December | 14

Development Trends and Vulnerability to Severe Storms

A Case Study Analysis in Nova Scotia

Thesis Proposal by Jacqueline Wightman

Table of Contents

1. Introduction

Nova Scotia lies in the northern limit of the Atlantic Hurricane system. These storms often dissipate before reaching the coast; however, in recent memory, they have been landing in Nova Scotia more frequently. Extreme storms have profound impacts on communities in the province. For example, Hurricane Juan, one of the most destructive hurricanes to hit Atlantic Canada, caused over $200 million in damages, 8 fatalities, and widespread power outages (Fogarty, 2003). Scientists suggest that the frequency with which hurricanes hit the Maritimes may increase due to climate change (Walmsley, 2009). Sea level is rising due to melting glaciers, ice sheets, and the expansion of warming water (IPCC, 2007). Sea level will continue to rise, moving the sea's reach further inland and compounding the damage to coastal development due to intense storms and storm surge. In addition, the number of people and infrastructure at risk is increasing as development on the coast intensifies.

The magnitude of the storm combined with land use, infrastructure, and development patterns determines the amount of devastation that a hurricane inflicts on a community. Vulnerability to storms arises from both societal and physical factors, and the combination of these factors results in the uneven distribution of impacts of an extreme event (Clark et al, 1998). This study will examine the change in vulnerability to hurricanes of a community in Nova Scotia by comparing the damages from past storms to the type and pattern of land use at the time of each storm. Land use plans for the future will be assessed to determine the degree to which each community is prepared for potential changes in the frequency and intensity of severe storms.

2. Research Problem

A shift in hazard trends, exposure, and vulnerability affect a community's overall risk to extreme weather. Of primary interest is how the vulnerability of coastal communities in Nova Scotia increases due to changing climate and development factors. A comprehensive understanding of the change in risk over time is necessary to assess future risk. By analyzing historic storm risk patterns, I hope to gain insight into how development trends may affect future vulnerability to storms. I will therefore attempt to address the following research question:

How has the relationship between storm damages and development patterns in a community in Nova Scotia changed over time, and what do these trends imply for future storm risk?

3. Background and Literature Review

3.1 Risk: Hazard, Exposure, and Vulnerability

A community's level of risk to severe weather is determined by environmental and geographic factors as well as planning, development and social factors. Cutter (1996) and Granger (2003) look at the relationship between these factors for environmental hazards in general. Schmidt et al. (2009) uses Granger's study to categorize factors that influence the magnitude of damages from hurricanes. I will also use Granger's work as a basis for distinguishing between the different components of risk – hazard, exposure, and vulnerability.

Cutter (1996), an American social scientist who studies social vulnerability, created a "hazards of place model" (Figure 1) to portray the relationship between risk, mitigation, hazard potential, geographic context, social fabric, biophysical vulnerability, and social vulnerability. Cutter considers three themes that existed in vulnerability studies at the time of writing (1996): risk/hazard exposure, vulnerability as a social response, and vulnerability of places. Studies under the first theme are "characterized by a focus on the distribution of some hazardous condition, the human occupancy of this hazardous zone…and the degree of loss (life and property) associated with the occurrence of a particular event" (Cutter, 1996, p.532). The second group of studies looks at social resistance and resilience to hazard, and the third involves a combination of biophysical risk and social response within a specific area (Cutter, 1996). Cutter (1996) notes that little research had been done on the temporal aspect of vulnerability, that is, how a society's vulnerability changes over time due to various social and physical factors.

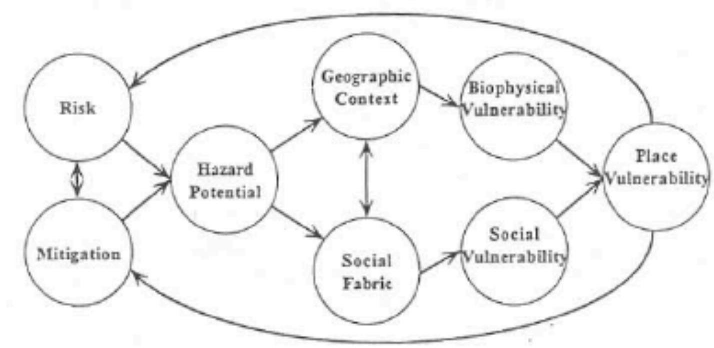

Figure 1. Susan Cutter's "hazards of place model of vulnerability. The various elements that constitute vulnerability interact to produce the vulnerability of specific places and the people who live there." (Cuter, 1996, p. 536)

Similarly, Granger (2003) created an equation to describe the elements of risk; however, he used only three elements, stating that total risk is the product of hazard, exposure, and vulnerability (cited in Fedak, 2012). Later, Schmidt et al. (2009) categorized factors that impact losses from tropical cyclones based on the elements of risk defined by Granger (2003). In a study done by Schmidt et al. (2009), factors that determine the frequency and severity of the hazard include natural climate variability and human caused changes. Factors that determine exposure and vulnerability include changes in population, demographics and per capita assets, and the settlement and industrialisation of exposed areas.

Based on Granger's definition, extreme storms and the associated storm surges are the hazard, the elements exposed to the hazard are buildings and people, and vulnerability is the ability of these buildings and people to recover from the storm. The number of hazards is expected to increase with climate change, as sea level rises and the frequency and intensity of tropical storms increases (see section 3.2). As development along the coast intensifies, the amount of exposure will also increase; more people and infrastructure occupying the coast means more potential for damage. Vulnerability also increases as the type of development along the coast changes from agricultural and industrial to residential and commercial uses (explained further in sections 3.4 and 3.5). Risks associated with storm surge in Nova Scotia are expected to grow as sea level rises, storms become more frequent and intense, and waterfront development changes and intensifies.

3.2 The Changing Dynamics of Storm Hazards

Research shows that intense cyclonic activity has increased since the 1970s, and that these trends are strongly correlated to sea surface temperature (Walmsley, 2009). Shmidt et al. (2009) analyzed losses due to cyclones on the US Atlantic and Gulf coasts. The study adjusted the losses to exclude increases in the capital stock of the affected region. The data was adjusted to isolate the socio-economic effects to determine if climate change is affecting storm frequency and intensity. No trend was found for the period between 1950 and 2005; however, the period between 1971 and 2005 showed an increase in intense cyclone activity.

A study conducted by O'Gormon (2010) revealed that the seasonal cycle of storm tracks intensity might increase in amplitude in both hemispheres in the 21st century due to global warming. O'Gormon also noted a poleward shift of storm tracks in some global warming scenarios. This poleward shift of storm tracks will increase the likelihood of a hurricane reaching Nova Scotia. While the frequency and intensity of storms increase, sea-level rise increases the baseline for flooding (Clark, 1998). Therefore, storm surges for any given storm will reach further inland in the future than they would today. Climate change will have profound impacts on coastal communities in Nova Scotia.

3.3 Socio-Economic Vulnerability and Resilience

Studies done by Clark (1998), Elsner (1999), Morrow (2000), Franck (2009), Helman et al. (2010), and Cochran et al. (2012) have attempted to quantify and categorize the economic and social vulnerability of communities and individuals to extreme events and can be used as a basis for further research on hurricane vulnerability in Nova Scotia. Franck (2009) created a Feedback-Rich Adaptation to Climate Change (FRACC) model in order to determine the economic and social resilience of a community to a devastating, stochastic storm. The FRACC model uses the following as its initial parameters: relative sea level rise, including subsidence; coastal slope; storm distributions, intensities, and arrivals; economic parameters such as population, labour force activity, and GDP per capita; the fraction of developed and developable land area; and the fraction of land with insurance. The FRACC model calculates expected storm damage, and then looks at changes in population, housing, jobs, etc. However, there are two problems with Franck's FRACC model. Firstly, it uses initial parameters that are in a constant state of flux; as such, the model would have to be updated often in order to retain its accuracy. Secondly, it makes estimates based on the region as a whole, and does not take into account the uneven distribution of damages within a community.

Morrow (2000) argues that the vulnerability of a community to storms depends on social factors, and successful mitigation requires an assessment of how vulnerability is distributed throughout the community. According to Morrow, a vulnerability map would show where at-risk people are concentrated, including the poor, elderly, youth, physically or mentally disabled, large households, renters, recent residents, homeless, ethnic minorities, and tourists. An overlay of Morrow's vulnerability map with storm surge scenarios, which are where most of the devastation occurs (Elsner, 1999), would provide a complete picture of where attention should be focused in light of a hurricane. This type of mapping was done by Clark (1998), who used census data analysis and flood plain maps to create storm vulnerability maps for the town of Revere, Massachusetts. By mapping societal factors such as poverty, transience, disabilities, immigrants, and young families, and overlaying these variables with the flood zone, Clark (1998) identified the most vulnerable areas of a community to storm surge. Cochran et al. (2012) conducted a similar study for the Town of Yarmouth, Nova Scotia, and the municipal District of Yarmouth. Cochran et al. used statistical data from the 2006 Census of Canada to map vulnerability indicators for these municipalities, and overlaid this information with storm surge scenarios generated in a companion Atlantic Climate Adaptation Solutions (ACAS) project.

3.4 Land Use and Exposure

A community's policies, actions, and social conditions affect vulnerability to hazards such as extreme storms (Elsner, 1999). The economic loss from hurricanes has risen dramatically over the past several decades (Elsner, 1999; Brody et. al, 2011), indicating that more people and infrastructure are located in vulnerable areas. Residents in low-lying coastal zones face the greatest risks from hurricanes due to storm surge. Since there is an increasing tendency for people to settle in exposed areas (Schmidt, 2009), the number of people at risk is continually increasing. Oftentimes people are not aware of the risks they face when deciding to move into a coastal zone. Helman et al. (2010) examined people's perceptions of their risks to extreme weather and found that when interviewed during a period of calm weather, over 90% of beachfront residents (in the study community in Australia) thought that they would not be affected by erosion. When a severe storm is not fresh in people's minds, or when people are new to an area, the perception of risk is dramatically lower, which can lead to poor decision-making on the part of both planners and residents (Helman et al., 2010).

Brody et al. (2011) examined the notion that flooding problems in the United States are not getting worse due to changes in flood patterns, but due to changes in land use and development. Little empirical research has been done to determine how intensity and development patterns across coastal landscapes have an effect on property damage from floods (Brody et. al, 2011, p. 440). Brody et al. (2011) studied the relationship between development patterns and insured flood loss claims over a period of 5 years across 14 counties and parishes that fringe the Gulf of Mexico. They measured the following variables: flood loss, high-intensity development, soil permeability, flood plain area, wetland alteration, precipitation volumes, number of storm surge events, number of housing units, and the median household income. The results indicated that areas with clustered, high-density development patterns tended to have lower total flood damage claims, whereas flood loss was greater in areas that had sprawling, low-intensity development. The study conducted by Brody et al. (2011) looks at a broad region; they recommend that further research be done that analyzes more detailed measures of urban/suburban form, such as diversity, shape, connectivity, etc., to provide a better understanding of the consequences of development (p. 447).

In 2003, Davidson and Rivera developed a method of analyzing building inventory change for the purposes of assessing potential storm damage; they created a model that shows how the amount and characteristics of buildings in an area change over time. The objective of the model was to provide information on what the future building inventory might look like in order to better predict future damages from hurricanes. Davidson and Rivera (2003) analyzed available future population projections in conjunction with current and historical census data for the following categories: the number of buildings in each census tract, as well as the units in each structure, year built, value, type of roof covering, predominant roof shape, and number of stories. The study graphically presents the estimated total number of buildings in New Hanover County from 1990 – 2020; the other data are presented as percent changes. Davidson and Rivera (2003) made the assumption that household variables will change in the same manner they did in the past. They looked at broad geographic trends in building inventory, but did not consider how these changes affect hurricane vulnerability. Davidson and Rivera (2003) were also limited by the availability of census and survey data; they note the potential usefulness of other data gathering techniques such as aerial photography or parcel records, for example.

Seto and Fragkias (2005) developed a broader-scale method of looking at land use change. They conducted a spatial-temporal analysis of urban land use change in four cities in China over the period from 1988 – 1999. They used a change detection procedure applied to ten Landstat Thematic Mapper images. First, they created “change vectors” by subtracting values of brightness, greenness, and wetness for the year 1988 from values for the subsequent years (Seto and Fragkias, 2005, p. 876). The second step involved identifying areas that remained stable and areas that had undergone land use change. Seto and Fragkias (2005) then used the Patch Analyst software application to analyze the urban landscape in terms of absolute size, relative size, and complexity of urban form. The study showed that the four cities exhibited common patterns in their shape, size, and growth rates. The researchers suggest use of the analysis to determine how social, economic, and political processes drive the observed urban forms; however, having an understanding of changing land use would be valuable to any research looking at changing exposure to physical hazards.

3.5 Storms and Land Use Planning in Nova Scotia

On September 29th, 2003, category 2 Hurricane Juan hit Nova Scotia and caused over $200 million in damages and 8 fatalities (Boon, 2012). The highest sustained wind recorded from McNabs Island, in Halifax Harbour, was 152 km/h. The storm surge reached a maximum height of 2 metres in Cole Harbour (Fogarty, 2003). The hurricane caused a lot of damage to coastal infrastructure, and damage to buildings, trees, cylos, barns, and signs. This damage demonstrates the potential that a hurricane has to destroy property, towns, ecosystems and lives. Hurricane Juan is now used as a "benchmark storm" in many studies on potential maximum storm surge in Nova Scotia (Critchley, et al., 2012; Richards, et al., 2011).

Nova Scotia has 7600 km of coastline and lies on the northern end of the Atlantic Hurricane track (Pinfold, 2012). Most of the damage from hurricanes in Nova Scotia is due to storm surge (Walmsley, 2009). However, the harm that a hurricane inflicts on a community depends not solely on the storm surge, but also on societal factors and planning decisions. Anderson (2000) explains that trends associated with development have increased our vulnerability to extreme events; technology gives people a false sense of security, which results in the development of marginal lands. In the 19th and early 20th century, much of the coast was used for infrastructure such as wharves, docks, railways and roads; today, land use of the coast is changing to residential, commercial, recreational, and institutional uses (Walmsley, 2009). Statistics show a steady increase in the rate of subdivision development along coastal land through the 20th century, primarily due to two factors: improved highway access resulting in an increasing willingness of people to commute to work, and an increase in disposable income that allows people to buy second homes (Walmsley, 2009). On the other hand, the amount of coastal industrial waterfront infrastructure has been decreasing over the past century. These trends have important implications for Nova Scotia's vulnerability to hurricanes: industrial development usually involves high standards of compliance with environmental regulations, while residential developments are rarely inspected after construction (Walmsley, 2009). Also, many more individuals have investments at the coast; with industrial uses, the number of invested individuals is much smaller. Furthermore, recreational (such as cottages) and residential development tends to occur within a strip close to the water (Walmsley, 2009), which makes more people susceptible to storm surge. The increase in development and more intensive human use of land in coastal areas (Walmsley, 2009) has lead to a greater number of people at risk to hurricanes and storm surge.

Development trends in Nova Scotia show that the number of people living on the coast is increasing, which means that more and more people are becoming vulnerable to the effects of hurricanes. Meanwhile, the frequency and intensity of hurricanes that make landfall in Nova Scotia is increasing, and is projected to increase over the next century (O'Gormon, 2010). While projected storm surge scenarios have been deduced for many coastal towns and cities throughout Nova Scotia (Forbes et al., 2009; Webster, 2011; Richards et al., 2011; Critchley, 2012), further studies on the implications of extreme storm surge scenarios to land use planning are crucial as more people move to the coast and the likelihood of an extreme event in Nova Scotia increases over time.

Land use planning that ensures that development avoids high-risk areas is the primary emergency management strategy with respect to climate change (Pinfold, 2012). Pinfold points out the general lack of knowledge in Nova Scotia about individuals and communities' connection to climate change impacts. *The State of Nova Scotia's Coast Technical Report* (Walmsley, 2009) also identifies data gaps in terms of the socio-economic value of vulnerable property, infrastructure, and natural systems in Nova Scotia and the threats communities face due to climate change. The Government of Nova Scotia created the *Draft Coastal Strategy* (Provincial Oceans Network, 2011) as a response to the issues outlined in the *2009 State of Nova Scotia's Coast.* One of the actions presented in the Strategy includes assessing the vulnerability of communities to coastal hazards, and establishing coastal development standards. The Strategy explains that more research is needed in regards to coastal hazards and the threat they pose to property and infrastructure.

3.6 Assessing Future Risks

Having the most up-to-date storm surge and flooding scenarios readily available for planners and residents ensures that people are aware of the risks associated with coastal development. Studies done by Forbes (2009), Webster (2011), Richards and Daigle (2011), Fedak (2012), and Critchley (2012) provide various storm surge scenarios at the local level. Although future water levels are impossible to predict with absolute certainty, these scenarios illustrate the potential change in magnitude of storm effects, and should be integrated into planning policies. Storm surge scenarios should be used in conjunction with social, economic, and physical vulnerability maps of Nova Scotian communities, such as the one created for the Town of Yarmouth (Cochran et. al, 2012), in order to have a complete picture of where the most susceptible areas lie when planning for extreme events.

However, planners should be aware that global and local sea level rise predictions are constantly changing as new information becomes available, and that research into the effects of climate change on hurricane variability is ongoing and debated. In addition, it is difficult to predict potential damages for a storm of any given magnitude. An analysis of the historic relationship between storm damages and land use change is one way to establish trends; a study of this relationship over time would show the direction development is taking in terms of vulnerability to storms. There has been little research done on historic storm damage trends in Nova Scotia. An examination and analysis of variables associated with past storm damages in a coastal Nova Scotian community is needed to assist decision makers plan for the future in a way that minimizes risk.

4. Goals and Objectives

Goal

Examine how changes in land use and development patterns influence the vulnerability of a Nova Scotian community to storms.

Objectives

- Select a town to use as a case study based on the degree to which it is prone to extreme storms and has undergone development changes.
- Map development changes over time for the selected town, including type, density and form.
- Identify the damages associated with every storm that affected the community.
- Compare damages for each storm to the development and land use at the time.

Goal

Use conclusions drawn about the relationship between storm damages and development patterns to determine how the community can minimize its vulnerability to future storms.

Objectives

- Examine current land use and zoning and identify areas at risk based on past trends.
- Determine the degree to which planners and policy-makers address risks associated with storms.
- Create a set of recommendations explaining how the community can develop in a way that minimizes storm risk.

5. Research Approach

Since there are many variables that determine the amount of damages caused by a storm, I will use a specific methodology that isolates the relationship between storm damages and land uses in a community. I will use spatial, quantitative, and qualitative data analysis to examine how land use and development affects the vulnerability of a community to storms. I will choose the community based on its storminess and rate of land use and development change. The spatial analysis will illustrate changes in land cover, building type, and building use over time. I will compile a list of storms that caused damages to the town and compare the level of damage from each storm to the type of development at the time. I will only draw comparisons of damages between storms of similar scales, with a similar capacity to do damage. Next, I will use the correlations drawn from the data (if any) to determine the town's current vulnerability to storms, and how this vulnerability could change in the future with an increase in sea level and storm frequency. Finally, I will assess the degree to which storm risks are addressed in the community's plans and policies.

6. Methodology

6.1 Case Study Selection

For the case study analysis, I will select a community that has experienced frequent storminess and undergone development intensification or change. That way, there will be more opportunities to draw connections between storm damages and development.

I will determine which communities have undergone changes in land use and development intensification over the past few decades using information from the State of Nova Scotia's Coast Technical Report (Walmsley, 2009) and the Union of Nova Scotia Municipalities. I will then use the National Oceanic and Atmospheric Administration (2012) Historical Hurricane Tracks database to determine which of these communities lie in an area frequently exposed to extreme storms. This database has a record of the paths and intensities of global extratropical/subtropical storms and hurricanes for the past 150 years. I will conduct a database query to identify and count all of the extreme storms that have passed within a 45-kilometer radius of each community. I will choose the community that has had frequent exposure to storms and that has the data available to perform the analysis outlined in the subsequent steps.

6.2 Historic Development Patterns and Storm Damages

I will conduct a spatial analysis of the community's development over time and compare these trends to incurred storm damages. The results of this stage will include a map of land use and development for each time period that experienced a major storm. Adjacent to each map, I will create a table that includes information about the storm: date, average wind speed, duration, amount of precipitation, and high water mark (which includes storm surge and tidal effects). The table will also include a list that describes the qualitative and quantitative damages that occurred as a result of the storm. If possible, I will identify on the map which buildings were affected by the storm. Development maps and their corresponding storms will be grouped based on the magnitude of the storm so that comparisons can be drawn between storms that have a similar capacity to do damage.

I will use the NOAA Historical Hurricane Tracks database and Environment Canada's Historic Storm data to create a list of all of the major storms that hit the community. I will geo-reference the storm tracks to a map of the community and surrounding area using GIS ArcMap 10. In the attribute table, I will input the velocity and duration of each storm, as well as the amount of precipitation and high water mark associated with each storm. I will classify each storm based on its potential to do damage to the community.

Using Environment Canada's storm information as well as historic accounts from newspapers and archives, I will determine the amount of damage that each storm inflicted on the community. I will get more detailed information about storm damages from the Insurance Bureau of Canada. I will map losses due to flooding and wind damage for each storm using insurance claim data.

To analyze land use and development change, I will use old air photos, zoning maps, and census data. I will obtain old air photos from Service Nova Scotia, Nova Scotia Archives, and from the case study community's database. I will then geo-reference these air photos using GIS ArcMap10. These air photos, in conjunction with old zoning maps obtained from the municipality, will indicate changes in land use. Land use and development changes will be assessed based on four categories: built-up area, type of use, building density, and building form. I will collect census data for each dissemination district that corresponds to the dates of the photos obtained. I will create an attribute table for each photo and input the census information on housing type and number of units. I will also collect data from the Atlantic Provinces Business Directory and include this information in the attribute table. This data will be used to analyze changes in the amount and type of residential and commercial development.

I will illustrate and map correlations between storm damages and land use using the best data available. Ideally, I will illustrate the land use of the community before and after each major storm, and outline and map the types of damages that occurred due to the storm. I will only make comparisons between storms of similar capacity to do damage. That way, I can isolate the relationship between land use and storm damages.

6.3 Preparing for Future Storms

Using the trends and conclusions drawn from stage two, I will analyse the community's vulnerability to future storms. I will use current land use maps to identify which areas will likely undergo damages based on historic trends, and I will discuss the relationship between current development trends and storm risks. Using Richards and Daigle's (2011) downscaled climate change scenarios, I will discuss how sea level rise and storm pattern changes will exacerbate storm damages.

I will examine the Planning Strategy and Zoning By-Law for the community to determine how these documents address future risks associated with storms. I will use the trends established from the data as a basis for creating a list of recommendations for how the town can reduce its vulnerability to storms.

Implications of Study

Understanding the past is key to planning for the future. This study will detail the damages from storms over time in a community, as well as the change in land use over time. By analyzing and correlating this historic data, I will attempt to understand and illustrate the relationship between storm damages and development patterns. The results of this research will show the influence that a community's development has on its vulnerability to storm impacts. It will also illustrate whether the community is becoming more or less vulnerable to storms. Planners can use this understanding of historic storm impacts to better prepare for future storms.

Sea level is rising due to climate change, which means that storm surges have the potential to reach further in land. In addition, storms may become more frequent and intense as global temperature rises. The result of these combined effects is that storm impacts will likely have the potential to be more severe in the future. An understanding of how our development patterns influence the amount of damage incurred from a storm is thus crucial. If the community's current development is occurring in a way that increases its vulnerability to potential storm damages, this exacerbates the effects of climate change. By illustrating the correlations between storm damages and development trends, I hope to provide decision makers with an understanding of the importance of developing in a way that minimizes the community's vulnerability.

Work Plan

The table below shows the number of hours and material required to complete each task. The deadlines indicate the date by which I will complete each task. The final task, writing the report, will be ongoing; I will write sections of my thesis as I complete each step in my method.

Task	Notes and Materials	Hours	Deadline
Select case study	Provincial storm tracks and development trends		7-Jan
Compile Storm Data	Each storm: date, path, wind speed, duration, high water mark	16	13-Jan
Input storm data into GIS		16	16-Jan
Classify Storms Based on Damage Potential	Rank variables listed above	6	20-Jan
Compile Historic Land Use Data	Air photos, zoning maps, census data	20	28-Jan
Input Land Use information into GIS	Organise temporally	20	05-Feb
Illustrate land use changes on maps	Variables: built up area, type of use, building density and form	24	13-Feb
Examine and map relationship between land uses and major storms	Show types of land uses affected by each storm; illustrate changes that occurred as a result of each storm	24	25-Feb
Analyse and discuss trends		16	04-Mar
Determine the community's current risk to storms based on trends	Create storm surge maps or use existing	18	11-Mar
Determine degree to which community is prepared for future storms	Read and assess community plans	24	19-Mar
Create a list of recommendations		12	25-Mar
Finish Writing Thesis and Edit		38	08-Apr
	Total Hours	234	

The calendar below shows the general progression that I will take to complete the research and thesis report. The deadline for each component is shown in brackets (month/day).

December	January	February	March	April
Select Case Study (1/1)				
	Compile Storm Data, Input into GIS, Rank storms (1/20)			
	Compile Development Data, Input into GIS, Map land use change (2/13)			
		Map Relationship between Land Use and Damages, Analyse Trends (3/4)		
		Determine current risk, Read and Assess Community Plans (3/19)		
			Recommendations (3/25)	
	Draft Thesis and Edit --> (4/08)			

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