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Assessing the Vulnerability and Resilience of Coastal Connecticut to Sea Level Rise

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Abstract

Following an increase in large storm events, coastal communities have begun developing vulnerability assessments to prepare for future natural disasters and to provide a step towards the eventual development of resilience management plans. The goal of this study was to assess the vulnerability of coastal communities in the state of Connecticut to the impacts of sea level rise together with an analysis of the extent of inundated land and the economic impacts of such environmental phenomenon. Societal impacts as well as impacts on critical infrastructure were also investigated. The scope of the study focused on precision at the local level rather than regional generalizations. Impacts have been assessed at the municipality level, parcel by parcel.

The shoreline of New Haven County, which was analyzed in this study, consists of seven municipalities located in the south central region of the state of Connecticut, in the U.S. The study analyzed impacts for 1 m and 2 m sea level rise scenarios. Land inundation was calculated as 15 km^2 and 25 km^2 for the two scenarios. The direct economic cost through residential property losses in the seven municipalities analyzed was estimated to be \$1.3 billion and \$2.2 billion due to land inundation and flooding, for 1 m and 2 m sea level rise scenarios, respectively. The estimated economic impacts to residential property is significant when considering that only seven municipalities stretching 94 km of coastline were analyzed in the study. The overall weighted average was \$15 million/km coastline and \$24 million/km coastline for 1 m and 2 m sea level rise, respectively. These values do not take into account increased flood risk during storm events, which are expected to increase in frequency and severity, and therefore may be considered to be conservative.

Effects of sea level rise would be felt at the local level, which is unique for every location, and so should be the potential solutions. A variety of strategies have been identified that could be applied to the municipalities analyzed, including implementing green infrastructure in the form of restoring wetlands and creating living shorelines, adjusting building codes and zoning ordinances, and reinforcing existing infrastructure.

Keywords: Resilience; Sea level rise; GIS; Coastal flood vulnerability assessment; Adaptation planning

Highlights:

- Estimated residential property losses of \$1.3 billion for a 1 m sea level rise
- Average economic cost at \$15 million/km coastline for a 1 m sea level rise
- 15 km^2 land inundated with a 1 m sea level rise over a 94 km coastline
- Properties that lie adjacent to inland waters or rivers are equally vulnerable
- Wetlands and open spaces expected to undergo drastic changes moving forward

1 Introduction

Following the increase in large storm events and the resulting period of intense flooding, coastal communities have begun developing vulnerability assessments to prepare for future disasters of similar magnitude and intensity (Seenath et al., 2016). Such assessments provide a fundamental first step in the eventual development of robust resilience management plans. Therefore, such assessments play a key role in helping communities look towards the future and plan for potential changes. However, spatial information at a detailed scale useful to those responsible for mitigating the local effects of natural hazards are typically not available (Lichter and Felsenstein, 2012).

Despite the state of Connecticut's shoreline being severely impacted by Hurricane Sandy in 2012, resiliency planning has not been as proactive as that in neighboring states. After the devastation of flooding events, state and local officials were most concerned with rebuilding homes and infrastructure where they stood prior to destruction, perhaps with the addition of minor features such as storm shutters and disaster-proof windows (CT DOH, 2013). However, these measures will only be good until an even larger storm or flood event devastates the coastal region, which are expected to occur more frequently than past trends for the region. Rather than solely diverting resources to rebuild damaged property, communities in Connecticut should focus on long term climatic trends that affect the region and various strategies to minimize future impacts. The first step in this process would be to precisely identify regions at high-risk, quantify the magnitude of the risk, and evaluate the potential future consequences.

The goal of this study was to assess the vulnerability of coastal communities in the state of Connecticut to the impacts of sea level rise together with an analysis of the extent of inundated land and the economic impacts of such environmental phenomenon. Societal impacts as well as impacts on critical infrastructure were also investigated.

While there are studies with comparable goals conducted at the national or regional level, effects of sea level rise would be felt at the local level, which would be unique for every location, and so should the potential solutions (Department of Climate Change, 2009; Kuhn et al., 2014). The scope of the study focused on precision at the local level rather than regional or national generalizations. Impacts have been assessed at the municipality level, parcel by parcel.

1.1 Climate change and sea level rise

In the past century, the New England region has experienced 12 inches (0.3 m) of sea level rise (Horton et al., 2014). Sea level is predicted to rise between 0.5 m and 2 m by the end of the century if current climate trends continue to yield a 4º C increase in average temperature (Nicholls et al., 2011). While the maximum sea level rise expected by 2100 is near 2 meters, sea levels are expected to continue to rise at an accelerated speed for the next several centuries due to the momentum in climate patterns (Parris et al., 2012).

It is estimated that 8 million people live in vulnerable coastal areas in the United States alone, with the majority of these areas within 1-m elevation of sea level (Williams, 2013). Coastal megacities are growing in frequency, with most new development focused in these areas (Nicholls et al., 1995). At the global level, Hinkel et al. (2014) estimate that 0.2-4.6% of human populations would experience annual flooding by the year 2100, with an expected drop in global gross domestic product of 0.3-9.3%. Adaptation measures to reduce the occurrence and impacts of flooding were reported to require annual investments in the order of $12-71 billion. However, it is worth noting that the study by Hinkel et al. (2014) was based on a sea level rise of 0.25-1.2 m, and hence may be a low-end estimate for potential impacts.

Furthermore, erosion becomes an increasingly large issue as sea level rises (Smith, 2006; Gedan et al., 2011). Erosion taking place in areas with developed shorelines threatens the destruction of coastal property (Kettle, 2012), increasing the risk of insured damages, and the loss of human life (Gedan et al., 2011).

Changing climate patterns have important implications for coastal communities. Sea level rise, while being of utmost importance, is not the only phenomenon coastal communities need to plan for. The Intergovernmental Panel on Climate Change (IPCC) has predicted increased precipitation across the Northeast region of the U.S., alongside greater frequency of hurricanes and extreme flood events impacting the region (Christensen et al., 2013; Parr et al., 2015; Sweet et al., 2014). Sea level rise also has the ability to magnify the damage potential of smaller storms that would not have caused a great impact on their own. Inland areas that rarely experience flooding now could, with a higher mean sea level. Gornitz et al. (2002) report that metropolitan areas in the U.S. Northeast could experience a 100-year storm flood event once in 19 years by 2050, and once in 4 years by 2080 in the most extreme scenario. The effects of these storms could potentially be catastrophic for the society and economy.

The state of Connecticut has already been impacted by the severe impacts of climate change; Hurricane Sandy devastated the coastal communities throughout New England in 2012. The Federal Emergency Management Agency (FEMA) has allocated $125.9 million towards recovery efforts in New England following the natural disaster (FEMA, 2013). Additionally, the Department of Housing and Urban Development (HUD) has provided Connecticut with $71.8 million to assist in the recovery process (HUD, 2013). However, these numbers are dwarfed by the estimated cost of $71 billion for the U.S.

Though efforts have been taken to make the reconstructed housing more resilient, homeowners were still allowed to rebuild in the same high-risk areas. They would only be required to partake in Flood Resistant Construction, using stronger materials that would lessen damage from future storms and the addition of protective building measures (CTDOH, 2013). However, these limited measures are at the individual building level and do not translate into local or regional plans or changes that would be necessary to change the outcome of another storm of equal or higher intensity that would strike in the future. To that end, the desired improvements in regional resilience are not realizable through these efforts alone. The potential impacts of a future storm of similar or stronger magnitude, occurring more frequently, could be catastrophic (NOAA, 2016).

1.2 Vulnerability and Resilience

Broadly stated, vulnerability is defined as the potential for loss. More specifically, the United Nations Disaster Relief Organization defines it as the measure of the hazard risk multiplied by damage potential (Wu et al., 2002). Vulnerability assessments are not one-size-fits-all but must be analyzed at the local or regional level. The concept of vulnerability is used to describe the characteristics of a geography related to their ability to anticipate, cope with, resist, and recover from the impact of a natural hazard (Maantay and Maroko, 2009; Taramelli et al., 2015). These characteristics rely not only on the geology of the area, but also on the types of infrastructure impacted, social groups existing there, and economic characteristics (Boruff et al., 2005; Kunte et al., 2014). Generally, areas with aging infrastructure or those containing large minority or low-income populations are more vulnerable to disaster than wealthy communities with new infrastructure (Maantay and Maroko, 2009).

Resilience, on the other hand, measures a geography's mechanisms in place to reduce the impact of natural hazards. These could include solid structures and natural infrastructure along the coast to reduce flooding potential, land use and zoning regulations that limit development along the coast and in other flood-prone areas, and up-to-date disaster preparedness plans that allow communities to respond to disaster in a timely manner (Goklany, 2007; Hamin and Gurran, 2009).

The local geography is not the only factor used in evaluating vulnerability and resiliency; breaking down the population into segments is important in measuring social vulnerability (Nicholls and Vega-Leinert, 2008; Özyurt and Ergin, 2010). A study by Arkema et al. (2013) found that the poor and the elderly are more vulnerable than other segments of a community. When doing analysis of vulnerability and resiliency, it is just as important to include social factors as it is geographical information (Cutter, 2005).

The use of Geographic Information Systems (GIS) has been a key component of many vulnerability assessments, allowing communities to locate their most critical areas and plan accordingly (Wu et al., 2002; Schleupner, 2007; Taramelli et al., 2015; Seenath et al., 2016). These assessments allow local and regional governments to plan for a future of uncertainty, using readily available data.

2 Methods

Identification of high-risk zones and communities together with economic and social data through the integration of multiple spatial layers was conducted using ArcGIS version 10.3. Data collected for this analysis included:

- Connecticut Town polygon shapefile (CT DEEP, 2005a)
- Connecticut Waterbody polygon shapefile (CT DEEP, 2005b)

- Elevation raster for New Haven County (USDA, 2000)
- Sea level rise estimates (NOAA, 2016)
- Census Block polygon shapefile (UCONN MAGIC, 2010)
- 2014 Median House Values per Census Block (ACS, 2014a)
- 2014 Median Household Income per Census Block (ACS, 2014b)
- Parcel Land Use polygon shapefile (SCRCOG, 2008)
- Critical Infrastructure points shapefile (SCRCOG, 2016)

Based on the moderate-to-high predictions for end-of-century sea level rise provided by IPCC and NOAA, this analysis used values of 1 and 2 meter sea level rise scenarios. Land that would be inundated by a rise was highlighted in the analysis, and developed land and parcels that would be affected were identified.

Data from the 2015 American Community Survey (ACS) was obtained through the Census database, containing information on median household values based on census block. The data was joined with the Census Block polygons, and was used in conjunction with parcel land use data. By intersecting these layers together, a new shapefile was created that listed the median home value for every parcel in each municipality analyzed. This new shapefile was the basis for the economic impact section of this study. The median household values of residential parcels that intersected the 1m and 2m sea level rise polygons were summed for each town, and for each scenario of sea level rise.

The economic analysis was carried out using parcel data that shows the location of the parcel but not the location of the building within the parcel. Therefore, it was assumed that any presence of flooding within the parcel would result in an economic loss equal to the worth of the parcel and hence the value of the property. The assumption is not unrealistic when the effects of tides, heavy precipitation events that might lead to local flooding, or the effects of coastal erosion associated with rising sea levels are considered.

A separate analysis was done to understand the impact of sea level rise on critical infrastructure, such as hospitals, schools, and public transit centers. The critical infrastructure dataset was overlaid onto the map of the seven towns and intersected with the 1m and 2m sea level rise scenarios. The result is a list of each town's critical infrastructure that would be impacted by sea level rise.

Social vulnerability was assessed through the integration of income data at the census block scale with the sea level rise maps gathered from the previous steps. Income ranges provided by the Current Population Survey conducted by the U.S. Census Bureau were used in the study, and the residents were effectively grouped into five categories: low income (≤$21430); lower-middle income ($21431 - $41166); middle income ($41167 - $68199); upper-middle income ($68200 - $112253); and high income (≥$112254) (Census, 2015). Furthermore, the percentage of inundated land used by each income group was calculated in conjunction with the total land area inundated for each group.

In line with the goal of the study, the scope was limited to the above mentioned factors. Impacts that may arise from extreme weather events such as potential storm surge flooding were not assessed in the study. While climate models predict more frequent and severe precipitation events for the region as a whole, which can be expected to result in more frequent localized flooding, the impacts of changing precipitation patterns were not included in the study.

2.1 Study Area

New Haven County is located in the south central region of the state of Connecticut, in the U.S. It contains a total of 27 municipalities, with seven of them falling along the coast of Long Island Sound. From west to east, these seven municipalities are: Milford; West Haven;

New Haven; East Haven; Branford; Guilford; and Madison. These seven municipalities have been studied for their vulnerability to the effects of sea level rise and their resilience.

The location of New Haven County together with the seven municipalities that lie along the Long Island Sound coast are presented in Figure 1. These coastal towns have a combined population of 336,029 residents, that make up more than a third of the county's, and nearly one-tenth of the state's total population (Census, 2010). The region is predominately flat, gradually changing to rolling hills further inland. The towns along the coast are varied in composition, ranging from highly industrialized to primarily residential with large areas of open space. Table 1 breaks down the land use type in each of the seven coastal towns analyzed in this study.

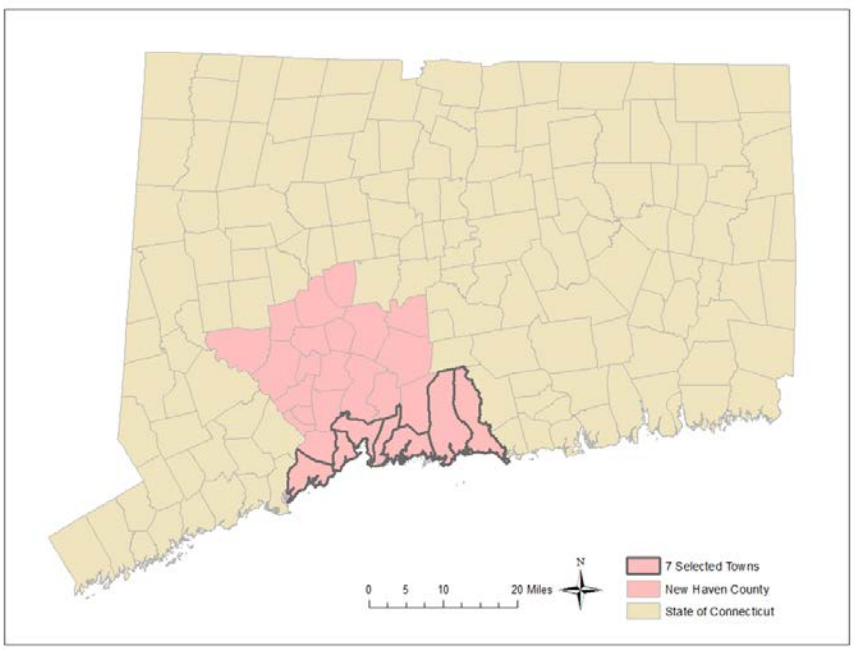

Figure 1: Map of Connecticut highlighting New Haven County and the seven coastal municipalities of the region analyzed in the study.

Table 1: Land use type and percentage in each of the seven selected municipalities

Municipality	**Land Use Type**			
	Residential, %	Commercial, %	Industrial, %	Open Space, %
Branford	45	5	6	29
East Haven	47	7	7	10
Guilford	48	2	1	40
Madison	45	1	0	42
Milford	51	8	8	9
New Haven	35	7	8	21
West Haven	43	6	9	15

3 Results and Discussion

Results of the analysis indicate that the seven coastal towns analyzed have varying levels of vulnerability to sea level rise. Figure 2 depicts the estimated sea level rise land cover at 1 and 2 meters. It highlights that the impacts will be felt primarily along the shoreline, while inland communities situated along rivers that drain into Long Island Sound are equally at risk of flooding at least as much as those along the shoreline.

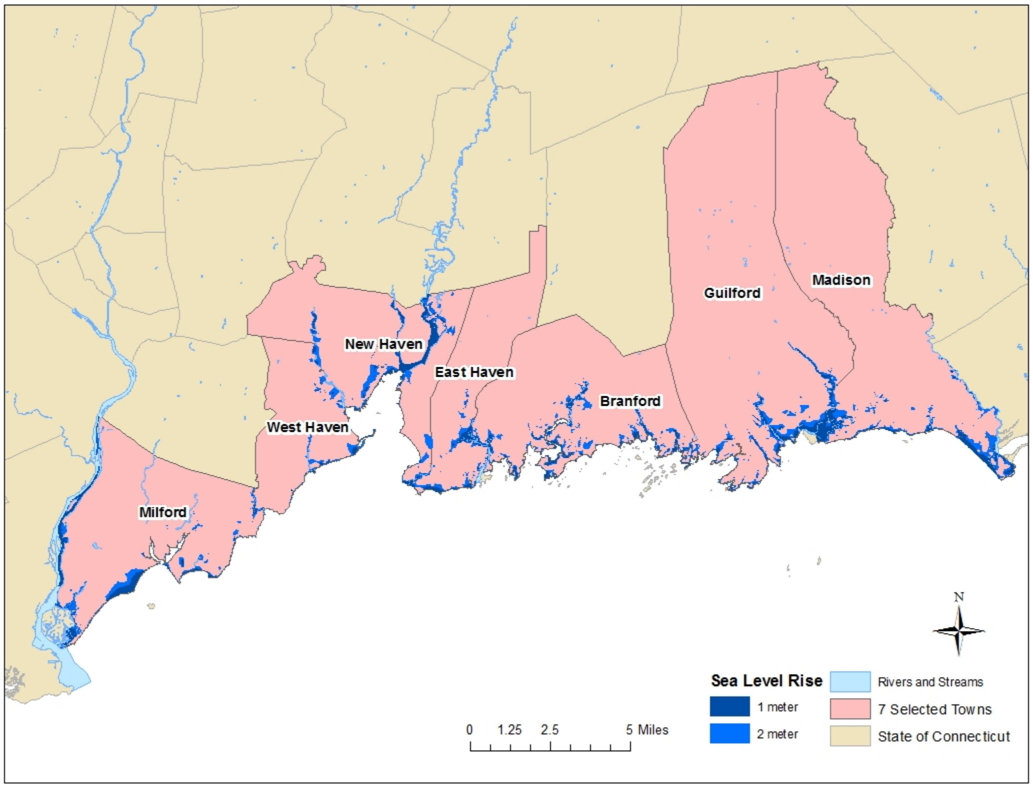

Figure 2: Map depicting the area affected by 1 meter and 2 meter sea level rise scenarios for the seven municipalities analyzed in New Haven County, Connecticut

Despite the proximity of each town with one another, each town has a unique urban development pattern along the shoreline due to economic, social, or historical differences. While East Haven and Milford have predominantly residential coastlines, New Haven and West Haven are industrial in the way they were planned and developed. Therefore, the social and economic impacts of sea level rise were found to be different among the seven adjacent towns analyzed. Figure 3 shows the areas of the region that have the highest social vulnerability based on income ranges used in the study. Census blocks shaded in red report income below $21400 designated as the lowest quintile by the U.S. Census Bureau, whereas the light green and dark green areas are upper-middle and high income areas, respectively. Figure 3 indicates that the income level of shoreline residents is not uniform across the seven municipalities. While the majority of Guilford and Madison residents fall into upper-middle to high income quantiles, West Haven and New Haven residents fall into lower-middle to middle income quantiles, with sporadic low income communities. While those extremely vulnerable regions were not directly along the coastline but rather concentrated inland, still, the proximity of rivers and inland waters puts these communities at an increased level of vulnerability. Table 2 presents the area of land estimated to be inundated under both a 1 m and a 2 m sea level rise and the breakdown of total inundation based on income quintiles.

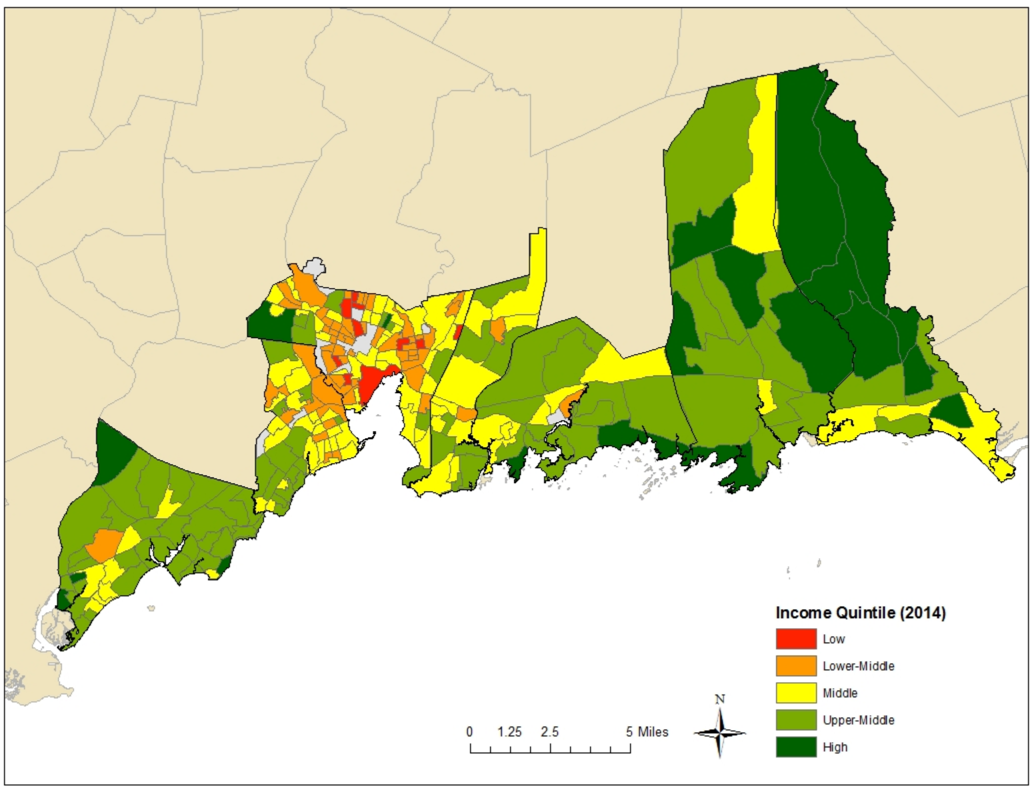

Figure 3: Social vulnerability of each census block based on income.

Table 2: Inundated land area and percentage of total inundation for each income quantile according to average household income for census blocks for both 1 m and 2 m sea level rise

Income Quintile	Household Income ($)	1 m Sea Level Rise		2 m Sea Level Rise	
		Land Inundation (km^2)	Percentage of Total Inundation	Land Inundation (km^2)	Percentage of Total Inundation
Low	≤ 21430	0.23	2%	0.87	4%
Lower-Middle	21431 – 41166	0.89	8%	1.75	7%
Middle	41167 – 68199	4.12	37%	8.55	35%
Upper-Middle	68200 – 112253	4.59	42%	10.41	42%
High	≥ 112254	1.24	11%	2.85	12%

Land area that would be inundated that is owned by low and lower-middle income quintiles were found to be a near 10% of the total land estimated to be inundated. The majority of inundation would occur on property owned by middle to upper-middle income populations. However, considering that the parcel sizes were comparatively small in low income properties indicating a larger segment of the population than represented by these numbers alone, together with the fact that these communities would be less likely to be able to afford to move or rebuild as compared to middle and upper-middle income quintile households, such households are at higher vulnerability to the effects of sea level rise or its induced effects.

Results in Table 3 present the total land area that is expected to be inundated together with the estimated economic losses on residential properties. For normalization purposes, the cost of sea level rise per km coastline has also been presented in Table 3. Due to different development patterns and land use, proximity to the shoreline, different topographies, and differing property values, the correlation between land inundation and residential economic impacts was not linear. Neither did the impacts increase linearly from a 1 m sea level rise to a 2 m sea level rise due to multiple factors affecting total impacts.

Table 3: Land area that will be inundated under a 1 m and 2 m sea level rise and estimated residential property losses. Economic impacts normalized based on length of coastline in each of the seven municipalities were also presented.

Municipality	Coastline (km)	1 m Sea Level Rise			2 m Sea Level Rise		
		Total inundated land (km^2)	Residential property loss ($ million)	Residential property loss per km coastline ($ million / km)	Total inundated land (km^2)	Residential property loss ($ million)	Residential property loss per km coastline ($ million / km)
Milford	20.4	2.8	320	15.7	4.5	560	27.5
Branford	19.5	2.6	320	16.4	3.9	540	27.7
Guilford	15.5	3.5	270	17.4	4.0	390	25.2
Madison	12.8	1.4	250	19.5	4.9	380	29.7
East Haven	4.0	1.5	130	32.5	1.8	200	50.0
New Haven	11.0	2.9	19	1.7	4.5	58	5.3
West Haven	11.0	0.7	14	1.3	1.4	42	3.8
Total	94.2	15	1300		25	2200	

The social and economic impact of inundation is not directly correlated to the amount of flooded land. The land use characteristics of each town's shoreline plays an important role in the amount of devastation felt by citizens and local governments. Towns with highly developed residential shorelines would feel impacts differently than those with historically industrial shorelines, or those that have been preserved or undeveloped in order to protect marshland and other natural habitat. Wetlands especially play an important role in providing flood control benefits and help dissipate storm surges. As time progresses, these wetlands' ability to handle the influx of sea level rise inundation will gradually decrease, leading to devastation of wetlands as well a decrease in the overall resilience of coastal communities against storm surges or floods.

This is important to remember when reviewing the economic analysis of the residential properties impacted by 1 m and 2 m sea level rise. The estimated total damage of $1.3 and $2.2 billion for 1 m and 2 m sea level rise scenarios, respectively, is not distributed equally between the towns analyzed. Branford and Milford carry the highest burden of residential damage, with Guilford and Madison following closely behind. The potential residential loss of these four towns makes up 86% of the residential loss of this entire region. While all of the municipalities analyzed had highly developed coastlines, these four towns have developed residential shorelines, with high real estate prices. The remaining three towns of East Haven, West Haven, and New Haven are more unique. East Haven remains relatively unaffected largely due to its comparatively short length of shoreline. West Haven and New Haven on the other hand, still carry the industrial heritage and development patterns that have shaped and defined these cities historically.

As a means to normalize the results and use for further comparison, residential property loss per km of coastline has also been calculated. Accordingly, average values of $15 million/km coastline and $24 million/km coastline has been calculated for a 1 m sea level rise and 2 m sea level rise, respectively. The range of results, $1 – 33 million/km coastline for the former and $4 – 50 million/km coastline for the latter, indicate large variation among the seven neighboring municipalities analyzed. While results of the study can be used to estimate economic impacts for the state of Connecticut that shares similar characteristics and high levels of urbanization, caution is advised before extrapolating results to other regions of the U.S. or other countries. Development patterns and characteristics, and real estate prices are only some of the factors that may lead to differences when these numbers are applied elsewhere.

Figures 4 – 10 show the residential parcels that are impacted at 2 m of sea level rise. In addition to the shoreline, properties that lie adjacent to inland waters or rivers were also seen to be susceptible to inundation. Designated wetlands and other open spaces, including a state park, can be expected to undergo drastic changes under a 2 m sea level rise, as in the case of Guilford and Madison shown in Figures 9 and 10.

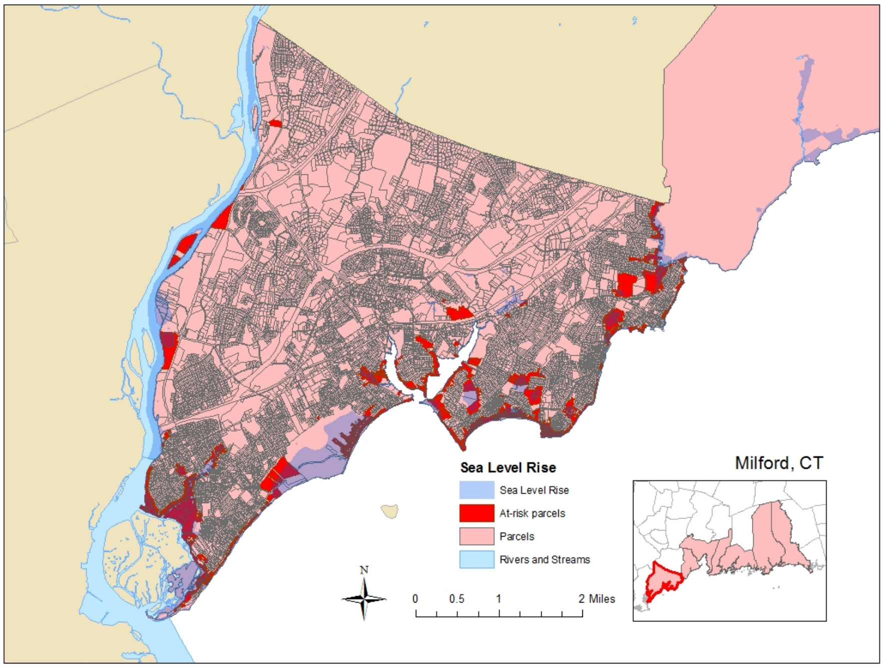

Figure 4: Impacted residential parcels in Milford, Connecticut at 2 meters of sea level rise

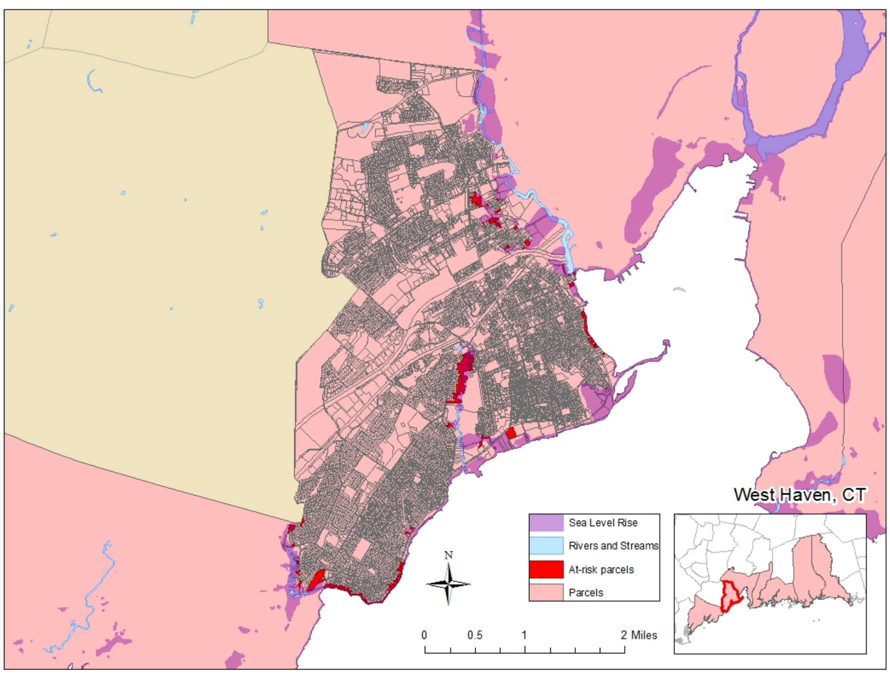

Figure 5: Impacted residential parcels in West Haven, Connecticut at 2 meters of sea level rise

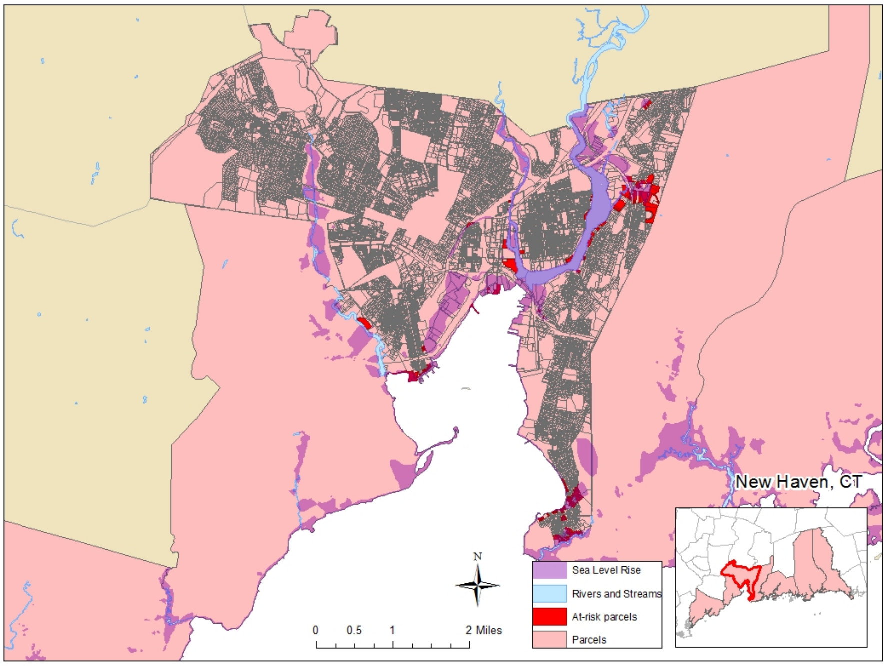

Figure 6: Impacted residential parcels in New Haven, Connecticut at 2 meters of sea level rise

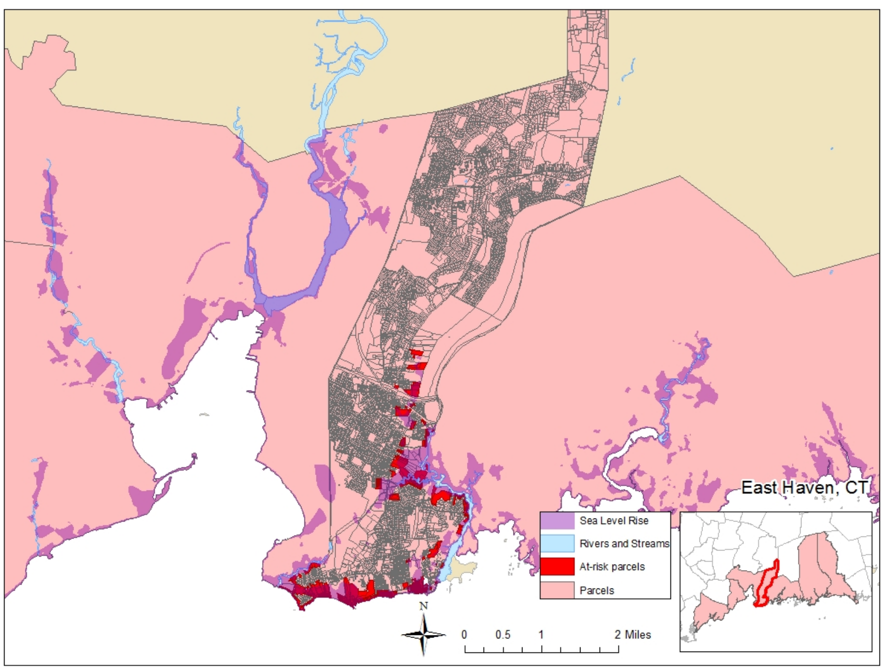

Figure 7: Impacted residential parcels in East Haven, Connecticut at 2 meters of sea level rise

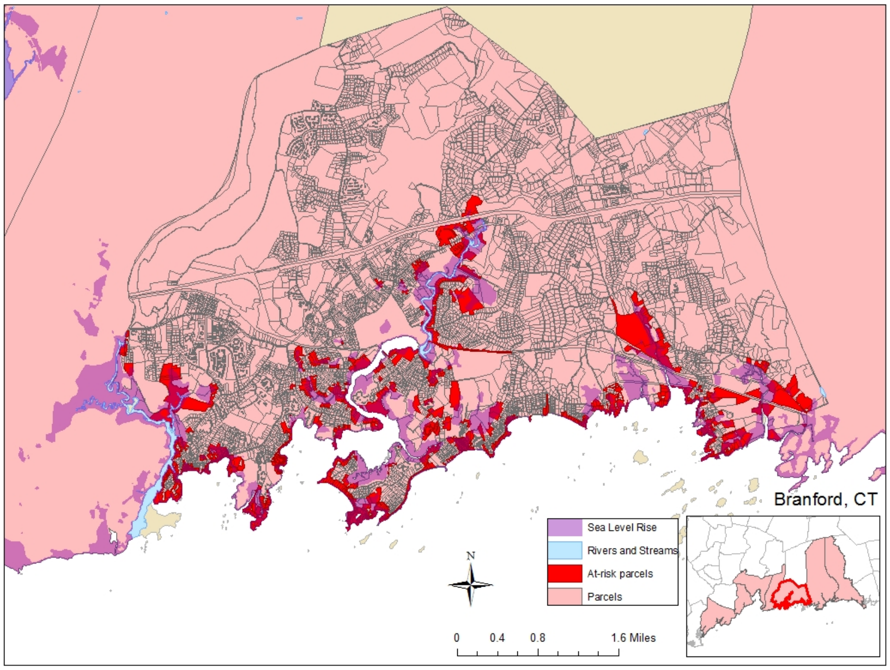

Figure 8: Impacted residential parcels in Branford, Connecticut at 2 meters of sea level rise

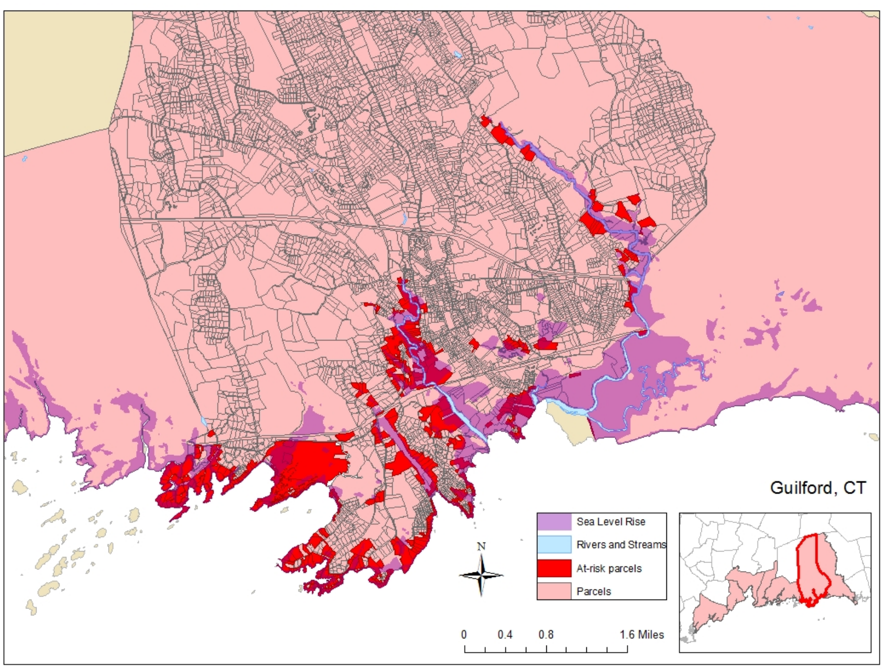

Figure 9: Impacted residential parcels in Guilford, Connecticut at 2 meters of sea level rise

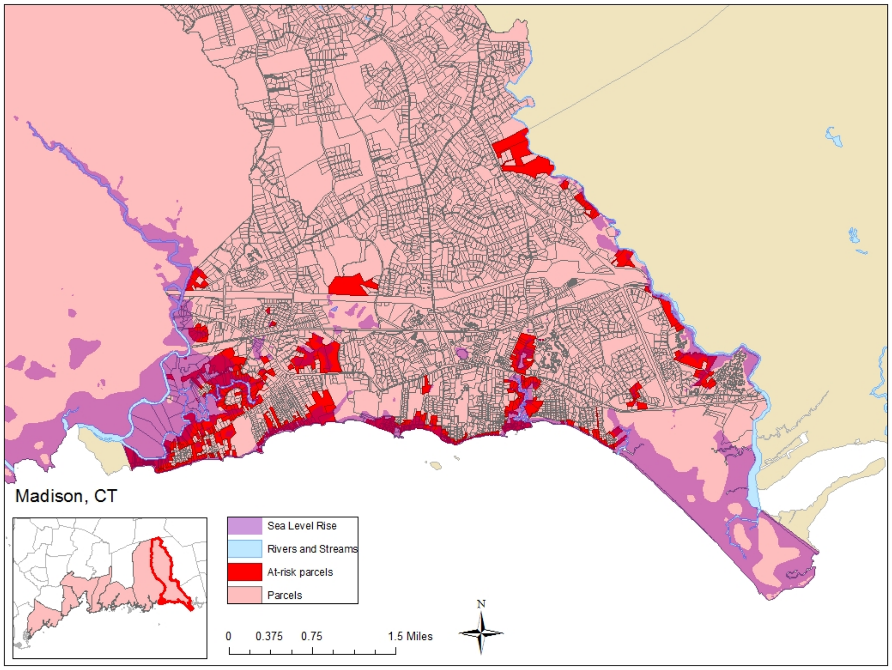

Figure 10: Impacted residential parcels in Madison, Connecticut at 2 meters of sea level rise

In order to better assess the impacts of sea level rise on the various land uses of the shoreline, commercial and industrial parcels were included in the analysis. Table 4 compares the inundated land area of municipalities for residential, commercial, and industrial use. Three distinct differences were observed from this analysis. Branford, Guilford, and Madison all share a highly residential shoreline with minimal commercial and industrial property. Milford and East Haven have a unique combination of residential and industrial parcels with very little commercial use on the coast. Lastly, New Haven and West Haven have coastlines with more industrial use than both residential and commercial combined.

These results indicate that commercial and industrial properties would also be impacted by either a 1 m or a 2 m sea level rise, in addition to impacts to residential properties. While this has important implications for the local society and economy in the form of amenities, economic activity, or number of jobs available, such aspects of impacts to industrial and commercial properties could not be assessed in the study due to a lack of comprehensive data.

Table 4: Land area that would be inundated under a 1 meter and 2 meter sea level rise, together with a breakdown of inundation per zoning type

Municipality	Affected Land (km^2) – 1 m / 2 m sea level rise		
	Residential	Commercial	Industrial
Milford	1.8/3.4	0.1/0.3	0.9/1.2
Branford	2.4/4.0	0.2/0.3	0.0/0.0
Guilford	3.1/4.5	0.3/0.4	0.1/0.2
Madison	1.4/2.8	0.0/0.2	0.0/0.0
East Haven	0.8/1.3	0.1/0.2	0.6/0.8
New Haven	0.4/0.7	0.7/1.2	1.8/2.3
West Haven	0.2/0.4	0.1/0.2	0.4/0.7
Total	10.1/17.0	1.5/2.8	3.8/5.2

The analysis of critical infrastructure indicate that out of all the schools, hospitals, train stations, and highways that were present in the data file, only one piece of infrastructure was within the flood zone for a 2 meters sea level rise. The Sound School in New Haven, CT is located on the shoreline and would be completely inundated in the case of a 2 m sea level rise. However, the critical infrastructure file lacked important facilities such as wastewater treatment plants and public water supply utilities, and energy and electricity generators. Failure of any one of these infrastructure due to the effects of climate change would jeopardize the wellbeing of local residents and their ability to cope with disaster, together with their economic impacts.

4 Potential Adaptation Strategies

Until recently, the focus of governmental attention, both federal and local, has been on mitigation of the effects of climate change rather than adaption (Baker and McGowan, 2013). While mitigation efforts are important in limiting the progression of sea level rise, it is important to note that impacts will be seen within the current century regardless of the proposed international emissions reduction strategies. Therefore, it is important to analyze potential adaptation strategies as part of a coastal resiliency study.

4.1 Wetlands, living shorelines, and green infrastructure

Wetlands, natural or restored, reduce damage from flooding in inland areas in addition to reducing storm surge and flooding in coastal communities, and successful case studies indicate a high return on investment (Foster et al., 2011; Arkema et al., 2013; APA 2014). While wetlands are predicted to be a powerful tool in mitigating the effects of sea level rise and erosion, many studies have addressed concern that rising seas will reduce the protective capabilities of these ecosystems (Craft et al., 2009; Geden et al., 2011; Kirwan and Megonigal, 2013; Nelson et al., 2013). Due to sea level rise by the end of the century, it is expected that salt marshes will decline in area by 45% while tidal freshwater marshes will decline by 39% (Craft et al., 2009).

Living shorelines, as an alternative to sea walls, have the ability to manage coastal erosion (Smith, 2006; Swann, 2008). However, there is no universal approach that can be mimicked everywhere, as each location requires a different combination of flora and fauna species, making it difficult to learn from the successes and failures of existing projects and rapidly implement projects (Smith, 2006).

Green infrastructure can also be effective at managing inland flooding, restoring the capacity of the natural environment to handle large amounts of water. While traditionally it is used to manage stormwater runoff to minimize pollution to rivers and streams, when implemented on a watershed scale it can reduce flooding from even a large 100-year storm (Medina et al., 2011). Pilot projects of large-scale green infrastructure, such as the Greenstreets

Program in New York City were deemed successful at managing extreme flooding during Hurricane Sandy (NYC, 2013).

Among the seven municipalities analyzed in this study, Guilford and Madison both contain large areas of wetlands, which help to increase their resilience to flooding. Branford, East Haven, and Milford, on the other hand, contain high development along their coastlines, which gives them a different set of challenges. On the opposite side of the spectrum, New Haven and West Haven have highly industrialized coastlines where residential resilience may not be top priority. The response of these different municipalities should be different. Guilford and Madison, which have large areas of residential development to be inundated and therefore large economic impact, should engage in wetlands restoration projects or invest in living shorelines to protect the ecosystems that already exist. Limiting development within and adjacent to the wetlands will provide space for those ecosystems to retreat inland as sea levels rise. All municipalities along the coast can be said to benefit form green infrastructure to manage heavy precipitation induced local flooding.

4.2 Retreat

While viewed as the least desirable option, retreat from at-risk areas is an option for the most vulnerable communities where other forms of protection would be ineffective. Often, this includes land acquisition, economic incentives for abandonment, and blockage of redevelopment after a natural disaster. Although economic costs of acquiring existing residential homes, and the political cost of blocking future development may be high, the alternative of continually providing state and federal funds for redevelopment may be significantly higher (Alexander et al., 2012; Bray et al. 1997; Salik et al., 2015).

Branford, East Haven, and Milford, which have highly developed coastlines are recommended to limit future shoreline development, and may be faced with relocating some of their current residents and infrastructure further inland, especially if an intense storm results in significant damages similar to those experienced with Hurricane Sandy in 2012. Rather than rebuilding structures in the same spot with similar faults, a proactive approach led by adaptation planning and policy would be recommended as compared to limited reactive actions.

4.3 Policy and Planning

A successful adaptation strategy requires careful planning and simultaneous policy implementation (Boateng, 2012). This may be realized at the local level through zoning changes or revising building codes such as mandating raised buildings and bridges above predicted future flood-levels (Foster et al., 2011). It may also be supported at the federal level. Insurance is a powerful tool to incentivize against developing in vulnerable areas. However, there is potential for improvement with the current process of evaluating insurance costs. The National Flood Insurance Program under FEMA considers flood elevations for the 100-year storm; elevations that were set in the past based on different precipitation patterns and climatic conditions. Unfortunately, the program falls short in that it does not consider future changes in flooding with climate change driven precipitation changes and sea level rise.

5 Conclusions

Seven coastal towns in Connecticut were analyzed in this study in terms of their vulnerability to the effects of sea level rise together with an analysis of the extent of land inundation and its economic and societal impacts. Regarding residential properties, the estimated total cost for the seven municipalities was calculated as $1.3 billion and $2.2 billion for 1 m and

2 m sea level rise, respectively. These values are significant when considering that only seven municipalities stretching 94 km of coastline were analyzed in the study. Furthermore, these values may be deemed conservative as the economic impacts to the commercial and industrial sectors have not been directly captured, but rather were limited to land inundation impacts.

This analysis highlights some of the various challenges facing these seven communities, each with somewhat different characteristics and methods to preserve their coastline. Guilford and Madison both contain large areas of wetlands, which help to increase their resilience to flooding. Branford, East Haven, and Milford, on the other hand, contain high development along their coastlines, which gives them a different set of challenges. On the opposite side of the spectrum, New Haven and West Haven have highly industrialized coastlines where residential resilience may not be top priority. The response of these different municipalities should be different. Guilford and Madison, which have large areas of residential development to be inundated and therefore large economic impact, should engage in wetlands restoration projects to protect the ecosystems that already exist. Limiting development within and adjacent to the wetlands will provide space for those ecosystems to retreat inland as sea levels rise. Branford, East Haven, and Milford are recommended to limit future shoreline development, and may be faced with relocating some of their current residents and infrastructure further inland, especially if an intense storm results in significant damages similar to those experienced with Hurricane Sandy in 2012. Rather than rebuilding the structure in the same spot with similar faults, a proactive approach led by adaptation planning and policy would be recommended as compared to limited reactive actions.

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