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Thesis Proposal

Risk Analysis in Coastal Communities Decision Making

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Abstract

The analysis of decision making under risk involves (i) risk assessment - the preparation of appropriate probability assessments of stochastic events; (ii) risk management – the application of quantifiable measures of the impacts of the stochastic events under alternative strategies; and (iii) risk communication – through the governance of structured decision making processes, and tracking and monitoring of the event. This work involves the application of the steps of the risk analysis process on coastal communities facing short-term operational decisions and long-term strategic decisions to deal with the pending impacts of climate change. These impacts include the immediate impacts from the increased frequency of severe storms and storm surge, and the long-term impacts of rising sea levels. The analysis of risk is in support of coastal communities' decision support systems. This work is applied to the C-Change International Community-University Research Alliance (ICURA) program that is examining the adaptation of selected coastal communities in Canada and the Caribbean. In all these cases, the foundation to support community-based decision making for adaptation is required in the event of mounting evidence that coastal communities are especially susceptible to the changing climate, that coastal communities are under-resourced with respect to their abilities to respond to the climate threats, and that coastal communities are in need of defensible structures on which to make critical decisions on adaptation that will ensure community sustainability. The work draws on: (1) statistical, time-series analysis for predicting the event of storms; (2) the profiling of community threats and vulnerabilities, as well as community environmental, economic, social, and cultural priorities; (3) the calibration and interpretation of storm impacts through utility curve analysis; and (4) the application of the risk analysis to decision making in complex, multi-criteria environments.

Contents

1. Introduction

This document presents ongoing research in the form of a thesis proposal in partial fulfillment of the M.Sc. degree in Systems Science at the University of Ottawa.

1.1. Background and Motivation

In recent decades, climatic changes have manifested itself as sea level rise, changing precipitation patterns, more frequent intense weather events, storm surges and flooding, salinisation of fresh water aquifers and wells, coastal erosion, sedimentation of coastal waters, and pollution from flooded or destroyed infrastructure and storm runoff (Lane & Watson, 2011).

At the end of October 2012, Hurricane Sandy hit east coast of the United States of America. It had begun from the coast of Africa as a tropical depression on October 11 and gradually grew into an Atlantic hurricane by October 24. Moving up the eastern seaboard of the U.S., it developed into a strong hurricane by October 27. The highest tides reported in New Jersey and New York were recorded 8.5 feet (2.6 m) over normal level at Sandy Hook, and more than 12.5 (3.8 m) feet at Kings Point on the western edge of Long Island Sound (Huffington Post Canada, Feb. 2013).

Recorded as the second-costliest hurricane in northeastern U.S. in 40 years, hurricane Sandy destroyed 305,000 houses in New York State. The damages caused by Sandy are estimated to be at least $ 71.3 billion, with 121 deaths in overall (Irish Central, Nov. 2012).

The threats posed by changing climate on coastal populations around the globe are inevitable. Over the coming decades, climate-driven changes are expected to happen and become increasingly more severe. Hence, effective management of coastal risks and adaptation to the climate related changes are considered as immediate needs (Brian, 2008).

For every coastal community, there is a wide range of responses to climate change impacts in terms of cost, time, severity of climate event, and the vulnerabilities and threats to the area. The geographical situation of coastal communities differs among communities. Therefore, the threats and vulnerabilities of each area and the impacts of the changing climate vary by region. Selection of proper adaptation strategies is influenced by these variations.

For example, short term and long term responses may be considered in order to deal with increasingly frequent and extreme rainfall events. Short-term solutions may include various responses including better warnings, increased maintenance of storm sewers, reduction of storage levels in dams and reservoirs. While, long term responses may involve replacement of sewer pipes, re-routing major arteries, reduction of asphalt and concrete surfaces (Bruce, Egener, & Noble, 2006).

The question that can arise here is which adaptation strategy suits the area and has higher priority in the area exposure to increasingly frequent and extreme rainfall. Responses to the climate change impacts are even more complicated if the condition under which the decision must be made is uncertain. What coastal communities are dealing with currently is making right decisions for an unanticipated and uncertain future.

Assessing and managing under risk related to alternative strategies enables coastal communities to find the answers to these fundamental questions. Evaluation and analysis of the variations are part of the risk assessment topic of this research. Assigning priority to multifaceted impacts and choosing vulnerability reduction strategies are supported by risk management. A practicable approach is provided by risk management to achieve acceptable level of decision making under risk and uncertainty for comparing a range of factors and for using predictive information (Bruce et al., 2006).

This proposal generates a framework to support effective and reliable decision-making process by involving risk analysis and multi-criteria decision making methods. Adaptation alternatives, which are currently recognized being less necessary to be implemented, may become necessary, or vice versa, in this case since other factors such as the project lifecycle, cost, and probability are taken into account.

1.2.Research Questions and Objectives

The main focus of this research is to form a framework to provide coastal communities with a more reliable decision making process through risk analysis.

The main questions of this proposed research are as follows:

1) How can the multidimensional coastal communities be evaluated with respect to adaptation strategies against climate change scenarios?
2) How can the likelihood occurrence of different severe coastal storm hazards be predicted?
3) What is an appropriate time frame for the analysis of severe storms in order to determine effective strategic actions to protect coastal communities from extreme damages?
4) How can sustainable decisions be made under the uncertain and unanticipated future of climate change using risk analysis?

In order to address the main question of the research, sequential and complementary objectives needed to get answer are as follows:

1. Profiling the coastal communities in terms of society, economy, culture, and environment.
2. Establishing coastal community asset profile, and determining community priorities
3. Assessing the vulnerabilities of coastal communities to sever storm hazards correspondence with each decision alternative and scenario.
4. Determining the probability distribution of different storm hazards by historical data.
5. Predicting the likelihood occurrences of storm hazards over alternative time frames.
6. Using utility curve analysis to readjust the impact assessment of climate change.
7. Analyzing alternative decisions arising from different time frames, short time horizon decisions versus, more strategic, long term decisions.
8. Deciding for more reliable and sustainable adaptation strategy (ies) that lowers the vulnerability of the coastal communities within the time frame.

1.3.Thesis Proposal Outline

This research proposal document includes six chapters. The current chapter introduces background and motivation, a brief statement of the motivation behind this research. As well, this chapter presents the main questions of the research and associated objectives. The second chapter, literature review, reviews coastal communities profiling by considering their special threats and vulnerabilities, provides information on risk analysis, and discuss the application for the research as a case study. The third chapter is methodology which encompasses research process; risk assessment, risk management, and risk communication.

The fourth chapter presents expected analysis and results. Consideration for future research is provided in the fifth chapter. Chapter six shows the research timeline. This proposal document is completed with the bibliography of references and the appendices.

2. Literature Review

This section reviews the important components of this research in the literature. It is divided into three main sections; profiling coastal community, vulnerabilities and threats of coastal communities, and risks analysis

2.1.Profiling Coastal Community

A community profile describes the community of interest. The community profile captures a number of dimensions of the community and provides a more comprehensive picture of a community based on its asset. To profile the coastal community, a framework is needed to capture all of its diverse aspects of vulnerabilities to a coastal community. This subsection describes coastal community profiles in the literature.

In order to integrate the multiple dimensions of problems related to C-Change coastal communities, a C-Change framework is developed towards community profiling. Development of the C-Change community profile data template is part of this framework. Four principle dimensions covered by the community data profile template are the environmental, economic, social and cultural dimensions of coastal communities. Every dimension is broken into a number of sub categories (Lane & Watson, 2010) as noted below in the table 2.1.

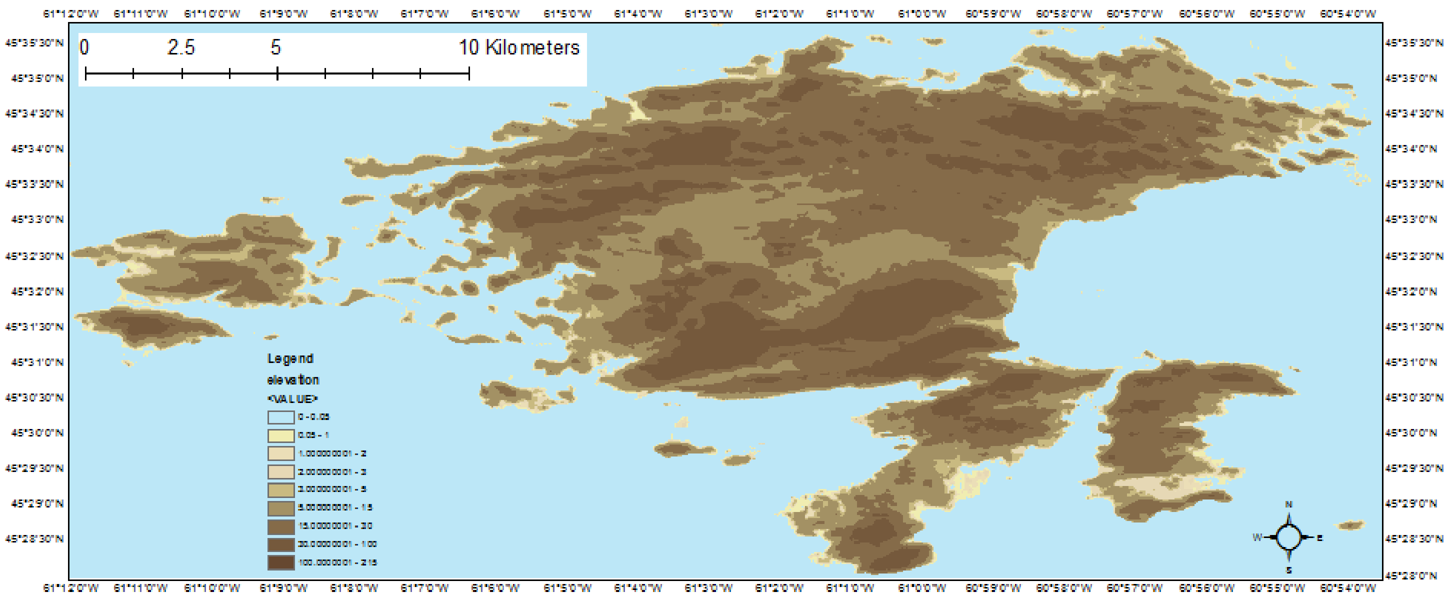
Environmental	Economic
• Topography	• Employment and Earnings
• Hydrology	• Occupation
• Coastal Geomorphology	• Industry Sector
• Habitats and Species	• Industry Revenues ($)
• Land Cover	• Real Estate Values ($)

• Land Use • Marine Use • Climate • Natural Resources	• Public Works • Built Environment
Social	**Cultural**
• Population Statistics • Language • Health Status • Education • Employment • Communication Resources	• Places of cultural significance • Community groupings • Cultural events and festivals (dates, attendance numbers, area) • Governance Systems • Community dynamics

Table2.1. Communities Data Profile Elements. Source: (D. E. Lane & Watson, 2011)

The main inspiration of the community data profile comes from Ahmed and Simonovic (2004) who were interested in combining system dynamics (SD) with geographic information system (GIS) to develop a Spatial System Dynamics (SSD).

Hartt (2011) and Pakdel (2011) developed C-Change community profiles for Charlettown, P.E.I., and Isle Madame, Cape Breton using ArcGIS and linked the geo-referenced asset-based layers to simple SD models. The GIS was used to develop information for vulnerable areas in their respective communities under different storm scenarios. The SD model presented the dynamism inherent in the four key pillars and models components interrelationships, either direct or indirect, of the community using the STELLA SD software.

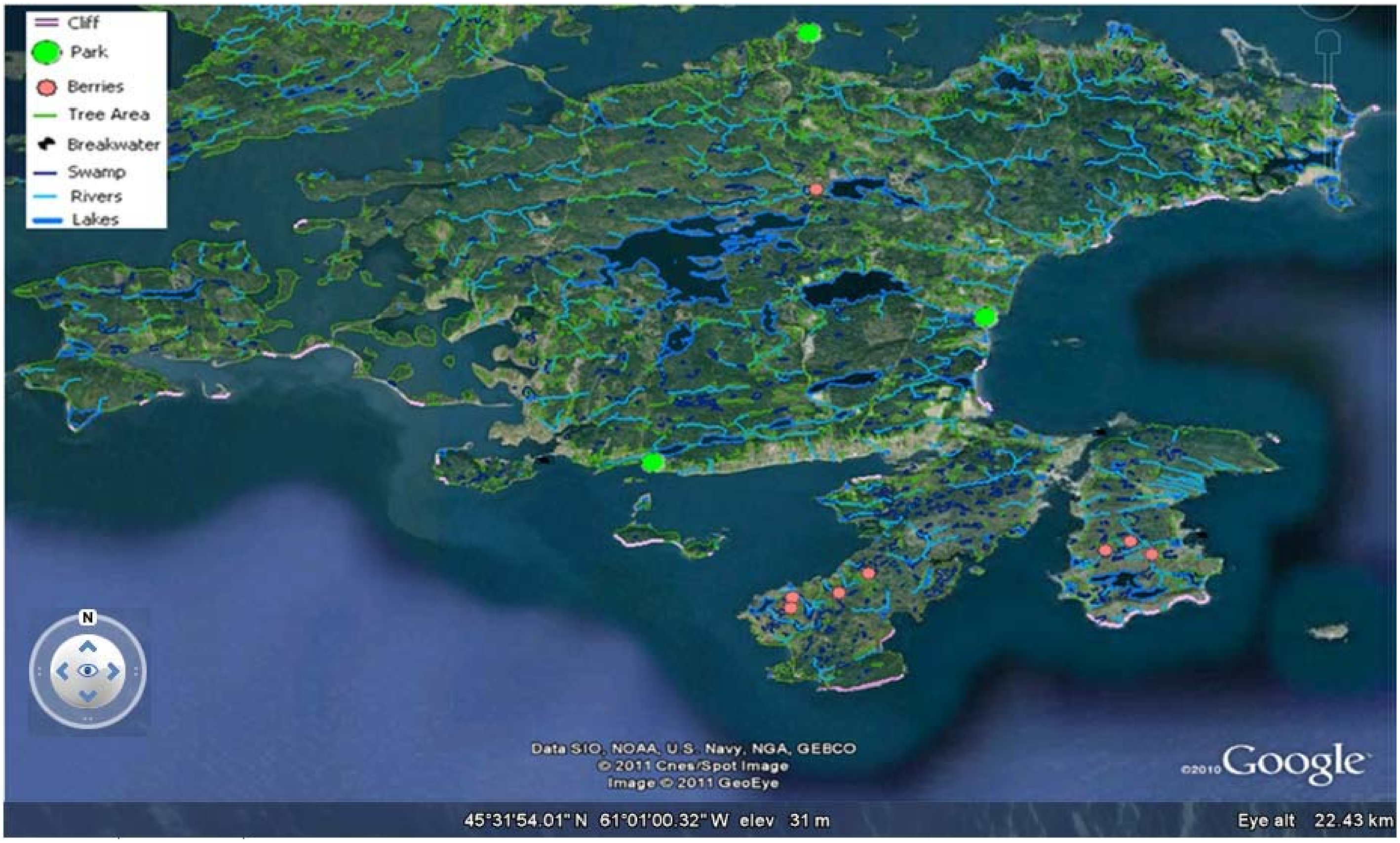


To collect the community profile for Isle Madam, Pakdel uses four databases: Statistics Canada (2006), Desktop Mapping Technologies Inc. (DMTI 2009), DataLocator spatial dataset from the GeoNova Graphic Gateway to Nova Scotia website (GeoNova 2006), and Geo Base (2010).

Isle Madam elevation is featured by coastlines, which are generally less than 2 meters above sea level. Thus, they are vulnerable to storm surge and sea level rise. Elevation data is gained from GeoBase (2010), and GeoNova (2006) for Isle Madam presented in the figure 2.1 (Pakdel, 2011).

Figure2.1. Isle Madam's elevation data. Source: (Pakdel, 2011, page 57)

Every pillar is characterized by several subcategories (i.e. indicators, items) represented spatially. Accordingly, environmental dimension that is depicted in figure 2.2 is consisted of



many layers (Pakdel, 2011).

Figure2.2. Isle Madam's Hydrology, Land use, and Land Cover item.

Source: (Pakdel, 2011, page 58)

The environmental layers in Isle Madam database, based on Pakdel's study, and the number of available points (or polylines) can be found in Appendix B.

2.2.Vulnerabilities and Threats of Coastal Communities

In the following subsections, unified definitions, throughout this research, are presented for vulnerability, threat (hazard), and disaster. It is continued by difficulties around measuring the vulnerabilities of coastal communities, and the necessity of a conceptual framework for vulnerability studies. At the end, the differences among the biophysical, social, and environmental vulnerabilities are specified by some examples.

2.2.1. Vulnerability, Threats, and Disaster Definition

Generally, "the vulnerability of a system, population or individual to a threat relates to its capacity to be harmed by that threat". Only talking about the vulnerability of *a specified system or exposure unit to a specified hazard or range of hazards* is meaningful. A system or exposure unit may be a region, population groups, community, ecosystem, country, economic sector, household, business or individual (Adger, Brooks, Bentham, Agnew, & Eriksen, 2004).

The term hazard (Threat) here refers particularly to a physical demonstration of climatic change including a drought, flood, storm, episode of heavy rainfall, a long-term change in the mean value of a climatic variable, a potential future shift in a climatic regime and so on. Hazards can be classified in three categories: 1) discrete recurrent hazards such as storms, droughts and extreme rainfall events, 2) continuous hazards, for example increases in mean temperatures over several years or decades, 3) discrete singular hazards, which is sudden climate change events related to the beginning of a new climatic conditions that dominated for centuries or millennia (Adger et al., 2004).

A disaster is the outcome of a hazard, which is measured in human terms (e.g. live lost, people affected, and economic losses). A disaster depends on the properties of the human system that is exposed to and affected by the hazard (Adger et al., 2004).

2.2.2. Difficulties in Vulnerability Assessment and Measurement of Coastal Community (Profiling the Community Dimensions)

In studying climate change and its impacts, two main approaches can be considered; impact-led approach and vulnerability-led approach. Impact-led approach concerned with future human exposure to climate change. Analysis of the underlying socio-economic and institutional elements, and political and cultural elements, in lesser degree, is defined as vulnerability-led approach. It assesses the people's ability to respond to and cope with climate hazards. Vulnerability assessment, in spite of impact-led approach, does not require detailed climate change information created by models and information about climate change over time. Lack of this information is not an impediment in developing adaptation policies for future threats. The emphasis has moved from an impacts-led approach to a vulnerability-led approach as climate change and its impacts came in interest (Adger et al., 2004).

Assessing vulnerability and adaptive capacity can be done on various scales ranging from household, local, regional, to national and global level (Adger et al., 2004). A conceptual framework is needed in order to assess them in a qualitative or quantitative manner.

A qualitative approach is suitable for self-assessment such as practices for the purpose of identifying vulnerable systems, regions and groups at the sub-national level. The latter approach provides comparative indicators to compare the vulnerability and adaptive capacity of various systems. Indicators are "quantitative measures intended to represent a characteristic or a parameter of a system of interest" (Cutter et al. 2008: 7) using a single value (Cutter et al., 2009). Cutter (2009) and Adger (2004) present indicators as for measuring the vulnerability of a system in local and national level respectively.

Comparing the vulnerability and adaptive capacity of different countries based on national level indicators brings up some arguments. Since vulnerability is a very specific context, and is distinguished within countries, some argue that vulnerability in national scale is not appropriate. Nevertheless, the processes operating at the national scale have effects on vulnerability and adaptive capacity at the local level. For example, economic-well being of vulnerable groups can be influenced by national economic policy, by determining the cost of essential needs such as food, education and healthcare, as well as the market price of commodities which are basis of the livelihoods of vulnerable groups (Adger et al., 2004).

The potential conflict between vulnerability indicators in national level and local level must not be ignored. One action that ameliorates the vulnerability of one group may have negative implications on the other group. Likewise, national level indicators of adaptive capacity represent the factors and processes which ameliorate or exacerbate further adaptation. National level is still the main political unit on which emission targets and political policies, and resource allocation are formed (Adger et al., 2004).

According to dynamic nature of vulnerability, any measures should capture steady-state situation and any trend in that situation. Vulnerability persistently evolves as a function of interaction between physical processes and human dimension. Complexity in conceptualizing the understanding of vulnerability is a result of this dynamic character (Adger et al., 2004).

In indicator studies, there are two aspects critical to capturing dynamism: first, local capacity and command over resources and vulnerability formed by processes and difference in time and space; and second, multiple pressures, besides climate change, such as economic change or political conflict affect on individuals, household, social groups and communities (Adger et al., 2004).

The effects of changing climate are unevenly distributed in time and space. According to Taylor and Flit (2000), national level functions as a broker between global and local scales. The local and global levels are respectively the level of experience (or impacts), and level of reality (where many influencing processes operate). The fundamental scale of vulnerability is local because of differentiation within the community. Processes operating at broader spatial scales contribute considerably to patterns of vulnerability at the local level. Analysis at national level may encompass other levels, both in understanding international trends and processes affecting vulnerability (Leichenko and O'Brien 2002), and local differentiation in vulnerability that is hidden by a national indicator (Brooks and Adger 2003).

In attempting to generalize or select indicators on a greater scale than the scale of vulnerability hotspots, scale issues become of crucial significant. Therefore, identification of these hotspots and then aggregation to an ultimate spatial scale is contributed to any assessment of overall threat posed by climate problem.

Studies differ based on present-day and future patterns of vulnerability. Estimation of future patterns of vulnerability is conditioned on indistinct projection of environmental changes and socio-economic trends. Completely integrating socio-economic change has been enabled by few studies. In this regard, they most have imposed the future environmental stress on present-day society (Adger et al., 2004).

In measuring the vulnerability towards the goal of effective resource allocation, the selection of indicators must be based on present-day exposure and capacity as precisely as possible. In order to select measurements of vulnerability in the context of a future threat, the approach of using indicators based on observed impacts or diversity, is not, at this time, a viable choice and equivalents have to be used (Adger et al., 2004).

For better understanding of vulnerability, and identifying ways of reducing vulnerability, a focus on the causes of, or processes shaping, vulnerability is needed (Adger et al., 2004).

Two general approaches can be considered for indicators selection. One is deductive research approach, which is based on theoretical understanding of relationships. The other, which is called inductive research approach, is based on identifying statistical relationships of a large number of variables and relating variables to vulnerability. However, conceptual understanding contributes in both. Inductive research finds the patterns in data that can be generalized, which is called theory. It often uses empirical generalizations, filled with empirical content and statement of empirical regularities (Adger et al., 2004).

Since vulnerability cannot be measured directly, indirect measurements need to be applied to both approaches. They can be achieved through a focus on processes forming vulnerability.

Studies that were successful in closely integrating theory, conceptualization and indicator selection are more commonly performed at the sub-national level, for example, a case study of Georgetown County, South Carolina (Cutter et al. 2000) and a study of three global coastal cities (Schiller et al. 2001).

2.2.3. The need for a conceptual framework

From the mid-1990s to the present, the majority of the research focused on the conceptual models accompanied with few examples of how such models operate in real-world contexts (Cutter et al., 2009). Transparency in theoretical and conceptual understanding that bases indicator selection is significant. It is inevitable to have a varying degree of subjectivity in the assumptions made.

Multi-varied facets of vulnerability studies can be summarized in one table as follows.

Facet	Example
Purpose	Comparison Assessment of threat Enhanced understanding of causes (and identification of measures to reduce vulnerability)
Definition of vulnerability	Yes/No
Scale	Scale at which processes operate Unit of investigation/unit at threat
Dynamism	Multiple pressures Processes affecting factors of vulnerability
Conceptual framework	Yes/No Assumptions transparent?
Research approach	Deductive/Inductive (Subjective/objective) Statistical/Process based
Data	Reliable and representative, Selection of indicators defensible to community/ Stakeholders? Reproducibility

Verification	Evaluate validity and plausible outcome Compare with findings of relevant studies Analogue past event Case study Explaining relationships

Table2.2. Facets of vulnerability studies. Source: (Adger et al., 2004)

Accordingly, the term "adaptive capacity" is used to represent numerous factors, but there is no consensus on what these factors should be. Vulnerability and adaptive capacity are sometimes discussed without any precise statements of what factors (e.g. hazards) constitute them, and why, and the timescale over which these factors are credible (Adger et al., 2004).

2.2.4. Social, Environmental, Economical, and Cultural Vulnerability

Vulnerability in climate related changes falls into two categories:

1) Impact approach- the amount of (potential) damage to a system caused by a specific climate-related event or hazard, e.g., storm, storm surge, or
2) Hazard approach- the state that exists within a system before it encounters the hazardous event.

The impact approach focuses on the factors such as number of people at risk of flooding by projection of sea level rise. In fact, this approach examines human exposure to hazard rather than the ability of people to cope with hazards when they occur. A combined approach is compatible with the IPCC Third Assessment Report's (TAR) definition of vulnerability, as a function of hazard, exposure, and sensitivity. Since the vulnerability of a human system to a hazard, the frequency occurrence of the hazard, the degree of human exposure to the hazard, and the system's sensitivity to the impacts of the hazard are considered in the combined approach. (Adger et al., 2004).

Hazard and exposure have different meaning here: a region may frequently experience flood hazards but its population may have less exposure to these hazards by situating settlements away from flood plains and low-lying coastal areas (Adger et al., 2004).

The second view of vulnerability has arisen from studies of structural factors that make human societies and communities vulnerable to damage from external hazards. It may be termed "social vulnerability", as it illustrates the population's characteristics that influence the capacity of the community to prepare for, respond to, and recover from hazards and disasters. Social vulnerability is not a proper term when vulnerability arising purely from the inherent properties of non-human system. The term "inherent vulnerability" might be more suitable. Social vulnerability is determined by factors such as poverty and inequality, marginalization, food entitlements, and access to insurance and housing quality. Determinants of social vulnerability can be viewed as two classifications; 1) generic determinants such as poverty, inequality, health, access to resources and social status, and 2) specific determinants to particular hazards (Adger et al., 2004).

Social vulnerability is not a function of hazards, but certain characteristics of a system will make it more vulnerable to certain types of hazards than to others. For example, an important determinant of a community's social vulnerability to a flood or windstorm is quality of housing, while it is less likely to influence the vulnerability to drought. Situation of dwellings in relation to river flood plains or low-lying coastal areas can be considered as specific determinants to flooding and storm surges (Adger et al., 2004).

Social vulnerability describes all factors of a system, independent of the hazard(s) to which it is exposed, that determine the outcome of a hazard event. These may encompass environmental variables and measures of exposure. Exposure and the state of the environment within a system will be socially determined to a large degree. Since exposure depends on where people prefer to (or are forced to) live, and their community construction and livelihoods. Environmental variables will vary by human activity, as populations use resources and manage the environment for their benefit in the short or long term (Adger et al., 2004). To be brief, without people, there is no disaster (Neil Adger, 1999).

Recent Oklahoma twisters happened in Moore, which reached around 474 km/h, has a path very similar to another destructive tornado that happened 14 years ago. The ridge Creek-Moore tornado, in 1999, was classified as the most devastating kind with a wind speed of 484 km/h. It killed 41 people and ruined thousands of homes (CBC News, June 2013). The heartland is being overbuilt and tornadoes are going to be more frequent, and much more worse than recent tornados, as climate is changing. Consequently, damages and deaths increase.

The ability of individuals and communities to recover from losses from hazards is affected by socioeconomic status. Poor people are more susceptible than wealthy people to hazards impacts. During the disaster, it is less probable that poor people have access to critical resources and lifelines, like communications and transportation. Even though the losses of the wealthy, in terms of monetary value of the economic and material losses, are more, the losses burdened on poor people are great (Cutter et al., 2009). Also, it can point out cultural dimension since poor people face with lack of resources more.

The severe impacts associated with Hurricane Katrina in August 2003 were more a result of underlying socioeconomic inequalities within the population rather than the intensity of the hurricane. The union of race and class (socioeconomic status) creates inequalities. The vulnerability of racial and ethnic minorities considerably increases by discrimination (Fothergill et al. 1999; Bolin 2006). If discrimination manifests itself in real estate, it may limit minorities to settle in certain hazard-prone areas. Moreover, minorities may be hindered in obtaining policies with more-reliable insurance companies. In particular, minorities who emigrated from non-English-speaking countries have language difficulties in their communication. It in turn can increase vulnerability to a disaster and amelioration (Cutter et al., 2009).

Gender is another determinant of social vulnerability. Women, in comparison to men, are more probable to work in low status jobs in the service industry, which are often more greatly affected when a disaster strikes. When a disaster is about to strike, women are less able to find safety because of their responsibilities as mothers and caregivers. Altogether, women are more vulnerable to disasters (Cutter et al., 2009).

Children and the elderly are also identified as the most affected groups by disasters (Cutter et al., 2003). Children need family's support for disaster response. Children are affected psychologically and physically by disruptions created by disasters. To respond effectively to a disaster, the elderly have less physical and economic resources. The elderly may also have mobility constraints and are more unwilling to evacuate their homes, which increase the burden of care and lack of resilience (Cutter et al., 2009).

Mentally or physically disable people require extra support in the post-disaster period and after disasters for recovering (Cutter et al., 2003).

It is important to know how each indicator interacts to produce a socially vulnerable population. The aggregation of variables, not only a single variable, can represent a comprehensive view of communities. The most common characteristics (indicators) influencing social vulnerability over time are listed in the table 2.3. These are the most often found characteristics, in the scale and context of the coastal community, in the literature. In addition, the positive or negative effects of these are noted here (Cutter et al., 2003; Cutter et al., 2009).

Concept or Characteristic	Proxy Variable	Effect on Social Vulnerability
Socioeconomic Status	%Poverty Per capita income	Increase High decreases; Low increases
Gender	%Female headed households	Increases
Race and/or ethnicity	% African Americans %Hispanic	Increases Increases
Age	%Elderly %Under 18	Increases Increases
Housing tenure (Ownership)	%Renters %Homeowners	Increases Decreases
Employment	%Unemployed	Increases
Occupation	% Agricultural workers % Low skilled service jobs	Increases Increases

Family Structure	% Single parent households large families	Increases Increases
Education	%Less than high school	Increases
Population growth	Rapid growth	Increases
Access to medical services	Higher density of medical establishments and services	Decreases
Special needs populations	Homeless, tourists, transients, nursing home residents	Increases
Social dependence	% Social security recipients	Increases
Commercial and industrial development	Density Value	Increases Increases/decreases
Rural/Urban	Rural Urban	Increases Increases
Residential property	Mobile homes	Increases
Infrastructure and lifelines	Extensive infrastructure	Increases

Table2.3. Selected Population Characteristics influencing Social Vulnerability

Source: (Cutter et al., 2009)

According to Adger and Cutter, all dimensions have been defined under one title, which is social vulnerability. To the interest of this research, each dimension is to be considered individually based on Pakdel's, Mostofi's, and Hartt's classification.

2.3.Risk Analysis

This section starts with a discussion on importance of risk analysis in adaptations to climate change. It continues with descriptions of frameworks developed for risk analysis in regard to climate variability and change in the coastal zone.

2.3.1. Why Risk Analysis?

Identifying different vulnerabilities (the previous subsection) associated with climatic change hazards is the first step in reducing future damages, vulnerabilities and exposure. Understanding the risk associated with taking action or not assumes communities must also identify strategies to address potential impacts of future damages. In order to meditate appropriate strategies, coastal communities need to determine the level of risk that underlies their tolerable position. Communities that are moved to act to protect their environments do not tolerate the status quo if inaction. Alternatively, under similar circumstances, communities that consider the status quo acceptable, are de facto asserting that the forecasts of potential impacts of future changes represent an acceptable level of risk. The task of risk analysis is to ascertain clearly what would be the community's level of acceptable risk, and to encourage adaptive action in the case where future trends are expected to alter the status quo to unacceptable positions for the community.

The relationships between climate changes and events, vulnerability, exposure, disaster risk, and sustainable development are depicted in Figure 2.1, which is the core concept of SREX, the IPCC Special Report on Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (IPCC working groups I & II, 2012).

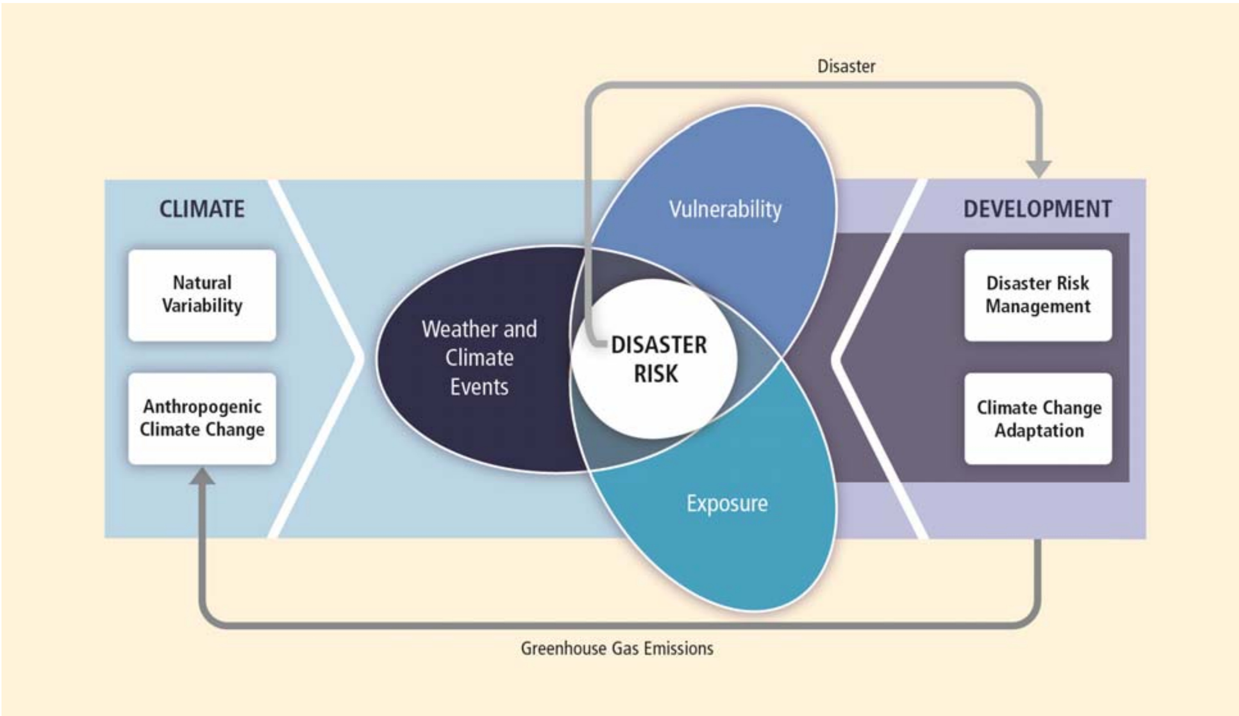


Figure2.3. Systematization of climate change related events, vulnerability, exposure, risk and development. Source: (IPCC working groups I & II, 2012)

Figure 2.3 illustrates the effect of natural climate variability and anthropogenic climate change on weather and climate events that can contribute to disaster risk. Similarly, exposure and vulnerability of society and the natural ecosystem have contribute (left to right forcing) to "disaster risk". Disaster Risk Management and Climate Change Adaptation decrease exposure and vulnerability to weather and climate events (right to left resistance). This in turn reduces disaster risk, as well as increases resilience to the risks that cannot be eliminated.

Disaster Risk Management and Climate Change Adaptation are stressed more in climate change studies in recent years because they have been demonstrated to not only save lives, but also incur less costs when responding to a disaster, e.g.:

"Estimates suggest that incorporating comprehensive disaster protection into

new health facilities and schools would add only 4 percent to their cost." (UNFCCC, 2008, P 44)

2.3.2. Risk Analysis Overview

The risk analysis is broadly defined to include risk assessment, risk management and risk communication. Risk analysis is not only a systematic approach, which considers the interaction between all components, also is an iterative and repeatable approach. Applying the risk analysis method to climatic change issues improves insight into the uncertainty, complexity, and risk features of climatic variability.

Figure2.4. Structure of Risk Analysis

The following subsections discuss alternative applied risk analyses methods, namely UK's risk assessment, FEMA Risk MAP method, Ontario Ministry of Municipal Affairs and Housing approach, and a risk analysis framework for decision making. These are described in more detail below.

2.3.2.1. UK Climate Change Risk Assessment (CCRA)

Recent research done in risk analysis related to climate change was funded by U.K. Department for Environment, Food & Rural Affairs (DEFRA), the Scottish Government, the Welsh Government, and the Department of the Environment Northern Ireland. This refers to substantive UK Climate Change Risk Assessment (CCRA), 2012. The CCRA uses current evidences to create an initial picture of how a climate change may affect the UK in future to decide how to respond. In the other words, important risks to UK infrastructures (11 sectors) are showed in the absence of any actions taken. The projection is made in three time frames: 'the 2020s' (2010-2039), 'the 2050s' (2040-2069) and 'the 2080s' (2070-2099) (UKCCRA, 2012a).

The CCRA method provides the possibility of comparison of approximately 100 'risks' in 11 different sectors, which each 'risk' is a projection of uncertain future climate change on key issues of one particular sector. For example, water is a key issue in Agriculture and Forestry sector. Each 'risk' is developed within one sector and can be considered as either opportunity or threat for that sector (UKCCRA, 2012a). For example less water is available to meet increased demand for crop irrigation is considered as a "risk" in Agriculture and Forestry (UKCCRA, 2012b).

UKCCRA compares 100 'risks' in terms of magnitude of consequence and the confidence of future occurrence in the evidence base. The confidence ranges from "low" and "medium" to "high" and indicates how much confidence exists in the projected timing and intensity of each potential risk (UKCCRA, 2012a). Classification table for confidence level on which CCRA relies is presented in Appendix A.

This method uses the term “risk metric” to describe the indicators of social, economic, and environmental consequences of the event impacts (UKCCRA, 2012a).

The key phases of the UKCCRA method are demonstrated as follows.

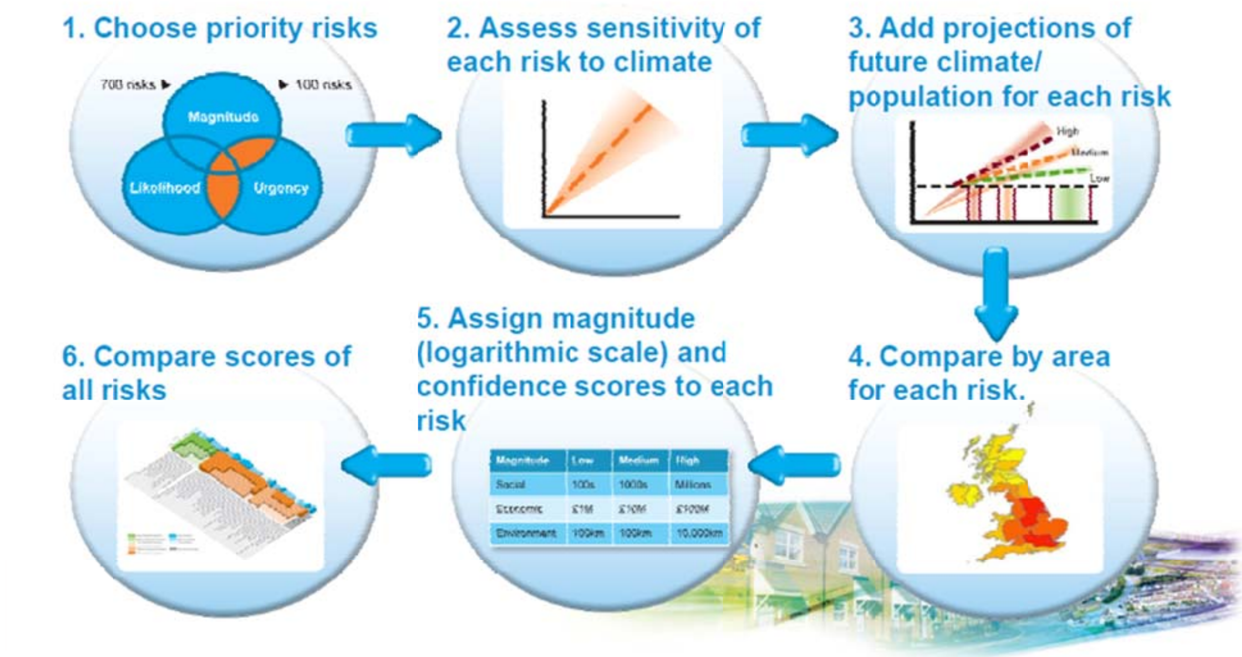


Figure2.5. CCRA Method Overview. Source: (UKCCRA, 2012c)

The CCRA assess the sensitivity of each ‘risk metric’ to climate changes by using sensitivity analysis, historical data, or expert elicitation methodology. In order to estimate the magnitude of consequences, CCRA projects the future climatic and socio-economic changes for every consequence. The sensitivity of the consequences is estimated to both climate change scenarios; three different emission scenarios (High, Medium, and Low emission), three future 30-year time periods (2020s, 2050s and 2080s), and to socio-economic scenarios; three variant population (High, Principal, and Low). The consequences are evaluated in three dimensions: (i) society, (ii) economy, and (iii) environment (UKCCRA, 2012a).

Then the measured vulnerability level is compared with UK risk classification table of the area (which is provided by judgment and moderation of the project team) to determine the appropriate level of each 'risk', which ranges from low and medium to high (UKCCRA, 2012a). One sample of classification table created for damages and loses presented in Appendix A.

For example, "flood risk is projected to increase significantly across the UK". If the frequency of flooding increases, peoples' homes and well-being will be affected. Annual damages to the UK properties will rise from £1.3 billion to £2.1-12 billion by 2080s, based on future population growth and if no adaptive action is taken. Compared with the risk classification table, this risk stands in the high level (UKCCRA, 2012b).

By having the magnitude and confidence level for each 'risk' and by identifying the nature of the 'risk' (threat or opportunity), the final graph can be drawn. The CCRA do not deploy quantities estimates of risk (probability * magnitude of consequence), instead uses categories and descriptive labels. Providing a baseline level for risks and opportunities, the CCRA outputs enable UK decision makers to prioritize and evaluate different types of risks (UKCCRA, 2012a).

UKCCRA is not able to analyze some of the more complex interactions such as the whole risks to ecosystems or to assess two or more sector (infrastructure) failures caused by severe weather events (DEFRA, 2012).

2.3.2.2. Federal Emergency Management Agency (FEMA)

The Federal Emergency Management Agency (FEMA) manages various risk analysis programs, which attempt to reduce the impacts of risky events by providing appropriate adaptation strategies. FEMA assesses the natural hazards whether caused by climate change or non-climate change origins. One of the climatic change related projects done by FEMA, delivered through FEMA's Risk Analysis Division is Risk MAP. The Risk MAP is a solution includes new designed strategies and products developed by FEMA to achieve goals and objectives of the Risk Map Multi-Year Plan. Risk MAP attempts to establish an integrated risk management approach and integrated national assessment flooding risk map based on digital hazard data, web-accessible data, and updated information (FEMA, 2009).

The Risk Map lifecycle including risk identification, risk assessment, risk communication and risk mitigation is drawn as follows.

Figure2.6.Risk MAP Lifecycle. Source:(FEMA, 2009)

Risk MAP framework encompasses three key processes including Mapping, Assessment, and Planning. The first two processes can be captured by four steps: 1) develop GIS data to capture community assets, 2) develop hazard data which resulted in flood, 3) estimate losses such as economic losses, building damages, displaced population, 4) develop problem statement which outlines the vulnerable areas (Perkins, 2009).

Risk Map enables communities to assess the risks by using product and technologies which visualize the risks (FEMA, 2009). (Description around risk assessment procedures here is out of this research purpose since technical tools assist Risk MAP in this regard)

The new risks are identified as a result of risk assessment. After realizing the gap between current risk reduction requirements and the previous mitigation plan targeted, Planning can be started. For Risk MAP implementation, FEMA collaborates with local, state, regional, tribal, and national entities and other federal partners.

Risk Map intends to reduce losses of life and property to coastal communities through more precise quality flood hazard data and risk assessments, and enhancement of local mitigation activities. Risk MAP aims to increase the public awareness of risk and reinforces local ability to make informed management decisions for reducing vulnerability (FEMA, 2009).

2.3.2.3. Ontario Ministry of Municipal Affairs and Housing

The Ontario Ministry of Municipal Affairs and Housing, in cooperation with Natural Resources Canada and Institute for Catastrophic Loss Reduction, developed a management guide for municipalities to understand and manage the risks related to climatic changes and remaining uncertainties about future changes. This guide incorporates the risk management to future planning and management activities related to climate adaptation (Bruce et al., 2006).

The general framework presented by Ontario Municipality to manage risks is as follows.

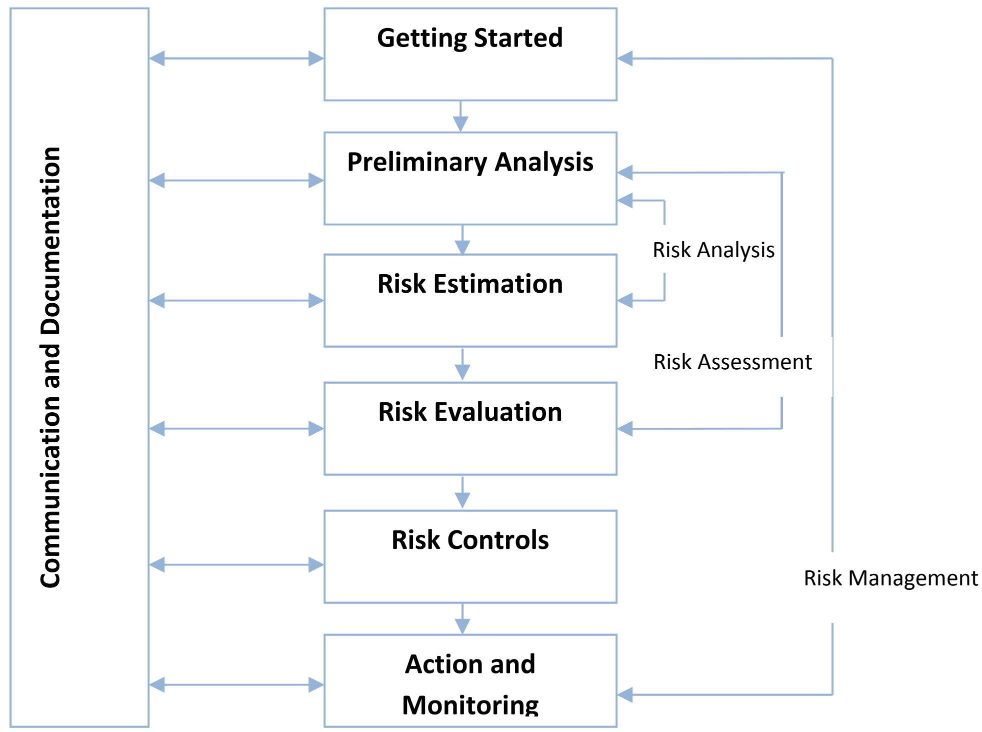


Figure2.7. Risk Management Process. Source: (Bruce et al., 2006)

At a very early stage hazards, vulnerabilities to the area and individual or any groups with effect on decision making is identified. Risk scenarios are developed, one of which represents probable type of loss or impact could occur as a result of exposure to the hazard. Afterwards, the frequency and severity, and consequences associated with each scenario are estimated. The frequency can be presented by either quantitative or qualitative methods.

Quantitative method describes likelihood in terms of either frequency or probability:

- Frequency: gives the number of times of occurrence over a chosen timeframe. 3/year, 1/decade, 10/week.
- Probability: expresses the outcome as a measure between 0 and 1, or as a percentage between 0% and 100%.

Qualitative method assesses likelihood relative to other potential scenarios and ranges from "occurs very often" to "occurs almost never".

- Very unlikely to happen: not likely to occur in a given year
- Occasional occurrence: may occur sometime but not often in a given year
- Moderately frequent: likely to occur at least once in a given year
- Occurs often: likely to occur several times in a given year
- Virtually certain to occur: happens often and will happen again in a given year (Bruce et al., 2006)

Then, consequences of each particular scenario on environment, economy, society, and culture, which have been defined as vulnerable assets of coastal community to threats, are estimated. It can be presented by either qualitative or quantitative measurement. Qualitative measures for consequences range from "very minor effects" to "extremely serious effects". If explicit data and values are accessible for losses and damages of a particular scenario, consequences can be presented based on these values, such as death and fatalities, injuries and damages (Bruce et al., 2006).

Direct losses feel immediately after disaster for example fatalities, injuries, community response cost, cleanup cost, temporary housing cost, and loss of agriculture inventory. Indirect losses emerge much later, and are not caused directly by disaster for instance mental illness, bereavement, loss of income, and reductions in businesses. Losses can be either tangible, for which dollar value can be assigned, or intangible like stress (FEMA, Section 18).

The frequency and consequence results would differ in short-term horizon from long-term horizon. Selection of an appropriate time horizon for climatic changes is important.

For more illustration, the consequences ranking matrix for one particular scenario is showed as follows;

Impact / Degree	Social Factors			Economic Factors		Environmental Factors		
	Health & Safety	Loss of Livelihood	Cultural Aspects	Property Damage	Financial Impact	Water	Land	Ecosystem
Very Low			×	×				
Low		×			×			
Moderate	×				×			
Major				×		×		×
Very Severe							×	

Table2.4.Impact rating matrix for one particular scenario. Source: (Bruce et al., 2006)

Risk evaluation (assessment) matrix used to define different level of risks as a result of hazard probability and hazard severity. Dividing risks into five categories; extreme, high, moderate, low, and negligible risks, Risk assessment matrix can be developed as follows.

1	Very Severe	Moderate Risk	High Risk	High Risk	Extreme Risk	Extreme Risk

	Major	Low Risk	Moderate Risk	High Risk	High Risk	Extreme Risk
	Moderate	Low Risk	Low Risk	Moderate Risk	High Risk	High Risk
	Low	Negligible Risk	Low Risk	Low Risk	Moderate Risk	High Risk
	Very Low	Negligible Risk	Negligible Risk	Low Risk	Low Risk	Moderate Risk
		Very unlikely to happen	Occasional Occurrence	Moderately Frequent	Occurs Often	Virtually Certain to Occur
	Frequency/Probability					

Figure2.8. Risk Assessment Matrix. Source: (Bruce et al., 2006)

- Immediate controls required
- High priority control measures required
- Some controls required to reduce risks to lower levels
- Controls not likely required
- Do not require further consideration

In two last steps, operational aspects, costs and benefits of each scenario are taken into account as supplementary information for prioritizing risk and identifying unacceptable risks. Residual risk scenario is assessed to unfold beneficial or adverse effects. Monitoring of implementation of adaptation strategies (or risk control strategies) and process, from the first to the last step, is considered to efficiently improve the decision making process(Bruce et al., 2006).

Stakeholders' feedbacks have an undeniable influence on all steps of risk management process so that communication with stakeholders is an integral part of all steps. Stakeholders' perception of risk and its consequences must be contributed to risk estimation step. In addition, ranking and prioritizing the risk in risk evaluation step need stakeholders' participation (Bruce et al., 2006).

2.3.2.4. A Framework for Risk Analysis in Fisheries Decision Making

Among risk analysis frameworks published, Lane and Stephenson's paper can be mentioned as a valuable attempt towards quantitative risk analysis. It modifies fisheries management framework by including risk assessment, and risk management in decision making process.

A 5-year strategic plan is targeted in biological and socio-economic dimensions. In order to achieve the target different scenarios (decreasing, increasing, constant, and pulse) are developed. Degree of achievement is evaluated by performance measurements (i.e. indicators) for each dimension. For instance, harvestable stock size for juvenile and adults combined (of age 1+) and for adult (of age 4+) are performance measures for biological dimension, and total labor (like employment) and cash position for harvesting and processing sectors are performance measurements for social and economic dimensions (Lane & Stephenson, 1998).

The input values are provided by the deterministic model (best estimation) over 5 year for every scenario and performance measurement. The advantage of this projection is ignoring the scenario which is too unrealistic from further consideration (Lane & Stephenson, 1998).

Stochastic models are developed for estimating output performance, which capture uncertainties regarding input variable and calculate the probability of possible outcomes under each scenario. For this purpose, Monte Carlo simulation is involved that randomizes key model elements (variables). It pictures the probability distribution of decision alternatives (scenarios) for each performance measurement. The figure 2.9 illustrates one of the Mote Carlo graphs created for discounted cash (performance measurement) and different scenarios (Lane & Stephenson, 1998).

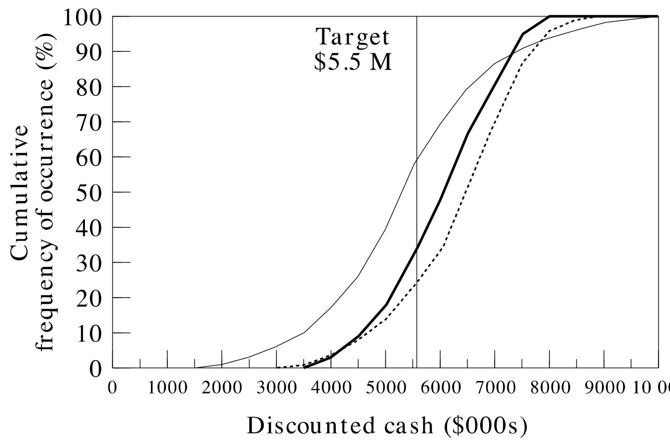


Figure2.9. Cumulative probability distributions for Monte Carlo simulation modeling. Source: (Lane & Stephenson, 1998)

Then risk assessment can be started by using the outputs of the Monte Carlo simulation experiment. The decision alternatives are evaluated in terms of their probability in meeting the target. For more illustration, if all probabilities of one output performance, with respect to the target, are very low, it may not be considered acceptable by decision makers (Lane & Stephenson, 1998).

In order to capture relative acceptability of risks assessed before, a general utility function over all dimensions is developed. Utility functions are able to describe the preferences towards acceptability of one specific output in different circumstances. However, the fact that outputs are considered under uncertainty adds a special structure to the problem. In general, how a person values an alternative in one state as compared to another will depend on the probability that the state in question will actually occur. In decision making field, utility curves can be drawn empirically by profoundly analysis of decision maker's preferences and trade-offs (Lane & Stephenson, 1998) In this case, the biological, economical and social aspects must be integrated into one utility function.

For comparing and evaluating the decision alternatives decision makers start risk management process, which uses the results from risk assessment, and utility curve.

To identify the overall utility for each alternative, this paper represents a linear multi-attribute function as described below.

$$U(\mu_j) = \sum_{i=1}^{4} \alpha_i U_i(\mu_j)$$

$\propto_i$: Relative importance of each performance measure so that $\sum_{i=1}^{4} \propto_i = 1$, it can be obtained by asking trade-off questions from decision makers

$U_i(\mu_j)$: The expected utility for performance measurement i and strategy j

For different weight assigned to the utility function weights ($\propto_i$), the solution will vary. Hence, the optimal solution can be obtained by a set of weights (Lane & Stephenson, 1998).

2.4.Summary

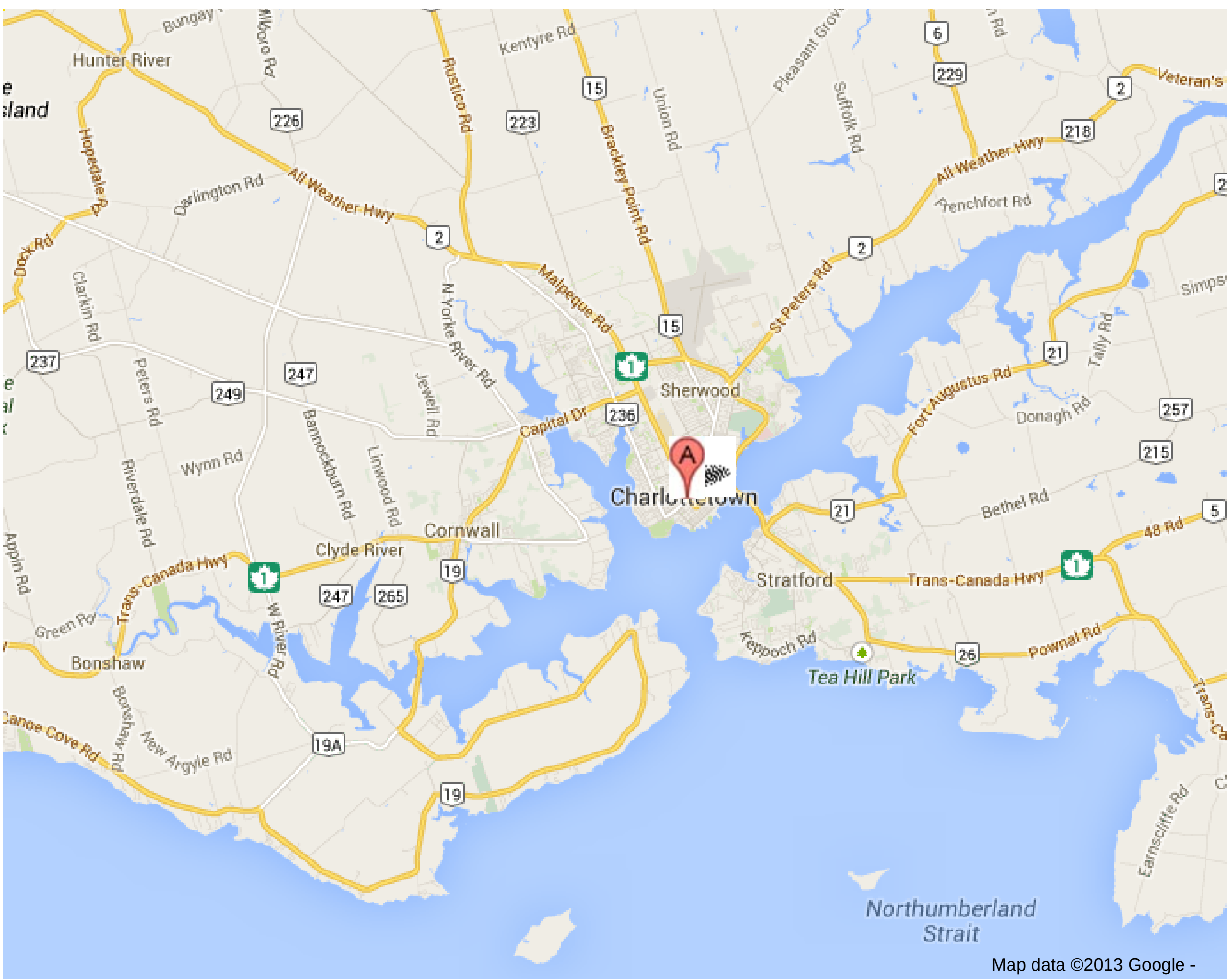
2.5.Application

This research assesses the risks that Isle Madam and Charlottetown communities are dealing with, since they are motivated by severe storms and sea level rise. The specifications of both communities are described as following.

2.5.1. Charlottetown, Prince Edward Island

On the southern shore of Prince Edward Island is located Charlottetown city, the province of PEI. The city is concentrated on the harbor where three rivers are merged (C-Change, 2011). The population of Charlottetown community reaches to 34,562 residents (2011 Census).

The Charlottetown harbor opens to Northumberland Strait. It is protected against Northumberland Strait and the Gulf of St. Lawrence, however sea level and storm surge are



increasing.

Figure2.11. Charlottetown, Prince Edward Island. Source: (GoogleMap2013)

As a tourism destination for Canadians and non-Canadians especially in summer, Charlottetown has numerous historic sites. Recreational fishing and boating, and indoor and outdoor festivals in Charlottetown harbor attracts a number of tourists, not to mention parks and green spaces (Approximately 400 acres), and an extensive system of walking and recreation trails throughout the city (C-Change, 2011 & Shaw, 2001).

Charlottetown is the main center of industrial and commercial activities in the province. The well-developed waterfront area, where commercial businesses, houses, public resources are established, is situated in the most vulnerable zone to storm surge. Therefore, the property of both residential and commercial sectors in Charlottetown is in danger of storm surge events (Shaw, 2001).

2.5.2.Isle Madam, Nova Scotia

The largest in an archipelago, Isle Madam is located on the Southeastern side of Cape Breton Island, Nova Scotia. The residents of Isle Madam community are 2,644 people in 2011, according to Government of Nova Scotia.

Isle Madame is made of three main island communities; Isle Madame, Petit-de-Grat to the east, Janvrin's Island to the west. Separated from mainland Cape Breton Island by a narrow strait to the north, named Lennox Passage, Isle Madam is part of Richmond County. Today, Isle Madam is connected to two neighbor islands; Petite-de-Grat, by bridge, and Janvrin's Island, by Causeway and bridge (C-Change,2011b).

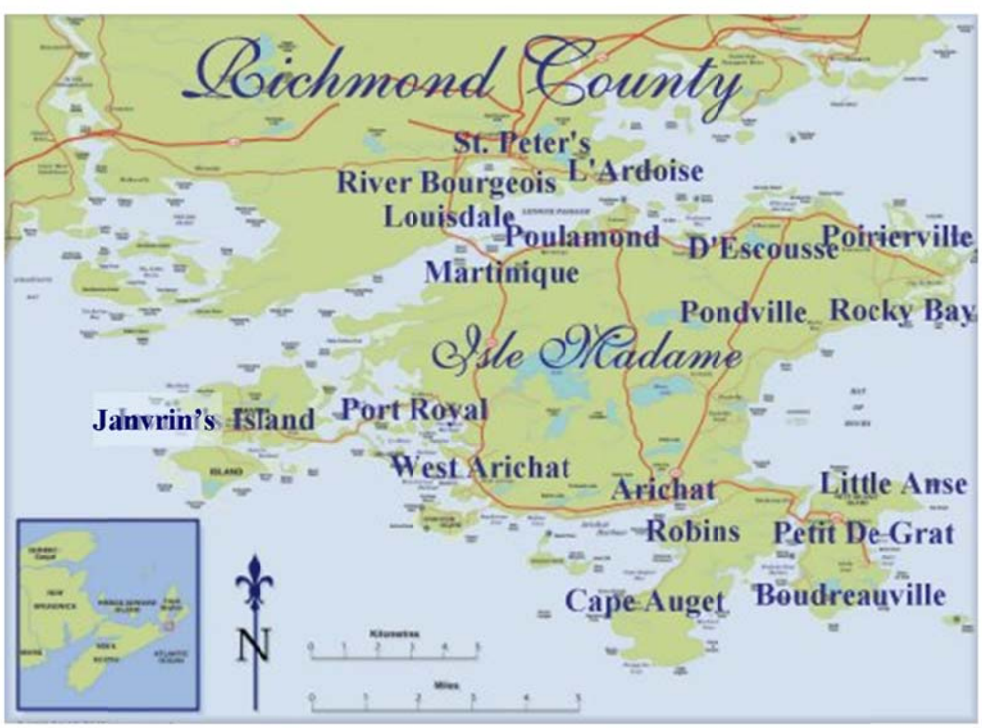


Figure2.12. Isle Madam, Nova Scotia. Source: (C-Change, 2011b)

Isle Madam has been a port of cod fishing and sea trade since years ago. The fishery is continuing to keep its importance for Isle Madam. Some fishery f operations are still active such as Premium Seafoods, Ltd., in Arichat (C-Change, 2011b).

3. Methodology

The methods of this research are an extensive analysis of the frameworks reviewed in the literature before. This chapter is started with a brief description about research process which includes risk assessment, risk management, and risk communication. As following, each element of the research process is broken down to the techniques and details that will be used throughout the research.

This research aims to estimate the probabilities and impacts of storm hazards on Charlottetown and Isle Madam communities in future, and advise the more suitable adaptation strategies with respect to community's attitude towards risk, and the results of the risk assessment.

3.1.Research Process

Under this section, the three main components of risk analysis process, as mentioned before, are explained; risk assessment, risk management, and risk communication.

3.1.1. Risk Assessment

Risk assessment is to identify the probability of hazards threatening coastal communities, and estimate and analyze the consequences of the hazards on coastal communities. The purpose of risk assessment is to highlight significant risks associated with coastal communities.

As mentioned in application, part 2.5, coastal communities in both areas, Isle Madam and Charlottetown, are vulnerable to storm hazards. The consequences of storm hazard are to be assessed in terms of four pillars: environment, society, culture, and economy.

According to Ontario Ministry of Municipal Affairs and Housing framework, risk assessment encompasses preliminary analysis, risk estimation, risk evaluation, and risk communication.

3.1.2. Risk Management

Risk management identifies the highest priority risks that need to be treated first, and responds to the risk factors within the lifecycle of the project and with respect to the objectives. A proper risk management considers potential future events and is proactive rather than reactive.

According to Ontario Ministry of Municipal Affairs and Housing framework, risk management contains risk assessment, risk control, risk monitoring, and risk communication.

3.1.3. Risk Communication

Risk communication is to be considered in all steps, which varies based on information and possibilities are available. It is applied in various ways such as comparison against benchmark or standard, using survey, or listening to the other experts' opinion.

3.2. Risk Assessment

Completely done risk assessment requires data and information for storm hazards, vulnerability measurement, adaptations strategy, and probability assessment. They can be considered as main parts of a puzzle needed to be collected and be fitted into their own places to complete risk assessment.

3.2.1. Prediction of Storm Occurrences by Statistical Analysis

In order to predict the likelihood of storm hazard occurrence, the probability distribution of storm event must be discovered. It makes the prediction of uncertain future storm events possible. The distribution relies on historical data currently in hand.

The data from November 1961 to December 1998 available for Charlottetown storm surge are quality-controlled. While, between January 1911 and October 1961, especially before 1938, the collected data are partially complete. Therefore, two series of calculation, including more and less reliable, have been done by Beigzadeh: one from 1968 to 2004, and the other from 1911 to 2004. To find a proper statistical distribution for Charlottetown's historical data from Environmental Canada (2006), three tests of goodness-of-fit are examined. The tests, Kolmogorov-Smirnov, Anderson-Darling, and Chi-Squared test, are implemented by EasyFit application. The best-fitted distribution is chosen where 5 to 6 out of 58 distributions are evaluated (Beigzadeh, 2013).

3.2.2. Providing Solutions and Alternative Strategies

Alternative strategies mediating the impacts of severe storms are developed to be compared with status quota. The amount of vulnerability reduction and the cost of implementation for each option count for important factors in decision making. Mostofi did a comprehensive study around the adaptation strategies in the case of Little Anse, located in Isle Madam, severe storms. In his study, section 5.4, new breakwater strategies, and cost estimations of each option are provided.

Existing breakwater has technical deficiencies that make it more vulnerable to storm events. Orientation of the current breakwater, lack of maintenance, and wave directions towards the location, where Mostofi studied on, were discussed as deficiencies.

Adaptation strategies analyzed and evaluated by Mostofi are as follows,

1) "Protection"- improving the engineered breakwater systems in three different ways;
    a. Protection 1. Rehabilitation of the existing breakwater
    b. Protection 2. Close the existing opening and create a new north facing opening
    c. Protection 3. Create a modified opening with a new breakwater arm extending from the south
2) "Accommodation"- building up a new road which will be less vulnerable to storm surge impacts
3) "Retreat"- moving a position of Little Anse household that are known more vulnerable to sever storms (Mostofi, 2011).

The tables 3.1 to 3.3 show the cost estimation, done by Mostofi, for each adaptation option. The estimations are done based on Baird & Associates (2010).

	Range	Capital Cost ($ Millions)	Soft Cost ($ Millions)	Total Cost ($ Millions)	Maintenance ($ Thousands)
Protection 1	Lower Bound	1.1	0.3	1.4	35
	Upper Bound	1.6	0.4	2.0	50

Average				1.7	42.5
Protection 2	Lower Bound	3.1	0.8	3.9	97.5
	Upper Bound	4.2	1.1	5.3	132.5
Average				4.6	132.5
Protection 3	Lower Bound	3.5	0.9	4.3	107.5
	Upper Bound	4.6	1.2	5.8	145
Average				5.05	126.25

Table3.1. Cost estimations for "Protection" strategies; Protection 1, 2, and 3. Source: (Mostofi, 2011)

The upper bound prices are reflecting the availability of contactors, fuel costs, competition for stones and weather delays. More ideal condition is reflected in lower bound prices. Soft cost is a combination of Mobilization and Demobilization, Engineering, Contingency, and Annualized Maintenance costs. Contribution of each in soft cost is by 10%, 5%, 10%, and 2.5%, respectively (Mostofi, 2011).

Capital Cost ($ Millions)	Mobilization Cost ($ Millions)	Engineering Cost ($ Millions)	Total Cost ($ Millions)
1,520,400	152,040	76,020	1,748,460

Table3.2. Cost estimations for "Accommodation" strategy. Source: (Mostofi, 2011)

A few indicators are affected by "accommodation" strategy, including the road itself, income, and safety while other are leaved intact (Mostofi, 2011).

	Houses	Buildings	Residential Land	Mobilization Cost	Total Cost of Relocation
Houses	29	8	75400 (sq m)	29 (Hoseholds)	
Per Value ($)	31,750	8,000	12	15,000	2,338,614
Total Cost	920,750	64,000	918,864	435,000	

Table3.3. Cost estimations for "Retreat" strategy. Source: (Mostofi, 2011)

The retreated strategy is not able to protect all assets in danger. The influence is considered only for the dependent indicators; buildings, wells, residential land, income and safety (Mostofi, 2011).

3.2.3. Scenario Development

In development of a model, which plans ahead for the future, different scenarios are deemed based on historical data, or the expertise in the field. Since the future weather circumstance is unpredictable, these scenarios should be defined wisely to cover all possibilities.

The scenarios can be extracted based on storm speed, wind speed and pressure. These elements can be a basis for categorizing storm hazards affecting coastal communities. As an example, two different storm scenarios are defined for Isle Madam as follows:

- Scenario I has a speed of 45 to 50 Kph, wind speed of 55 to 75 Kph, and a atmospheric pressure of 1000 t0 990 mb. And the expected water level is between 2 and 2.5 meters above chart datum.
- Scenario II has a speed of 50 to 55 Kph, wind speed of 75 to 95 Kph, and a atmospheric pressure of 990 t0 980 mb. And the expected water level is between 2.5 and 3 meters above chart datum.

3.2.4. Vulnerability Assessment

The question is that how much vulnerable are Charlottetown and Isle Madam to storm hazards in the uncertain future. The vulnerabilities of either community are a function of adaptation strategies and different possible scenarios.

The impacts on four aforementioned pillars are to be estimated. Having the assets of each community classified into four dimensions, we can start valuation of community assets where are vulnerable to storm hazards. The indicators selected to measure these impacts should represent the features discussed before, in section 2.2.

To illustrate more, the assets at risk, and total assets of economical dimension under Status Qua are depicted in the table 3.5. Two indicators used to estimate economical demotion are houses, and buildings.

Status Qua	Indicators		Scenario I	Scenario II
Economy	Houses	Assets at risk	666,750	793,750
		Damages	84,000	125,000

	Buildings	Assets at risk	64,000	64,000
		Damages	8,000	12,000

Table3.5. Summary of assets at risk and total assets for two indicators of economical dimension.

Source: (Mostofi, 2011)

The "Assets at risk" is distinguished from "Damages" here, since not all assets at risk are damaged by storm hazards.

3.2.5. Probability Assessments of Stochastic Events by Monte Carlo Simulation

The purpose of Monte Carlo simulation is to estimate the distribution of the potential outcome, which depends on several probabilistic input variables of a model. Often, Monte Carlo simulation is used for analyzing the expected impacts of policy changes or risks associated with making different decisions.

The probability distribution for input variables is defined and their values randomly are selected from the distributions. The model is simulated many times to bring out the probability of the outcome. It is known as a sampling method since the inputs are generated randomly to simulate the process of sampling from an actual or estimated population.

3.3.Risk Management

3.3.1. Utility Curve Development

Sometimes the risks associated with decision alternatives are not adequately factored into the analysis by taking into account decision maker's risk acceptance (preferences). People differ in how much they are willing to take the risk. The desirability of decision alternatives to decision makers is presented by Utility Function (Chastain, 2010).

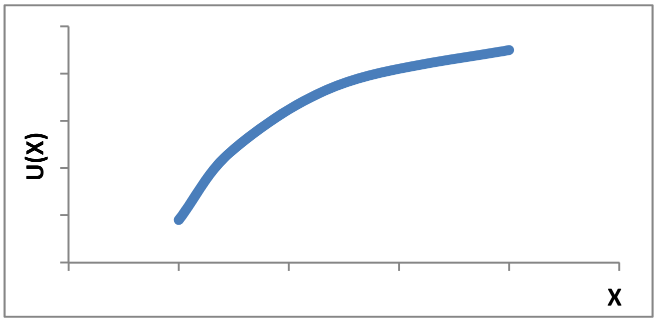
> " "Utility" is an abstract measure of the relative strength of preference/desirability for a particular outcome" (Lane & Stephenson, 1998).

Utility Function is classified in terms of decision makers' attitudes towards risk. Three behaviors towards risk are risk averse, risk neutral, and risk seeking, which are explained below.

Risk Averse is when a certain amount preferred for an alternative is less than the expected amount for that alternative (ASU, October 2013). In the other words, every extra dollar of cost is preferred slightly more costly than the previous dollar, where cost is any value of X (Wayne & Albright, 2012, p. 526). Its Utility Function is shown in the figure 3.1a.

Risk Neutral is when a certain amount preferred for an alternative is equal to the expected amount for that alternative (ASU, October 2013). Its utility Function is shown in the figure 3.1b.

Risk Seeking is when a certain amount preferred for an alternative is greater than the expected amount for that alternative. Its Utility Function is shown in the figure 3.1c (ASU, October 2013) a)



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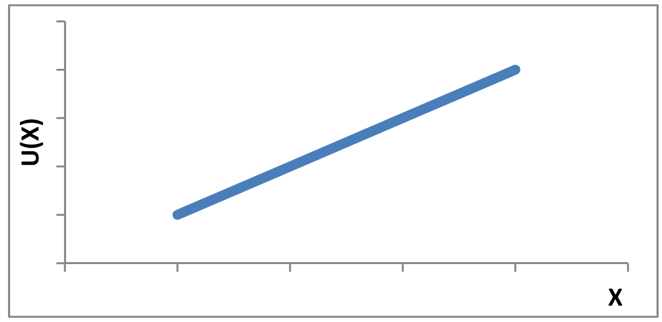

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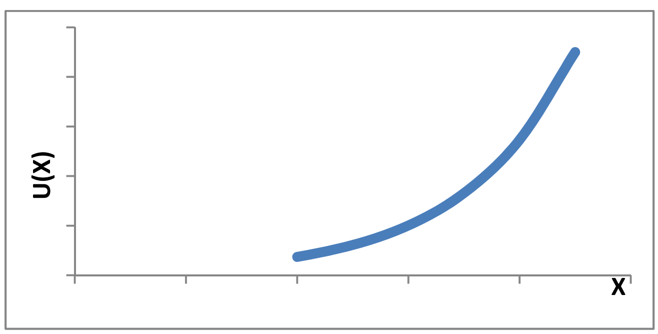

Figure3.1. The Utility Functions. a) Risk Averse, b) Risk Neutral, and c) Risk Seeking. Source: (ASU, October 2013)

The increasing part of all curves means that the decision maker prefers more of a good thing rather than the less.

Utility analysis enables decision makers to consider various outcomes in their analytic decisions. Utility function can be developed for either only one indicator, or more than one. On the other side, outcomes can be examined in different decision makers' perspectives.

In this research, the utility functions are to be established for every dimension, over all possible outcomes, and based on one decision maker's perspective.

3.3.2. Application of Multi Attribute Utility Theory in Risk Management

3.3.3. Utility Function Weights

3.3.4. Multi Criteria Decision Making

3.4. Risk Communication

3.4.1. Monitoring of The Event

4. Analysis and Expected Results

5. Consideration for Future Research

6. Research Timeline

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Appendices

A

Table below is an instance for classification table applied by UKCCRA to classify the confidences.

Class	Definition
High	Reliable analysis and methods, with a strong theoretical basis, subject to peer review and accepted within a sector as 'fit for purpose'.
Medium	Estimation of potential impacts or consequences, grounded in theory, using accepted methods and with some agreement across the sector.
Low	Expert view based on limited information, e.g. anecdotal evidence, or very simplistic estimation methods.

Table A.1. Summary classification of confidence. Source: (UKCCRA. 2012a, page 29)

Classification used by UKCCRA to describe magnitudes of consequences is showed below.

Class	Economic	Environmental	Social
High	• Major and recurrent damage to property and infrastructure • Major consequence on regional and national economy • Major cross-sector consequences • Major disruption or loss of national or international transport links • Major loss/gain of employment opportunities *~ £100 million for a single event or per year*	• Major loss or decline in long-term quality of valued species/habitat/landscape • Major or long-term decline in status/condition of sites of international/national significance • Widespread Failure of ecosystem function or services • Widespread decline in land/water/air quality • Major cross-sector consequences *~ 5000 ha lost/gained* *~ 10000 km river water quality affected*	• Potential for many fatalities or serious harm • Loss or major disruption to utilities (water/gas/electricity) • Major consequences on vulnerable groups • Increase in national health burden • Large reduction in community services • Major damage or loss of cultural assets/high symbolic value • Major role for emergency services • Major impacts on personal security e.g. increased crime *~million affected* *~1000s harmed* *~100 fatalities*
Medium	• Widespread damage to property and infrastructure • Influence on regional economy • Consequences on operations & service provision initiating contingency plans • Minor disruption of national transport links • Moderate cross-sector consequences • Moderate loss/gain of employment opportunities *~ £10 million per event or year*	• Important/medium-term consequences on species/habitat/landscape • Medium-term or moderate loss of quality/status of sites of national importance • Regional decline in land/water/air quality • Medium-term or Regional loss/decline in ecosystem services • Moderate cross-sector consequences *~ 500 ha lost/gained* *~ 1000 km river water quality affected*	• Significant numbers affected • Minor disruption to utilities (water/gas/electricity) • Increased inequality, e.g. through rising costs of service provision • Consequence on health burden • Moderate reduction in community services • Moderate increased role for emergency services • Minor impacts on personal security *~100s thousands affected,* *~100s harmed,* *~10 fatalities*
Low	• Minor or very local consequences • No consequence on national or regional economy • Localised disruption of transport *~ £1 million per event or year*	• Short-term/reversible effects on species/habitat/landscape or ecosystem services • Localised decline in land/water/air quality • Short-term loss/minor decline in quality/status of designated sites *~ 50 ha of valued habitats damaged/improved* *~ 100 km river quality affected*	• Small numbers affected • Small reduction in community services • Within 'coping range' *~10s thousands affected etc.*

Table A.2. Sample for classification of relative magnitude. Source: (UKCCRA. 2012a, page 37)

B

Environmental items (i.e. indicators), layers, the number of available points or polylines, and approximate length and area of each point are presented in table below.