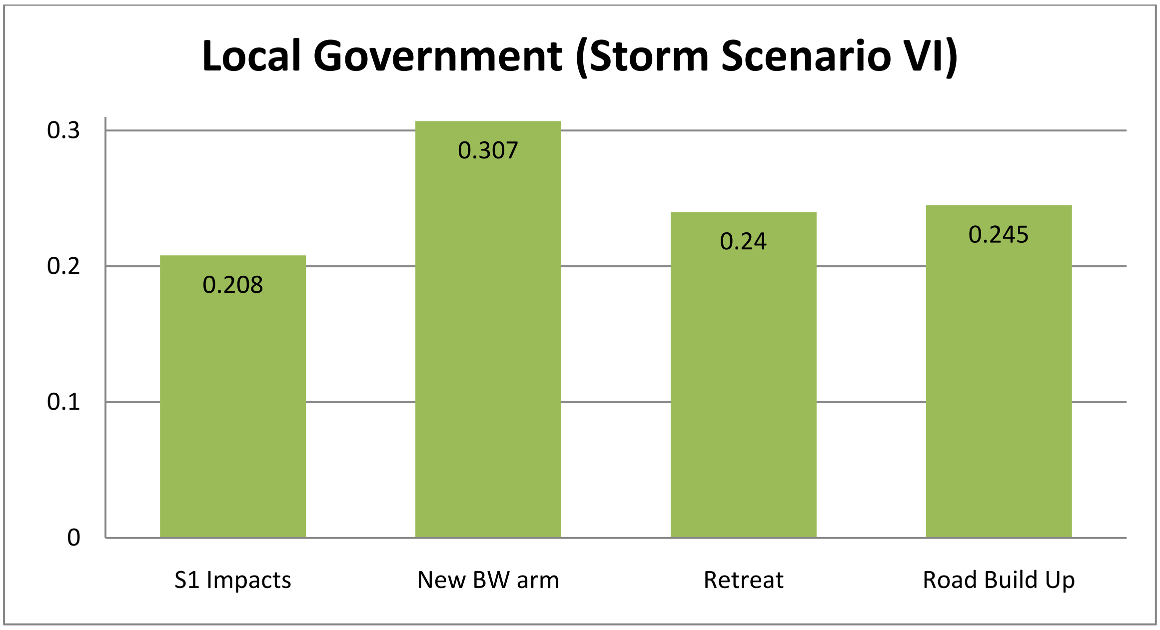


Figure J45: "Retreat", "Road Build Up" and "New Breakwater arm" priorities from the perspective of Local Government for Storm Scenario VI

From the perspective of Local Government- for scenario VI- all strategies are superior to "Status Quo" with "New breakwater arm" alternative being better than others.

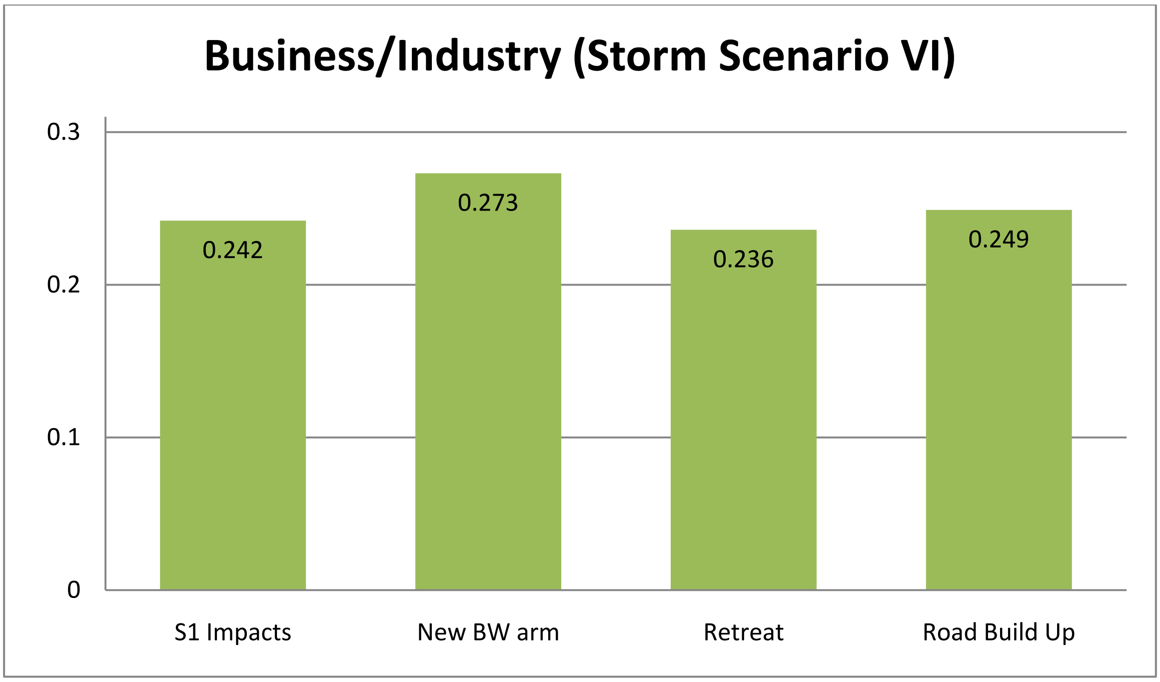


Figure J46: "Retreat", "Road Build Up" and "New Breakwater arm" priorities from the perspective of Business/Industry for Storm Scenario VI

From the perspective of Business/Industry- for scenario VI- apart from “retreat” alternative all other strategies are superior to “Status Quo” with “New breakwater arm” alternative being better than others.

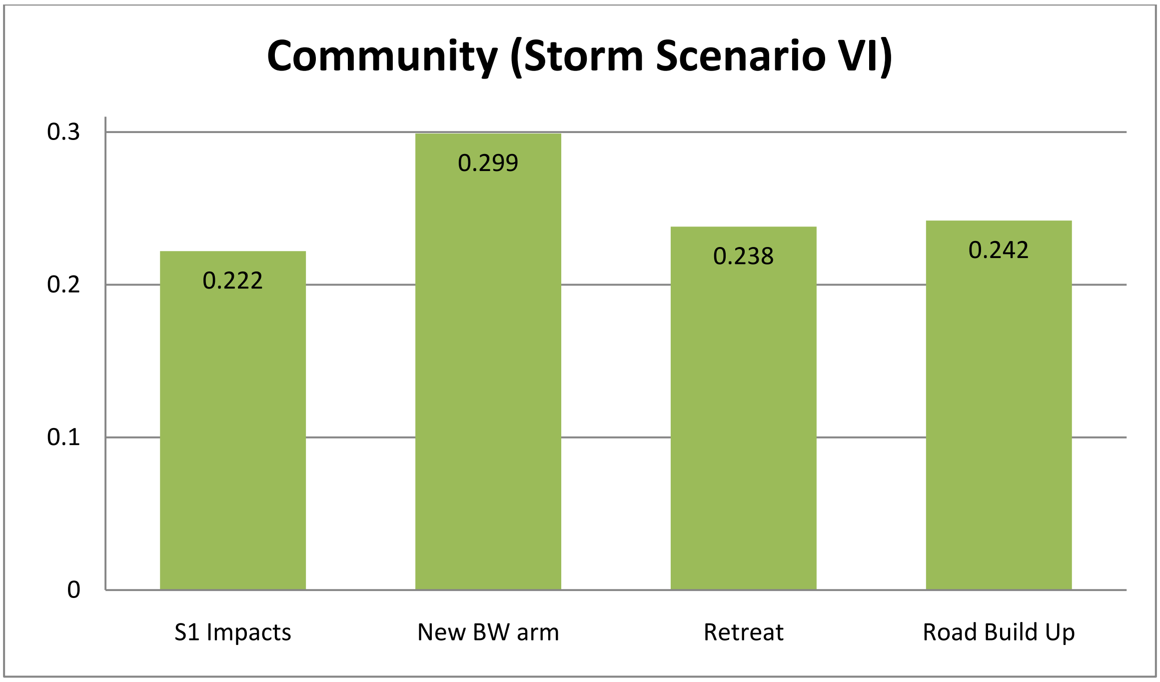


Figure J47: “Retreat”, “Road Build Up” and “New Breakwater arm” priorities from the perspective of Community for Storm Scenario VI

From the perspective of Community- for scenario VI- all strategies are superior to “Status Quo” with “New breakwater arm” alternative being better than others.

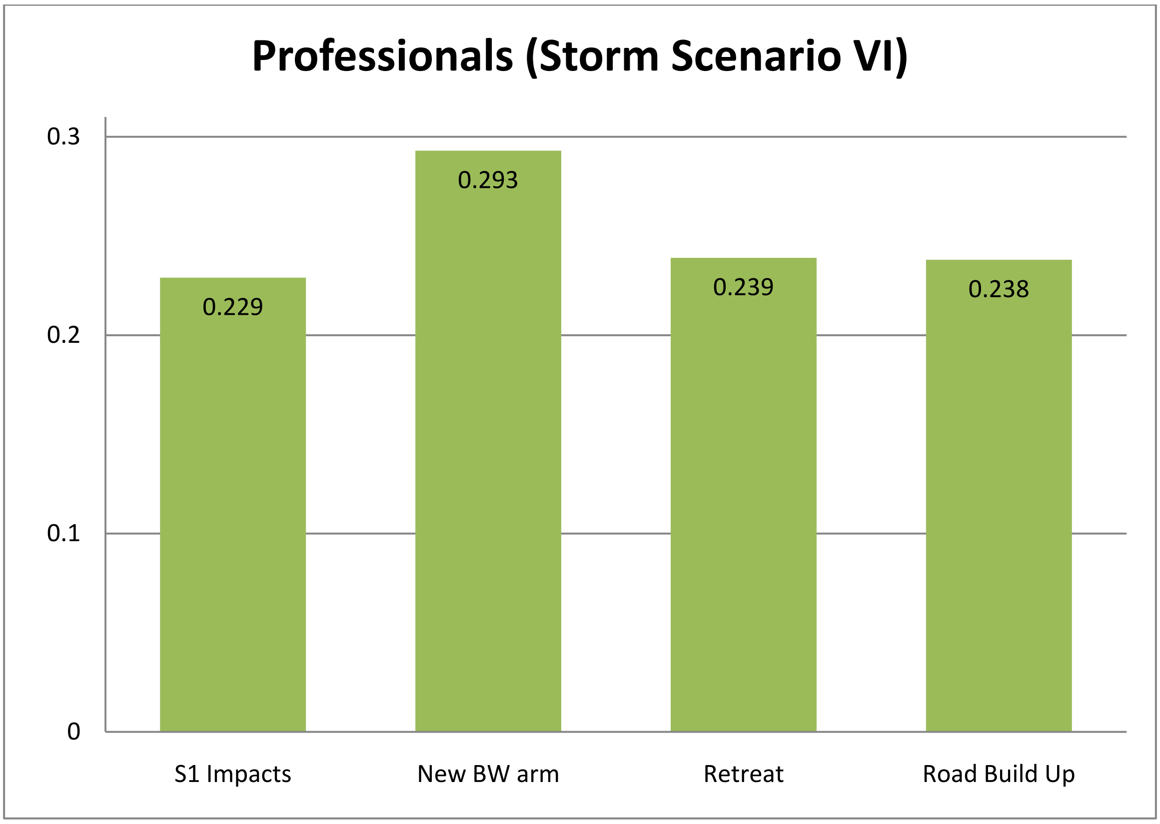


Figure J48: "Retreat", "Road Build Up" and "New Breakwater arm" priorities from the perspective of Professionals for Storm Scenario VI

From the perspective of Professionals- for scenario VI- all strategies are superior to "Status Quo" with "New breakwater arm" alternative being better than others.