

State of Connecticut, Dept of Environmental Protection,
Office of Long Island Sound Programs

Coastal Hazards in Connecticut

The State of Knowledge: 2009 - Version 2

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Coastal Hazards in Connecticut: The State of Knowledge and Management in 2009

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1 Introduction

Living in coastal Connecticut can be hazardous. For example, in the middle of the 20th century, Connecticut endured six hurricanes in seventeen years. Two of these were category 3 hurricanes (maximum sustained winds between 111 and 130 mph) when they made landfall. Storms roughly comparable in power to Hurricane Katrina have come to Connecticut and will likely come again. In fact, a strong category 3¹ hurricane is the most probable worst-case disaster scenario facing the state.² It has been decades since a severe hurricane visited Connecticut and during that time the coast has become increasingly crowded with people who may not remember the effects or realize the potential dangers.

While most people can understand that a hurricane can be a hazard to the coast, what are other examples of coastal hazards? Broadly defined, coastal hazards are natural or man-made phenomena that threaten both the life and health of human beings as well as necessities, such as transportation, sanitation, water, and energy infrastructure.

The purpose of this report is to provide a summary of the state of knowledge and management of coastal hazards in Connecticut. In other words, establish what we know, what we don't know, what we are doing, and what we aren't doing about coastal hazards in Connecticut. To begin, we frame the basic characteristics of the Connecticut coast (physical and demographic qualities) and the legal/policy framework of coastal management in Chapters Two and Three. The report then focuses on the natural coastal hazards most pertinent to Connecticut: flooding, erosion, wind, and precipitation.³ Our state of knowledge and management of these hazards is summarized in Chapter Four.

Discussing what we know about these individual hazards is useful, but they usually come in combinations produced by storms. Tropical cyclones (e.g. hurricanes) produce storm surge flooding, heavy rain, high winds, and severe erosion in a matter of hours. Winter storms can produce rain, snow, ice, sustained gale-force winds, and severe erosion over the course of several days. Our state of knowledge of tropical cyclones and winter storms is summarized in Chapter Five.

Climate change can be thought of as a “multiplier” or “accelerator” of coastal hazards. As the earth warms, flooding, erosion, wind and precipitation will change, possibly for the worse. Our state of knowledge on climate change and coastal hazards is summarized in Chapter Six.

Information about coastal hazards and coastal hazards management spans academia, non-governmental organizations, all layers of government, and general public knowledge. It also bridges broad disciplines: law, economics, planning, geology, meteorology, marine sciences, climate sciences, etc. Since this report is designed as a synthesis of some of the main focus areas, it is not possible to provide in-depth information on all

¹ “Category 3” is a designation of the Saffir-Simpson Hurricane Intensity Scale, and refers to a hurricane with maximum sustained windspeed of 111 to 130 miles per hour. See table in Definitions section of Appendix.

² State of Connecticut. (2006). *Natural Disaster Plan..* Hartford, CT: State of Connecticut Department of Emergency Management and Homeland Security, p. A-1

³ See <http://www.csc.noaa.gov/themes/coasthaz/problems.html> for a complete list of coastal hazards, including man-made hazards and seismic natural hazards.

potential elements. In situations where more information may be warranted and is available, we have attempted to direct the reader to other sources.

2 Connecticut's Coastal Environment: Geography, Geology, Climate, Oceanography

The purpose of this chapter is to provide basic information about the environment of Connecticut's coast and Long Island Sound. The locations of coastal features like beaches, bluffs, river-mouths, marshes and their interactions with dynamic coastal processes are critical for assessing hazards. Erosion hazards in a particular section of coast, for example, are largely a function of the geology in that area. Sandy islands and beaches are more erodible than gravel areas, while bedrock is practically unaffected by erosion. Likewise, the orientation of different sections of coast affects their exposure to wave and wind energy.

2.1 Geography

The coast of Connecticut is located in the relatively low energy environment of the Long Island Sound Estuary. Long Island, NY creates the southern border of Long Island Sound and protects Connecticut's coast from ocean waves.

The coast runs generally east to west, but there are many beaches and headlands along the coast that have westerly or easterly exposures. This is an important consideration for hazard planning, because different sections of the coast face different patterns of sediment transport and react differently to prevailing winds and varying storm tracks. Hammonasset Beach in Madison, for example, faces southwest and is exposed to a large fetch, so the prevailing southwesterly winds and waves create significant erosion problems. The coast between Stratford Point and the mouth of the Housatonic River, on the other hand, faces northeast. It is thus protected from southwesterly winds and waves, but exposed to episodic erosion and wind-driven precipitation hazards from winter storms.

The mouths of the Housatonic, Connecticut, and Thames Rivers are also located on Connecticut's coast. These rivers provide sediment that nourishes beaches along the coast, and provide the freshwater that makes Long Island Sound an estuary. The flow of these rivers typically reaches maximum volume in the spring, when upland snow is melting and the spring freshet pulses down the rivers to Long Island Sound. As summer progresses, the rivers lose speed and volume and a wedge of salt water creeps up the rivers from the Sound. Recent science⁴ suggests climate change will likely alter the flow of rivers, with potentially serious implications for coastal erosion, alluvial floodplains, and freshwater supplies.

2.2 Geology

Through recent geologic history Connecticut's coast has been shaped by sea level changes and glaciers.⁵ As recently as the last ice age 22,000 years ago, when the

⁴ Northeast Climate Impacts Assessment (NECIA). (2006). *Climate Change in the US Northeast: A Report of the Northeast Climate Impacts Assessment*. Cambridge, MA: Union of Concerned Scientists.

⁵ An overview of the geologic history of Connecticut, including color drawings, is available at the Long Island Sound Resource Center (LISRC): http://www.lisrc.uconn.edu/lisrc/geology_simple.asp

Wisconsin Glacier was advancing over present-day New England, sea level was about 350 feet lower than it is today. The teeth of Mastodon and Mammoth have been discovered near the edge of the continental shelf 100 miles off the south shore of Long Island. During this period Long Island Sound was actually a large river valley draining the coastal plain.⁶

During the last ice age, glaciers shaped the coastline in Connecticut by scouring bedrock and depositing drift, comprised of various types of rocks and sediment, including sand, silt, and clay. The action of these glaciers on the variety of bedrock across Connecticut caused the unique variation in coastal geology across present-day Connecticut. The middle of the state's coast is characterized by fine sediment because the bedrock in the Connecticut River Valley is made of sedimentary and igneous rock. As the glaciers advanced southward, they were able to create sediment by eroding this bedrock. By contrast, the western and eastern portions of Connecticut's coast, characterized by rockier terrain, are abutted by inland areas of the state with relatively hard and consolidated metamorphic bedrock. This bedrock was more resistant to erosion and thus became a smaller source of sediment for the adjacent coastline.⁷

In addition, as the Wisconsin Glacier retreated, meltwater streams carried sediment down river valleys such as the Connecticut River Valley and the Housatonic River Valley. This sediment was deposited at the mouth of these valleys, forming deltas:

“Therefore, where the coast today is sandy and where it is rocky was decided, in large part, 16,800 years ago by the path of meltwater streams and the location of sand and gravel deltas.”⁸

These sand and gravel deltas provide material for beaches and are highly erodible compared to rockier coastal formations.

After the retreat of the Wisconsin Glacier, rising sea levels became the primary force shaping the Connecticut coastline. Sea level reached present-day Long Island Sound 11,000 years ago. As sea level continued to rise, it eroded and reshaped the glacial features of the area that is now Connecticut's coastline, creating the complex variety of beaches and headlands that are present today.⁹

In addition to the interaction of sea level rise and coastal geology, climate and oceanographic forces continue to shape Connecticut's coastline. Climatic factors include regional wind patterns and infrequent storms, including winter storms and cyclones. Oceanographic factors include tides, currents (generated by tides and winds), and wind generated waves.

2.3 Oceanography

2.3.1 Waves

Waves in Long Island Sound are generated locally because Long Island restricts fetch and protects Connecticut's coast from larger waves generated in the open ocean.

⁶ Patton, P. C., & Kent, J. D. (1992). *A Moveable Shore: The Fate of the Connecticut Coast*. Duke University Press.

⁷ Patton and Kent (1992), p. 28

⁸ Patton and Kent (1992), p. 37

⁹ Patton and Kent (1992), pp. 35-37

Ocean swells can enter the sound if they approach from the east-southeast, but even under these conditions, they only affect the eastern part of Connecticut's coast.

Because they are local, waves in Long Island Sound are normally short and steep, and reflect directly the patterns of local winds. Seasonal variation in wind direction elicits similar variation in wave direction.

A 1976 document¹⁰ published by the US Army Corps of Engineers (USACE) reported that no wave measurements or statistical data were available for Long Island Sound. It reported that fetches range from 30-62 miles from the northeast to the east, 19-62 miles from the east to the southeast, 14-24 miles from the southeast to the south, and 17 to 38 miles from the south to the southwest. The document also calls for more wave research.

A 1979 document¹¹ published by the Connecticut Department of Environmental Protection Office of Long Island Sound Programs (CT DEP-OLISP) reported observations of wave heights and directions recorded at Stratford Point Light Station between October, 1954 and October 1957. A quick summary from the text:

“The record is dominated by waves varying in height up to 4 feet. Waves with heights up to 2 feet occurred nearly 90 percent of the time during the period of observation. No recorded waves exceeded 15 feet in height and only once, in October 1955, were waves in excess of 10 feet recorded.”¹²

Today, the Long Island Sound Integrated Coastal Observing System (LISICOS)¹³ contains two buoys, one in central Long Island Sound (LIS) and one in western LIS that provide real-time wave data (heights, period, and direction).

2.3.2 Littoral Transport

Waves, tidal currents, and wave-generated currents move sediments and other shoreline materials up and down the shoreline (longshore transport) and between shallow water near shore and deep water off shore (onshore-offshore transport).

Onshore-offshore sediment transport depends largely on wave type. Plunging breakers are steep, usually larger waves that curl over and break all at once, breaking material from beaches, dunes, bluffs, etc, and moving it offshore. Spilling breakers are not as steep and tend to break gradually and gently. These waves tend to move sediment towards and onto the shore.

Longshore transport is mostly a function of the direction of waves and currents. Wave direction is mostly a function of wind direction, and currents are created by winds, waves and tides. Sediment transport is highly variable and localized. Two adjacent beaches separated by headland, for example, may have opposite directions of longshore transport, with the headland splitting incoming wave energy and creating two diverging currents traveling parallel to the shore. Winds, waves, and currents vary on daily and

¹⁰ US Army Corps of Engineers. (1976). *Connecticut Coastline Study: Effects of Coastal Storms*. Boston, MA: US Army Corps of Engineers, New England Division, p. D-26

¹¹ State of Connecticut. (1979). *Shoreline Erosion Analysis and Recommended Planning Process*. Hartford, CT: State of Connecticut Department of Environmental Protection.

¹² Planning Report No. 29, p. 20

¹³ <http://lisicos.uconn.edu>

seasonal timescales, so the rate and direction of littoral transport varies even at a single stretch of beach.

Despite this variability, most sections of coast have a net rate and direction over multi-year time scales. From a coastal hazards management perspective, these net rates and directions of littoral transport are important, because the proper functioning and management of erosion control structures and navigation channels are dependent on them. Existing jetties and groins, for example, were built to trap sediment with these net rates and directions in mind.

Prevailing winds in Connecticut are from the western half of the compass. Depending on the strength of net directions of sediment transport, a relatively small change in regional wind patterns due to global warming could reverse net directions of littoral transport, drastically changing the functions of existing erosion control devices creating new problems for management of navigation channels, inlets, and harbors.¹⁴

From 1949 through 1958, USACE observed and recorded net directions of longshore transport for all sections of Connecticut directly fronting on Long Island Sound. Some of this information can be found in the USACE Beach and Erosion Control Reports from the 1950's, which CT DEP-OLISP scanned and keeps on digital file. In 1979, the coastal management office at CT DEP did a new analysis of net directions of longshore littoral transport. CT DEP-OLISP has mylar sheets that show the results of this analysis.. The book by Patton and Kent, A Moveable Shore, also contains maps showing net directions of longshore transport for sections of Connecticut's coast.¹⁵

2.3.3 Tides

Long Island Sound has a semi-diurnal tidal cycle, like the rest of the US East Coast. There are two high tides and two low tides in every 24 hour 50 minute period. Because Long Island Sound is basically a bay with a constricted opening to the ocean at the eastern end (locally known as "the race"), the tides are different than on the open coast in Rhode Island, Massachusetts, or the south shore of Long Island, NY. For example, tidal elevations in the eastern part of CT are lower than those in western LIS: the mean tide range varies from 2.6 feet at Stonington to 7.2 feet at Greenwich. East-west variation in mean spring tide ranges is greater, from 3.1 in the east to 8.3 feet in the west.¹⁶ Water flows west on the incoming tide (flood phase) and east on the outgoing tide (ebb phase).

Tidal data is important for hazards management because storms are much more destructive when their peak storm surge coincides with spring high tide. Consider the implications of a storm surge peaking in Greenwich at a spring high tide versus a spring low tide: the tidal influence would account for an additional 8 feet of water height. Tidal conditions affect hazards incrementally over the long run as well:

“The most important influences of tides on physical shoreline processes (erosion and deposition) are their effects in producing tidal currents and in controlling the depths of water in shoreline areas which can affect

¹⁴ Sediment transport analyses for localized areas of Connecticut's coast can be found in Planning Report No. 29 and in Patton and Kent (1992).

¹⁵ Patton and Kent (1992).

¹⁶ NOAA tide data is available at: <http://tidesandcurrents.noaa.gov>

the ways and locations in which waves break and expend erosive energy on the shore.”¹⁷

2.3.4 Currents

The term current refers to the movement of water.¹⁸ Currents in Long Island Sound and around the globe can be created by winds and/or tides. Sustained winds create currents flowing in the direction the wind blows.

However, because Long Island Sound is an embayment, tides play a larger role in current formation than they do on ocean-fronting coasts. These tidal currents can be much stronger than wind-driven currents. The tidal current at “the race,” between Great Gull Island and Fisher’s Island, can reach 5 knots during spring tides. Tidal currents are also very strong at the mouth of the Housatonic River, and at major headlands at Long Point in Darien, Shippan Point in Stamford, and Greenwich Point. Currents work with waves to transport sediment and other littoral materials.

LISICOS uses a high-frequency radar system called Coastal Ocean Dynamics Applications Radar (CODAR) to monitor real-time surface currents in Long Island Sound.¹⁹

2.3.5 Winds

Winds affects waves and currents that move sediment around the coast, eroding some shore areas and building up others. Very strong winds can accompany storms, and often blow in a different direction than the normal prevailing winds. In many storms, the wind blows hard from the east or northeast, impeding the ebb of the tide at the mouth of Long Island Sound, piling water up in the Sound, and thus creating a temporarily elevated sea level known as storm surge. By understanding wind patterns, we can better understand other coastal hazards like erosion and flooding.

Wind roses illustrating historical wind data from the Bridgeport Airport from 1951 to 1970 show the general wind patterns for the coast of Connecticut.²⁰ Winds from the southwest prevail during the summer months, and winds from the northwest prevail during the winter months. In late winter and spring, when winter storms (northeasters) are most likely, the wind rose indicates a significant component of strong winds from the east. Wind patterns in New Haven are unique because of the funneling effect of Connecticut’s central valley.²¹ If data is available, it may be useful to gather more data from other airports and construct wind roses for other sections of the coast, and ideally for a longer time span, perhaps a goal of 1900-present. Since wind is a factor in flooding and erosion on the shoreline, a good understanding of historical wind patterns and can improve our understanding of flooding and erosion and help visualize how future changes in the regional climate might affect flooding and erosion.²²

¹⁷ Planning Report No. 29, p. 12

¹⁸ <http://oceanservice.noaa.gov/education/kits/currents/welcome.html>

¹⁹ Access surface current data at <http://lisicos.uconn.edu/>

²⁰ Planning Report No. 29, p. 14

²¹ Planning Report No. 29 and USACE (1976)

²² USACE (1976) tabulates wind observations from United States Weather Bureau at New York City, Block Island, RI and New Haven, CT for the periods 1921-1939, 1932-1942, and 1921-1942, respectively.

2.4 Climate

The following overview of Connecticut's climate is excerpted from the website of the Connecticut State Climate Center.²³ Keep in mind that this information is based on historical records. The general characteristics of Connecticut's climate are likely to change with recent forecasts of global climate change. For climate change impacts specific to Connecticut and the northeast United States in general, refer to chapter six and climate change-related publications in the bibliography at the end of this report.

“GENERAL CLIMATE. The pertinent characteristics of Connecticut's climate are: (1) equable distribution of precipitation among the four seasons, (2) large ranges of temperature both daily and annually, (3) great differences in the same season or month of different years, and (4) considerable diversity of the weather over short periods of time. Connecticut lies in the “prevailing westerly,” the belt of generally eastward air movement which encircles the globe in middle latitudes. A large number of storm centers and air-mass fronts pass near or over Connecticut during a year. Three types of air affect this State: (1) cold, dry air pouring down from sub arctic North America, (2) warm, moist air streaming up on a long overland journey from the Gulf of Mexico and subtropical waters of the Atlantic, and (3) cool, damp air moving in from the North Atlantic. Because the flow of air is usually from continental areas, Connecticut is more influenced by the first two types than it is by the third. The third type of air is often associated with severe winter storms popularly known as “northeasters”.

TEMPERATURE. There is a difference of about 6 °F. in mean annual temperature from north to south of the State. The greater contrast of temperature occurs during the winter season. The number of days with minimum temperatures of zero or below average about 10 per year at the higher elevations, about five in the lower uplands and central valley, and two or less along the shore of Long Island Sound. Summer temperatures are comparatively uniform over the State. Over most of the State the average July minimum temperature is within a degree or two of 60 °F.

PRECIPITATION. Precipitation tends to become evenly distributed throughout the year in all parts of Connecticut. Variations in precipitation from month to month are sometimes extreme. Prolonged droughts and widespread floods are infrequent. Measurable precipitation falls on an average of one day in three, with the yearly total approximating 120 days. Periods of five days or more of successive daily precipitation occur a few times during most years. The average annual snowfall increases from the coast to the

²³ <http://www.canr.uconn.edu/nrme/csc/>

northwestern corner of the State. Most of the snow falls in January and February, but in the majority of winters substantial amounts fall in December or March storms as well.

OTHER CLIMATIC ELEMENTS. During the colder months the prevailing wind is northwest to north over Connecticut, while from April through September southwest or south winds predominate. Thunderstorms occur on an average of 20 to 30 days per year, with the greatest frequency during the summer months and in the afternoon or evening hours. Aside from infrequent tornadoes and hurricanes, coastal storms or “northeasters” are the most serious weather hazard in Connecticut. They generate very strong winds and heavy rain and produce the greatest snowstorms in the winter. The percentage of possible sunshine averages 55 to 60 percent. An average of about 140 cloudy days occur per year. Heavy or dense fog is observed on an average of about 25 days per year in both coastal and inland sections. In the former section, heavy fog is most common during the late winter and spring seasons, while inland the late summer and fall is the period of maximum occurrence. The humidity tends to be lowest in the spring and highest in the late summer and early fall.”²⁴

In terms of coastal hazards in Connecticut, perhaps the most significant feature of the climate is storm activity. Storms can radically alter the coastal landscape and create major flooding and erosion hazards. Read about tropical cyclones (hurricanes and tropical storms) in section 5.1, and winter storms in section 5.2 of this report.

²⁴ <http://www.canr.uconn.edu/nrme/csc/CTweatherstationintroduction/conncticutintroduction.htm>

3 Population and Development Trends and Coastal Management Framework

Relative to other coastal states, Connecticut's coast is densely populated and full of highly valued real estate. Towns like Greenwich and Darien along the western coast of Connecticut are frequently included among the wealthiest in the United States. These high levels of population and development along Connecticut's coast are likely to continue to increase. The US Census estimates that Connecticut's population will grow by 283,000 (8.3%) between 2000 and 2030. Following the recent historical trend, much of that growth will occur in coastal communities.

As stated in the introduction, coastal phenomena such as erosion, flooding, wind, and precipitation are hazardous because of their ability to destroy human life and property. The first section of this chapter discusses population trends and development on Connecticut's coast. The second section of this chapter describes the authority of state and local governments to regulate land use, development, and flood and erosion control projects on Connecticut's coast.

3.1 Population and Development Trends

Connecticut's population is expected to be 3,688,630 by 2030, an 8.3% increase from 2000 (Census 2000). Connecticut is densely populated (702.9 people per square mile) compared to the US as a whole (79.6 people per square mile). Only five other states (Illinois, New Jersey, Rhode Island, Massachusetts, and Pennsylvania) have greater population density in coastal counties.²⁵ In coastal municipalities the population grew 4.65% from 893,526 in 1970 to 935,077 in 2000, and continues to grow.²⁶ In coastal Connecticut the population density decreases from west to east. In 2000, Fairfield County had 1410 people per square mile, New Haven County had 1360 people per square mile, Middlesex County had 420, and New London County had 389.

Most of the development that accompanies this population growth is expensive residential development, including new home construction and the conversion of seasonal cottages to year-round homes. Over 70% of the state's shoreline is privately owned and unprotected from development. The vast majority of this property is devoted to residential uses, and waterfront residential property has attained an extremely high market value.²⁷

Increased residential development demands increased public infrastructure. Many residential areas along the coast do not have access to public sewer. Septic systems designed and built to service seasonal cottages are often inadequate when cottages are converted to year-round use. Transportation infrastructure is also dangerously inadequate in some coastal areas. For example, some densely developed waterfront areas ("shoobox

²⁵ Crosset et al. (2004)

²⁶ State of Connecticut. (2007). *2007-2010 Natural Hazards Mitigation Plan*. Hartford, CT: State of Connecticut Department of Environmental Protection., p. 2-44

²⁷ Connecticut Dept. of Environmental Protection, Office of Long Island Sound Programs. 2005. *Long Island Sound Shoreline Classification and Ownership Statistics Project*. Unpublished investigative report. Hartford, CT

villages” as in Stratford) have only one or two low-lying roads providing access. Many of these roads depend on undersized bridges and culverts that convey tidal flow to inland marshes and waterways.

The period from 1960-1990 saw population grow by 35% in eastern coastal Connecticut, compared to less than 2% in western coastal Connecticut. Barring major changes in land-use management, this trend will likely continue as market forces build out the less developed central and eastern coastal areas.²⁸

The University of Connecticut Center for Land Use Education and Research (CLEAR) has land cover change maps that help illustrate the changes in development over the last twenty years.²⁹ The maps can be used by municipal planners to quantify changes in the landscape and identify priority areas for conservation and preservation of open space.

3.2 Connecticut’s Coastal Management Framework

The State of Connecticut's Coastal Management Program is administered by the Connecticut Department of Environmental Protection’s (CT DEP) Office of Long Island Sound Programs (OLISP) and is approved by NOAA (National Oceanic and Atmospheric Administration) under the federal Coastal Zone Management Act (CZMA). Enacted in 1972, the CZMA’s purpose is to "preserve, protect, develop, and where possible, to restore or enhance the resources of the nation's coastal zone."

Under the statutory umbrella of the Connecticut Coastal Management Act³⁰ (CCMA), enacted in 1980, CT DEP-OLISP ensures balanced growth along the coast, restores coastal habitat, improves public access, protects water-dependent uses, public trust waters and submerged lands³¹, promotes harbor management, and facilitates research.

CT DEP-OLISP also regulates work in tidal, coastal and navigable waters waterward of the high tide line and in tidal wetlands under the Structures Dredging and Fill statutes (Connecticut General Statutes Section 22a-359 through 22a-363f) and the Tidal Wetlands Act (CGS Section 22a-28 through 22a-35), applying the substantive standards of the CCMA (CGS Section 22a-92). Development in the coastal boundary landward of mean high water is regulated at the local level through municipal planning and the zoning boards and commissions under the policies of the CCMA, with technical assistance and oversight provided by Program staff.³²

3.2.1 Connecticut Coastal Management Act (CCMA)

The CCMA defines coastal hazards areas for the purposes of defining its policies related to managing coastal hazards:

²⁸ US Army Corps of Engineers. (1994). *Connecticut Hurricane Evacuation Study Technical Data Report*. Boston, MA: US Army Corps of Engineers, New England Division. PDF available here:

<http://coastalhazards.uconn.edu/docs/ACE1994TDR.pdf>

²⁹ <http://clear.uconn.edu/>

³⁰ CGS 22a-90 to 22a-113

³¹ The concept of the public trust is explained here:

http://www.ct.gov/dep/cwp/view.asp?a=2705&q=323804&depNav_GID=1635

³² From the DEP website: http://www.ct.gov/dep/cwp/view.asp?a=2705&q=323536&depNav_GID=1622

“Coastal Hazard Areas” means those land areas inundated during coastal storm events or subject to erosion induced by such events, including flood hazard areas as defined and determined by the National Flood Insurance Act, as amended (U.S.C. 42 Section 4101, P.L. 93-234) and all erosion hazard areas as determined by the commissioner.”³³

The Reference Guide to Coastal Policies and Definitions in the State of Connecticut Coastal Management Manual highlights 9 policies, backed by language in the CCMA, for managing these statutorily-defined coastal hazard areas.³⁴ Among other things, these policies recognize the risks of damage from flooding, erosion, and high winds associated with hurricanes and winter storms. They call for maintaining the natural relationship between eroding and depositional coastal landforms and for permitting structural solutions (e.g. seawalls, revetments) only as a last resort to protect water-dependent uses, infrastructure, and existing inhabited structures.

In terms of coastal hazards, one of the legislative goals of the CCMA is

“To consider in the planning process the potential impact of coastal flooding and erosion patterns on coastal development so as to minimize damage to and destruction of life and property and reduce the necessity of public expenditure to protect future development from such hazards;”³⁵

3.2.2 Municipal Authority

Following the “home rule” tradition in New England, coastal municipalities have most of the authority for regulating human activity in the coastal area. The state’s only areas of direct regulatory jurisdiction over private activities are those waterward of the high tide line and in tidal wetlands as discussed above in section 3.2. However, municipal plans for development in the coastal area must be consistent with the goals set forth in the CCMA, including preserving and enhancing coastal resources, placing high priority on water-dependent uses and facilities, and ensuring public access to the water.

Municipalities must conduct a “coastal site plan review” as part of the zoning, subdivision, or other land use approval process for many proposed activities within the Coastal Boundary.³⁶ In order to approve a coastal site plan application, the municipal board or commission must find that the activity is consistent with the standards and policies of the CCMA. CT DEP-OLISP may review coastal site plan applications and provide comments and recommendations to municipalities, but municipalities are not required to refer the coastal site plan review application to CT DEP-OLISP unless it pertains to a shoreline flood and erosion control structure or to a change in a zoning map or regulation. However, CT DEP-OLISP has the authority to provide testimony on any

³³ CGS section 22a-93(7)(H)

³⁴State of Connecticut. (1992). *Reference Guide to Coastal Policies and Definitions*. Hartford, CT: State of Connecticut Department of Environmental Protection. Retrieved from: http://www.ct.gov/dep/lib/dep/long_island_sound/coastal_management_manual/manual_section_5_08.pdf

³⁵ CGS 22a-92(a)(5)

³⁶ CGS 22a-94(b)

coastal site plan review application and to appeal a municipality's decision to superior court if it is inconsistent with CCMA policies. In addition, coastal development activities that include work within tidal wetlands or waterward of the high tide line in the tidal, coastal or navigable waters of the state are subject to direct state regulatory jurisdiction and require authorization from CT DEP.

3.2.3 Building Codes

The 2005 State Building Code, currently in effect, is the most rigorous to date with respect to hazards protection.³⁷ It combines several international building codes, including the 2003 International Building Code (IBC), and the 2003 International Residential Code (IRC). The current state building code meets the minimum requirements of the National Flood Insurance Program (NFIP). Although the state building code applies to all municipalities, Connecticut general statutes allow municipalities, with approval of the State Building Inspector, to make minor adjustments to the State Building Code.

Since the first state building code was adopted in 1970, periodic revisions have generally increased the level of protection required for flooding and wind protection in coastal hazard areas. Structures built before 1970 ("pre-existing" structures) should be considered at highest risk of damage from coastal hazards such as flooding, wind, and precipitation. Structures built between 1970 and 1990 are also at high risk of flood and wind damage, because 1990 was the first year the state code included provisions from international building codes. Of all the coastal structures in Connecticut, structures built since 2005 are likely to have the best protection from flood and wind damage due to hurricanes and winter storms.³⁸

3.2.4 Municipal Floodplain Regulations and Ordinances

CT DEP is the state's designated National Flood Insurance Program (NFIP) coordinating agency³⁹ and acts as liaison between the Federal Emergency Management Agency (FEMA) and municipal governments. Within the Inland Water Resources Division (IWRD) of the CT DEP, the Flood Management Program (FMP) manages various FEMA programs, including the Community Assistance Program – State Support Services Element (CAP-SSSE), the Map Modernization Program (MAP MOD)⁴⁰, Flood Mitigation Assistance (FMA), and Pre-disaster Mitigation (PDM) grant programs.⁴¹

All of Connecticut's coastal municipalities participate in the NFIP, which insures structures in federally-defined floodplains. As a condition of municipal participation and access to federal flood insurance, the NFIP sets forth minimum standards for municipal floodplain management policies. Municipalities that do not meet these minimum standards in their floodplain ordinance or enforce their floodplain ordinance may be suspended from the NFIP. In this case, local residents are denied access to federal flood

³⁷ More information about the state building code, including the history of state building codes, can be found at the website of the Office of The State Building Inspector (<http://www.ct.gov/dps/cwp/view.asp?a=2148&Q=294226&dpsNav=1>)

³⁸ State of Connecticut (2007). *2007-2010 Natural Hazards Mitigation Plan*, page 3-7.

³⁹ CGS 25-68b through 25-68h

⁴⁰ See section 4.1.1.2 for a summary of MAP MOD in Connecticut.

⁴¹ The FMA and PDM grant programs provide money for municipalities to manage coastal hazards.

insurance and municipalities may also become ineligible to receive other types of federal financial assistance for projects in Special Flood Hazard Areas (SFHAs).

In Connecticut, CT DEP-IWRD provides a “model ordinance,” which serves as a guide for municipalities to develop regulations and ordinances for the coastal floodplain. Regional land use planning agencies also assist municipalities in the development floodplain management plans that meet or exceed NFIP minimum standards. CT DEP-IWRD reviews municipal regulations and ordinances for compliance with the NFIP, and conducts community assistance visits (CAVs), which include a review of enforcement of municipal regulations and ordinances in the coastal floodplain. For any given coastal municipality CAVs occur roughly every 7-8 years. When CT DEP-IWRD finds the enforcement of municipal regulations and ordinances to be noncompliant with the NFIP, it refers the municipality to FEMA for possible disciplinary action, including suspension from the NFIP.

The Community Rating System (CRS) is a voluntary program within the NFIP. It reduces NFIP premiums for policy holders in communities that show how their floodplain management activities exceed NFIP minimum requirements. Communities earn points for one or more of 18 activities across four “series,” or types of activities. The series are Public Information, Mapping and Regulation, Flood Damage Reduction, and Flood Preparedness. The number of points determines the community’s rating on a scale of 1-10 and an attendant discount on NFIP premiums. For example, a community earning 500-999 credit points gets a rate class of 9 and a 5% discount. The maximum discount is 45%, which requires 4500 credit points and a class 1 rating.

Participation in the CRS improves a community’s hazard resilience, but there are two problems that limit participation with the program. First, it is a voluntary program that requires a significant investment of time and labor for municipal employees. Even towns that contain hundreds of properties with NFIP policies and are already engaging in activities that would earn points under the CRS may not make the effort to document their activities and do the paperwork to enroll in the CRS program.

Second, the incentives are not properly aligned. The municipality itself does not actually benefit from enrolling in the CRS program and documenting floodplain management activities that earn CRS credit points. Individual NFIP policy holders within the town benefit from premium discounts, but the town must do the work to enroll and maintain involvement in the CRS program.

The Connecticut coastal communities that participate in the CRS program are summarized in Table 1.

<u>Community</u>	<u>CRS Rating</u>	<u># of NFIP Policies</u>
Stamford	7	2482
Westport	8	1320
East Haven	8	1307
Westbrook	9	579
East Lyme	9	327
Stonington Borough	9	300
Stonington Town	9	951

There are many Connecticut coastal towns that have a significant number of NFIP policies but do not participate in the CRS program. Fairfield and Milford, for example, have 2675 and 2719 policies respectively, but do not participate in the CRS program. At minimum, two state programs - the dam safety program and the flood warning system - earn points for any Connecticut community that enrolls in the CRS.

3.2.5 Municipal Flood and Erosion Control Boards

State statutes authorize municipalities to establish a Flood and Erosion Control Board (FECB), which manages flood and erosion control projects in the municipality and serves as a conduit for state and federal money for such projects:

“CGS Sections 25-85 through 25-98, inclusive, enable municipalities to form a municipal Flood and Erosion Control Board (FECB) with the power to plan, layout, acquire, construct, reconstruct, repair, maintain, supervise and manage flood and erosion control systems, flood control projects, and dam repair projects. These boards may also enter upon, take and hold by purchase, condemnation or otherwise, property which it determines necessary for use in connection with flood or erosion control systems; defray the cost of such systems by issuing bonds or other evidence debt, or from general taxation, special assessment or any combination thereof; and assess those properties benefiting from such project according to such rules as the FECB may adopt. The FECB is further empowered to negotiate, cooperate, and enter into agreement with: 1) The United States, 2) The United States and the State of Connecticut or 3) The State of Connecticut in order to satisfy the conditions imposed by the United States or the State of Connecticut in authorizing any system for the improvement of navigation of any harbor or river and for protection of property against damage by floods or by erosion, provided such system shall have been approved by the DEP Commissioner... The Statutes listed above enable a municipality, which has recognized a particular flood or erosion hazards potential and is dedicated to reducing or eliminating the hazards, to work with, and receive assistance from federal and state agencies.”⁴²

State money, when available, is provided on a non-competitive basis for municipalities that apply for assistance.⁴³ The State Legislature budgets this money biennially. For state/municipal project cost-sharing, the state provides one-third of the money for projects that benefit privately owned property, and two-thirds of the money for projects that benefit municipal property. The municipality is responsible for continuing maintenance and operation costs.

Federal money can be made available for flood and erosion control projects, through partnerships with the US Army Corps of Engineers, or through the Natural Resources Conservation Service. Federal guidelines determine cost-sharing for these projects.

⁴² State of Connecticut (2007). *2007-2010 Natural Hazards Mitigation Plan*, p. 3-38

⁴³ See CGS 25-69 thru 25-83.

While having these mechanisms in place is helpful, it should be noted that no state or Federal money has been available for use in quite some time.

3.3 Summary

Connecticut's coast is densely populated and contains extensive high-value residential property and important human infrastructure necessities, such as rails, roads, airports, drinking water resources, wastewater treatment facilities, and commercial/industrial businesses. By discouraging structural solutions for flood and erosion hazards and directing state and local government to manage coastal hazard areas so as to insure that development proceeds in such a manner that hazards to life and property are minimized, the CCMA has an implicit policy of retreat from hazardous coastal areas. Although Connecticut is a "home rule" state (meaning municipalities have a significant degree of autonomy to enact and enforce local regulations and policies), municipalities must nevertheless abide by the state CCMA in their decisions about land use and development in coastal hazard areas.

4 Coastal Hazards: The Current State of Knowledge and Management

4.1 Flooding

Floods are the most frequent and destructive natural disasters in New England.⁴⁴ In coastal hazard areas, the primary concern is storm surge, which can accompany winter storms and tropical storms. Storm surge is a temporary increase in the height of the local sea level, and is defined as the difference between the observed water level and expected water level in the absence of the storm, according to the normal astronomical tide. Davies et al (1973)⁴⁵ breaks down storm surge into the following elements:

1. Low Central air pressure in the storm center causes water level to rise at a rate of 13 inches for every 1-inch drop in barometric pressure (Hobbs, 1970). The ratio is probably lower on Long Island because of the small basin size.
2. Stress produced by onshore wind pushes water towards shore resulting in raised water surface level called wind set up.
3. Waves produced by onshore winds transport additional water into nearshore areas in the form of wave set up. Wave set up may account for as much as 3 to 7.0 feet additional increase in water surface elevation.
4. Wave run up resulting from the shoreward progression of water in the form of breaking waves extends the influence of water level further inland.
5. Heavy rainfall associated with the storm contributes to increased runoff which raises water levels in coastal streams particularly where they drain into Long Island Sound.

The 2007-2010 State of Connecticut Natural Hazard Mitigation Plan (NHMP) describes how the shape and east-west orientation of Long Island Sound increases the risk of storm surge flooding under certain conditions. According to the NHMP⁴⁶, moderate to severe coastal flooding occurs if the following three criteria are met:

1. Winds greater than 30 mph lasting more than 12 hours.
2. Wind direction in a range from the northeast to the east-southeast.
3. Astronomical high tides.

Although storm surge is the unique concern in coastal hazard areas, heavy precipitation and swollen upland water courses also create flooding on the coast. Links between the sea and rivers, marshes, and ponds are often constricted by manmade culverts, riverbanks, bridges, and tide gates that create flooding problems when upland water bodies quickly fill with water. Rivers, marshes, and stormwater systems can fill

⁴⁴ <http://www.nesec.org/hazards/floods.cfm#risk>

⁴⁵ as cited in Planning Report No. 29, p. 29

⁴⁶ State of Connecticut (2007). *2007-2010 Natural Hazards Mitigation Plan*, p. 2-36

faster than they drain. Overflowing water then spills out of normal watercourses and cuts new paths to the sea.

4.1.1 State of Knowledge

4.1.1.1 *Flood Mapping*

A sound management plan for coastal flooding requires accurate estimates of flood areas and depths. These estimates are typically obtained by modeling storm and flood events and displaying the model output on maps. Accurate flood maps can provide important information for a wide variety of users. Homeowners want to know if they will be inundated with future sea level rise and storm surges; coastal managers want to identify “refugia” to which coastal wetlands can retreat from rising seas or find out what natural resources may be threatened; emergency managers need to identify evacuation routes from coastal areas and critical infrastructure at risk of flooding.

Like any form of scientific modeling, flood modeling is part art, part science. Accurate flood modeling is particularly difficult because of the limited availability of data for model inputs and calibration, and because of the stochastic components of storm behavior, precipitation, riverine dynamics, and coastal and oceanographic processes. Notwithstanding these inherent difficulties, there is plenty of room for improvement on the flood maps currently available for coastal Connecticut. For example, FEMA Flood Insurance Rate maps (FIRMs) currently in effect were created with outdated modeling techniques and are based on elevation data with 10-foot contour intervals. Such vertical resolution is insufficient for accurate flood mapping.

4.1.1.2 *Flood Insurance Rate Maps*

FEMA Flood Insurance Rate Maps⁴⁷ (FIRMs) are available for all communities in Connecticut, and constitute a comprehensive map of coastal areas susceptible to flooding from coastal storms. A FIRM is a component of the Flood Insurance Study⁴⁸ (FIS) conducted for the town. FIRMs serve many purposes. Lending institutions and federal authorities use them to identify structures that require flood insurance and to determine federal flood insurance rates. Private insurance, real estate, and citizens in turn, use them to determine flood risks. State and local governments use them for planning and zoning purposes, including floodplain ordinances, hazard mitigation plans, and emergency response plans.

Special Flood Hazard Areas (SFHAs) on FIRMs comprise V-zones and A-zones. Under the NFIP, flood insurance is mandatory in these areas. The A and V zones are delineated using Base Flood Elevation (BFE): the predicted height of wave crests or wave run-up, whichever is greater, during 100-year floods. By definition a 100-year flood is a flood that has a 1-percent probability of being equaled or exceeded in any given year. (This is not the same as saying that it’s a flood that will only happen once every hundred years.) FEMA refers to it as the Base Flood.⁴⁹

⁴⁷ For more information about FIRMs, refer to FEMA’s website at http://www.fema.gov/plan/prevent/fhm/fq_main.shtm.

⁴⁸ For more information about FISs in general, go to <http://www.fema.gov/hazard/map/fis.shtm>

⁴⁹ FEMA: http://training.fema.gov/emiweb/downloads/is386appdx_a.pdf

V-zones are coastal hazard areas with a 1% or greater annual chance of flooding and an additional hazard associated with storm waves, where the depth of flooding above the ground can support a 3' or greater wave. Structures in V-zones have a 26% chance of flooding over the life of a 30-year mortgage. The A-Zone, directly landward of the V-Zone, can have waves up to 3' high, so structures in this area are prone to damage from waves as well. Like V-Zones, A-Zones are areas with a 1% annual chance of flooding and a 26% chance of flooding over the life of a 30-year mortgage, but are at lower risk of damage from wave action.

Outside of the SFHAs, flood insurance is available through the NFIP, but it is not required. B, C, and X zones are considered low to moderate risk areas where any of the following designations may apply: areas outside the 1-percent annual chance floodplain, areas of 1% annual chance sheet flow flooding where average depths are less than 1 foot, areas of 1% annual chance stream flooding where the contributing drainage area is less than 1 square mile, or areas protected from the 1% annual chance flood by levees.⁵⁰

FIRMS for coastal Connecticut municipalities were originally produced between 1973 and 1990. Numerous minor modifications have been made to many individual FIRMs via Letters of Map Change⁵¹ (LOMC) or Letters of Map Amendment⁵² (LOMA), but these modifications do not reflect changes in flood hazards due to increased rates of erosion, sea level rise, or the possibility of stronger storms due to climate change.

A recent initiative by FEMA called the Map Modernization Program (MAP MOD) seeks to update all of these maps by converting them to digital format, and on occasion, studying specific areas that would have flood boundaries redrawn to reflect current conditions. FEMA has developed mapping technical bulletins that specify map revision guidelines, however, the guidelines do not take into consideration changes in flood hazards due to the anticipated changes associated with climate change.

The schedule for the county-by-county modernization under MAP MOD was determined by CT DEP and FEMA and is based upon numerous factors associated with flood risk including but not limited to: population, area, miles of streams or water frontage, number of claims, and the age of existing maps. Once a community's maps have been updated they are presented in preliminary status by FEMA to communities to allow for local input. After the closure of a mandated appeal period, the maps will usually become effective the following year. Due to the limited nature of MAP MOD funding, not all counties will have their FIRMs converted to a digitized product in this current effort. The second phase of flood map modernization is called RiskMAP.

The vision of the RiskMap effort is build on the data and mapping products created during MapMod to "deliver quality data that increases public awareness and leads to action that reduces risk to life and property."⁵³ To do this, FEMA and State and Local stakeholders will collaborate to achieve the following goals:

⁵⁰ For more information about reading and interpreting FIRMs, go to

http://www.fema.gov/plan/prevent/fhm/fq_main.shtm

⁵¹ http://www.fema.gov/plan/prevent/fhm/fmc_rev1.shtm,

⁵² http://www.fema.gov/plan/prevent/fhm/fmc_loma.shtm

⁵³ http://www.fema.gov/plan/prevent/fhm/rm_main.shtm

- Flood Hazard Data: Address gaps in flood hazard data to form a solid foundation for risk assessment, floodplain management, and actuarial soundness of the [National Flood Insurance Program](#) (NFIP).
- Public Awareness/Outreach: Ensure that a measurable increase of the public’s awareness and understanding of risk results in a measurable reduction of current and future vulnerability.
- Hazard Mitigation Planning: Lead and support States, local, and Tribal communities to effectively engage in risk-based mitigation planning resulting in sustainable actions that reduce or eliminate risks to life and property from natural hazards.
- Enhanced Digital Platform: Provide an enhanced digital platform that improves management of Risk MAP, stewards information produced by Risk MAP, and improves communication and sharing of risk data and related products to all levels of government and the public.
- Alignment and Synergies: Align Risk Analysis programs and develop synergies to enhance decision-making capabilities through effective risk communication and management.⁵⁴

4.1.1.3 SLOSH Maps

The “Connecticut Hurricane Evacuation Study: Technical Data Report,” produced in 1994 by the USACE⁵⁵, provides an analysis of Connecticut’s vulnerability to hurricanes, including storm surge flooding. This document is the current source of information for hurricane evacuation planning and decision making for Connecticut’s state emergency managers.⁵⁶ It provides an estimate of the time needed for evacuation of coastal areas and a “Decision Arc Method,” which supports hurricane evacuation decision-making by combining information about possible storm tracks and speeds, potential inundation and evacuation areas, and estimated evacuation times and routes. For example, if the estimated evacuation time for an area is eight hours, and a fast-moving hurricane is headed toward Connecticut at 50 knots, then the “decision arc” for this hurricane is 400 nautical miles from the estimated point of landfall. This document also assessed, and updated in 2006, shelter capacity for coastal municipalities, and gives the locations of public shelters, information about mobile home/trailer parks, and medical/institutional facilities.

The Inundation Map Atlas accompanying the Technical Data Report provides the results of storm surge analysis using the Sea, Lake, and Overland Surges from Hurricanes (SLOSH) model. SLOSH is a numerical, computerized model developed by NOAA to estimate storm surge heights from historical, hypothetical, or predicted hurricanes. In this case, storm surges from 533 hypothetical hurricanes were modeled. Values for four parameters were specified for each hurricane: the storm track, the direction of travel, forward speed, and hurricane intensity as measured by the Saffir-Simpson Hurricane

⁵⁴ http://www.fema.gov/plan/prevent/fhm/rm_main.shtm

⁵⁵ US Army Corps of Engineers (1994)

⁵⁶ Mark Scerra, State of Connecticut Department of Emergency Management/Homeland Security, Personal Communication, February, 2008.

Intensity Scale. The National Hurricane Center (NHC) selected the ranges of values for these parameters based on the region's historical hurricane activity and their assessment of probable storms that could be sustained by the region's weather and climate. For example, hurricanes approaching from due west or due east, and category 5 hurricanes were not considered because they were considered highly unlikely for the region at the time. For each of the 533 individual storm simulations, the maximum storm surge area was calculated by using the maximum water level predicted in each grid cell, regardless of when the maximum water level in each cell was attained over the course of the individual storm simulation.

Surge heights at a given location depend, in part, on the distance between that location and the track of the storm's center. Since the exact storm track is difficult to predict, emergency planning requires storm surge predictions for an entire section of coast (e.g. the coast of Connecticut). To accomplish this, maps depicting a maximum envelope of water (MEOw) were created by taking the maximum surge height for each grid cell across an "ensemble" of individual storm simulations that vary only by storm track. Individual storms in each ensemble are exactly the same in terms of direction of travel, intensity, and forward speed. 52 MEOws were thus produced, based on six possible directions of storm travel, three possible forward speeds, and categories 1-4 on the Saffir-Simpson hurricane intensity scale. These maps are available in Appendix A of the USACE Connecticut Hurricane Evacuation Study.⁵⁷

In preparation of a Natural Hazard Mitigation Plan in 2004,⁵⁸ DEP repackaged some of the storm surge flood maps produced in the 1994 Connecticut Hurricane Evacuation Study. Estimated flood extents produced by the SLOSH analysis were overlaid on USGS base maps of land and water and US Census 2000 maps of roads. These maps are available on request from the Inland Water Resources Division of CT DEP (IWRD) and will also be available for download on the CT DEP web site when the next version of the Natural Hazards Mitigation Plan (2010-2013, currently in progress) is formally adopted.

At UCONN, a team of students advised by Dr. Daniel Civco produced sample versions of revised SLOSH inundation maps for the town of Milford, CT to examine the effect of different elevation basemap data on inundation areas.⁵⁹ They overlaid SLOSH output over several different digital elevation models (DEMs) to determine which model produced the most accurate estimates of flood areas. As expected, they found that high-resolution LiDAR data produced the best results, and thus recommended updating all Connecticut SLOSH maps produced by USACE in 1994 and later reproduced in 2004 by DEP/DEMHS by replacing the old National Elevation Dataset (NED) DEM with a high-resolution LiDAR DEM.

4.1.1.4 Data Required for State-of-the-Art Flood Maps

Although high-resolution LiDAR elevation data is available for the entire Connecticut coast, there are several more types of data inputs needed for state-of-the-art

⁵⁷ US Army Corps of Engineers (1994)

⁵⁸ State of Connecticut. (2007). *2007-2010 Natural Hazards Mitigation Plan*. Hartford, CT: State of Connecticut Department of Environmental Protection. PDF available here:

<http://coastalhazards.uconn.edu/docs/NHMP.pdf>

⁵⁹ <http://clear.uconn.edu/projects/develop/index.htm>

inundation and storm surge and inundation modeling. These data include bathymetry; inventories of flood control and water management infrastructure; precipitation, river and stream flow data; and observations from past storm events. For an inventory (not intended to be exhaustive) of elevation and bathymetry data, see section 4.1.1.1. The discussion of flood control and water management infrastructure, precipitation, river and stream flow data, and observations from past storm events follows below.

High-resolution flood modeling requires information about flood control and water management infrastructure, including culverts, tide gates, dikes, levies, sluices, and causeways. Modelers need attributes of these features such as geographic location, elevation, and physical dimensions. For example, features like culverts may inundate areas that they would drain under normal conditions.

CT DEP has a document from 1972 called “Tide Gates and Other Tidal Restrictions in the State of Connecticut.”⁶⁰ This is an inventory of tide gates, culverts, sluices, dikes, bridges, causeways, and anything else that restricts tidal flow. A total of 180 such structures are shown on maps. A table describes how the structure operates (i.e.: is it an open culvert, a culvert with flapper valves, an operable tide gate, a dilapidated tide gate, etc.), the ostensible purpose of the structure, and information about its size. This document should be a starting point for researchers gathering information to support storm surge modeling. However, since the document is over thirty-five years old, a new inventory of tide gates, culverts, and other tidal restrictions should be undertaken. Some of this information may be recovered from internal sources at CT DEP-OLISP, but a comprehensive inventory would require canvassing municipal offices for this data.

Precipitation, river and stream flow data are necessary for accurate storm surge and coastal inundation modeling because coastal flooding is influenced by precipitation and river and stream dynamics. The state-of-the-art of coastal flood modeling efforts in other states increasingly seeks to couple precipitation and stream flow models with coastal storm surge and oceanographic models.⁶¹ In Connecticut, some of this precipitation, river and stream flow data is available from the USGS, which maintains and monitors river and stream gauges in Connecticut.⁶²

Aside from these data inputs for flood modeling, quantitative evaluation of model performance requires observations from past storm events. These include records of flood extents and depths, flood damages, and wrack and debris lines from past storms. This data can be used to calibrate models and check their performance by hindcasting past events with known information about those events: wind speeds, wind directions, tide cycles, precipitation, etc; and then comparing model predictions of flooding with actual flood data from the event.

Historic flood events that are obvious candidates for this kind of data collection are the hurricanes of 1938 and 1954. At CT DEP-OLISP’s request, the USACE in Concord, MA recently scanned books of flood profile data collected in the field in the aftermath of

⁶⁰ Templeton, C. (1972). *Tide Gates and Other Tidal Restrictions in the State of Connecticut*. Hartford, CT: State of Connecticut Department of Environmental Protection.

⁶¹ See for example a NWS project on the Lower Mississippi River:
<http://www.srh.noaa.gov/lmrfc/about/tech/HurrStormSurgeMiss.pdf>

⁶² <http://ct.water.usgs.gov/main/aboutus.htm>

the 1938 and 1954 hurricanes. These data include the observed elevations of high water marks on various structures, including public buildings, bridges, and private businesses. The observations contained in these books should be put into a GIS for use in quantitative evaluation of model performance.

The USACE also dispatched survey teams to collect flood data after the 1955 flood events in Connecticut. A five-part report entitled *New England Floods of 1955* contains this data. Part One is Storm Data, Part Two is flood discharges, Part Three: Flood Profiles, Part Four: Flood Damages, Part Five: The Effect of Flood Control Projects. OLISP has Part One and Part Three in digital (PDF) format. Part One describes the storms of 1955 and puts them in historical perspective, and Part Three presents the findings the survey teams who “were instructed to obtain high water marks above and below all bridges, dams, natural hydraulic controls, and at the mouth of major tributaries as well as data on normal river stages and the areal extent of flooding.” In some cases, the findings were plotted against high water marks from other floods. In total, the survey covered eight river basins: Blackstone, Thames, Chicopee, Naugatuck, Westfield, Farmington, Shepaug, and Lower Housatonic.

Another possible way to obtain historical flood data for the evaluation of surge models may be to sift through aerial photographs of the flooding caused by the 1938 hurricane and georeference the flood extents as approximated by wrack and debris lines shown in the photographs. This would be labor-intensive and probably provide poorer accuracy than survey data, but may still prove useful for modelers.

4.1.1.5 *Elevation and Bathymetry Data Inventory*

Over the last decade, Connecticut has been fortunate to acquire several sets of high-resolution elevation data. The data range from a statewide Light Detection And Ranging (LiDAR) coverage in 2000, to more recent LiDAR data sets focused on smaller regions, such as the floodways along the coast and the Connecticut River. Comparatively the bathymetric data suite is less recent for the entirety of Long Island Sound, although smaller sections have been the subject of various scientific studies (sidescan sonar, multi-beam sonar, etc.) in recent years. As a result of a settlement action involving several cable and pipeline installations, a bi-State Committee with representatives from Connecticut, New York, the EPA, and SeaGrant currently oversee a fund that will be dedicated to expanding the set of data on the geology and benthic habitats of the Sound.

For more information on this data, the reader is directed to the CT Geospatial Information Systems Council Data Inventory and Assessment Working Group on Elevation and Bathymetry⁶³ and the Connecticut Geographic Framework Data Report.⁶⁴

4.1.1.6 *Flood Damage Estimation*

Accurate flood maps can be used to develop secondary data to aid management of social and economic impacts of flooding. For example, planners and decision-makers need estimates of the physical and monetary damage that flood events might have on

⁶³ <http://www.ct.gov/gis/cwp/view.asp?a=3034&q=400022>

⁶⁴ http://www.ct.gov/gis/lib/gis/Connecticut_Framework_Data_Themes_Final_Report_010708.pdf

buildings and public infrastructure. Emergency managers want to assess the viability of evacuation routes and know how many nursing homes, trailer parks, and group homes are located in flood hazard areas. Estimating damages and assessing vulnerability is difficult. For example, what magnitude storm surge or long-term sea level rise will it take to disable a sewage treatment plant or infiltrate public drinking water supplies? Or, what will be the total cost of damages from a category four hurricane that hits at high tide?

FEMA produced HAZUS-MH (Hazards United States Multi-Hazard), a software program for estimating damages from hurricanes and earthquakes. HAZUS-MH considers physical losses, including damage to residential and commercial buildings, schools, and infrastructure; economic losses, including job losses, business interruptions, and repair and reconstruction costs; and social impacts, including the number of people exposed to the hazard, households displaced, and shelter requirements.

In 2004, DEP and the Northeast States Emergency Consortium (NESEC) used HAZUS-MH to estimate the damages of a category 3 hurricane similar to the Great New England Hurricane of 1938. Although this was helpful in providing rough estimates of damages statewide, the data used as inputs to this model need to be improved. For example, large errors in the locations of buildings were only partially corrected using hand-held Global Positioning System (GPS) units. In addition, state critical facilities are not included in the HAZUS-MH database. Given FEMA is not likely to collect better data for Connecticut on their own volition, the state should consider collecting and improving the quality of HAZUS-MH input data and sending the updates to FEMA. The first step in such an effort would be to brainstorm a list of possible data acquisitions and upgrades, estimate their costs, and then prioritize them. Estimates of monetary damage from hurricanes are necessary to provide policy-makers with information about hurricane risk in a language they can understand.

A 1983 report by CT DEP⁶⁵ estimates the number of structures in A, V, X, and Riverine A flood zones for all of Connecticut's coastal municipalities. It also estimates the number of these structures uninsured for flood damages. The motivation for this study was to see how the boom in development that had taken place since the time of the last major hurricane in 1955 had increased vulnerability to flood damages. At the time, the authors concluded that adequate laws were in place to protect life and property, but enforcement was often lacking; however, it is unclear at this time if those conclusions are still valid.

This inventory of structures in flood zones and their flood insurance status is important baseline information that should be updated now and regularly in the future. In addition, it should be crosschecked with the information contained in FEMA's HAZUS-MH database.

Overall, Connecticut lacks good damage estimates for various coastal hazard scenarios, including inundation from long-term sea level rise and wind and flooding from storm events. The first step in this process is getting accurate estimates of the depths and extents of flooding. The challenges and current state of the science for these estimates

⁶⁵ Rummel, C. J., & Hudak, G. J. (1983). *Connecticut Coastal Flood Vulnerability Assessment: a Statewide Summary of Flood Susceptibility and Preparedness*. Hartford, CT: State of Connecticut Department of Environmental Protection.

are discussed in the previous section. Accurate estimates of damages are not possible without accurate flood maps.

Assuming accurate flood maps are available, estimates of damages and economic impacts rely on sound economic models and good information about the costs of rebuilding structures and infrastructure. These models and information can be developed and maintained independently of flood mapping efforts, so that when output from high-accuracy flooding/storm surge models becomes available, researchers can link the two types of models to produce estimates of damages and economic impacts.

4.1.2 Flood Management

Reducing coastal flood hazards can be achieved by reducing the frequency or intensity of flooding (flood mitigation) and/or reducing the vulnerability of human activity and the built environment to flooding (flood damage mitigation). Early in the history of government responses to flooding in the U.S., flood mitigation was the primary method of reducing flood hazards. Since the 1960's, people have realized that flood damage mitigation is at least as important as flood mitigation. Preventing an area from flooding is usually more difficult and more expensive than minimizing flood damages by controlling land use and development, and implementing higher building standards in flood prone areas.

4.1.2.1 *Flood mitigation*

Reducing the frequency or intensity of flooding requires protection projects that prevent floodwaters from reaching flood zones. “Soft” and “hard” protection measures can be used. Hard protection measures include groins, jetties, breakwaters, bulkheads, revetments, riprap, seawalls, tide gates, and pumping facilities (used in conjunction with walls or dikes). Soft protection measures include beach nourishment, wetland restoration, and dune management projects.

Coastal managers and planners now recognize that structural flood mitigation measures should be a last resort for flood mitigation. By fighting the forces of nature, structural protection measures are expensive and may actually exacerbate flooding and erosion problems, particularly in adjacent areas that rely on sediment from bluffs, escarpments, beaches, and dunes.

The general policy for coastal bluffs and escarpments should be, in accordance with the CCMA, to maintain the function of these features as natural sources of sediment supply for adjacent shoreline features, such as beaches and dunes. Beaches and dunes, in turn, provide significant flood protection in their own right by absorbing wave energy and providing higher elevations for floods to reach before they affect human-built structures.

In addition, as sea level rises, flood and erosion control structures impede the migration of tidal wetlands and marshes. This has harmful impacts for marine life, nearly all of which depends on healthy wetlands and marshes in some way.

Since many flood and erosion control projects are constructed waterward of the high tide line, CT DEP-OLISP can regulate where and how flood and erosion and control projects are constructed:

“Structural solutions are permissible when necessary and unavoidable for the protection of infrastructural facilities, water-dependent uses, or existing inhabited structures, and where there is no feasible, less

environmentally damaging alternative and where all reasonable mitigation measures and techniques have been provided to minimize adverse environmental impacts.”⁶⁶

In practice, the permitting and enforcement activities of CT DEP-OLISP must balance the statutory policies concerning the construction and repair of erosion control structures with strong economic, political and practical forces favoring the protection of waterfront property, so that hard shoreline structures are often authorized to protect existing properties or to be repaired.

However, sea level rise in the 21st century will be an increasingly important consideration for coastal property owners. Forward -thinking property owners might construct seawalls or other flood and erosion control structures now, landward of the high tide line, and thus protect their property from future flooding and erosion without being subject to the CT DEP-OLISP permitting process. This would be a simple way to circumvent strict policies that are meant to protect coastal resources and public access to the shore. The State needs to consider the inevitability of sea level rise and start planning how to adapt now. See Chapter 7 for more discussion of possible adaptation scenarios.

The USACE conducts dredging activities and constructs major public flood and erosion control projects at the request of municipalities and the State. Examples of USACE hazards mitigation projects include the following:

“At NEW LONDON, facilities to provide hurricane protection to the Shaw Cove area of this northern Long Island Sound community were completed in 1984 at a cost of \$11 million. The project, operated and maintained by the city of New London, provides protection both from high tides caused by coastal storms and hurricanes, and from interior flooding caused by Truman Brook in the industrial and commercial area in the vicinity of Shaw Cove and New London Harbor. Rock protected earthfill dikes, concrete floodwalls, a pumping station and a pressure conduit to evacuate interior drainage are features of the project. In a storm of the magnitude of the 1938 hurricane, New London would afford \$9.6 million in damage prevention.”⁶⁷

“The STAMFORD HURRICANE PROTECTION BARRIER was completed in 1969 at a cost of \$14.5 million. The project consists of three principal features. The West Branch Barrier, which protects the area between the West and East Branches, includes a 1,340-foot concrete wall and a 1,950 foot-long rock-faced earthen dike. The East Branch Barrier, which connects to the West Branch and extends across the mouth of the East Branch, includes 2,840 feet of rock-face earthen dike and a 90-foot-wide navigation gate. The Westcott Cove Barrier, which protects the residential area of Rippowam Street and skirts

⁶⁶ CGS, Section 22a-92(b)(2)(F) and Section 22a-92(b)(2)(J)

⁶⁷ Information retrieved on 1/26/09 from <http://www.nae.usace.army.mil/news/ct.pdf>

Westcott Cove in Cummings Park, includes 4,200 feet of rock faced earthen dike. Damages amounting to \$27.5 million have been prevented to date.”⁶⁸

“In Stonington, the PAWCATUCK-STONINGTON HURRICANE PROTECTION PROJECT is located on the West Bank of the Pawcatuck River at the Rhode Island - Connecticut state line. The \$920,000 project was completed in 1963. The project consists of

1,915 feet of earthen dike, 940 feet of concrete wall, two vehicular structures, and a pumping station. The works afford protection to a 31-acre industrial area and are operated and maintained by the town of Stonington.”⁶⁹

4.1.2.2 *Flood Damage mitigation*

Reducing the vulnerability of human activity and the built environment to flood damage is achieved primarily by creating and enforcing regulations and ordinances related to human activities and land use in the floodplain.

All of Connecticut’s coastal municipalities participate in the NFIP, and none are currently undergoing disciplinary action from FEMA, but there may be a problem with enforcement of floodplain regulations and ordinances. Even in 1983, the Connecticut Coastal Flood Vulnerability Assessment noted,

“an examination of the various floodplain zoning regulations and ordinances demonstrated that the towns have comprehensive and adequate laws for protecting life and property, but enforcement of those regulations is often lacking.”⁷⁰

To some extent, municipal tax revenue from valuable coastal properties can create an incentive for the development of coastal hazard areas and a reluctance to enforce floodplain regulations and ordinances. Under NFIP guidelines, FEMA can penalize municipalities for lax enforcement of their floodplain regulations and ordinances, but FEMA may not, as a practical matter, be able to execute this sort of monitoring and enforcement effort.⁷¹ Even if enforcement were perfect, NFIP minimum standards do not provide enough protection against present and future coastal hazards and therefore are not sufficient for ensuring responsible development in coastal hazard areas.

The Community Rating System, discussed in section 3.2.3, is FEMA’s attempt to encourage municipalities to go above and beyond NFIP minimum standards. It is a voluntary program that has relatively large fixed costs for a small community and an inadequate incentive structure.

The [Association of State Flood Plain Managers](#) (ASFPM) has created a concept called No Adverse Impact (NAI) that guides their recommendations for state and local

⁶⁸ Information retrieved on 1/26/09 from <http://www.nae.usace.army.mil/news/ct.pdf>

⁶⁹ Information retrieved on 1/26/09 from <http://www.nae.usace.army.mil/news/ct.pdf>

⁷⁰ Rummel and Hudak (1983)

⁷¹ Personal Communication with Carla Feroni, CT DEP-IWRD, December, 2007

floodplain ordinances. In a nutshell, NAI floodplain management takes place when the actions of one property owner are not allowed to adversely affect the rights of other property owners. The adverse effects or impacts can be measured in terms of any impacts the community considers important. This philosophy can shape the default management criteria: a community develops and adopts a comprehensive plan to manage development that identifies acceptable levels of impact, specifies appropriate measures to mitigate those adverse impacts, and establishes a plan for implementation. Because it is a local initiative, an NAI-based plan removes the mentality that floodplain management is something imposed by the federal government. Instead, it promotes local accountability for developing and implementing a comprehensive strategy and plan. With the flexibility to adopt comprehensive, locally tailored management plans (which would be recognized by FEMA and other federal programs as the acceptable management approach in that community) the community gains control of its land use decision-making process and is supported in adopting innovative approaches it considers appropriate for its situation.

ASFPM created a [NAI handbook](#) specifically for coastal state and local planners to create floodplain management plans and policies that go well beyond the NFIP standards of floodplain management. It shows communities how they can minimize hazard risks while simultaneously avoiding legal issues associated with property rights issues.^{72, 73}

4.1.2.3 *Flood Response and Recovery*

Despite our best efforts, flooding can and will happen. Hopefully, sound floodplain management practices will result in minimal disruptions and impacts, however, means for effective flood response are necessary. To this end, the Connecticut Department of Emergency Management and Homeland Security (DEMHS) [Emergency Management Division](#) leads flood response and recovery efforts. In the event of a disaster declaration, DEMHS initiates the detailed protocol established in the [State of Connecticut Natural Disaster Plan](#). This plan explains how DEMHS coordinates disaster response through the State Emergency Operations Center and defines the roles and responsibilities of various state agencies (such as the [Flood Management Program](#) in the Department of Environmental Protection's Inland Water Resources Division,) local municipalities, utility companies, and relief organizations such as the Red Cross. Please see Chapter 8 for a more complete summary of the State of Connecticut Natural Disaster Plan.

In addition, the Department of Environmental Protection has developed a FEMA-approved [Disaster Debris Management Plan](#) to help guide recovery and clean-up efforts as part of a disaster response. The Plan establishes the framework for proper management of debris generated by a natural disaster, with the goal of facilitating prompt and efficient recovery that is cost effective, eligible for FEMA reimbursement, and protective of the environment.

The Plan is an important planning document for all levels of government – federal, state and local, and describes the State contracts that are in place for use in response to a

⁷² Visit <http://www.floods.org> to read about NAI on the ASFPM website.

⁷³ Visit <http://www.mass.gov/czm/stormsmart/> for a comprehensive hazards management guide for coastal municipalities.

catastrophic natural disaster; the contracts are for both debris removal operations and the monitoring of these types of operations.

The Plan outlines the planning and operation functions for Temporary Debris Storage and Reduction Sites and the two phases of clean-up. It also includes a number of appendices that provide references to a number of waste management resources.

4.1.2.4 State of Connecticut Automated Flood Warning System

DEP-IWRD operates the State's Automated Flood Warning System, which currently contains 45 Automated Local Evaluation in Real Time (ALERT) gauges. The United States Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) and CT DEP installed the first components of this system in 1985, and the system has grown considerably since then. It has aided the National Weather Service (NWS) in issuing accurate flood watches and warnings in Connecticut and has helped communities respond more rapidly to floods.

The base station for the Automated Flood Warning System is at CT DEP in Hartford, where an antenna on the roof receives data from river, stream and precipitation gauges via Very High Frequency (VHF) radio. The base station relays data to the NWS via Internet. The City of Stamford and the South Central Connecticut Regional Water Company own and operate their gauge and flood alert systems.

Unfortunately, the Automated Flood Warning System covers only a few rivers and streams in the State, and coverage in coastal areas is sparse. There are only a handful of tide gauges linked to the system, and large swathes of the coastal area that do not have coverage. For areas covered by the system, the DEP does not monitor river or rainfall conditions during non-business hours. Municipalities must rely on their own observations and respond to NWS flood watches and warnings. CT DEP only has one staff member that operates and maintains the Automated Flood Warning System.

Given that municipalities are ultimately responsible for disseminating flood information among their residents and preparing for and responding to flood threats, more thought needs to be given to flood response procedures at the municipal level. In coastal towns, where flooding from storm surge is a concern, emergency management officials should review the municipal natural disaster plan, solicit advice from DEMHS and other coastal towns, and post the municipal emergency management/natural disaster plan on the Town's website.

4.2 Erosion

4.2.1 State of Knowledge

Erosion in Connecticut has occurred naturally for millennia as well as through the influence of man-made activities. It is typically when erosion threatens property or infrastructure that it is deemed problematic.

Human attempts at flood and erosion control have had mixed results and complicated the problem. Structural protection measures such as seawalls, revetments, bulkheads, groins, jetties, breakwaters, riprap may solve a problem in one area but create or worsen a problem in adjacent sections of the shoreline because they lock up sediment sources and/or impede the natural flow of sediment along the coast. In some cases, vertical seawalls actually induce erosion at their base because they focus wave energy there, scouring out supporting sediments and causing the walls to fail.

Reliance on water conduits, such as culverts and storm drains, to convey precipitation and inland water to the sea has created erosion hazards in new areas. Many culverts are too small to quickly drain floodwaters from heavy precipitation events, so catchments, stream channels, and basins can overflow and create erosion problems where the water creates new paths to the sea.



Figure 1: The foundation of this house in Lyme was destroyed by water escaping from an inland marsh serviced by undersized culverts

In 1947, in the aftermath of the 1938 and 1944 hurricanes, the Connecticut Legislature appropriated money for the USACE to begin work on a Beach Erosion Control Plan that would continue through 1955. The Beach Erosion Control Plan included a study of erosion along the entire Connecticut Shoreline and the construction of erosion control projects in specific problem areas, including Jennings Beach in Fairfield, Hammonasset Beach, and Sherwood Island.⁷⁴

In 1973, USACE oversaw two studies^{75 76} that constitute a brief survey of the entire Connecticut coast. The objective of this survey was to identify pronounced areas of erosion and deposition, and to collect information about surficial geology.

The shoreline erosion analysis in CT DEP's Planning Report No. 29 represents the most recent complete statewide inventory of shoreline erosion. The report found that 48 miles of Connecticut's coast, or 17%, is significantly affected by erosion. The report notes that most areas of erosion are located in two segments of the shoreline comprised

⁷⁴ US Army Corps of Engineers. (1957). *Beach Erosion Control Report on Cooperative Study*. Boston, MA: US Army Corps of Engineers New England Division.

⁷⁵ Gaines, A. G. (1973). *Connecticut Shoreline Survey: New Haven to Watch Hill*. Boston, MA: US Army Corps of Engineers, New England Division.

⁷⁶ Wibberley, J. T. (1973). *Connecticut Shoreline Survey: Port Chester, New York to Milford, Connecticut*. Boston, MA: US Army Corps of Engineers, New England Division.

primarily of glacial drift. The first is from Westport to West Haven, and the second is from Guilford to Old Lyme.⁷⁷

There is a lot of data collection and analysis to be done to inform management of erosion hazards. There have been some efforts in small sections of coastline to collect and analyze erosion data. For example, in 2006, CT DEP-OLISP looked at shoreline change, erosion and accretion trends, and sea level rise scenarios for the Hammonasset area in Madison and Clinton. USACE New England Division also provides periodic updates on coastal projects in New England States on their website.⁷⁸ Collecting and analyzing all of the USACE beach and erosion studies that have been conducted over the last fifty years is beyond the scope of this report, but more information about erosion, particularly in localized areas, can probably be found by searching USACE archives, contacting the USACE New England Division by telephone, and perhaps contacting Universities and colleges in Connecticut.

Such a research effort should be the first step in establishing a long term erosion monitoring program for the State of Connecticut. This would benefit managers, researchers, and private groups across many interests and disciplines.

4.2.2 Erosion Management

Since most erosion control projects are constructed waterward of the high tide line, the state of Connecticut has the authority (delegated to CT DEP-OLISP) to regulate flood and erosion and control projects constructed on the coast. The Connecticut Coastal Management Act (CCMA) dictates that non-structural solutions for erosion control must be considered and assessed before structural solutions are permitted. In general, permitting for “hard” erosion control structures is a last resort for CT DEP-OLISP. Non-structural solutions generally have smaller negative impacts on coastal resources, are easier to maintain, and provide recreation benefits.

For beach erosion, beach nourishment is a non-structural solution that provides a reasonable alternative to structural erosion control projects. The challenges with beach nourishment projects are finding suitable sources of sediment (uncontaminated, similar in size, texture, etc.), and finding continuing sources of funding to renourish regularly.

For erosion of coastal bluff and escarpments, the general policy is to maintain the function of these features as natural sources of sediment supply for adjacent shoreline features, such as beaches and dunes. Beaches and dunes, in turn, provide significant flood protection in their own right by absorbing wave energy and providing higher elevations for floods to reach before they affect human-built structures. The CCMA recognizes these dynamics and thus allows structural erosion control solutions only in narrowly defined circumstances.

There are instances where structural erosion control is necessary, such as heavily developed urban areas where erosion threatens critical infrastructure and key resources, including schools, sewage treatment plants, and highways. As will be discussed in Chapter 7, one of the major challenges of coastal hazards management in the future will be deciding where to retreat from shoreline erosion and flooding, where to armor against

⁷⁷ State of Connecticut. (1979). *Planning Report No. 29: Shoreline Erosion Analysis and Recommended Planning Process*. Hartford, CT: State of Connecticut Department of Environmental Protection.

⁷⁸ <http://www.nae.usace.army.mil/news/publicac.htm>

them, and where to pursue non-structural solutions such as beach nourishment and dune management.

Erosion control projects proposed in locations within the Coastal Boundary require a Coastal Site Plan Review by CT DEP-OLISP. Municipalities are not required to adhere to CT DEP-OLISP comments or recommendations for Coastal Site Plan Reviews, but they almost always do.

Neither the NFIP nor Connecticut has state-mandated coastal erosion setbacks for new development, but many municipalities have their own setback requirements.

Another important consideration for good erosion control management is the protection and restoration of tidal wetlands and marshes. Marsh vegetation stabilizes sediment on the shoreline and protects the shore from erosion. Connecticut has been a national leader in tidal marsh restoration efforts, but has also lost large swathes of tidal marsh to long-term sea level rise and manmade efforts to control mosquitos, such as ditching, draining, gating, and diking of marshes.⁷⁹ We should strive to minimize marsh loss.

4.3 Wind

4.3.1 State of Knowledge

While many storms have vast quantities of water that can lead to flooding, they also have powerful winds that can damage structures directly by destroying roofs, soffits, windows, doors, etc. High winds can also blow trees into structures and roadways, and destroy utility infrastructure. Strong winds can also pick up debris and other loose materials and propel them through the air or roll them along the ground, subsequently damaging property and infrastructure.

Normal wind patterns (those not associated with a specific storm event) also contribute to flooding and erosion by moving water and surficial materials around the coast:

“Wind and regional wind patterns are perhaps the most important feature of the physical environment of Connecticut’s shoreline. Wind generates surface waves which cause erosion and transport of shoreline materials. Strong onshore winds also contribute to storm surge by means of wind set-up. In addition, wind can cause the movement of sand or other loosely consolidated, fine-grained materials on to and off beaches and dunes through Aeolian transport.”⁸⁰

Planning report No. 29 provides wind roses constructed from wind velocity and direction data recorded at the Bridgeport Airport from 1951 to 1970.⁸¹ The wind roses show the general wind patterns for the coast of Connecticut. Winds from the southwest prevail during the summer months, and winds from the northwest prevail during the winter months. In late winter and spring, when winter storms (northeasters) are most

⁷⁹ For more information about tidal wetland data and restoration efforts contact CT DEP-OLISP at 860-424-3430.

⁸⁰ Planning Report No. 29, p. 13

⁸¹ Planning Report No. 29

likely, the wind rose indicates a significant component of strong winds from the east. Wind patterns in New Haven are unique because of the funneling effect of Connecticut's central valley.⁸² If data is available, it may be useful to gather more data from other airports and construct wind roses for other sections of the coast, and ideally for a longer time span, perhaps a goal of 1900-present. If we wish to better understand how climate change might affect waves, currents, longshore sediment transport, and long-term erosion rates at various places on the Connecticut coast, we need to keep an eye on the wind.

USACE created tables summarizing wind from United States Weather Bureau observations at New York City, Block Island, RI and New Haven, CT for the periods 1921-1939, 1932-1942, and 1921-1942, respectively.⁸³

The 2005 Connecticut State Building Code contains a list of basic wind speeds for every municipality in the state.⁸⁴ These wind speeds are based on a map produced by the American Society of Civil Engineers (ASCE). This national map uses contour lines to show the maximum (3 second gust at 10 m above ground) wind speeds that structures in a given location should be designed to withstand. The map is available in the 2005 FEMA Coastal Construction Manual.⁸⁵ The values for coastal Connecticut range from 100 mph in Greenwich to 120 mph in Stonington.

4.3.2 Wind Management

The insurance industry has significant role in managing the hazard of high winds, because unlike flood damages, wind damage is covered in many homeowner insurance policies. After Hurricane Andrew in 1992, insurers, reinsurers, and insurance ratings agencies realized their method of using historical data to assess risk wasn't good enough, because historical data did not reflect new conditions related to land use, population densities, building codes, and construction practices.

Insurers increasingly faced higher reinsurance costs and stricter ratings standards. As elsewhere in hurricane-prone areas, insurers in coastal Connecticut began reducing their exposure in hazardous coastal areas requiring more hurricane wind protection measures, including permanently-installed storm shutters. Southeastern Connecticut, lying in the 120 mph wind zone described above, was particularly affected by this decrease in insurance availability and increase in storm protection requirements.

The State of Connecticut thus conducted a study in 2006⁸⁶ and created new rules⁸⁷ for insurers to follow in coastal Connecticut. In addition to establishing rules for hurricane deductibles, they prohibited insurers from requiring permanently-installed storm shutters as the sole means of mitigation of hurricane hazards. Coastal homeowners, depending on their proximity to the coast, can use one of several methods (e.g. precut removable plywood shutters) of window protection recommended by the

⁸² Planning Report No. 29, p.15

⁸³ USACE (1976)

⁸⁴ The 2005 Connecticut State Building Code is available at http://coastal hazards.uconn.edu/docs/2005_state_building_code.pdf

⁸⁵ The FEMA Coastal Construction Manual is available at <http://www.fema.gov/rebuild/mat/fema55.shtm>

⁸⁶ The report of the study can be accessed at <http://www.ct.gov/cid/lib/cid/finalcoastalreport.pdf>

⁸⁷ These new rules are summarized in two documents, which can be accessed at <http://www.ct.gov/cid/lib/cid/underwritingcoastal.pdf> and <http://www.ct.gov/cid/lib/cid/HomeownercoastalGuidelines.pdf>

Institute for Business and Home Safety (IBHS). The Connecticut Department of Insurance (CT DOI) says they have struck a balance between consumer choice and affordability and the competitiveness and solvency of insurance companies in the Connecticut coastal homeowner's insurance market.

The State Building Code also helps manage coastal wind hazards. The current building code, as described in section 4.1.3 of this report, has specific requirements for houses in areas subject to strong winds. Unlike homeowners insurance though, building codes do not affect structures built before 1970. In addition, structures built between 1970 and 1990 were not subject to a building code as tough as the current one.

4.4 **Precipitation**

4.4.1 State of Knowledge

Precipitation can take the form of rain, freezing rain, snow, sleet, and larger ice forms like ice pellets and hail. All forms of wintry precipitation, such as sleet, freezing rain, snow, and ice can create hazardous conditions on roadways and walkways, as well as damage to electrical infrastructure like power lines, and damage to buildings and trees from the weight of ice or snow. These hazards are familiar to anyone who lives in Connecticut, not just coastal residents. However, coastal storms are unique because hazardous precipitation is often accompanied by other hazards, such as high winds and flooding from storm surges.

In Connecticut, the history of major storms has shown that precipitation in the run-up to the arrival of the actual storm center is a major cause of the destruction caused by flooding. Severe flooding in 1936 was brought on by almost 14 inches of rain over a nine-day period, leading to the highest recorded flood levels in the Connecticut River. The coastal devastation of the 1938 hurricane was the product of many factors, including the lack of warning from the National Weather Service, the coincidence of high tide with the landfall of the hurricane, category 3 winds, and a storm surge. However, much of the flooding in inland areas was caused by the three days of continuous rain that preceded the hurricane's arrival, saturating soils to the point where rivers and streams were filled to their banks. The rain subsequently delivered by the hurricane thus created disastrous flooding.

Frozen precipitation is a unique hazard associated with winter storms. Ice and snow make roadways and walkways treacherous. Large amounts of ice, in particular, can easily damage power and communications infrastructure and block roads by downing trees and power lines. Ice storms occur when warm air overrides cold air during a winter storm. Precipitation initially falls as rain and changes to ice on contact with the earth, including houses, cars, power lines, roads, trees, plants, etc. Ice storms require temperatures below 28°F for at least 12 hours and at least ½ inch of rain. These events are rare in Connecticut, particularly along the coast where the waters of Long Island Sound create a warmer winter climate than highland areas of the state.

A 2002 University of Connecticut publication called “Precipitation in Connecticut”⁸⁸ summarizes data from 73 precipitation gauges across the state and adjacent portions of New York, Rhode Island, and Massachusetts. The temporal range of data varies across the gauges.

Annual precipitation amounts are expected to increase in Connecticut due to climate change. Higher annual amounts of precipitation are expected to come in the form of more intense and more frequent heavy precipitation events.⁸⁹ In addition, new development brings more impervious surface areas,⁹⁰ increasing runoff during storms. This means that current storm drainage infrastructure, which is already insufficient in many areas, will need to be updated to accommodate heavier flooding associated with climate change and increased development.

In addition, although annual precipitation will likely increase in a warming climate, less of this precipitation will fall as snow. The smaller snowpack will reduce the amount of fresh meltwater in the spring, reducing river flow volumes during the spring and early summer. This reduced freshet, combined with accelerated sea level rise, will allow salt water to reach further up rivers flowing into Long Island Sound.

4.4.2 Precipitation Management

Connecticut Department of Transportation is aware of the problem with undersized culverts and has been upgrading them as they are repaired, but this ad hoc approach to the problem may not be good enough to minimize flood and erosion damages from heavy precipitation events. Municipalities should consider creating inventories of bottlenecks in their storm water systems and pursue federal and state funding to replace culverts and upgrade pipes. Perhaps Municipal Flood and Erosion Control Boards could handle this task. If some municipalities are already pursuing aggressive programs for culvert and storm water upgrades, CT DEP and CT DOT could help spread this knowledge and enthusiasm to other municipalities.

Municipalities should also review their policies and procedures pertaining to impervious surfaces because expanding impervious surfaces also increases flood risk by increasing the volume of water in storm water systems.

⁸⁸ Miller, D. R., Warner, G. S., Ogden, F. L., & DeGaetano, A. T. (2002). *Precipitation in Connecticut*. University of Connecticut, Connecticut Institute of Water Resources. Retrieved from http://digitalcommons.uconn.edu/ctiwr_specreports/36.

⁸⁹ Frumhoff, P. C., McCarthy, J. J., Melillo, J. M., Moser, S. C., & Wuebbles, D. J. (2007). *Confronting Climate Change in the US Northeast: Science, Impacts, and Solutions. Synthesis Report of the Northeast Climate Impacts Assessment (NECIA)*. Cambridge, MA: Union of Concerned Scientists (UCS).

⁹⁰ For a comprehensive study of impervious surface areas in CT, go to <http://clear.uconn.edu/projects/imperviouslis/project.htm>

5 Storms: The Current State of Knowledge and Management

5.1 Hurricanes

Hurricanes, tropical storms, and tropical depressions are three different types of tropical cyclones. The National Weather Service defines tropical cyclones as “nonfrontal, low pressure synoptic scale (large scale) systems that develop over tropical or subtropical water and have definite organized circulations. Tropical cyclones are categorized based on the speed of the sustained (1-minute average) surface wind near the center of the storm. These categories are: Tropical Depression (winds less than 34 knots/39 mph), Tropical Storm (winds 34-63 knots/39-74 mph), and Hurricanes (winds at least 64 knots/74 mph).”⁹¹

In addition to high winds, hurricanes usually bring heavy precipitation and storm surges that contribute to flooding and erosion. Of the coastal hazards discussed in chapter four, a hurricane is really four hazards in one event: flooding, erosion, precipitation, and wind. These hazards reinforce each other, for example heavy precipitation creates flooding, and high winds contribute to the height of storm surges, particularly in Long Island Sound, where any wind with an easterly component will impede tidal ebb at the eastern end of the sound.⁹² High winds also create massive amounts of debris from damaged trees and buildings, which can then become waterborne in a flood and cause more damage.

For its location in temperate latitudes, Connecticut is particularly vulnerable to hurricanes due to the southern exposure and east-west orientation of its shoreline. The idea that hurricanes lose intensity as they pass over Long Island and that the narrowness of Long Island Sound precludes large storm surges is inaccurate.⁹³ In fact, the State Department of Emergency Management and Homeland Security (DEMHS) “considers a strong Category 3 hurricane the most probable, worst-case disaster scenario facing the state.”⁹⁴ A review of the massive destruction of property and loss of life caused by mid-twentieth century hurricanes in Connecticut supports this statement. Six hurricanes struck Connecticut in 16 years, four of which were Category 3 hurricanes: The Great New England Hurricane of 1938, the Great Atlantic Hurricane of 1944, and Hurricanes Carol and Edna in 1955.

5.1.1 Historical Hurricanes in Connecticut

5.1.1.1 *The Great New England Hurricane of 1938*

The hurricane of 1938 was the deadliest disaster in the history of Connecticut and New England in general. A brief qualitative summary of the storm is best quoted directly from the USGS’s authoritative document on the storm, Hurricane Floods of September 1938 (1940):

⁹¹ US Army Corps of Engineers (1994), p. 1-4

⁹² NHMP, p. 2-36

⁹³ US Army Corps of Engineers (1994), p. 1-5

⁹⁴ State of Connecticut. (2006). *Natural Disaster Plan*. p. A-1

“During the brief interval of 6 hours on September 21, 1938, a West Indian hurricane passed over Long Island and New England. The hurricane as it struck New England was the climax of a 4-day period of rainfall which in itself was of outstanding amount and character and which produced river stages that inundated and damaged nearly everything on the river flood plains. When measured by the appalling loss of life and property by the combined forces of the hurricane winds and the associated ocean storm waves and river floods, these events constituted the greatest catastrophe in New England since its settlement by the white man.”⁹⁵

The hurricane of 1938 killed 125 people in Connecticut.⁹⁶ This hurricane wreaked coastal destruction by making landfall at high tide with winds up to 130 mph and generating a storm surge up to 12 feet high. Multiple days of rain prior to arrival of the hurricane contributed to flood damage from waterways overflowing their banks. The damages in Connecticut were estimated at \$53 million in 1938 dollars (\$810 million in 2009 dollars, adjusted for inflation). Property damage on the coast of Connecticut was \$22 million in 1938 dollars (\$336 million in 2009 dollars, adjusted for inflation).⁹⁷

5.1.1.2 *The Great Atlantic Hurricane of 1944*

Only six years later, the Great Atlantic Hurricane of 1944 hit Long Island and Connecticut as a category 3 hurricane. Injuries, deaths, and damages were less than in the 1938 hurricane due to better warnings and fewer structures because of a lack of rebuilding from the 1938 hurricane. Nevertheless, seven people were killed and damages were between \$3 million and \$5 million in 1944 dollars (\$37 million to \$61 million in 2009 dollars, adjusted for inflation).

5.1.1.3 *Hurricane Carol*

In 1954 Hurricane Carol struck Connecticut. The following quotations are from Vallee and Dion (1997):

“Hurricane Carol arrived shortly after high tide, causing widespread tidal flooding. Storm surge levels ranged from 5 to 8 feet across the west shore of Connecticut, and from 10 to 15 feet from the New London area eastward.”

“Rainfall amounts ranged from 2 to 5 inches across most of the area. The heaviest amounts, up to 6 inches, occurred in the New London, Connecticut area in the vicinity of landfall.”

“On the morning of August 31, Hurricane Carol, the most destructive hurricane to strike southern New England since the Great New England Hurricane of 1938, came crashing ashore near Old Saybrook, Connecticut, leaving 65 people dead in her wake. Carol had developed

⁹⁵ Paulsen, C. G., Bigwood, B. L., Harrington, A. W., Hartwell, O. W., & Kinnison, H. B. (1940). *Hurricane Floods of September 1938 (Water Supply Paper 867)*. US Geological Survey.

⁹⁶ Patton and Kent (1992), p. 11

⁹⁷ Patton and Kent (1992), p. 12

in the Bahamas several days earlier, making only slow progress northward. Carol began her rapid acceleration during the evening of August 30, while passing just east of Cape Hatteras, North Carolina. Carol made landfall on eastern Long Island and southeastern Connecticut about 12 hours later, moving at over 35 mph.”

“Sustained winds of 80 to 100 mph roared through the eastern half of Connecticut, all of Rhode Island, and most of eastern Massachusetts. Scores of trees and miles of power lines were blown down. Strong winds also devastated crops in the region. Nearly 40 percent of apple, corn, peach, and tomato crops were ruined from eastern Connecticut to Cape Cod. Several homes along the Rhode Island shore had roofs blown completely off due to winds which gusted to over 125 mph. The strongest wind ever recorded on Block Island, Rhode Island occurred during Carol when winds gusted to 135 mph.”⁹⁸

5.1.1.4 *Hurricane Edna*

Although this particular hurricane did not directly strike Connecticut (it made landfall around Martha’s Vineyard and Nantucket,) it nevertheless caused damage to southeastern Connecticut in areas that were already impacted by Hurricane Carol the month before. Between the two storms, rainfall totals for Connecticut were 5 to 7 inches west of the Connecticut River and up to 11 inches along the southeastern coastline.⁹⁹

5.1.1.5 *Tropical Storms Connie and Diane*

The remnants of hurricanes Connie and Diane occurred in early August 1955. Despite not making landfall in Connecticut as proper hurricanes, they bear mentioning for this reason: “These two hurricanes caused little damage to the coast but their combined maximum rainfall of 27 inches caused catastrophic flooding in western Connecticut.”¹⁰⁰

5.1.1.6 *Hurricane Donna*

Hurricane Donna made landfall in Connecticut September 12, 1960. Wind gusts off of Block Island, RI., were recorded at 130 mph, with sustained winds of 95 mph, and storm surges along the New England coastline ranged from 5 to 10 feet. Donna is the only hurricane on record to produce hurricane force winds in Florida, the mid-Atlantic, and New England combined.¹⁰¹

5.1.1.7 *Hurricane Gloria*

The last hurricane to directly strike Connecticut was Hurricane Gloria in 1985. Gloria was a category II hurricane when it made landfall at Westport, but relatively light rains and low tide upon landfall resulted in very little flood damage compared to storms

⁹⁸ Vallee, D. R., & Dion, M. R. (1997). *Southern New England Tropical Storms and Hurricanes, A Ninety-eight Year Summary 1909-1997*. Taunton, MA: National Weather Service.

⁹⁹ <http://www.erh.noaa.gov/box/hurricane/hurricaneEdna.shtml>

¹⁰⁰ Patton and Kent (1992), p. 17

¹⁰¹ <http://www.nhc.noaa.gov/HAW2/english/history.shtml#donna>

from earlier in the century. The peak surge observed at New London Harbor was approximately 5.8 feet, meaning the ocean's surface was 5.8 feet higher than it would have been under normal tide conditions. If this peak surge had occurred at high tide, flooding would have been much greater.

5.1.1.8 *Hurricane Bob*

Connecticut received an indirect strike from Hurricane Bob in August of 1991. The bulk of the storm hit to the east in Newport, RI., and brought sustained hurricane force winds to the immediate coastal communities of Rhode Island and southeast Massachusetts. Hurricane force winds were recorded as far west as the Connecticut River. The heaviest rainfall of over 7 inches affected western Rhode Island and extreme eastern Connecticut. Foster. Despite being primarily localized to the east, Bob was responsible for six deaths in the region, all in Connecticut.¹⁰²

5.1.2 Hurricane/Storm Surge Modeling

The current status of hurricane and storm surge modeling for Connecticut are discussed in the summary of the state of knowledge of flood mapping in Chapter Four.

5.1.3 Hurricane Response and Recovery

The State of Connecticut Natural Disaster Plan, prepared by the Department of Emergency Management and Homeland Security (DEMHS) is a blueprint for response and recovery from natural disasters, including hurricanes. It lays out policies and procedures for hurricane response, including evacuation decision-making, evacuation procedures, debris management, emergency shelter management, search and rescue, reporting by local authorities, damage assessment, and military assistance. The plan defines the roles that various state agencies, local municipalities, and private entities play, and explains how the State Emergency Operations Center (EOC) oversees the disaster response effort. Several pertinent facts include:

- In any type of disaster or emergency, state agencies must first fulfill departmental mandates established by state statutes, regulations or executive orders and then provide support to local authorities. Exceptions to these priorities are made only in cases of imminent peril to life and health.
- If necessary, the Governor may declare a state of emergency under C.G.S. Section 28-9, and invoke extensive emergency powers which allow the Governor to take any action reasonably necessary in light of the emergency. The Governor's emergency powers include (but are not limited to) taking operational control of all civil preparedness forces and functions in the state, modifying or suspending statutes and regulations, ordering evacuations, removing debris from public and private land or waters, and seizing property.

The section of the State Natural Disaster Plan (2006) that defines coastal evacuation policies and procedures is based on information provided in the 1994 Connecticut Hurricane Evacuation Study: Technical Data Report. The Connecticut Hurricane Evacuation Study established the general rule that in Connecticut it takes 7 hours from the time residents receive official notification to evacuate. An additional two hours of dissemination time must be added to account for the time it takes to notify the public to

¹⁰² <http://www.erh.noaa.gov/box/hurricane/hurricaneBob.shtml>

evacuate. Nine hours is thus required for coastal evacuations, “which should be completed before the arrival of dangerous ‘pre-landfall hazards’ such as gale force winds and flooding of low-lying evacuation routes. This means that evacuation decisions should be made before the leading edge of the storm system (measured as the radius of gale-force winds from the eye of the hurricane) is within 9 hours of landfall on the Connecticut coastline”¹⁰³

The Connecticut Hurricane Evacuation Study provides a “Decision Arc Method,” which supports hurricane evacuation decision-making by combining information about possible storm tracks and speeds, potential inundation and evacuation areas, and estimated evacuation times and routes. For example, with a nine-hour estimated evacuation time and a hurricane headed for Connecticut at 30 knots, the “decision arc” for this hurricane occurs where the leading edge of the storm system reaches 270 nautical miles from the estimated point of landfall.

Procedures for coastal evacuations defined in the Natural Disaster Plan cover communication with the National Hurricane Center (NHC) and local NWS offices to discuss if, when, and where evacuations should begin, communication with local officials before and after an evacuation recommendation (or evacuation order for a particularly intense hurricane) is issued, and the responsibilities of the Department of Emergency Management and Homeland Security (DEMHS) to notify media and federal, state, private agencies.

The Connecticut Hurricane Evacuation Study’s assessment of shelter capacity for coastal municipalities, including an inventory of locations of public shelters, information about mobile home/trailer parks, and medical/institutional facilities, was updated in 2006.

The State Disaster Debris Management Plan, September 2008 (Annex to the State Natural Disaster Plan) was approved by FEMA in 2008. In the event of an emergency declaration by the governor, preapproved contracts for debris clean-up and monitoring are activated. Contractors from Florida and Tennessee handle the clean-up and another contractor from Florida monitors the operation.¹⁰⁴

In 2006 CT DEP wrote an 8-page memorandum to municipal officials, providing an outline of disaster debris management procedures. The memo, called “Guidance for Connecticut Municipalities-Overview of Disaster Debris Management Planning, 2006,”¹⁰⁵ included a checklist of things to do before, during, and after a disaster.

Today, society is increasingly dependent on the Internet and mobile communications, so power outages are increasingly disruptive to the economy and personal communications. A major hurricane may disrupt power and communications infrastructure for up to three weeks. The potential impact of disabled electronic communications on commerce, workplace productivity, personal communication, and emergency communication systems is a “significant but quantitatively unknown risk in Connecticut.”¹⁰⁶

¹⁰³ State of Connecticut. (2006). *Natural Disaster Plan*. p. H-2

¹⁰⁴ More information on the Debris Management Plan and related contracts can be accessed at http://www.ct.gov/dep/cwp/view.asp?a=2718&Q=410492&depNav_GID=1646

¹⁰⁵ Accessible at http://www.ct.gov/dep/lib/dep/waste_management_and_disposal/debris_management/disasterdebrismanagementplanning.pdf

¹⁰⁶ State of Connecticut (2007). *2007-2010 Natural Hazards Mitigation Plan*, p. 2-37

5.2 Winter Storms

Winter storms, or “extratropical cyclones” can produce high winds, storm surges, and massive amounts of precipitation. Because these winter low-pressure systems can be up to 2,000 miles in diameter, and because they tend to move slowly along the coast, fragile coastal features such as marsh and beach systems can suffer large amounts of flooding and erosion. A “northeaster” is a strong winter storm:

“A northeaster that qualifies as a ‘serious storm’ is characterized here as a low-pressure system that moves-often slowly- northeast along the coast, with sustained winds reaching more than 45 knots at some point during its lifetime. Nearly two thirds of these storms produce tidal surges in excess of the 99th percentile. Source DeGaetano, A. 2007. Personal communication, May 11. Art DeGaetano is an Associate Professor in the Department of Earth and Atmospheric Sciences at Cornell.”¹⁰⁷

A northeaster that hit Connecticut in April 2007, for example, leveled a dune in Old Saybrook that was the subject of a beach grass restoration effort by CLEAR. In addition to the storm surge and wave action that destroyed this dune and wiped out sections of beach, this storm also produced heavy rains that contributed to coastal flooding in many areas of the Connecticut coast.

Coastal flooding is a major hazard associated with northeasters. A storm on December 10-13, 1992 produced continuous east/northeast winds up to 55 mph. As a result, Bridgeport, CT recorded a high tide of 10.16 ft NGVD, the third highest recorded in Long Island Sound. This storm destroyed 26 homes and killed three people. Perhaps the most famous winter storm in history is the so-called “Storm of the Century” which impacted the entire east coast of the US March 12-15, 1993. This catastrophic event produced record snowfalls from the northeast to the Florida panhandle. In total, the storm killed 270 people, with another 48 lost or missing at sea, and totaled in excess of \$6 billion dollars of damage.¹⁰⁸

Since they strike Connecticut frequently and often move slowly, winter storms cumulatively cause more frequent coastal flooding, more coastal erosion, and more annual damage to property than hurricanes.¹⁰⁹ Over the last thirty years, major winter storms struck Connecticut in 1979, 1983, 1992, 1996, 2003, and 2007. Although these storms are notable for their intensity, serious beach erosion is also caused by smaller but more frequent winter storms, which can often occur in rapid succession. Multiple storms occurring in rapid succession can severely erode beaches because they starve beaches of sediment brought by gentle, spilling waves.

Frozen precipitation is a unique hazard associated with winter storms. Ice and snow make roadways and walkways treacherous. Large amounts of ice, in particular, can easily damage power and communications infrastructure and block roads by downing trees and power lines. Ice storms occur when warm air overrides cold air during a winter

¹⁰⁷ Frumhoff et al. (2007), p. 130.

¹⁰⁸ <http://www.nssl.noaa.gov/primer/winter/century.html>

¹⁰⁹ State of Connecticut (2007). *2007-2010 Natural Hazards Mitigation Plan*, p. 2-16

storm. Precipitation initially falls as rain and changes to ice on contact with the earth, including houses, cars, power lines, roads, trees, plants, etc. Ice storms require temperatures below 28°F for at least 12 hours and at least ½ inch of rain. These events are rare in Connecticut, particularly along the coast where the waters of Long Island Sound create a warmer winter climate than highland areas of the state.

5.2.1 Winter Storm Response and Recovery

Response to winter storms is handled differently from hurricanes. Although northeasters can create coastal flooding comparable to a category 1 or 2 hurricane, there is no evacuation guidance developed specifically for winter storms. The official coastal evacuation procedures defined by the State Natural Disaster Plan:

“The State of Connecticut will not issue area-specific coastal evacuation recommendations for extra-tropical systems. Local officials, based on information provided by the National Weather Service, will make evacuation decisions for these events.”¹¹⁰

The Natural Hazards Mitigation Plan offers a detailed summary of the April, 2007 northeaster, the most recent in Connecticut. The summary of government response shows how municipal authorities opened local emergency operations centers, conducted evacuations and rescues, opened shelters, monitored and inspected dams and bridges, barricaded unsafe roads, detoured traffic, pumped basements, and towed vehicles swamped by flood waters. Westport, Greenwich, Danbury, Southbury, New Milford, Woodbury, Bristol and Stamford conducted evacuations. Stamford, for example, chose to evacuate 85 senior citizens and 25 handicapped people from their residences. The state role involved “maintaining state roadways and supporting municipal response operations by coordinating delivery of services and equipment to local officials including bridge and dam inspectors, sandbags, pumps, barriers, and evacuation vehicles and drivers. The Connecticut Department of Transportation (CT DOT) established a temporary bus service to transport passengers unable to use the Danbury Branch line of Amtrak, which was lost for a day due to track washouts in three locations.”¹¹¹

¹¹⁰ State of Connecticut. (2006). *Natural Disaster Plan*. p. H-3

¹¹¹ State of Connecticut (2007). *2007-2010 Natural Hazards Mitigation Plan*, p. 2-12

6 Climate Change and Coastal Hazards: The Current State of Knowledge

The United Nations Environment Programme established the Intergovernmental Panel on Climate Change (IPCC) in 1988. The IPCC's role is to "assess on a comprehensive, objective, open and transparent basis the scientific, technical and socio-economic information relevant to understanding the scientific basis of risk of human-induced climate change, its potential impacts and options for adaptation and mitigation." The IPCC itself does not conduct any original research, nor does it carry out any climate based monitoring; rather it serves as a vehicle to collect, analyze and report on peer-reviewed climatologically relevant scientific literature. To that end, the IPCC has produced a series of Assessment Reports in 1990, 1992, 1995, 2001 and 2007. The most recent, the Fourth Assessment Report, is the result of the work of over 2,500 scientific experts, over 800 contributing authors and 450 lead authors from more than 130 countries. It is comprised of the following materials: the Synthesis Report; The Physical Science Basis; Impacts, Adaptation and Vulnerability; and Mitigation of Climate Change.

According to the 2007 Fourth Assessment, warming of the earth's climate system is unequivocal. Warming is evident from increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level.

Human activities are at least partly responsible for this warming by increasing the atmospheric concentration of greenhouse gases as a result of burning fossil fuels and land-use changes, including deforestation:

"There is very high confidence [greater than 9 in 10 chance] that the net effect of human activities since 1750 has been one of warming... Most of the observed increase in global average temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic GHG concentrations. It is likely [greater than 66% confidence level] that there has been significant anthropogenic warming over the past 50 years averaged over each continent (except Antarctica)."¹¹²

Anthropogenic warming of the climate is expected to continue and perhaps accelerate in the 21st century, depending on greenhouse gas (GHG) emissions:

"Continued GHG emissions at or above current rates would cause further warming and induce many changes in the global climate system during the 21st century that would very likely [greater than 90%

¹¹² IPCC, 2007: Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, Pachauri, R.K and Reisinger, A. (eds.)]. IPCC, Geneva, Switzerland, 104 pp, p. 39.

confidence level] be larger than those observed during the 20th century.”¹¹³

The potential effects of this warming over the 21st century are numerous. An assessment of all these effects is well beyond the scope of this report, but often cited ones include rising sea levels, species extinctions, stronger storms, spread of disease, and greater frequency and severity of droughts and floods. For the purposes of this report, the effects of climate change on coastal hazards in Connecticut are considered.

The primary climate change-related concerns for coastal hazards management are sea level rise (SLR) and stronger/more frequent storms. Ultimately, many of the effects of sea level rise and stronger/more frequent storms will be the same. Examples include increased frequency and severity of flood events, saltwater intrusion in groundwater and wastewater treatment systems, accelerated rates of erosion, and inundation of coastal lands and habitats.

6.1 Sea level Rise

6.1.1 Past and Present Sea Level Rise

Global mean sea level rose 17 cm in the 20th Century. The Intergovernmental Panel on Climate Change concluded with high confidence (greater than 8 in 10 chance) that this rate of SLR was greater than in the 19th century. The rate of global mean sea level rise increased within the 20th Century as well. The rate was 1.8 mm/year from 1961 to 2003, while the rate from 1993 to 2003 was 3.1 mm/yr. It is unknown whether the high rate of SLR from 1993 was due to decadal variability or an increase in the long-term trend.

6.1.2 Future Sea Level Rise

Forecasts of sea level rise are uncertain. Rahmstorf (2007) describes the challenges of forecasting SLR:

“Understanding global sea level changes is a difficult physical problem, because complex mechanisms with different time scales play a role, including thermal expansion of water due to the uptake and penetration of heat into the oceans, input of water into the ocean from glaciers and ice sheets, and changed water storage on land. Ice sheets have the largest potential effect, because their complete melting would result in a global sea level rise of about 70 m. Yet their dynamics are poorly understood, and the key processes that control the response of ice flow to warming climate are not included in current ice sheet models [for example, meltwater lubrication of the ice sheet bed or increased ice stream flow after the removal buttressing ice shelves.] Large uncertainties exist even in the projection of thermal expansion, and estimates of the total volume of ice in mountain glaciers and ice caps

¹¹³ IPCC, 2007: Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, Pachauri, R.K and Reisinger, A. (eds.)]. IPCC, Geneva, Switzerland, 104 pp, p. 45.

that are remote from the continental ice sheets are uncertain by a factor of two.”¹¹⁴

Sea level rise is the product of two factors: thermal expansion of water in the ocean and the melting of land-based ice, most of which is contained in the Greenland and Antarctic ice sheets. Although thermal expansion of ocean waters is relatively well understood and can be predicted with reasonable confidence, ice sheet dynamics are poorly understood. As a result, scientists have produced a wide range of future sea level rise scenarios.

The 95% confidence interval of 2007 IPCC estimates of global mean SLR is 18-59 cm by 2090-2099, at an annual rate ranging from 1.5 to 9.7 mm/yr.¹¹⁵ Several individual studies, however, have estimated global mean SLR to 2100 to be an order of magnitude larger than the IPCC estimates. Overpeck et al. (2006) for example, suggest global mean SLR to 2100 will be on the order of meters, with large uncertainty about the actual value because of a poor understanding about how ice sheets will respond to warming.¹¹⁶ Although the IPCC considers the collapse of the West Antarctic Ice Sheet or the rapid loss of the Greenland Ice Sheet to be unlikely in the 21st century, they state “the occurrence of such changes becomes increasingly more likely as the perturbation of the climate system progresses.”¹¹⁷ The total amount of ice in the Greenland ice sheet represents 7m of sea level rise, while the total amount of ice in the West Antarctic Ice Sheet represents 5-6 m of sea level rise.¹¹⁸

The rate at which melting ice can discharge into the ocean from the Greenland and Antarctic Ice Sheets is dependent on the bedrock geology of those landmasses. The ice cannot simply slide off these rocks instantaneously; it must pass through outlet glaciers. Recognizing these “kinematic constraints” on ice sheet breakdown and subsequent rates of sea level rise, Pfeffer et al (2008) assessed the glaciological conditions on Greenland and Antarctica. They determined that global sea level rise greater than 2 meters (approx. 79 inches) by the year 2100 is “physically untenable.”¹¹⁹

6.1.3 Global vs. Local Sea Level Rise

Although observations and forecasts of global mean SLR (also called eustatic SLR) are important, local SLR (relative SLR) should be the metric used for planning purposes. Gornitz et al (2004) explain the main reason why relative SLR in Connecticut differs from the global mean:

¹¹⁴ Rahmstorf, S. (2007). A Semi-Empirical Approach to Projecting Future Sea Level Rise. *Science*, 315, 368-370., p. 368

¹¹⁵ Intergovernmental Panel on Climate Change (IPCC). (2007). *Climate Change 2007: The Physical Science basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, UK and New York, NY, USA: Cambridge University Press., p. 820

¹¹⁶ Overpeck, J. T., Otto-Bliesner, B. L., Miller, G. H., Muhs, D. R., Alley, R. B., & Kiehl, J. T. (2007). Paleoclimatic Evidence for Future Ice-Sheet Instability and Rapid Sea Level Rise. *Science*, 311, 1747-1750.

¹¹⁷ IPCC (2007), p. 818

¹¹⁸ IPCC (2007), p. 819

¹¹⁹ Pfeffer, W. T., Harper, J. T., & O'Neel, S. (2008). Kinematic Constraints on Glacier Contributions to 21st-Century Sea-Level Rise. *Science*, 1340-1343.

“During the last glaciation, the weight of the ice sheet caused the Earth’s crust to warp and Connecticut to be slightly uplifted. Now that the ice sheet has melted, the Earth’s crust is evening out, and Connecticut is slowly sinking at approximately 0.03-0.035 inches per year [0.76-0.89 mm/yr].”¹²⁰

Rates of relative sea level rise (geologic subsidence/uplift included), are available from NOAA tide gauges in coastal Connecticut at New London and Bridgeport.

- Over the period 1938-2006 (69 years), monthly tide gauge analyses at New London, CT show a mean sea level rise trend of 2.25 mm/yr +/-0.25 mm at the 95% confidence interval (alternatively, 0.09 inches/yr, +/- 0.01 inches.)
- Over the period 1964-2006 (43 years), monthly tide gauge analyses at Bridgeport, CT show a mean sea level rise trend of 2.56 mm/year +/-0.58 mm at the 95% confidence interval (alternatively, 0.10 inches/year, +/-0.02 inches.)¹²¹

These numbers exceed the eustatic rate of sea level rise of 0.06 ± 0.02 in/yr, or 1.5 ± 0.5 mm/yr, due to Connecticut’s rate of subsidence.¹²²

6.1.4 Impacts of Sea Level Rise on Coastal Hazards

Regardless the magnitude, we can expect coastal hazards to increase with SLR. Even the conservative IPCC estimates of SLR in the 21st century will lead to the inundation of low-lying coastal lands, more frequent and severe coastal flooding due to the higher base for storm surges, and increased rates of erosion in some areas.¹²³

Accelerated erosion rates can destroy natural flood protection such as dunes, beaches and wetlands, further contributing to flood hazards. Higher sea levels will also reduce the rate of drainage of coastal areas, thus increasing flood hazards from precipitation events and extending the length of flood events from storm surges.¹²⁴

Kirshen et al (2008) expect more frequent extreme storm surge flooding as sea level rises. Using sophisticated trend and frequency analysis of high water level anomalies in NOAA tide gauge data from Boston, Woods Hole, New London, New York City, and Atlantic City, they estimate the recurrence intervals of storm surge events under several future SLR scenarios. Under their high emissions scenario, which predicts eustatic SLR of 90 cm by 2100, a present-day 100-year storm surge event in New London is expected to be a 30-year event by 2050 and a 3-year event by 2100. Similarly for New London,

¹²⁰ Gornitz, V., Hale, S., Larsen, K., Nevine, N., Rosenweig, C., & Sacks, L. (2004). *Bracing for Climate Change in the Constitution State: What Connecticut Could Face*. New York: Environmental Defense, p. 22

¹²¹ Technical Report NOS CO-OPS 053. Sea Level Rise Variations of the United States 1854-2006. NOAA. US Dept of Commerce, National Ocean Service, Center for Operational Oceanographic Products and Services. Silver Spring, MD. December, 2009.

¹²² Gornitz et al (2004)

¹²³ Gornitz et al (2004)

¹²⁴ US CCSP. (2009). *Coastal Sensitivity to Sea Level Rise: A Focus on the Mid-Atlantic Region. A Report by the U.S. Climate Change Science Program and Subcommittee on Global Change Research*. Washington, D.C.: US Environmental Protection Agency, p.279

they estimate the MHHW 100-year storm surge elevation to be 2.2 m NAVD in 2005, 2.3 m NAVD in 2050, and 3.1 m NAVD in 2100.¹²⁵

Ashton et al (2007) discuss how accelerated sea level rise also increases rates of erosion, leading to loss of coastal land even greater than what would be lost by inundation alone. The oft-cited “Bruun Rule”, for example, expresses shoreline retreat as a function of sea level rise and the slope of the beach. In a typical formulation of this rule, “shore erosion due to waves with a raised sea level should be typically several orders of magnitude larger than the inundation caused by the rise in sea level itself.”¹²⁶

A combination of rising sea level and reduced spring freshet caused by a reduction in snowpack will cause saltwater to extend its reach up rivers. This has implications for human uses of freshwater drawn from the major rivers of Connecticut. Water taken from the Connecticut River and used for irrigation, for example, may become salty because of this upstream migration of the salt wedge.

Perhaps more urgently, sea level rise will cause more frequent or even permanent intrusion of salt water into underground freshwater aquifers and septic systems, threatening public drinking water and sanitation.

6.2 Stronger/More Frequent Storms

The scientific literature, as synthesized by the IPCC, shows that we can expect an increase in the intensity, but not necessarily the number, of tropical storms in the North Atlantic. Other research¹²⁷ suggests the possibility of a slight increase in the average annual number of winter storms received in coastal Connecticut, most likely occurring late in the winter.

¹²⁵ Kirshen, P. C., Watson, C., Douglas, E., Gontz, A., Lee, J., & Tian, Y. (2008). Coastal Flooding in the Northeastern United States due to Climate Change. *Mitigation and Adaptation Strategies for Global Change*, 13, 437-451.

¹²⁶ Ashton, A., Donnelly, J., & Evans, R. (2008). A Discussion of the Potential Impacts of Climate Change on the Shorelines of the Northeast United States of America. *Mitigation and Adaptation Strategies for Global Change*, 13 (7), 719-743, p. 7.

¹²⁷ Frumhoff et al. (2007)

7 Summary and Recommendations

7.1 Summary of the Current State of Knowledge and Management

The current state of knowledge of coastal hazards is more advanced than the current state of coastal hazards management. Scientists know that hurricanes are a threat to Connecticut, and that damage from the next hurricane will cost a lot of money. Scientists generally agree that global warming will continue to accelerate sea level rise, and may change storm and precipitation patterns, likely for the worse. These changes will expand flood and erosion hazards to new areas and worsen them where they already exist. However, our knowledge of coastal hazards has yet to change the way we manage human lives and property on the coast of Connecticut.

Connecticut lacks some important knowledge that could improve our understanding of coastal hazards, such as high-resolution shallow water bathymetry to support state-of-the-art storm surge modeling, but scientists and managers will always be updating “wish lists” of desirable information. Scientific efforts will continue to advance our knowledge of coastal hazards. At the international and federal level, we will improve storm warning systems and refine our estimates of sea level rise as we improve our understanding of ice sheet dynamics and ocean warming. In Connecticut, we must do more research to identify and anticipate areas of hazardous erosion and flooding, and identify wetland refugia sites to protect and/or acquire. These and other gaps in the current state of knowledge are summarized in section 7.2.

However, the management of coastal resources, coastal infrastructure, human activities, and land-use in coastal hazard areas—must change to reflect our current state of knowledge. Our policies and planning activities have not yet incorporated what we already know: sea level is rising, and storms are coming sooner or later. Recommendations for management are summarized in sections 7.3 thru 7.6.

7.2 Gaps in the Current State of Knowledge

Major gaps in the current state of knowledge of coastal hazards in Connecticut include but are not limited to the following:

1. Outdated flood maps. Flood Insurance Rate Maps (FIRMs) are generally outdated and thus inaccurate because of the rapidly changing nature of the coastline.¹²⁸
 - Missing data required for State-of-the-Art Flood Maps:
 - i. Updated, comprehensive, state-wide inventory of flood control and stormwater infrastructure (tide gates, culverts, sluices, storm drains, etc.)
 - ii. High-resolution shallow water bathymetry

¹²⁸ The findings of the congressionally-ordered study of sea level rise and FIRMs by FEMA can be found in Chapter 8 of US CCSP (2009).

- iii. High-resolution topography beyond the existing 100-year floodplain.
2. Incomplete and outdated inventory of structures in flood zones and their flood insurance status. We need this information for flood damage estimation. A new inventory similar in spirit to the 1983 Connecticut Coastal Flood Vulnerability Assessment¹²⁹ should be created and updated regularly in the future. This information should be synchronized with the information contained in FEMA's HAZUS-MH database.
 3. A statewide critical infrastructure/key resources database does not exist.¹³⁰ Such a database is crucial for prioritizing what to protect from sea level rise and what to relocate or abandon. It is also crucial for storm response and recovery.
 4. A statewide inventory of municipal floodplain regulations and building codes does not exist. What towns have freeboard requirements? What are the setback requirements in each town? This inventory would reveal relative differences in hazards management between towns. It would help the state focus on towns that need extra assistance or encouragement, and maybe create an incentive for towns to do better. It would also help identify specific vulnerabilities in each town.
 5. Connecticut lacks erosion data that are spatially and temporally complete. The state should implement a coast-wide long term erosion monitoring program.

7.3 The Outlook for Coastal Hazards Management

Most coastal managers and scientists recognize that retreat from the shoreline is the only sensible long-term approach to coastal development. However, CT DEP-OLISP's regulatory experience at the state and local levels suggests that waterfront property owners are instead continually pushing the closer to the water. People are proposing more and bigger houses closer to the water, and more elaborate walls and structures to protect property boundaries (and amenities such as patios, pools, and lawns) far away from the house. At the same time, sea level rise and storms will, through direct flooding as well as impairment of water and septic infrastructure, render existing and new waterfront development increasingly untenable. This represents a cost that someone must pay.

Whether managing the immediate threat of a category 3 hurricane or the longer term threats associated with sea level rise and stronger hurricanes, the fundamental question is thus: Who pays the costs of risk and damage? Thus far, the coastal real estate market has failed to make developers and property owners pay the true cost of development in

¹²⁹Rummel and Hudak (1983)

¹³⁰ Connecticut Geospatial Information Systems Council. (2007). *Connecticut Geographic Framework Data*. Retrieved from http://www.ct.gov/gis/Connecticut_Framework_Data_Themes_Final_Report_111607.pdf#47746.

hazardous areas. By subsidizing insurance, mitigation programs, and disaster response and recovery, government at all levels currently pays for risky development. As a result, we believe that there is more risky development than is optimal and the best interests of society and the environment are not being served.

Managing the problem in the short run starts with floodplain management that sets rigorous, legally-defensible standards for coastal development. The NFIP minimum standards in many cases may not be good enough. Getting Connecticut municipalities to adopt floodplain management programs based on ASFPM's No Adverse Impact guidelines is a worthy, albeit ambitious goal. This requires, at minimum, improving relationships and communication with municipalities. This approach would be enhanced by the addition of technical support and funding. State mandated development standards and an incentive structure that rewards sound management and discourages development in hazardous areas would further improve management of coastal hazard areas.

Damage to existing residential and non-water-dependent development must be minimized without armoring the shoreline, which represents a loss of coastal resources, a loss of public access to the shore, and can often exacerbate hazards. In the short run, some of this work can be accomplished by raising inhabited structures and infrastructure,, overhauling septic systems, and pursuing non-structural erosion and flood control projects. In section 7.4.1 we offer specific recommendations for State management of coastal hazards in the short run. There is a lot of work that can be done at reasonable cost to the state and within the current political/legal framework.

Over the long run however, on a decadal timescale to 2100 and beyond, Connecticut is headed for a collision between rising seas and immovable, expensive private property, most of which is devoted to non-water-dependent residential development. The entire range of possible options for dealing with this problem has significant economic and/or environmental costs, no matter who pays for it. From a risk-management, with the goal of enforcing the Connecticut Coastal Management Act, we can conceptualize the range of possible outcomes, from lowest to highest risk, as follows:

Low: A mandated retreat such as a rolling easement or moving setback, whereby existing development and structures would have to be moved out of the path of rising seas. This option would require waterfront property owners, who are often wealthy and well-connected, to lose some or all of the considerable economic value of their property. This option would allow coastal resources to migrate landward to the extent possible, but would be very difficult to achieve in the face of current political and legal constraints.

Moderate: The purchase of rolling easements, rights-to-rebuild, or setbacks such that the public bears the cost of retreat. Especially if such purchases must be negotiated and not imposed through eminent domain (nearly impossible politically), there is not enough money available at any level of government to purchase such expensive property. There is not even enough funding to maintain existing publicly-owned infrastructure, or relocate it landward, let alone acquire at-risk private properties. It's possible that land prices may fall after a devastating storm, but it's likely that funding will be overwhelmingly allocated to reconstruction.

Status Quo: Continue to regulate waterfront sites on a case-by-case basis, using existing Coastal Management Act policies. This will be a continuing struggle, as it is now, with uncertain outcomes. Enforcement of the CCMA may become increasingly difficult as coastal development continues and property rights are vigorously defended.

High: Allow all existing development to be armored at the property owner's expense. Assuming the government refuses to pay for insurance costs and rebuilding costs after inevitable storm events, there is little budgetary cost to government for construction of flood protection. Regardless, the public will suffer the loss of any and all coastal resources that lie between open water and the armored shore.

The actual outcome will likely be some combination of the above, but the status quo or worse will probably prevail unless the State of Connecticut takes steps to control development in coastal hazard areas. To minimize costs to the public and protect coastal resources in the long run, the state should consider the recommendations outlined in section 7.4.2 below.

7.4 Management Recommendations for the State of Connecticut

Coastal Managers must address immediate threats like winter storms and hurricanes, and more the longer term but serious threats associated with sea level rise and changing storm activity. These threats are closely related, so actions to prepare for sea level rise and stronger/more frequent storms fifty years hence will surely help prepare for the immediate threat of hurricanes and winter storms. However, sea level rise will create permanently inundated areas and long-term problems that cannot be solved in the current legislative/policy framework. For the immediate threat of storms, however, there are certainly things that can be achieved immediately, within the current political and legal framework.

7.4.1 Managing Hazards in the Short Run

1. One of the simplest things the state can do is conduct outreach and education about coastal hazards to municipalities, and facilitate outreach and education between municipalities and their coastal residents. David Vallee, the Hydrologist-in-Charge at the National Weather Service in Taunton, MA, recently said, "The greatest obstacle to dealing with [the hurricane] risk is an inexperienced and complacent population."¹³¹
2. Beyond outreach and education, Connecticut must help towns. This assistance could come in many forms, and support many activities at the municipal level. An analysis of all possible assistance is beyond the scope and purpose of this report, but some examples include increasing technical assistance and funding for planning activities and flood and erosion mitigation projects, and giving legal support for towns seeking to tighten their floodplain management, zoning regulations, etc. to improve coastal hazards readiness. A logical place to start would be to devote more staff resources to assisting communities enroll in or augment the status of their NFIP or Community Rating System profiles.
3. A detailed spatial data inventory of critical infrastructure and key resources should be developed and a risk assessment developed for each piece of infrastructure and each key resource. Then the state can prioritize their

¹³¹ David Vallee, Hydrologist-in-Charge, National Weather Service, Taunton, MA., personal communication, November, 2008.

protection and create a plan for protecting them from the immediate threat of coastal storms and the longer term threat of sea level rise.

4. Continue to build partnerships and collaborations with other states and federal agencies. This helps get more leverage for funding and increase capacity for coastal hazards management and data collection. The Northeast Region Ocean Council (NROC) and the regional ocean observing associations (NERACOOS and MACOORA) are good examples of regional partnerships where the State and the University of Connecticut have provided leadership.
5. Require disclosure of flood and erosion hazards in real estate transactions. The flood hazard information should be based on the most up-to-date flood maps available, and it should include flood risks based on a category 3 hurricane and sea level rise projected out to 30 years or more. This information would inform potential property owners about the risks of living on the coast.

7.4.2 Managing Hazards in the Long Run:

1. Amend the Coastal Management Act to add climate change policies. Assess the potential effects of establishing legislative policies that explicitly establish retreat from the shore, with the understanding that private property is expected to be lost, as the primary response.
2. Establish statewide minimum setbacks from coastal waters or resources (particularly those able to migrate), based on demonstrated/predicted SLR rates, or tied to Mean High Water (which should be amended every tidal epoch). No new permanent structures should be allowed within setback area, but as an accommodation to landowners, towns could be required to assess the setback area at a reduced tax reduced rate.
3. Clarify the CCMA shoreline structures policies to ensure that structures are not used to protect property boundaries, but accept that existing residences and infrastructure may be armored if they can't be moved.
1. Provide municipalities with state-level mandates and funding for long-range planning activities. Leadership on climate change adaptation needs to flow from the State to municipalities. Town governments are too busy with immediate needs and may lack the resources and incentives to relocate infrastructure, acquire refugia sites or establish land-use policies that could impair waterfront property values. With a risk such as sea level rise that approaches gradually over several decades, the do-nothing option may seem attractive and even rational.

7.5 **Management Recommendations for Municipalities**

In Connecticut, with one of the strongest traditions of home rule in the nation, coastal management landward of the high-tide line is ultimately the responsibility of municipalities. Towns are also responsible for maintaining plans for natural disasters.

1. Municipalities should make sure their disaster management plans are complete, update their plans and conduct drills regularly. Towns should also post the plans on their website, and encourage their residents to become acquainted with them. For towns that have yet to complete their disaster plans, The StormSmart Coasts website¹³² is a comprehensive guide to coastal hazards management for municipal officials. It has a list of items that typical storm response plans should include, and a link to FEMA resources for municipalities who wish to create or update their plans.
2. Towns should communicate the risks of coastal hazards to their residents. This can be done with mailings, meetings, special events, etc. The StormSmart Coasts website has concrete ideas for outreach and education and links to outreach materials. Again, Connecticut's coastal population is dangerously inexperienced and unaware of the risk of hurricanes and the dangers inherent in smaller but more frequent storms.
3. Municipalities should assess the vulnerabilities of their land, buildings, and infrastructure and look for ways to minimize exposure to risk and mitigate potential damages from coastal hazards and the exacerbating effects of climate change. The Association of State Floodplain Managers (ASFPM) has created a Coastal No Adverse Impact handbook¹³³ for coastal municipalities who want to better protect people, structures, infrastructure, while simultaneously protecting property rights. Again, StormSmart Coasts is an easy-to-use website, geared for coastal municipal officials, with plenty of practical information and guidance for responsible coastal floodplain management.
4. All of Connecticut's towns should enroll in the Community Rating System. Due to State-wide programs already in place (e.g. Dam Safety Program), all Connecticut towns earn enough points to qualify for at least a 5% discount on NFIP premiums. Many towns may already be doing things that qualify them for more points and discounts. As a loftier goal, adopting ASFPM No Adverse Impact guidelines would make individual NFIP policy holders eligible for significant flood insurance premium discounts under the Community Rating System

7.6 Actions for Home and Business Owners

Property owners should familiarize themselves with their town's natural disaster/emergency management plans, so they know what to do to prepare for a storm and evacuate if necessary. They should also consult the FEMA Flood Insurance Rate Maps for their town to find out if their property is located in a floodplain, and if so, what

¹³² <http://stormsmartcoasts.org/>

¹³³ Association of State Floodplain Managers. (2007). *No Adverse Impact in the Coastal Zone*. Retrieved from <http://www.floods.org>.

flood zone it is in. If they don't have flood insurance already, they should purchase it through the National Flood Insurance Program.

Beyond these basic steps, property owners in flood zones may wish to take action to protect their property from damage. Short of relocating it, there are steps they can take to floodproof their home or business. Floodproofing involves keeping water out of the building and reducing the amount of damage possible when water does get in. Keeping water out can be accomplished by installing temporary or permanent closures or raising the structure - adding "freeboard". To minimize damage when water does get in the structure, homeowners must elevate utility infrastructure and valuable belongings. The authoritative guide for these techniques is FEMA's Coastal Construction Manual. Another good resource for homes and businesses preparing for natural disasters--especially storms and flooding--is the website of the Institute for Business and Home Safety.¹³⁴ It provides a number of suggestions for flood damage mitigation, including critical preparations like anchoring fuel tanks and raising electrical components. The USACE also provides guidance for floodproofing structures.¹³⁵

Creating "freeboard" for a new or existing structure involves elevating the lowest floor above predicted flood elevations by a small additional height (generally 1-3 feet above NFIP minimum height requirements). There are many reasons why flood heights indicated by FIRMs might be wrong, including poor elevation data, sea level rise, and changes in the developed landscape and hydrology. Flooding from storms can easily exceed the minimum flood elevations indicated by FIRMs. Freeboard provides a safety buffer against these uncertainties, and can significantly reduce flood insurance premiums, sometimes paying for the cost of elevating the home within a few years.¹³⁶

Lastly, property owners can encourage municipal elected officials to make protecting and improving public infrastructure from storms and flooding a priority. Also, encourage local officials to enroll in the Community Rating System to save money on flood insurance and reduce the risk of flood hazards.

¹³⁴ <http://www.disastersafety.org/>

¹³⁵ US Army Corps of Engineers. (1995). *Hurricane and Storm Damage Reduction Study*. Boston, MA: US Army Corps of Engineers, New England Division.

¹³⁶ See the freeboard primer at <http://www.mass.gov/czm/stormsmart/regulations/freeboard.htm> for more information.

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9 Appendix

9.1 Acronyms used in this Report:

ALERT- Automated Local Evaluation in Real Time
AR4- Fourth Assessment Report (from the IPCC)
ASCE- American Society of Civil Engineers
ASFPM- Association of State Floodplain Managers
BFE- Base Flood Elevation
CAP-SSSE- Community Assistance Program- State Support Services Element
CAV- Community Assistance Visit
CCMA- Connecticut Coastal Management Act
CGS- Connecticut General Statutes
CLEAR- Center for Land Use Education and Research
CODAR- Coastal Ocean Dynamics Applications Radar
CRS- Community Rating System
CT- Connecticut
CT DEP- Connecticut Department of Environmental Protection
CT DEP-IWRD- Connecticut Department of Environmental Protection Inland Water Resources Division
CT DEP-OLISP- Department of Environmental Protection Office of Long Island Sound Programs
CT DOI- Connecticut Department of Insurance
CT DOT- Connecticut Department of Transportation
CZMA- Coastal Zone Management Act
DEM- Digital Elevation Model
DEMHS- Department of Emergency Management and Homeland Security (CT)
DFIRM- Digital Flood Insurance Rate Map
FECB- Flood and Erosion Control Board
FEMA- Federal Emergency Management Agency
FIRM- Flood Insurance Rate Map
FIS- Flood Insurance Study
FMA- Flood Mitigation Assistance
FMP- Flood Mitigation Program
GHG- Greenhouse Gas
GIS- Geographic Information Service
GPS- Global Positioning System
HAZUS-MH- Hazards United States Multi-Hazard
HMGP- Hazard Mitigation Grant Program
IBC- International Building Code
IPCC- Intergovernmental Panel on Climate Change
IRC- International Residential Code
LiDAR- Light Detection and Ranging
LIS- Long Island Sound
LISICOS- Long Island Sound Integrated Coastal Observing System
LISRC- Long Island Sound Resource Center

LISS- Long Island Sound Study
LOMA- Letter of Map Amendment
LOMC- Letter of Map Change
MACOORA- Mid-Atlantic Coastal Ocean Observing Regional Association
MAP MOD- Map Modernization
MEOW- Maximum Envelope of Water
MHHW- Mean Higher High Water
NAVD88- North American Vertical Datum of 1988
NED-National Elevation Dataset
NERACOOS- Northeast Regional Association of Coastal Ocean Observing Systems
NESEC- Northeast States Emergency Consortium
NFIP- National Flood Insurance Program
NGVD29- National Geodetic Vertical Datum of 1929
NHC- National Hurricane Center
NHMP- Natural Hazards Mitigation Plan
NOAA- National Oceanic and Atmospheric Administration
NOS- National Ocean Service
NROC- Northeast Region Ocean Council
NWS- National Weather Service
PDM- Pre-Disaster Mitigation
SFHA- Special Flood Hazard Area
SLOSH- Sea, Lake, and Overland Surge from Hurricanes
SLR- Sea Level Rise
UCONN- University of Connecticut
UN- United Nations
USACE- United States Army Corps of Engineers
USGS- United States Geological Survey

9.2 Definitions

Astronomical Tides- Very long-period waves that move through the oceans in response to the forces exerted by the moon and sun. Tides originate in the oceans and progress toward the coastlines where they appear as the regular rise and fall of the sea surface. When the highest part, or crest of the wave reaches a particular location, high tide occurs; low tide corresponds to the lowest part of the wave, or its trough. (http://oceanservice.noaa.gov/education/kits/tides/tides01_intro.html)

Bulkhead- Wall or other structure, often of wood, steel, stone, or concrete, designed to retain or prevent sliding or erosion of the land.

Coastal Flooding- A temporary rise in sea level due to wind, low barometric pressure, astronomical high tides, or waves.

Erosion- Wearing away of land by natural forces.

Floodplain- Any land area susceptible to being inundated by floodwaters from any source. (http://www.floodsmart.gov/floodsmart/pages/glossary_A-I.jsp#F)

Freeboard- A factor of safety usually expressed in feet above a flood level for purposes of floodplain management. "Freeboard" tends to compensate for the many unknown

factors that could contribute to flood heights greater than the height calculated for a selected size flood and floodway conditions, such as wave action, bridge openings, and the hydrological effect of urbanization of the watershed. Freeboard is not required by NFIP standards, but communities are encouraged to adopt at least a one-foot freeboard to account for the one-foot rise built into the concept of designating a floodway and the encroachment requirements where floodways have not been designated. Freeboard results in significantly lower flood insurance rates due to lower flood risk.

<http://www.fema.gov/plan/prevent/floodplain/nfipkeywords/freeboard.shtm>

- Groin- A short, shore-perpendicular structure designed to trap littoral sediments.
- Jetty- Wall built out into the water to restrain currents or protect a structure. (FEMA)
- Littoral Transport- The movement of sediment (mud, sand, silt, gravel) waves and currents. Includes movement parallel (longshore transport) and perpendicular (onshore-offshore transport) to the shore.
- Mean High Water (MHW)- The average high tide level at a particular location, usually determined from hourly height observations at a permanent tide gauge over the National Tidal Datum Epoch.
- Mean Sea Level (MSL)- Average height of the sea for all stages of the tide at a particular location. MSL is usually determined from hourly height observations at a permanent tide gauge over the National Tidal Datum Epoch.
- National Tidal Datum Epoch (NTDE)- The specific 19-year period adopted by the National Ocean Service as the official time segment over which tide observations are taken and reduced to obtain mean values (e.g., mean lower low water, etc.) for tidal datums. It is necessary for standardization because of periodic and apparent secular trends in sea level. The present NTDE is 1983 through 2001 and is actively considered for revision every 20-25 years.
- NAVD88- North American Vertical Datum of 1988. A vertical control datum designed to replace NGVD29.
- NGVD29- National Geodetic Vertical Datum of 1929. (Known as the Sea Level Datum prior to 1976).
- Revetment- Facing of stone, cement, sandbags, or other materials placed on an earthen wall or embankment to protect it from erosion or scour caused by flood waters or wave action.
- Saffir-Simpson Hurricane Intensity Scale: A system, developed by the National Weather Service, of classifying hurricanes according to intensity:

Saffir-Simpson Hurricane Intensity Scale		
Category	Windspeed (mph)	Storm Surge (ft)
5	>155	>18
4	131-155	13-18
3	111-130	9-12
2	96-110	6-8
1	74-95	4-5
Tropical Storm	39-73	0-3
Tropical Depression	0-38	0

Seawall- Solid, usually vertical barricade designed to prevent erosion and protect property from waves and flooding. (FEMA)

SFHA- Special Flood Hazard Area. A FEMA-identified high-risk flood area where flood insurance is mandatory for properties. An area having special flood, mudflow, or flood-related erosion hazards, and shown on a Flood Hazard Boundary Map or a Flood Insurance Rate Map as Zone A, AO, A1-A30, AE, A99, AH, AR, AR/A, AR/AE, AR/AH, AR/AO, AR/A1-A30, V1-V30, VE, or V.

http://www.floodsmart.gov/floodsmart/pages/glossary_S-Z.jsp#S).

Spring Tide- A tide roughly coincident with full or new moon. During the full and new moon phases of the moon, the sun, moon and earth are roughly in line with each other. Tides occurring when the moon is new or full are called spring tides. They are generally characterized by high tides that are higher than normal and low tides that are lower than normal. Flood- An overflowing of water onto normally dry land.

Storm Surge- A temporary increase in the height of the local sea level, formally defined as the difference between the observed water level and expected water level in the absence of the storm, according to the normal astronomical tide. Storm surge is caused by low atmospheric pressure and onshore winds pushing water towards shore.

Tidal Current- A horizontal movement of water caused by the rising and falling of the tide.

Tidal Range- The difference in height between high and low tide.