Attachment 2: Coastal Flood Hazards

Old Saybrook Coastal Resilience and Adaptation Study **GZA**

Coastal Flood Hazards

Flooding within the Chalker Beach Neighborhood during Hurricane Sandy in 2012 (from CT Mirror File Photo February 7, 2014)

Old Saybrook's coastal flood hazards include: tides, storm surge, waves, wind and precipitation. The risks associated with each of these hazards will increase due to climate change, in particular the effects of sea level rise.

This attachment presents information that provides the basis for: 1) understanding coastal flooding at Old Saybrook, including the probability, frequency and extent of coastal floods; and 2) evaluating the vulnerability of Town neighborhoods, assets and natural resources. The report attachment presents:

- Overview: An overview of Old Saybrook's coastal setting, topography and shoreline features. Evaluation of the coastal setting sets the stage for understanding Old Saybrook's vulnerability to coastal floods.
- Tides: Tides and tidal flooding details.
- Extreme Water Levels: Published flood studies as well as the results of GZA computer simulations of extreme flood events.
- Sea Level Rise: The effects of sea level rise on tides and extreme floods.
- Precipitation Data: NOAA Atlas 14 predicted precipitation rates by return period and duration.
- Additional Climate Change Considerations: Additional considerations including predicted changes to air and water temperature.

To evaluate the coastal flood hazards at Old Saybrook, GZA performed:

1. a metocean analysis of observed wind, wave and water level data.
2. review of published flood hazard data including.
   a. the Federal Emergency Management Agency (FEMA) effective Flood Insurance Rate Map (FIRM) and the FEMA Flood Insurance Study (FIS);
   b. the National Oceanic and Atmospheric Agency (NOAA) tide gage data; and
   c. the U.S. Army Corps of Engineers (USACE) North Atlantic Coast Comprehensive Study (NACCS).
3. review of USACE and National Oceanic and Atmospheric Agency (NOAA) sea level rise projections.
4. numerical hydrodynamic modeling of tides, storm surge and waves using the Advanced Circulation Model (ADCIRC) and the Simulating WAves Nearshore (SWAN) models.

Flooding due to local intense precipitation (LIP) and stormwater run-off are a source of flooding. LIP events often occur during storms that also include storm surge and waves. Flooding due to precipitation, including the capacity of the existing stormwater infrastructure to provide drainage, was not evaluated as part of this study.

Coastal Setting

Old Saybrook is located where the Connecticut River meets Long Island Sound. **Figure 2-1** identifies Old Saybrook's coastal features.

Location: Old Saybrook is located within Middlesex County in south-central Connecticut on a peninsula along the northern shore of Long Island Sound. Old Saybrook is bounded to the south by Long Island Sound, to the east by the Lower Connecticut River, to the west by the town of Westbrook and to the north by the town of Old Essex.

Characteristics: Old Saybrook has the typical physical characteristics of a Long Island Sound coastal town, with uplands bordered by low-lying areas, tidal wetlands, salt marshes, tidal flats, and beaches. Old Saybrook has over 23 linear miles of shoreline abutting Long Island Sound (6 miles) and the Connecticut River (17 miles). The total area of Old Saybrook (excluding the North and South Cove coastal embayments) is about 15.2 square miles. The areas to the south of Interstate 95 are low-lying, consisting mostly of tidal marsh and coastal plain. The area to the north of Interstate 95 consists of rolling hills of bedrock and glacial till, with a network of valley streams and inland wetlands.

Beaches: Old Saybrook's southern shoreline consists of a series of beaches. Moving from west to east, are Chalker Beach, BelAire Manor Beach, Saybrook Manor Beach, Indiantown Beach, Great Hammock Beach, Harvey Beach, Town Beach (Plum Bank), Cornfield Point Beaches and Knollwood Beach.

Shoreline Structures: As shown on **Figure 2-2**, Old Saybrook's shoreline is extensively developed with hard coastal structures including piers, groins, revetments and bulkheads.

Harbors: There are several Town harbors and marinas, including Indiantown, a dredged channel and harbor with breakwaters; the Harbor One Marina located at the intersection of College Street and Bridge Street (Rt. 154); and five marinas located to the north of the Amtrak railway on the Connecticut River (Island Cove, Oak Leaf, Between the Bridges and Ragged Roak Marinas). A mooring field is also located in the North Cove.

Embayments: There are two large embayments (North and South Cove) along the Old Saybrook coastline with the Connecticut River. The embayments were natural coves that have been altered by the construction of a bridge (South Cove) and construction of shoreline structures (North Cove) along their mouths. These structures have affected the natural tidal flow, resulting in sedimentation.

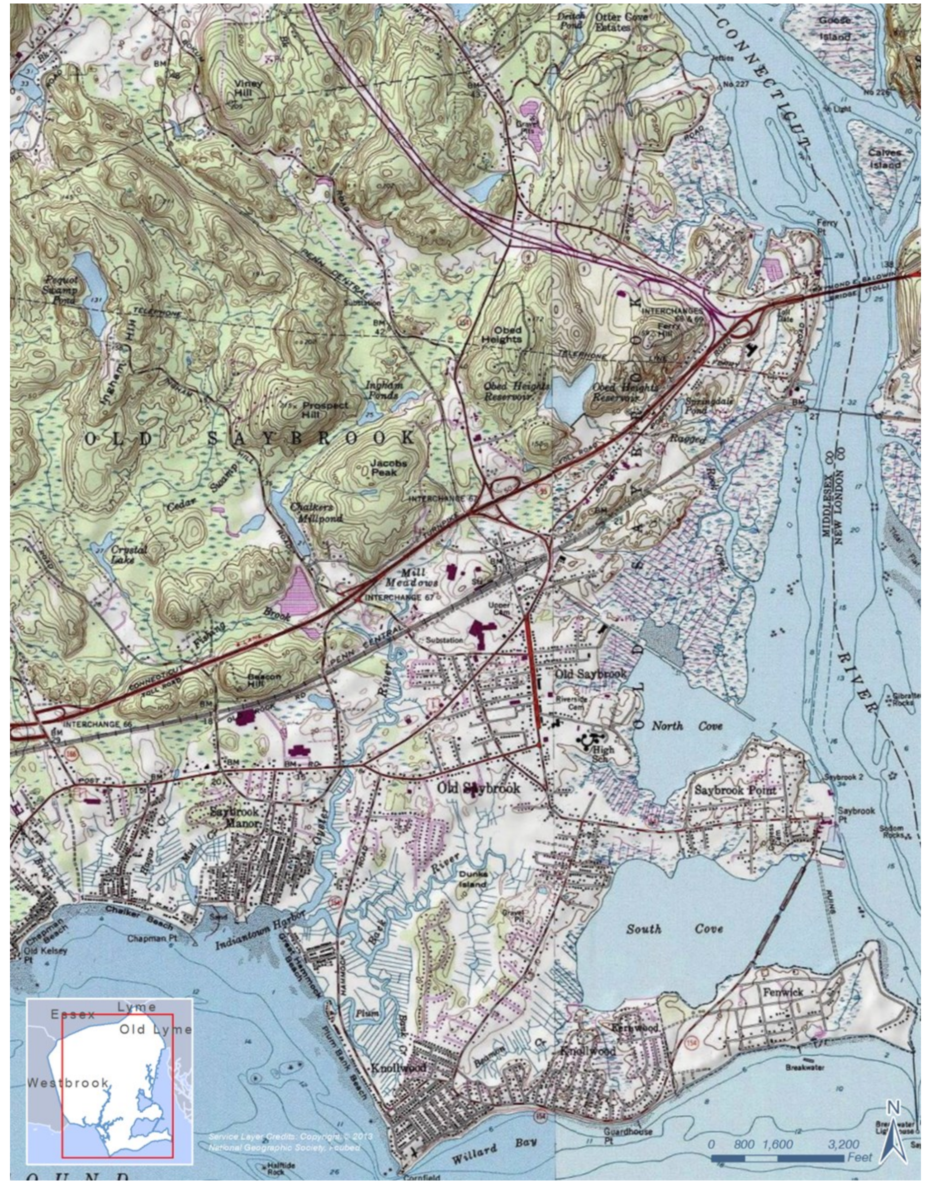


Figure 2-1: USGS Topographic Map Highlighting Coastal Features

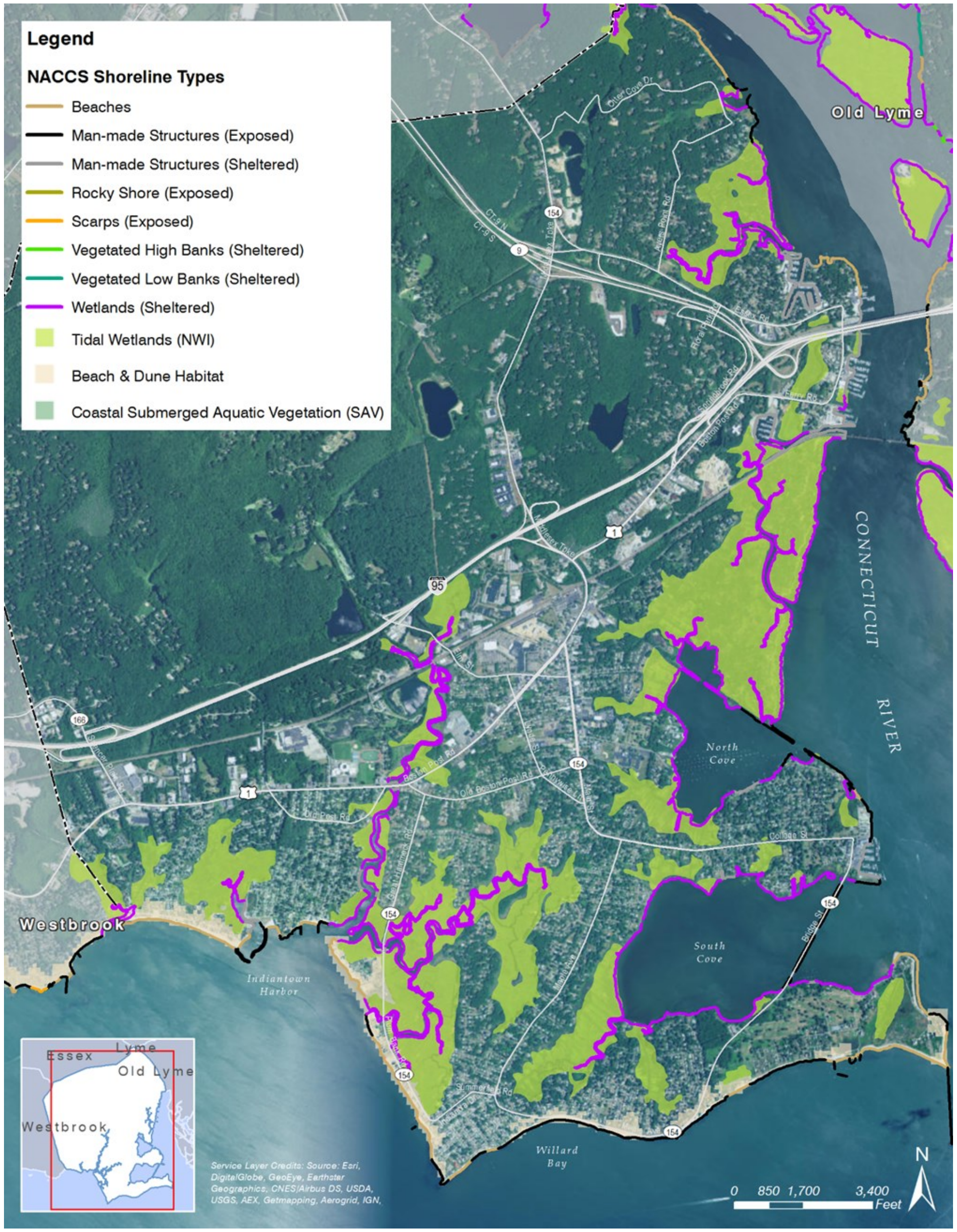


Figure 2-2: Old Saybrook Shoreline Features

Topography and Geology

Topography (the ground surface elevation and land form, relative to sea level) is one of the most significant factors that contribute to the vulnerability of Old Saybrook to flooding due to tides, coastal storm surge and sea level rise.

The most current Connecticut high resolution LiDAR (Light Detection and Ranging) topographic survey was utilized for this study. **Figure 2-3** presents color imagery reflecting the change in ground surface elevation within Old Saybrook based on the high-resolution LiDAR survey data. The colors are differentiated by ground surface elevation, relative to the North American Vertical Datum (NAVD88). NAVD88 is the datum used by FEMA, by the State, and by the Town of Old Saybrook. All elevations presented in this plan reference NAVD88.

Figure 2-4 presents the surficial geology of Old Saybrook. The surficial geologic features and materials are the result of glacial and postglacial actions. About 20,700 years ago, Glacial Lake Connecticut covered the area that currently is Long Island Sound. The freshwater lake consisted of meltwater run-off from the retreating glacial Laurentide Ice Sheet, which (at that time) covered most of Connecticut. Sea level was about 300 feet lower than it is today and the Atlantic shoreline was about 7.5 miles to the south of current-day Long Island Sound. As shown on Figure 2-3, the geologic materials to the north of Interstate 95 (I-95) consist predominantly of glacial till - ice laid deposits of dense mixed sand, silt, gravel and cobbles. To the south of I-95, the surficial geologic materials consist of sand and gravel glacial lake meltwater deposits and glacial moraine deposits and postglacial beach and dune deposits, tidal marsh deposits and artificial fill.

The topographic elevation data presented in **Figure 2-3** clearly delineates the transition from the upland portions of Old Saybrook (which are defined by bedrock and the ice-laid glacial till hills and valleys) to the southern coastal low-lying areas which are defined by the coarse-grained glacial meltwater deposits (sand and gravel) and salt marsh and tidal marsh deposits (peat and muck interbedded with sand and silt). The low-lying areas (which are reflected by the red to yellow colors, corresponding to elevations ranging from less than 1 foot to about 8 to 9 feet NAVD88) are dominated by tidal marsh and wetlands systems and the low elevation land areas abutting the tidal marshes and wetlands. Certain low elevation areas (near the shoreline) consist of former marsh areas that have been artificially filled. The areas located within the southern portion of Old Saybrook, characterized by blue, represent areas with thick deposits of sand and gravel glacial meltwater deposits and correspond to higher ground surface elevation (generally on the order of Elevation 10 to 15 feet NAVD88).

The tidal marsh and wetlands systems are developed around waterways (brooks, creeks and rivers), and are hydraulically connected to the Lower Connecticut River and the Long Island Sound. The tidal marsh and wetland systems are primarily irregularly flooded "high marsh". These areas are periodically inundated due to astronomically high tides and storm-related flood events. The marshes are channelized, with the channels regularly inundated due to tides. The marshes are also primary points of entry for inland flooding due to coastal storm surge. GZA computer simulations of flooding during a 100-year return period coastal flood, presented later in this attachment, demonstrate how these low-lying areas contribute to flooding of the inland areas of Old Saybrook during coastal storms.

Beaches, including beach communities, also represent low-lying Town areas. These areas are directly inundated by coastal flooding, including tides, storm surge and waves.

Tides

Tides are the daily rise and fall of the Earth's waters by long period waves that move through the oceans in response to astronomical gravitational forces, predominantly exerted by the moon and sun. The tides in Long Island Sound, including Old Saybrook, are diurnal, which means that during each lunar day (24 hours and 50 minutes) there are two high tides and two low tides. The high and low tides elevations vary during a daily tide cycle and over a lunar cycle.

Tidal datums are used to define tide elevations and include:

- Mean High Water (MHW), which represents the average of the two high tides over the "National Tidal Datum Epoch" (the 19 years between 1983 and 2001);
- Mean Low Water (MLW), which is the average of the two low tides;
- Mean Higher High Water (MHHW), which is the average of the higher of the two high tides during each tidal day observed over the National Tidal Datum Epoch;
- Mean Lower Low Water (MLLW), which is the average of the lower of the two low tides over the same time period;
- Mean Sea Level, which is the arithmetic mean of all hourly heights over the National Tidal Datum Epoch;
- The mean range of tide (MN), which is the difference between the Mean High Water and the Mean Low Water; and

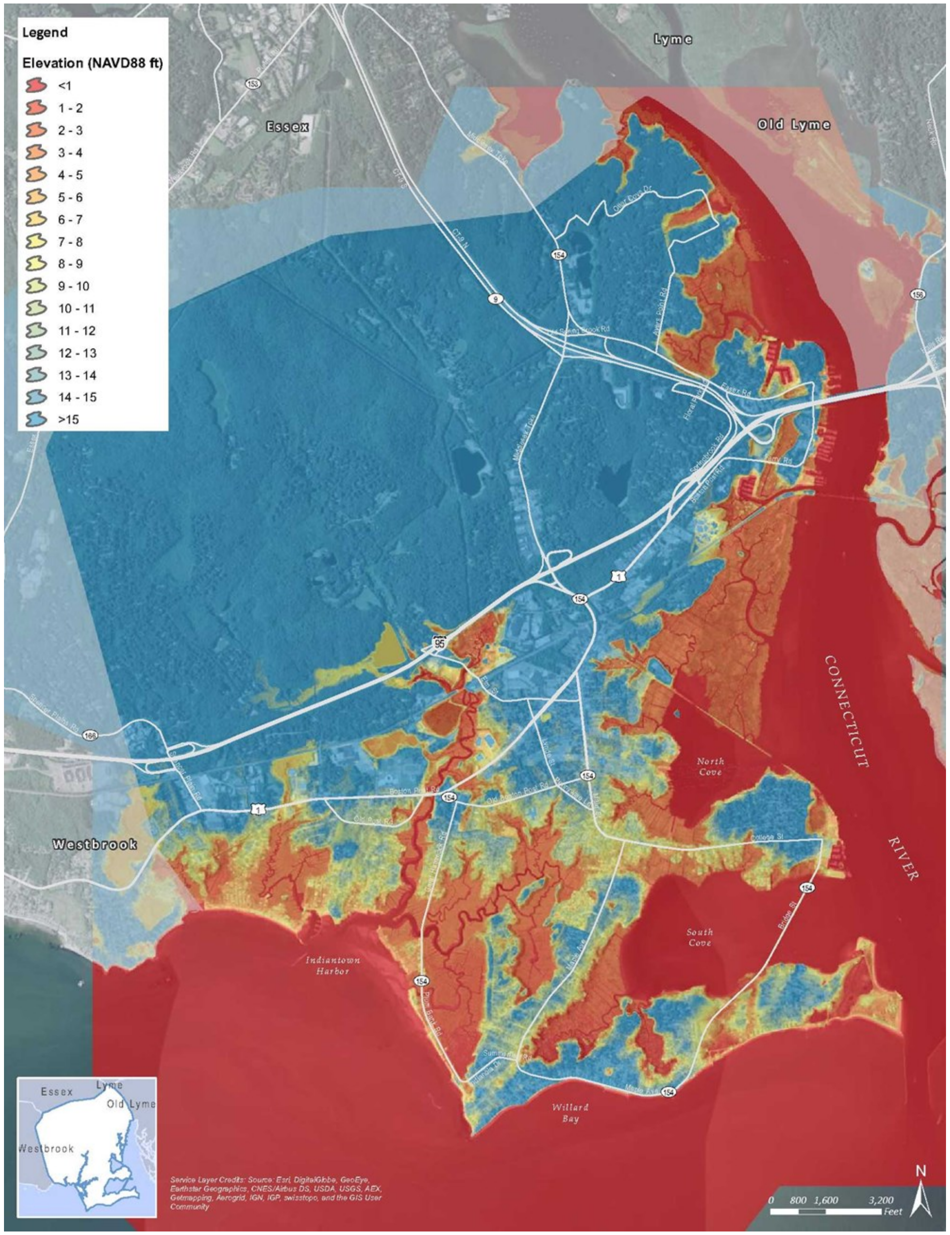


Figure 2-3: Digital Elevation Data based on Current Connecticut LiDAR

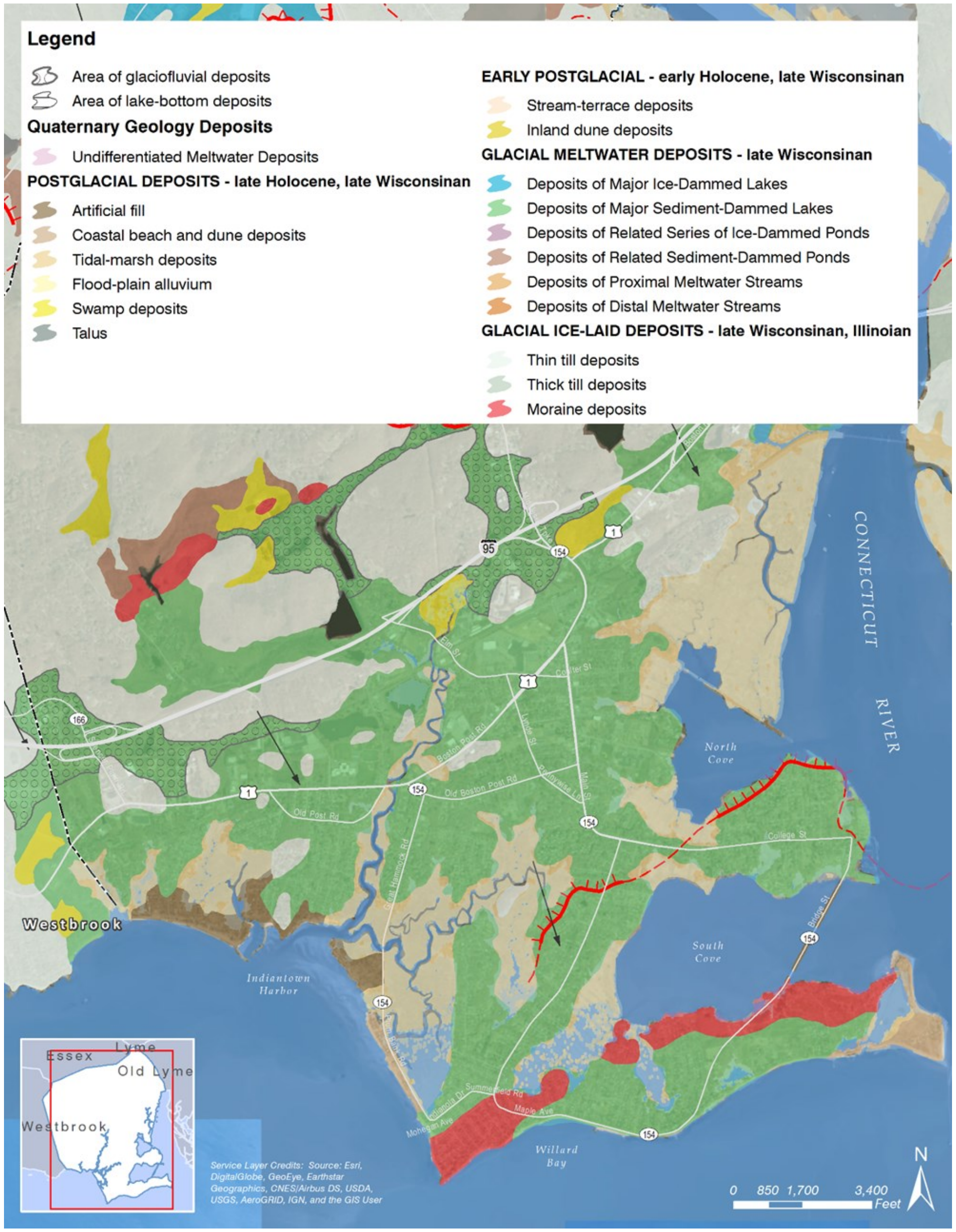


Figure 2-4: Old Saybrook Geologic Map

- Highest Astronomical Tide (HAT), which is the highest level predicted to occur under average meteorological conditions and any combination of astronomical conditions.

Tidal datums are developed based on observed water level data during the current National Tidal Datum Epoch at NOAA tide stations (the 19-year period between 1983 and 2001). NOAA tide stations are present at New London and Bridgeport, Connecticut. The NOAA tide gage at New London, CT (NOAA Station 8461490) provides a detailed record of water levels and tides applicable to Old Saybrook over the last, approximately, 80 years (1938 to 2016).

The mean range of tide (MN) at New London, the difference in height between the MHW and the MLW, is 2.57 feet. The current tide elevations, relative to the NAVD88 datum, at New London are indicated in Table 2-1. Tide corrections from the New London Tide Gage to Saybrook Point are 1.24 * New London (High Tide) and 1.25 * New London (Low Tide). Corrected values at Old Saybrook are indicated in parenthesis in **Table 2-1**.

Tide Condition	Elevation (ft); NAVD88
Highest Astronomical Tide (HAT)	2.04
Mean Higher-High Water (MHHW)	1.21 (1.5)
Mean High Water (MHW)	0.92 (1.14)
Mean Tide Level (MTL)	-0.36 (-0.33)
Mean Sea Level MSL)	-0.30 (-0.28)
Mean Diurnal Tide Level (MDTL)	-0.31(-0.22)
Mean Low Water (MLW)	-1.65 (-2.10)
Mean Lower-Low Water (MLLW)	-1.84 (-2.3)

Table 2-1: Tide Datum Elevations at New London (interpolated to Old Saybrook tides)

Sea Level Rise

Sea Level Rise (SLR) is the rise of global ocean waters. Relative SLR change (RLSC) is the drainage of sea level relative to the adjacent land mass and is unique to a given geographic location. RSLC is caused by several factors, including: 1) ground settlement due to post-glacial isostatic adjustment; 2) warming of ocean waters, resulting in volume expansion; 3) increase in ocean volumes due to melting Arctic and land ice; 4) ocean density gradients due to the infusion of lower density fresh water; and 5) changes to global ocean circulation patterns (e.g., the Gulf Stream and Labrador Current).

As shown in **Figure 2-5**, the observed RSLC at the NOAA New London station, over the last approximately 80 years, indicates a mean sea level rise trend of 2.55 millimeters (mm) per year (with a 95% confidence interval of +/- 0.23 mm per year) (2.55 mm/yr = 0.10 inch/year).

Compared to Global Sea Level Rise. Over the last century, sea levels along the New England coast have risen faster than the global mean rate (which is about 1.7 to 1.8 mm per year). In fact, the observed sea level rise along the Northeast coast (from Mid-Atlantic region to Boston) is experiencing some of the largest rates of sea level rise in the world. This has been due, in part, to post-glacial land subsidence (glacial isostatic adjustment). Consistent with global sea level rise, other factors include increases in the ocean volume (due to glacial ice melt) and thermal expansion (due to increasing sea temperatures). Recent studies (Geophysical Research Letters, 2013), however, attribute the recent significant increase in the rate of sea level rise along the New England coast to ocean dynamics, specifically the effects and movement of the Gulf Stream and its interaction with cold, less dense water flowing down from Greenland.

Sea Level Rise Uncertainty

While the sea level of Long Island Sound is clearly rising, predicting the future rate of sea level rise is complex, highly uncertain, and dependent on many unknown factors (such as future emissions of greenhouse gases, rate and amount of ice melt, etc.).

NOAA and the USACE have developed ranges of RSLC for use on federal projects in the United States. The 2013 USACE projections, used for the Study, range from Low to Intermediate to High. The USACE Low projections are generally consistent with the observed historical rates of RSLC. Observed RSLC over recent years indicate a trend of increased rates. As indicated in **Figure 2-6,** recent projections adopted by NOAA indicate the potential for even higher RSLC. The predicted sea level rise at New London between the years 2017 and 2116 (based on projections at NOAA tide station 8467150 at Bridgeport, CT and USACE 2013/NOAA2012 projections) are summarized in **Table 2-2** and Figure 2-5 below (in feet relative to the NAVD88 elevation datum). These projections were developed using the USACE Sea Level Change Curve Calculator (version 2017.42) and are based on USACE 2013/NOAA 2012 projections.

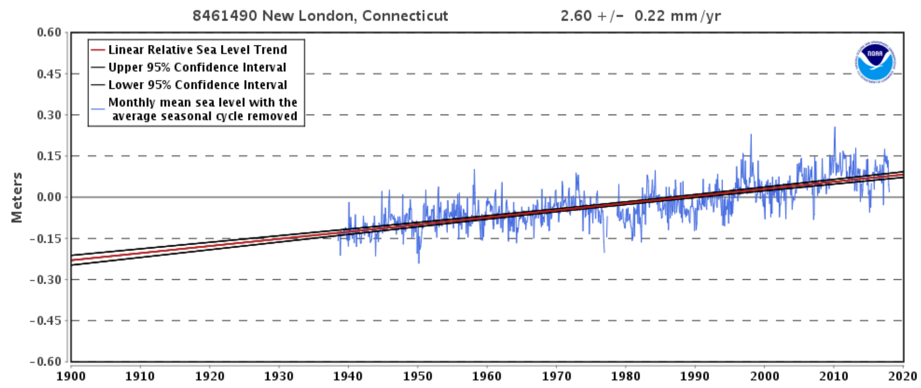


Figure 2-5: Observed Sea Level Rise at New London, Connecticut

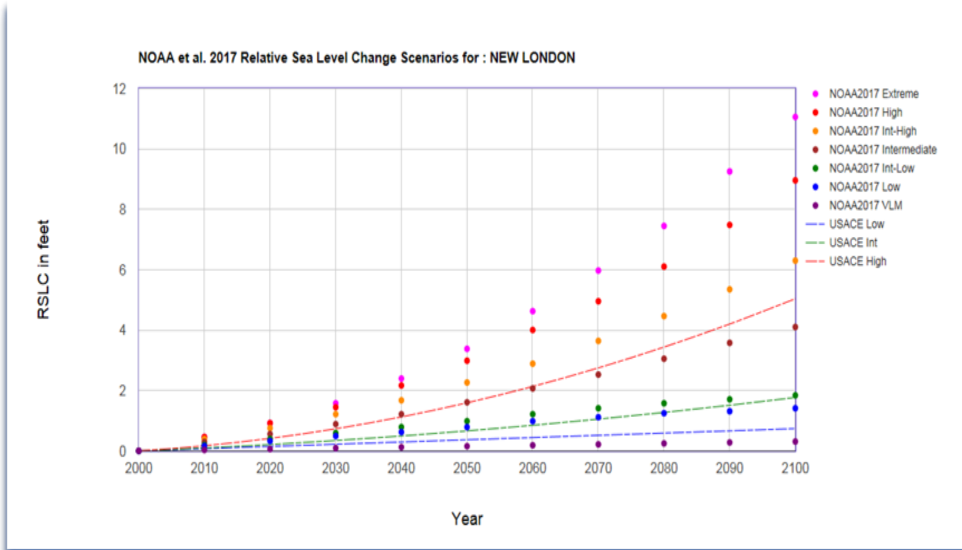


Figure 2-6: Sea Level Rise Projections (using the USACE Relative Sea Level Change Calculator for USACE2013/NOAA 2012 projections)

Year	NOAA (LOW)	USACE (LOW)	NOAA (INT-LOW)	USACE (INT)	NOAA (INT-HIGH)	USACE (HIGH)	NOAA (HIGH)
2017	-	-	-	-	-	-	-
2040	0.17	0.17	0.32	0.32	0.65	0.79	1.03
2050	0.13	0.13	0.43	0.43	1.09	1.38	1.85
2070	0.39	0.39	0.88	0.88	1.95	2.42	3.18
2100	0.61	0.61	1.59	1.59	3.77	4.71	6.25

Table 2-2: Sea Level Rise Projections (using the USACE Relative Sea Level Change Calculator for USACE 2013/NOAA 2012 projections; relative to the year 2017)

The NOAA sea level rise projections were revised subsequent to completion of GZA's analysis but prior to completion of the Study report. NOAA 2017 projections (mean values) are presented in **Figure 2-5** and **Table 2-3**. The USACE 2013 projections are shown for comparison. NOAA 2017 utilizes six descriptive categories: VLM (representing vertical land movement); Low; Intermediate-Low; Intermediate; Intermediate-High; High; and Extreme.

Year	NOAA (VLM)	NOAA (LOW)	NOAA (INT-LOW)	NOAA (INT)	NOAA (INT-HIGH)	NOAA (HIGH)	NOAA (Extreme)
2017	-	-	-	-	-	-	-
2040	0.06	0.29	0.46	0.88	1.34	1.84	2.07
2050	0.09	0.46	0.65	1.28	1.93	2.66	3.05
2070	0.16	0.79	1.08	2.20	3.31	4.62	5.64
2100	0.25	1.08	1.51	3.77	5.97	8.63	10.73

Table 2-3: Sea Level Rise Projections (using the USACE Relative Sea Level Change Calculator for NOAA et. al. 2017 projections; relative to the year 2017)

Table 2-3 presents the NOAA 2017 mean projections, interpolated from the year 2017. (These interpoltaions assume a RSLC of about 0.33 feet between the years 2000 and 2017.) **Table 2-4** presents estimated exceedance probabilities associated with the six NOAA 2017 projections (shown in Figure 2-5) for several possible future climate climate scenarios (Representative Concentration Pathways RCP 2.6, RCP 4.5, RCP 8.5) adopted by the Intergovernmental Panel on Climate Change (IPCC) for its fifth Assessment Report (AR5).

In general, the median "Intermediate-Low" is considered appropriate as an "analysis and planning lower bound" and either the median "Intermediate" or median "Intermediate-High" is appropriate as an "analysis and planning upper bound".

GMSL Rise Scenario	RCP 2.6	RCP 4.5	RCP 8.5
Low (0.3 m)	94%	98%	100%
Intermediate-Low (0.5 m)	49%	73%	96%
Intermediate (1.0 m)	2%	3%	17%
Intermediate-High (1.5 m)	0.4%	0.5%	1.3%
High (2.0 m)	0.1%	0.1%	0.3%
Extreme (2.5 m)	0.05%	0.05%	0.1%

Table 2-4: Probability of Exceeding Global Mean Sea Levels in 2100 for Several Representative Concentration Pathways (RCP) Scenarios (reproduced from "Global and Regional Sea Level Rise Scenarios for

The variance between the NOAA, 2017 projections increases significantly by mid-century. The NOAA 2017 Intermediate-Low projection has a high (possible to certain) likelihood of occurrence (49% to 96% by 2100). The NOAA 2017 Intermediate projection has low to moderate (possible to certain) liklihood of occurrence (2% to 17% by 2100). The NOAA 2017 Extreme GMSL scenario is a worst case scenario. For the New London area, the Extreme RSLC scenario for the year 2100 is about 11 feet. Note that the probabilities presented here are approximate; however, they are appropriate for use in understanding the risk of different sea level rise scenarios and planning.

The 2013 USACE projections, the latest projections available at the time of GZA's analyses, were used to model flooding for the Study. The exceedance probabilities associated with the USACE projections can be approximated using Table 2-5 as a guide along with the following: USACE 2100 RSLC High (lies between the NOAA 2017 Intermediate-High and Intermediate); USACE 2100 RSLC Intermediate (close to NOAA 2017 Intermediate-Low); USACE 2100 RSLC Low (between NOAA 2017 Low and VLM). At mid-century (2050) the USACE 2050 High RSLR is consistent with NOAA 2017 Intermediate; the 2050 USACE Intermediate is consistent with the NOAA 2017 Low. As an approximate guide, the 2100 USACE High RSLC projection has a very low to moderate chance of occurrence (exceedance probabilities of 0.4% to 17%) and the USACE Intermediate RLSC projection has a possible to certain chance of occurrence (exceedance probability of 49% to 100%).

The State of Connecticut, in PA 13-179, "An Act Concerning the Permitting of Certain Coastal Structures by the Department of Energy and Environmental Protection" references NOAA CPO-1 report (an earlier NOAA report, dated December, 2012) and requires that State and Municipal Plans of Conservation and Development, Civil Preparedness Plans and Municipal Hazard Mitigation Plans must "consider" the sea level change scenarios from the NOAA CPO-1 report. PA 13-179 also charged the University of Connecticut, Department of Marine Science to update the NOAA CPO-1 projections every 10 years based on local conditions and the state of the science.

Based on verbal communication with the University of Connecticut, we understand that forthcoming updates to the NOAA COP-1 projections will result in recommendations as follows: 1) for mid-range planning, assume that sea level will be 1.7 feet higher than the national tidal datum in Long Island Sound by the year 2050 (relative to the year 2000); 2) planners should be aware that the rate of sea level is expected to continue to increase, with a 3.25 feet rise in sea level by 2100; and 3) greenhouse gas emissions will be monitored and new assessments will be developed at decadal intervals. These recommended values are close to the NOAA 2017 Intermediate projections (see **Table 2-3**). They are also reasonably represented by the 2013 USACE High projections. See **Tables 2-2** and **2-3** for projections relative to the year 2017.

The report "Global and Regional Sea Level Rise Scenarios for the United States"; NOAA Technical Report NOS CO-OPS 083; January, 2017 (NOAA, 2017) presents general guidance about selection of projections for planning purposes. One planning approach is to: 1) use a scientifically plausible, but currently low expected likelihood of occurrence as a planning upper bound; and 2) define a mid-range scenario as a baseline for planning, such as adaptation plans covering the next three decades (2050). These projections would bound a planning "envelope".

In consideration of the information presented above, as well as State guidance, it is recommended that the USACE High RSLC Scenario, which was used for the Study, be considered as an appropriate projection for adaptation planning. It is also recommended that the USACE Intermediate RSLC Scenario be considered as having a very high (possible to near certain) likelihood of occurrence. However, projections representing greater rates of relative sea level rise should be considered on a case-by-case basis for design of costly or critical infrastructure.

Rising Tides

A reasonable estimate of the effects of RSLC on tides can be developed by linear superposition of the predicted RSLC to the current epoch tidal datums. **Table 2-5** presents the current and predicted changes to the tidal datums for Old Saybrook due to RSLC for the years 2040, 2070 and 2100, in feet NAVD88.

Figure 2-9 shows the predicted tidal inundation due to between 1 foot and 6 feet sea level rise, relative to MHHW. Assuming the 2013 USACE High RSLC scenario, RSLC amounts corresponding to future years are:

1 foot (MHHW = 2.5 feet NAVD88):	Years 2040 to 2045
2 feet (MHHW = 3.5 feet NAVD88):	Year 2060
3 feet (MHHW = 4.5 feet NAVD88):	Years 2075 to 2080
4 feet (MHHW = 5.5 feet NAVD88):	Year 2090
5 feet (MHHW = 6.5 feet NAVD88):	Year 2100

Except for areas along the beaches and near tidal wetlands, the effects of tidal flooding on the Town are currently minimal. The MHHW assuming the 2013 USACE High RSLC projection for the years 2080 to 2100 is very close to the water levels experienced during Hurricane Sandy peak flood. These conditions would result in flooding throughout the Town similar to that experienced during Sandy, but on a daily basis.

	Current	2040		2070		2100	
		USACE High SLR	USACE Int SLR	USACE High SLR	USACE Int SLR	USACE High SLR	USACE Int SLR
MSL	-0.28	0.51	0.04	2.14	0.60	4.43	1.31
MHW	1.14	2.12	1.54	4.14	2.23	6.98	3.11
MHHW	1.5	2.48	1.90	4.50	2.59	7.34	3.47
MLW	-2.06	-1.08	-1.66	0.96	-0.96	3.83	-0.07
MLLW	-2.3	-1.31	-1.90	0.73	-1.20	3.59	-0.31

Table 2-5: Projected Old Saybrook Tidal Datums Based on 2013 USACE High RSLC Projections

The following images present the results of GZA's model simulations of MHW (mean high tide) during the years 2041, 2066 and 2116, assuming the USACE Intermediate sea level rise projection which is considered to have a high likelihood of occurrence.

Figure 2-7: Predicted MHW Flood Inundation by the year 2041 assuming USACE Intermediate Sea Level Rise Projection

Figure 2-8: Predicted MHW Flood Inundation by the year 2066 assuming USACE Intermediate Sea Level Rise Projection

Figure 2-8: Predicted MHW Flood Inundation by the year 2116 assuming USACE Intermediate Sea Level Rise Projection

Chronic Flood Inundation

Per the Union of Concerned Scientists report "When Rising Seas Hit Home", "chronic flood Inundation" occurs within a coastal community when more than 10% of its developed land is inundated 26 times per year (on average, about every other week). This was considered as a threshold that disrupts people's routines, likelihoods, homes and communities to the extent that the communities are unsustainable.

GZA analyzed 20 years of water level data collected from the NOAA New London tide gage (19917 to 2017). GZA's analysis ranked water level to determine the water elevation corresponding to a flood condition that occurs 26 times per year. The data was then corrected for RSLC between the years 1997 and 2017 and averaged; the average was then adjusted for projected RSLC using the 2013 USACE High projection, as follows:

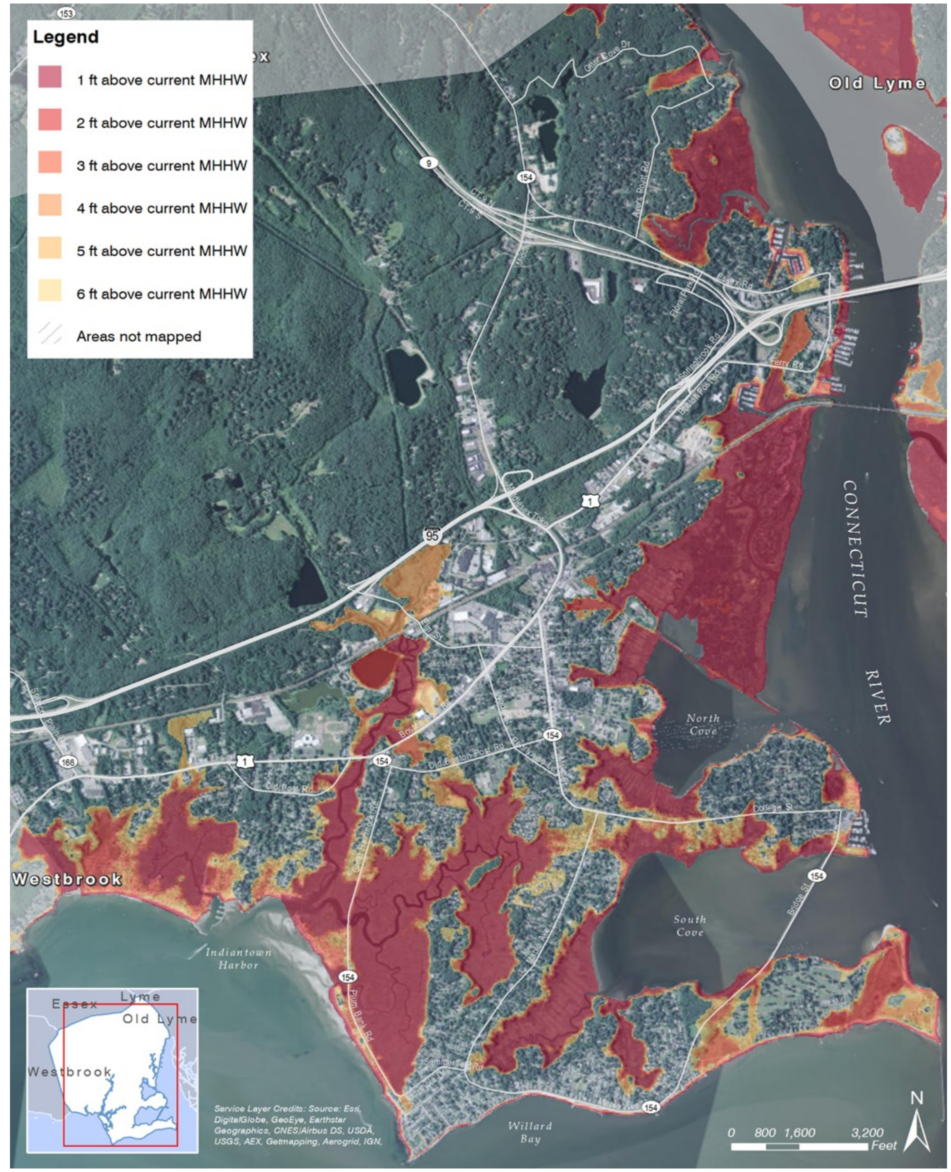


Figure 2-9: Limits of Flood Inundation due to Relative Sea Level Rise

Year 2017: Elevation 2.8 NAVD88 (1.3 feet above current MHHW)
Year 2040: Elevation 3.6 NAVD88 (2.1 feet above current MHHW)
Year 2050: Elevation 4.2 NAVD88 (2.7 feet above current MHHW)
Year 2070: Elevation 5.2 NAVD88 (3.7 feet above current MHHW)
Year 2100: Elevation 7.5 NAVD88 (6.0 feet above current MHHW)

The average 26th value adjusted for projected RSLC using the 2017 USACE Intermediate projection:

Year 2017: Elevation 2.8 NAVD88 (1.3 feet above current MHHW)
Year 2040: Elevation 3.7 NAVD88 (2.2 feet above current MHHW)
Year 2050: Elevation 4.1 NAVD88 (2.6 feet above current MHHW)
Year 2070: Elevation 5.0 NAVD88 (3.5 feet above current MHHW)
Year 2100: Elevation 6.6 NAVD88 (5.1 feet above current MHHW)

Extreme Flooding

Extreme flooding resulting from coastal storm surges at Old Saybrook result from two types of storms: Extra-tropical storms (Nor'easters) and tropical cyclones (Tropical Storms and Hurricanes).

Nor'easters are relatively common in New England during the spring, winter and fall. They are less intense than hurricanes but have a large wind field and are long in duration (sometimes lasting several days). These characteristics can result in significant storm surges. This is particularly true within Long Island Sound, where the long axis of the Sound trends northeast-southwest in line with the predominant wind direction during Nor'easters. Nor'easters often occur in conjunction with large snowfalls, which makes emergency response and recovery much more difficult.

Hurricanes occur relatively infrequently in New England. Hurricanes of high intensity with the tracks and landfalls necessary to cause large floods in New Haven are even rarer. However, as discussed below, hurricanes have historically resulted in the largest storm surge flooding effecting the Old Saybrook area. Tropical cyclones, including tropical storms and hurricanes, have also resulted in the most significant rainfalls.

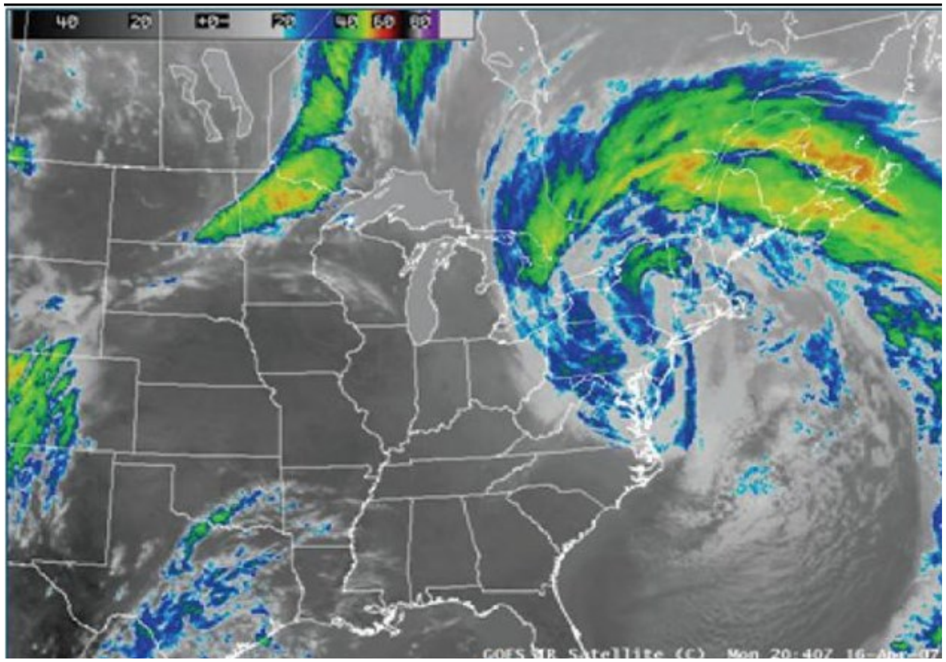


Figure 2-10: NOAA satellite image showing windfield and precipitation during a typical New England Nor'easter

According to the NOAA Office for Coastal Management, 40 tropical cyclones (including hurricanes and tropical storms) have tracked within a 50-nautical mile radius of Old Saybrook since the mid-1800s (see **Figure 2-11** for storm tracks). The most intense hurricane of record in the vicinity of Old Saybrook is the Hurricane of 1938 (track highlighted in **Figure 2-11**). According to NOAA, this hurricane was a Category 3 intensity at landfall along the Connecticut coast. The approximate peak water levels at New London during the Hurricane of 1938 were Elevation 8.5 to 9 feet NAVD88. There were also several high intensity hurricanes during the 1800s and early 1900s that made landfall along Long Island, although details about their intensity are limited.

Hurricane Sandy, although its landfall was over 200 nautical miles south of Old Saybrook, was one of the most significant flood events in Connecticut. Sandy's storm surge when combined with tides, caused peak water levels to reach approximately Elevation 6.5 feet NAVD88 at Old Saybrook.

Based on NOAA's HURDAT2 database, **Figure 2-11** indicates the hurricanes that have tracked within a 50-mile radius of Old Saybrook. **Table 2-8** summarizes the top ten water levels at the NOAA New London and Bridgeport tide stations relative to MHHW. The highest observed water levels resulted from hurricanes, with the highest documented flood water level observed during the Hurricane of 1938. The top observed water levels at New London have resulted from six hurricanes, one tropical storm and three Nor'easters.

Name	Date	Category	Landfall (relative to Old Saybrook)
Gloria 1985	9/16 to 10/02/1985	H1 (Category 1)	West
Unnamed 1858	9/14 to 9/17/1858	H1 (Category 1)	East
Unnamed 1894	9/26 to 10/12/1894	H1 (Category 1)	West
Unnamed 1894	10/01 to 10/12/1894	H1 (Category 1)	West
Unnamed 1934	9/05 to 9/10/1934	H1 (Category 1)	West
Donna 1960	8/29 to 9/14/1960	H2 (Category 2)	Landfall at Old Saybrook
Unnamed 1944	9/09 to 9/16/1944	H2 (Category 2)	East
Bob 1991	9/16 to 9/29/1991	H2 (Category 2)	East
Carol 1954	8/25 to 9/01/1954	H3 (Category 3)	East
Unnamed 1869	9/07 to 9/09/1869	H3 (Category 3)	East
Hurricane of '38	9/09 to 9/23/1938	H3 (Category 3)	West

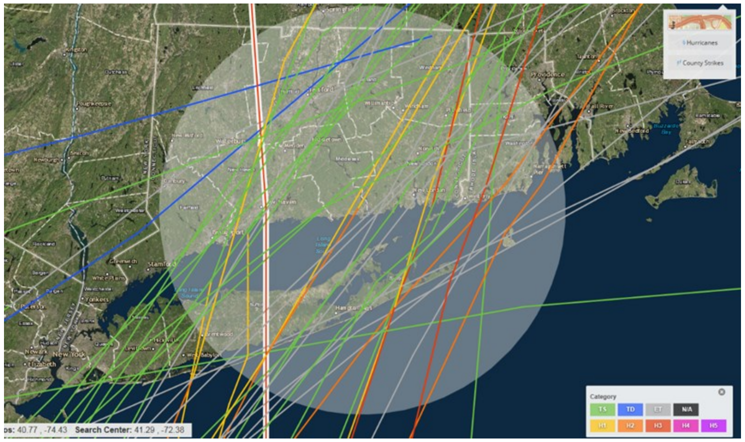
Table 2-7: NOAA Hurricanes within 50-mile Radius of Old Saybrook

Station	1	2	3	4	5
8461490	9/21/1938	8/31/1954	10/30/2012	11/25/1950	9/14/1944
New London[1]	7.53 feet	6.53 feet	4.89	4.53 feet	4.03 feet
	6	7	8	9	10
	9/12/1960	11/7/1953	10/31/1991	8/28/2011	11/12/1968
	3.83 feet	3.73 feet	3.42 feet	3.39 feet	3.33 feet
	1	2	3	4	5
8467150	10/30/2012	8/28/2011	12/11/1992	10/31/1991	10/25/1980
Bridgeport[2]	5.72	4.72	4.72	4.06	3.67
	6	7	8	9	10
	3/29/1984	9/27/1985	10/19/1996	11/12/1968	4/16/2007
	3.29	3.27	3.21	3.20	3.19

Notes: 1. Station data since 1938. 2. Station data since 1964. 3. Water levels not corrected for sea level rise.

Table 2-8: NOAA Station Top Ten Water Levels (in feet above MHHW)

Figure 2-11: NOAA Storm Tracks for Tropical storms and



Coastal Flood Probability

Flood hazard mitigation planning requires characterizing flooding in terms of risk, specifically associating different flood levels with a probability of occurrence. Flood probabilities are typically described in terms of the annual chance of occurrence. For example, the 1% annual chance flood elevation has, in any given year, a 1/100 chance of being met or exceeded. This flood is also known as the 100-year return period flood. There are several publicly-available, industry-accepted sources of flood probability data for the vicinity of Old Saybrook. These include:

1. Statistical analysis of the NOAA New London tide station water level data: Statistical analysis of the NOAA New London tide station water level data provides an indication of the recurrence interval of flooding based on an approximately 80-year period of record. The gage at New London has too brief a period of record for extrapolating extreme water levels without significant uncertainty.
2. FEMA Flood Insurance Study and Rate Maps: FEMA has characterized the current flood hazard within Old Saybrook for the purposes of the National Flood Insurance Program (NFIP). FEMA uses the 1% annual chance (100-year return period) flood event to characterize flood risk, presented on Flood Insurance Rate Maps (FIRMs). FEMA also presents the 0.2% annual chance flood inundation limits in these maps. Figure B-11 presents the effective (i.e., currently applicable) FEMA Flood Insurance Rate Map (FIRM) flood limits and elevations, used to calculate flood insurance rates for Long Wharf.
3. The USACE North Atlantic Coast Comprehensive Study (NACCS): The USACE performed extensive regional coastal flood hazard analyses after Hurricane Sandy (the North Atlantic Coast Comprehensive Study). These analyses utilized interpretation of meteorological parameters, numerical computer modeling of storm surge and waves, and statistical analysis (e.g., Joint Probability Method-Optimum Sampling, Empirical Simulation Technique) to characterize regional flood hazards.

There is no exact prediction of flood probability; rather, there are a range of probabilities (and corresponding flood elevations) that reflect different prediction methods, error and uncertainty. The NOAA New London, CT tide gage data has significant uncertainty for predicting floods beyond 20 to 50-year recurrence interval floods due to the limited period of record and likely under-predicts the flood hazard. The FEMA stillwater flood projections for Old Saybrook, which were also developed using tide gage data, have similar uncertainty (stillwater elevation is the flood elevation that occurs in the absence of wave effects). The USACE NACCS utilized the "state-of-the-practice" methodology; however, there is significant statistical uncertainty and some model error.

Overall, the USACE NACCS currently presents the most robust analysis of coastal flood hazards in the vicinity of Old Saybrook.

Figure 2-12: Temporary USGS Tide Gage on South Cove Causeway, measuring water levels during Hurricanes Irene and Sandy

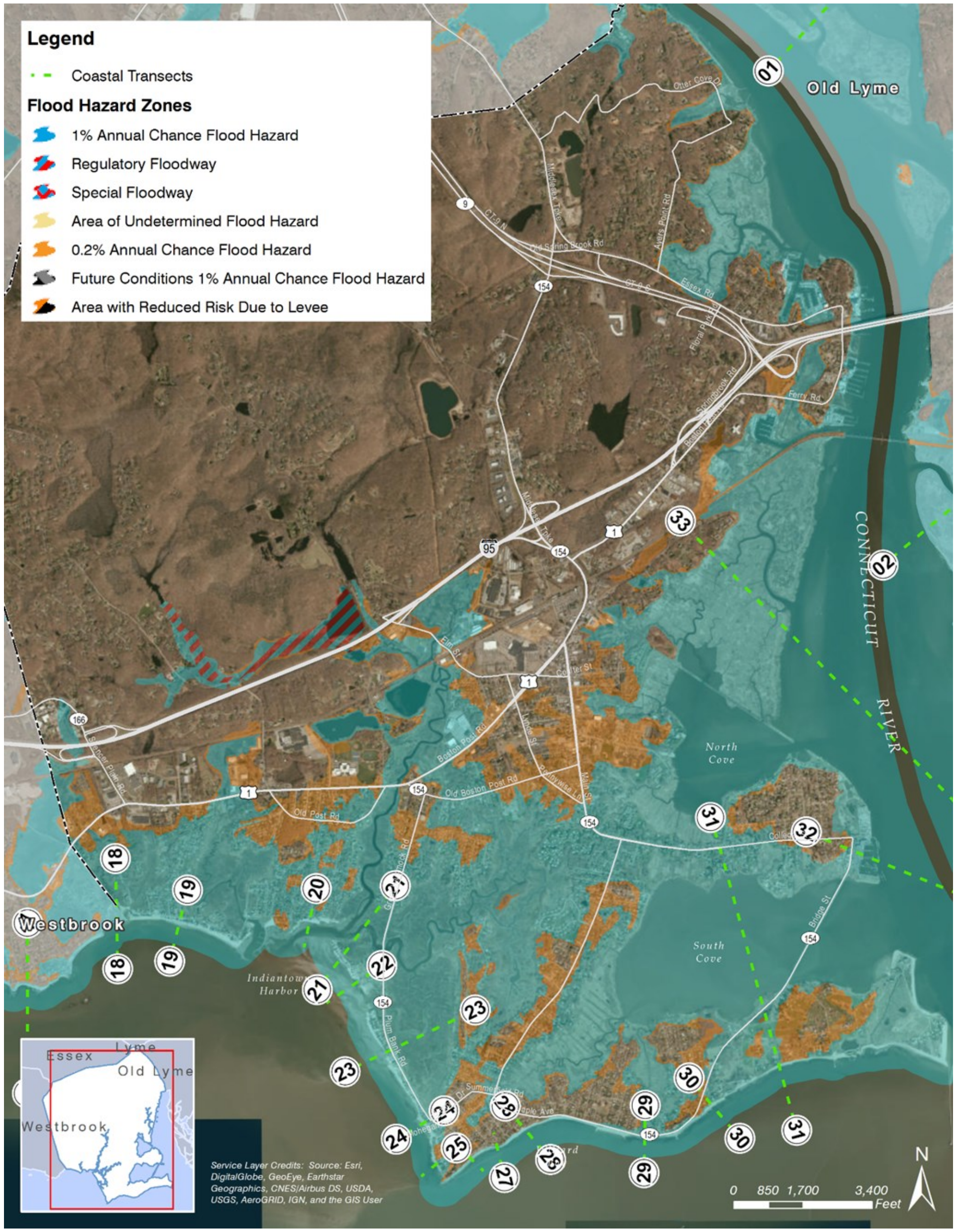
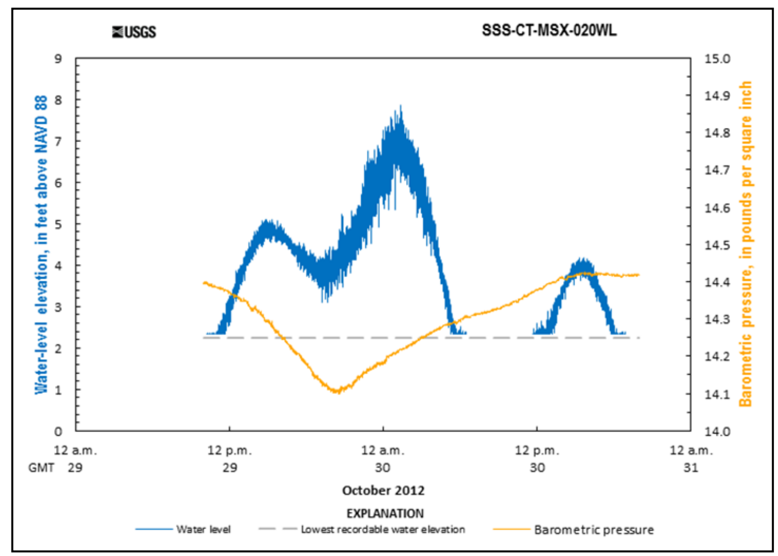


Figure 2-13: FEMA Flood Insurance Rate Map Flood Hazard Zones and Base Flood Elevations

South Cove Causeway during Irene showing wave overtopping bridge deck. The image above photo by Mara Lavitt won a first-place award in the Connecticut SPJ contest. "Thrill seekers on the causeway between Old Saybrook and Fenwick Point during Tropical Storm Irene, on Aug. 28, 2011." The tide gage data USGS gage data indicated a peak water level during Irene of about Elevation 6.5 feet NAVD (about or slightly higher than the bridge deck elevation). In comparison, the same tide gage (shown below) measured a peak water level of about Elevation 8 feet NAVD during Sandy. The gage data likely includes some wave effects and the actual stillwater flood elevation during Sandy was lower.



NOAA Tide Station Water Level Analysis

NOAA statistically analyzed annual water level data at the NOAA Bridgeport and New London tide gages using the Generalized Extreme Value (GEV) probability distribution. The results are shown in **Figure 2-14** (in meters relative above MHHW). The 95% confidence intervals are also shown.

GZA independently performed similar statistical analyses with comparable results. The mean 1% annual exceedance stillwater elevation is estimated using this analysis and corrected for Old Saybrook) is at about Elevation 7.5 feet NAVD88.

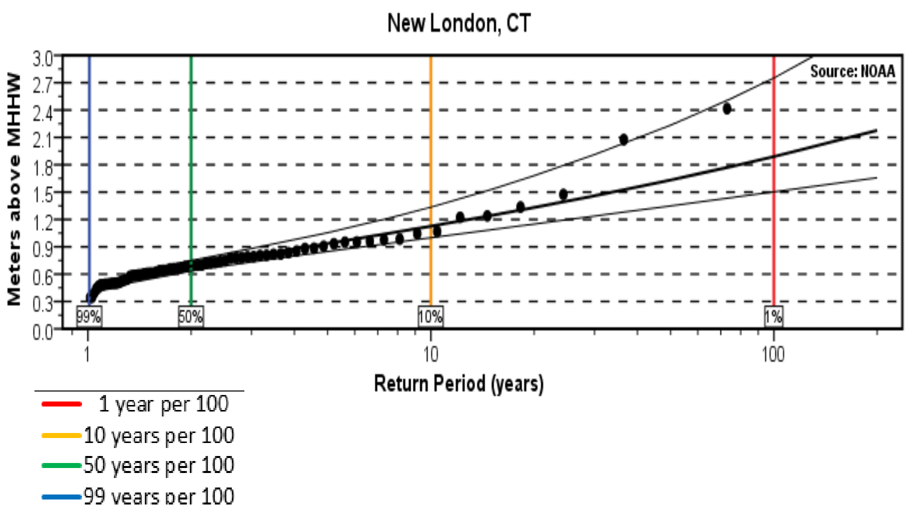


Figure 2-14: NOAA Annual Exceedance Probability Curve for the New London Station

USACE North Atlantic Coast Comprehensive Study

The results of the USACE NACCS are available at specific model "save point" locations. **Figure 2-15** shows the locations of "save points" along the Old Saybrook shoreline. USACE-predicted Total Water Level data, including the stillwater elevation plus wave setup, and wave heights are available at these locations.

Due to the updated methodology used by the USACE, the flood hazard data developed by the USACE NACCS are expected to be indicative of what future editions of the FEMA FIS and FIRMs will be for Old Saybrook.

Figure 2-15: USACE North Atlantic Coast Comprehensive Study Results Save Points

Summary of Predicted Summary of Predicted Flood Elevations and Probabilities

Table 2-9 summarizes the coastal, nearshore predicted flood stillwater elevations by annual exceedance probability (return period). The data presented in **Table 2.9** is relative to FEMA FIS Transect 29 and USACE NACCS Save Point 8244. Similar to tides, a reasonable estimation of the effects of RSLC on storm surge stillwater elevations can be developed by linear superposition of the predicted RSLR to the predicted stillwater elevation. **Figure 2-16** presents the flood-frequency curve (mean with uncertainty) for the USACE NACCS Save Point 8244.

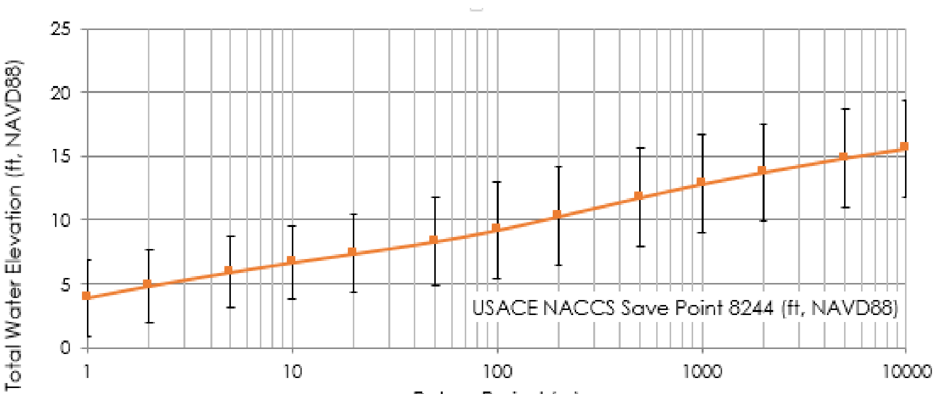


Figure 2-16: Flood Frequency Curve Base of USACE North Atlantic Coast Comprehensive Study along Old Saybrook Shoreline for the year 2017. Mean, upper and lower bounds shown.

Table 2-9: Summary of Predicted Flood Elevations and Probabilities for the Years 2017, 2041, 2066 and 2116; UB and LB indicate lower and upper bounds, respectively. In feet, NAVD88.

Recurrence Interval (years)	1	2	5	10	20	50	100	200	500	1,000
2017:										
NOAA MEAN	2.3	3.5	4.4	5.0	5.6	6.6	7.5	8.4		
NOAA UB	2.3	3.7	4.7	5.7	6.7	8.6	10.3	12.6		
NOAA LB	2.3	3.3	4.1	4.5	5.0	5.7	6.2	6.8		
FEMA				5.5		7.7	9.2		15.3	
USACE MEAN	3.9	4.8	5.9	6.7	7.4	8.3	9.2	10.3	11.8	12.8
USACE UB	6.9	7.7	8.7	9.6	10.4	11.8	12.9	14.1	15.6	16.6
USACE LB	0.9	2.0	3.1	3.7	4.3	4.9	5.5	6.4	7.9	9.0
2040:										
USACE MEAN (INT SLR)	4.2	5.1	6.2	7.0	7.7	8.6	9.5	10.6	12.1	13.1
USACE MEAN (HIGH SLR)	4.9	5.8	6.9	7.7	8.4	9.3	10.2	11.3	12.8	13.8
2070:										
USACE MEAN (INT SLR)	4.7	5.6	6.7	7.5	8.2	9.1	10.0	11.1	12.6	13.6
USACE MEAN (HIGH SLR)	6.2	7.1	8.2	9.0	9.7	10.6	11.5	12.6	14.1	15.1
2100:										
USACE MEAN (INT SLR)	5.9	6.8	7.9	8.7	9.4	10.3	11.2	12.3	13.8	14.8
USACE MEAN (HIGH SLR)	10.3	11.2	12.3	13.1	13.8	14.7	15.6	16.7	18.2	19.2

Seasonality of Coastal Flood Hazard

NOAA statistically analyzed water level data on a monthly basis showing the seasonal variability of coastal flood risk. The results are presented in Figure 2-15 for the NOAA Bridgeport tide gage (relative to meters above MHHW).

As shown on **Figure 2-17**, the greatest flood risk is during the late Summer, Fall and Winter which includes tropical storms, hurricanes and Nor'easters. The probability of extreme flooding during late Spring and Summer is low.

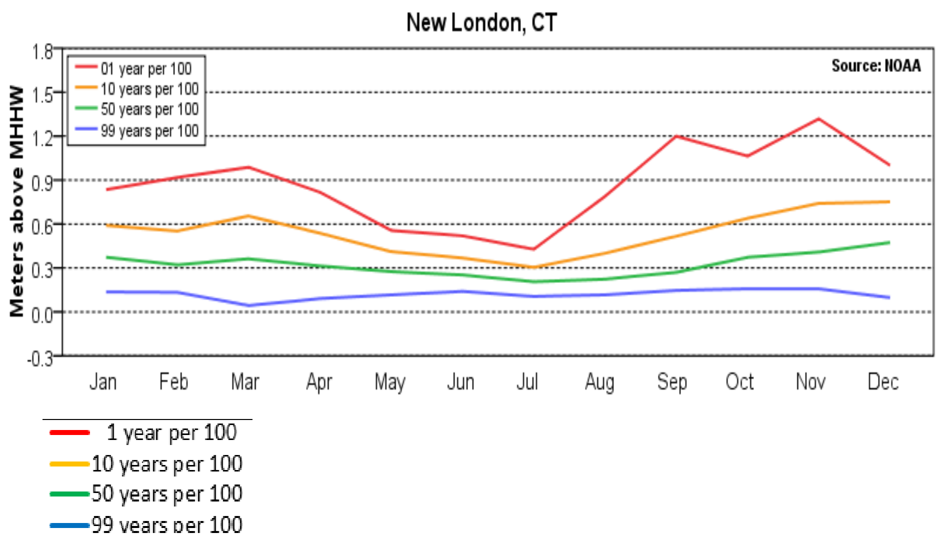


Figure 2-17: NOAA Seasonal Variation of Exceedance Probability Curve for the New London Station

Effect of Sea Level Rise of Flood Elevations

NOAA statistically analyzed monthly water level data to reflect the effect of past RSLC of flood elevations associated with different annual exceedance probability levels (see **Figure 2-18**). The monthly extreme probability levels include a MSL trend of 2.25 mm/year RSLR with a 95% confidence interval of +/-0.25 mm/yr based on the years 1938 to 2006 (0.74 foot per 100 years).

Table 2-9 shows the estimated effect of future RSLC on the USACE NACCS-predicted annual exceedance flood elevations for different projections of RSLC.

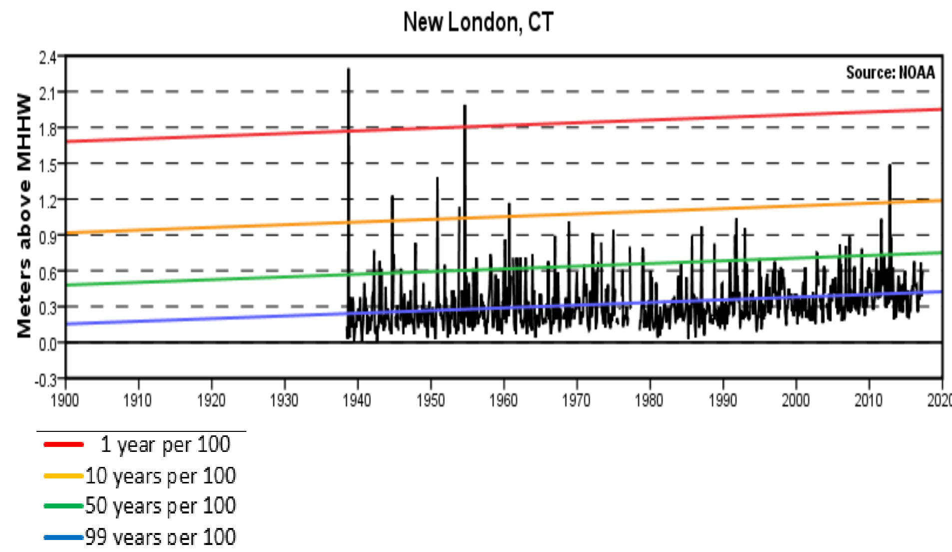


Figure 2-18: NOAA Water Levels with Exceedance Probability Curves for the New London Station

Prevailing Wind Analysis

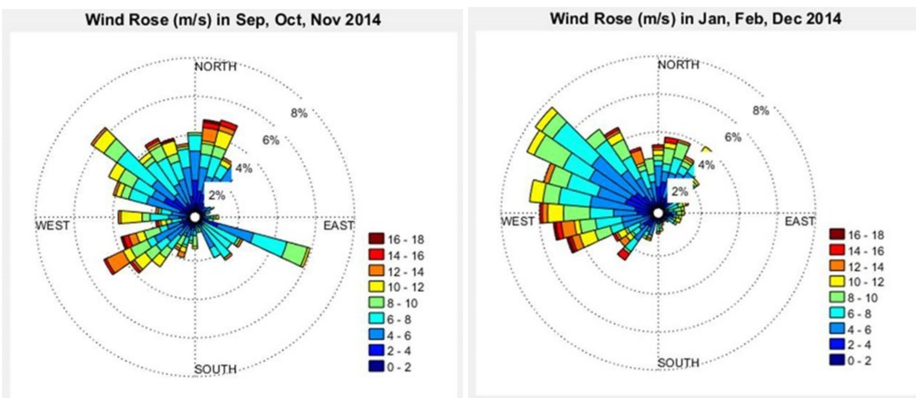
The prevailing wind (and resulting wave) direction is a key factor in the direction of longshore sediment transport. "Prevailing" refers to the dominant, non-storm winds. GZA performed a statistical analysis of 1-minute sustained at 10-meter wind speed data collected by the anemometer at the New London airport for the period of record (1943 to 2017). The results of that analysis indicate the following:

- The prevailing, low velocity, winds are from the south to southwest and from the northwest to north. The south to west winds (in particular, the southerly winds) are prevailing during the summer months and the northerly winds during the Fall, Winter and Spring.

- About 49% of the 1-minute sustained wind speeds are less than 10 miles per hour (mph); about 45% of the sustained wind speeds are between 10 mph and 20 mph and about 6% are between 20 mph and 30 mph.

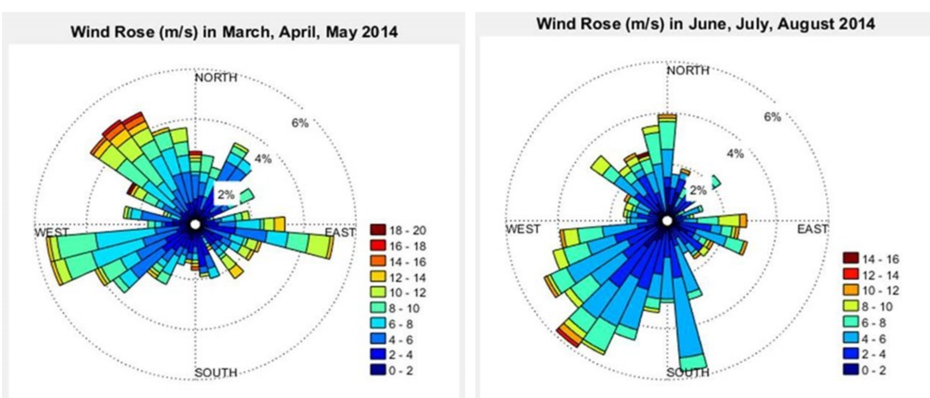
- Less than 1% of the winds are greater than 30 mph, with less than 0.05% (90 events between 1943 and mid-2017) equal to or greater than 50 mph. Of these 90 events with wind speeds equal to or greater than 50 mph (representing Nor'easters, tropical storm and hurricanes), about 80% were from the east-southeast to west-southwest (southerly direction) and about 14% were from the west-northwest to the east-northeast (northerly direction).

In general, the data indicate that the prevailing winds (and associated waves) are from the south to southwest. **Figure 2-19** presents seasonal wind roses at Old Saybrook. **Figure 2-20** presents a plot of annual wind direction distribution and **Figure 2-21** presents an annual wind rose.



Fall

Winter



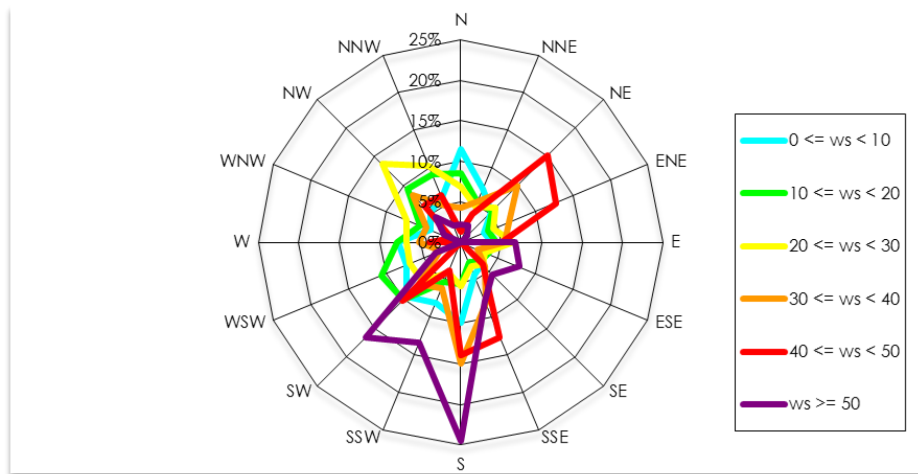


Figure 2-21: Wind Rose of Wind Speeds (miles per hour) and Direction at New London Airport

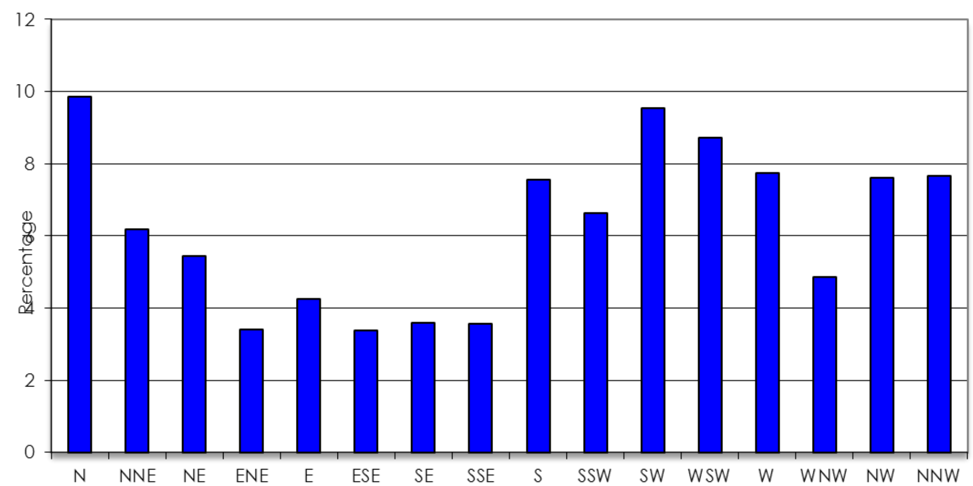


Figure 2-20: Distribution of Wind Directions at New London Airport

Figure 2-19: Distribution of Wind Directions and Intensities; Seasonally during 2014

Extreme Wind Analysis

Extreme sustained winds (greater than 40 mph and associated with storms) are also predominantly from: 1) the south to southwest; and 2) the east-northeast to northeast (Nor'easters). Sustained wind speeds 50 mph and greater are typically due to tropical cyclones (tropical storms and hurricanes). The following presents the results of GZA's statistical analysis of New London Airport wind data, representing the 1 and 2-minute sustained wind speed at 10 meters in mph.

Wind Direction	GEV Fit Wind Speed (mph)				Recommended Values (mph) for Modeling			
Return Period	10-year	50-year	100-year	500-year	10-year	50-year	100-year	500-year
All Direction	69	97	112	154	70	100	120	160
North	--	--	--	--	--	--	--	--
Northeast	43	53	57	68	45	55	60	70
East	49	71	82	117	50	75	90	120
Southeast	49	69	80	108	50	70	80	110
South	56	68	72	81	60	70	80	90
Southwest	48	66	75	99	50	70	80	100
West	43	59	69	98	45	60	70	100
Northwest	--	--	--	--	--	--	--	--

Table 2-10: Summary of Extreme Wind Speeds based on GZA Statistical Analysis of New London Airport

GZA Numerical Flood Model Simulations

GZA performed flood simulations using numerical hydrodynamic models of tides and storm surge and wave models. The coastal floods corresponding to tidal flow, the 100-year return period flood (1% annual chance) and the 500-year return period flood (0.2% annual chance) were modeled. The model simulations were performed using the two-dimensional, hydrodynamic computer model ADvanced CIRCulation model (ADCIRC). Waves were modeled using the Simulating WAves Nearshore (SWAN) model.

The purposes of GZA's model simulations were to: 1) evaluate flooding hydrodynamically and temporally; and 2) reflect the current topographic methodology. GZA also utilized GIS technology to evaluate flood inundation using "average" stillwater elevations for return periods ranging from 2-years to 50-years.

Model Flood Inundation Simulations

The ADCIRC storm surge flood simulation process utilized a robust, but simplified approach and included: 1) creation of a local area, high resolution model mesh; 2) development of synthetic hydrographs representative of storm types associated with the 100-year and 500-year return period floods (1% and 0.2% annual chance); 3) utilization of the USACE NACCS-predicted peak stillwater elevations at the model boundary to develop the peak hydrograph water level; and 5) stressing the model with the synthetic hydrograph and model domain wind field. This approach provides the benefits of numerical hydrodynamic models, approximating scenario-based simulations, but ties the overall flood hazard definition (model boundary water levels) to those developed by the USACE NACCS. Validation was performed by comparison of GZA model output to representative NACCS output for save points located within the model domain.

A high resolution ADCIRC mesh was developed to represent the detailed topographic features of Old Saybrook. The mesh covers Old Saybrook and extends approximately 4 miles off the coast into Long Island Sound (location of the open model boundary). The mesh consists of 190,968 finite elements, and the grid resolution across Old Saybrook land area is approximately 10 to 20 meters. The Digital Elevation Model utilized the following source topographic and bathymetric data based:

- Lidar provided by the Town (1 meter resolution); and
- 3 arc-second (approximately 30 meter) resolution Estuarine Bathymetric Digital Elevation Models in Long Island Sound, derived from NOAA source hydrographic survey data.

ADCIRC is a two-dimensional, depth integrated, barotropic time-dependent long wave, hydrodynamic circulation model, and can be applied to domains in deep oceans, the continental shelf, near-shore, and small-scale estuarine systems. The model input included synthetic hydrographs with peak water elevations corresponding to predicted USACE NACCS Save Point data at the model boundary.

2013 USACE Intermediate scenarios were simulated for the years 2040, 2070 and 2100 and 2013 USACE High scenarios for the years 2040 and 2070. RSLC was added to antecedent water levels and the synthetic hydrograph. The simulations were performed for tidal flow, the 100-year return period flood (1% annual chance) and the 500-year return period flood (0.2% annual chance). A time-stepped simulation of the 100-year return period flood was performed to evaluate flood progression.

Non-hydrodynamic simulations were also performed utilizing GIS to simulate the 2-year, 10-year, 20-year and 50-year return period flood inundation under current and future sea levels. The USACE NACCS flood levels from seventeen NACCS Save Points were utilized to estimate the mean water levels for these simulations.

Figures 2-19 through 2-23 present the simulated flood inundation limits for several different return period coastal floods.

Following Pages: Figures 2-22 through 2-25: GZA Flood Simulations corresponding to the 2-year, 10-year, 50-year, 100-year and 500-year Return Period floods. Return periods 2 through 50 years were developed using simple GIS technology of elevation overlay, with "average" stillwater flood elevations for that return period. These do not capture hydrodynamic effects which cause the peak stillwater flood elevation to vary in elevation throughout Old Saybrook – generally higher to the north). The 100-year and 500-yaer maps were made using hydrodynamic modeling. One limitation to the hydrodynamic models is that flooding within one location to the north of I-95 is not captured on these model simulations but is captured on the other maps as well as the FEMA FIRM.

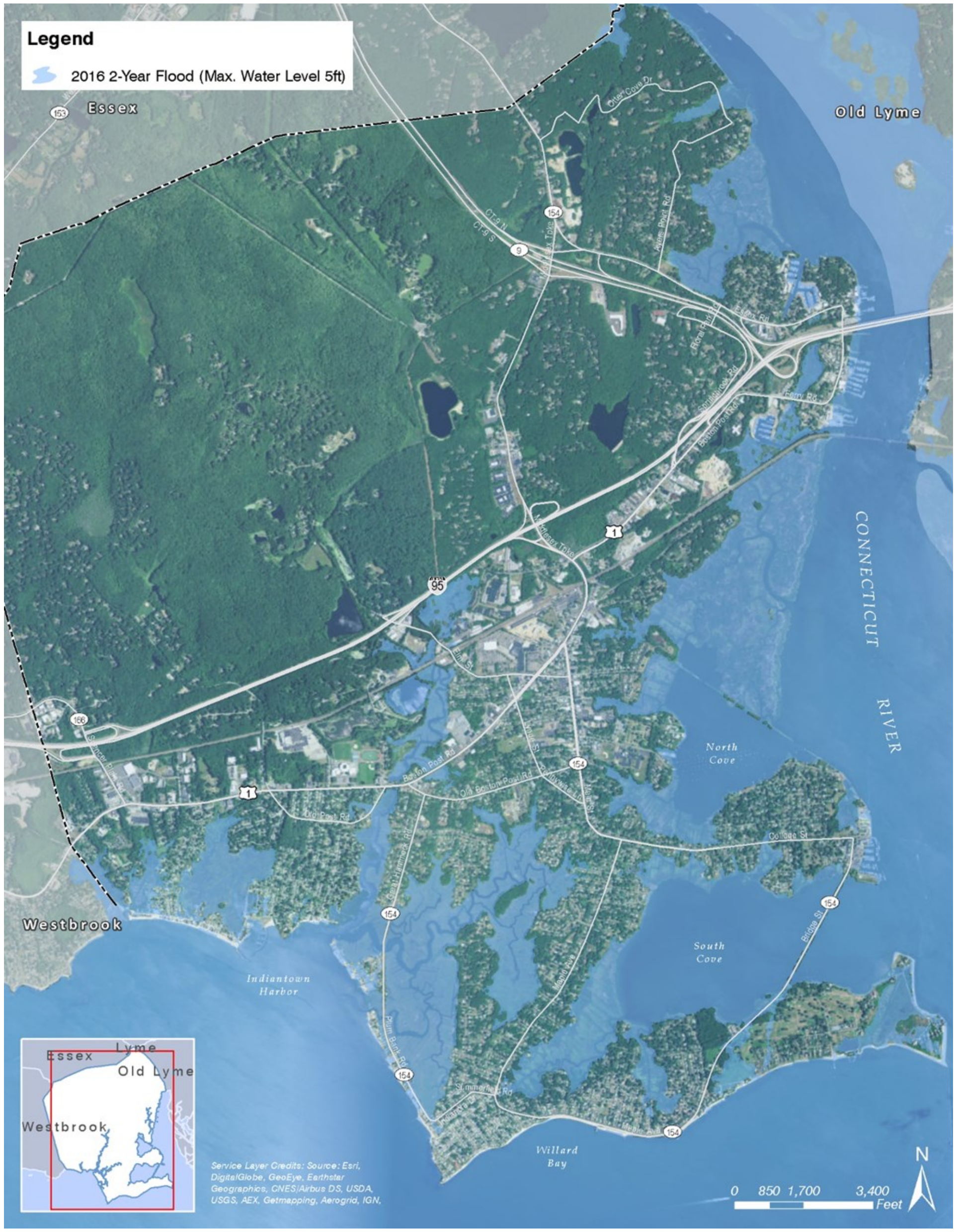


Figure 2-22: 2-year Recurrence Interval Flood Inundation

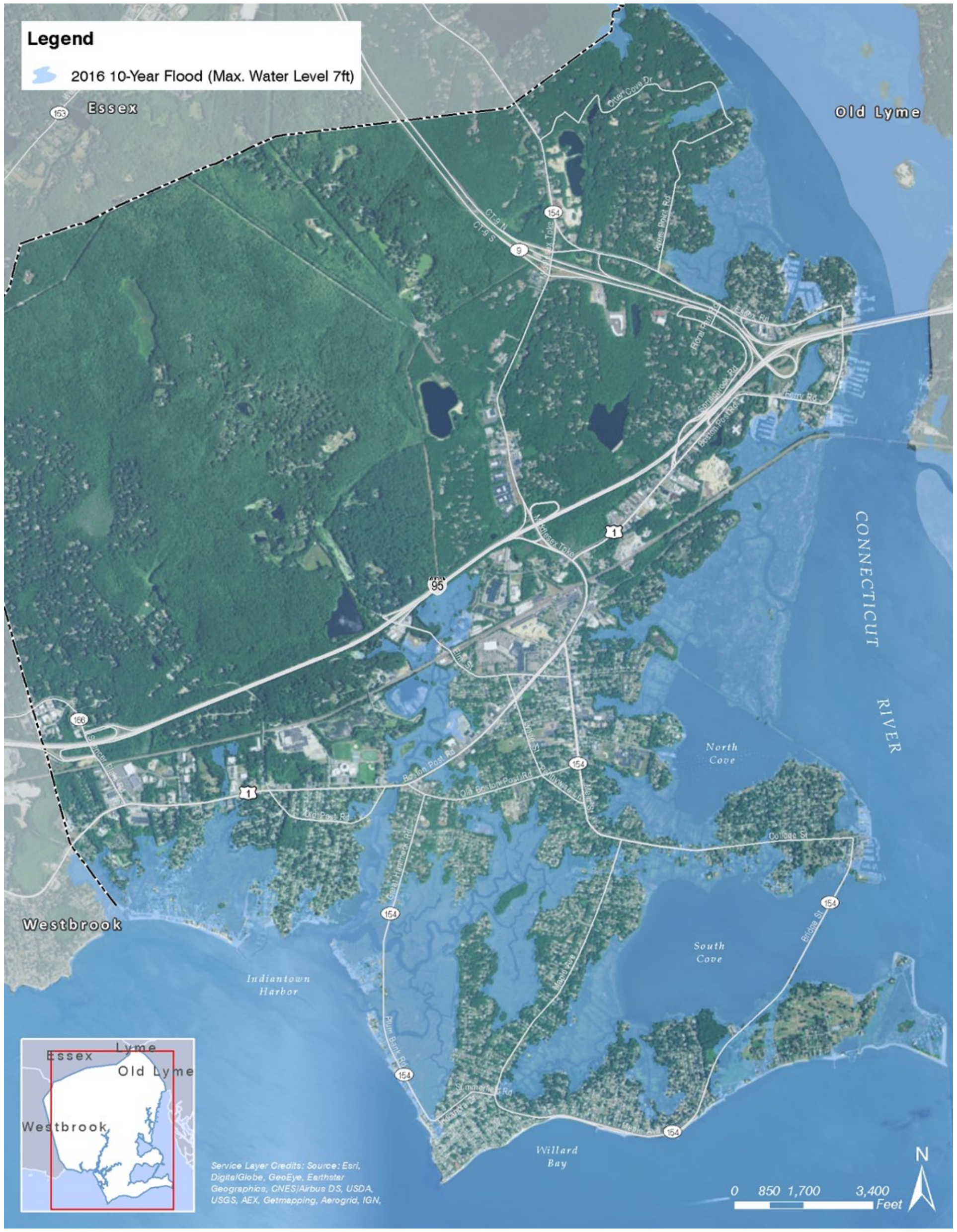


Figure 2-23: 10-year Recurrence Interval Flood Inundation

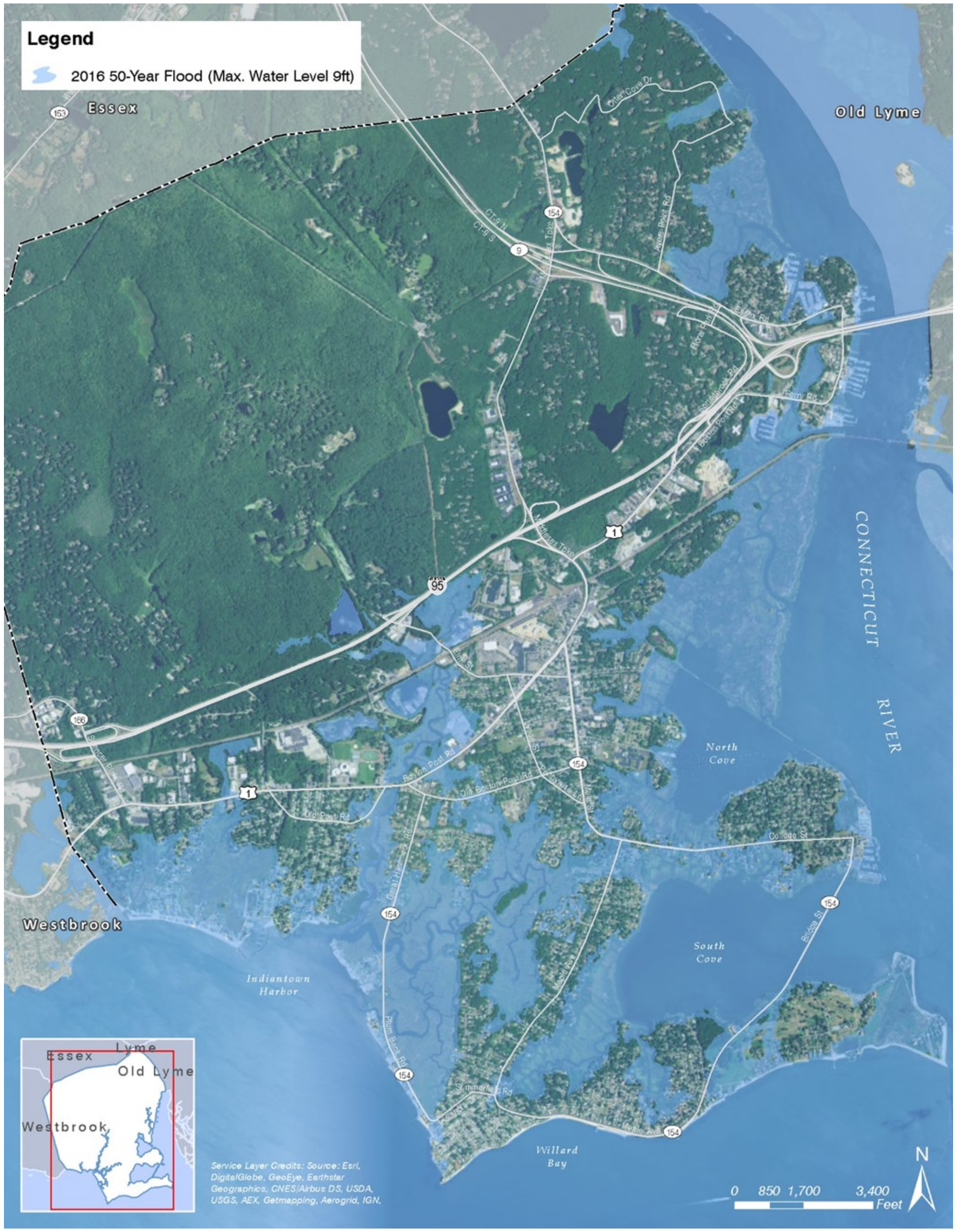


Figure 2-24: 50-year Recurrence Interval Flood Inundation

Figure 2-25: 100-year Recurrence Interval Flood Inundation

Figure 2-26: 500-year Recurrence Interval Flood Inundation

Model Wave Simulations

The Simulating WAves Nearshore (SWAN) model was used to model wave heights for the 100-year and 500-year return period floods.

The waves were modeled using the same model mesh and Digital Elevation Model as the ADCIRC storm surge simulations. Boundary condition waves were input at the Long Island Sound model boundary based on wave results for USACE NACCS Save Points located at the boundary. A local wind field was applied with wind intensities consistent with ASCE 7-10 3-second gusts converted to 1-minute sustained 10-meter winds.

Extreme Flood Wave Conditions:

ASCE 7-10 specified wind speed (3-second gust) for the project area is 107 miles per hour (mph) for the 100-year recurrence interval wind. This value is converted to a 1-minute sustained wind speed at 10 meters height of approximately 79 to 87 mph and a 10-minute sustained wind speed at 10 meters of approximately 71 mph to 77 mph, consistent with offshore winds to onshore winds at a coastline, respectively. Similarly, the 500-year recurrence interval wind is converted to a 1-minute sustained wind speed at 10 meters height of approximately 88 to 98 mph and a 10-minute sustained wind speed at 10 meters of approximately 79 mph to 87 mph, consistent with offshore winds to onshore winds at a coastline, respectively.

The waves were conservatively modeled coincident with the 100-year and 500-year return period flood water levels. **Figures 2-27** and **2-28** present the simulated significant wave heights for the 100-year and 500-year return period waves. Wave heights are also calculated by the USACE NACCS and predicted significant wave heights are available at NACCS save points. The results differ from GZA's wave model results at some locations. The differences may be due in part to the NACCS model capturing ocean swells from the southeast. The difference is less important as the waves encroach the shoreline and for overland waves.

Prevailing (Typical) Wind and Wave Conditions:

Typical wave conditions were modeled using the GZA-calculated prevailing wind speeds and directions (**Figures 2-29** and **2-30**). The wave vectors indicate a strong northerly direction of longshore transport from Cornfield Point to Plum Bank Creek (north of Town Beach). Between Plum Bank Creek and the mouth of Oyster River, the waves generally refract and attenuate due to the tidal flat. Along Chalker Beach, the shallow nearshore depths and cove shape of the shoreline attenuate wave heights somewhat. Longshore transport is expected to be variable and limited along this stretch of shoreline. The shoreline from Cornfield Point to Fenwick generally faces south and is exposed to larger waves. Longshore transport along this stretch of shoreline will generally be to the east, but locally variable due to the effects of shoreline structures and Cornfield Point.

USACE NACCS data offshore at representative locations are summarized below:

Recurrence Interval (yrs)	Mean Significant Wave Height (ft)				
	Plum Bank Road near Cornfield Point	Maple Avenue near Revetment	Within South Cove	Fenwick/ near Hepburn Beach	Off Saybrook Point (Dock Road)
1	3.4	5.0	2.6	3.9	3.1
2	4.6	6.7	3.1	4.8	4.0
5	5.8	7.8	3.6	5.4	4.8
10	6.6	8.5	3.9	5.8	5.4
20	7.3	9.2	4.2	6.2	5.9
50	8	9.9	4.5	6.6	6.6
100	8.6	10.4	4.7	6.9	7.1
200	9	10.9	4.9	7.2	7.5
500	9.5	11.5	5.2	7.4	8.1

Table 2-11: Summary of Predicted Flood Elevations and Probabilities for the Years 2017, 2041, 2066 and 2116; UB and LB indicate

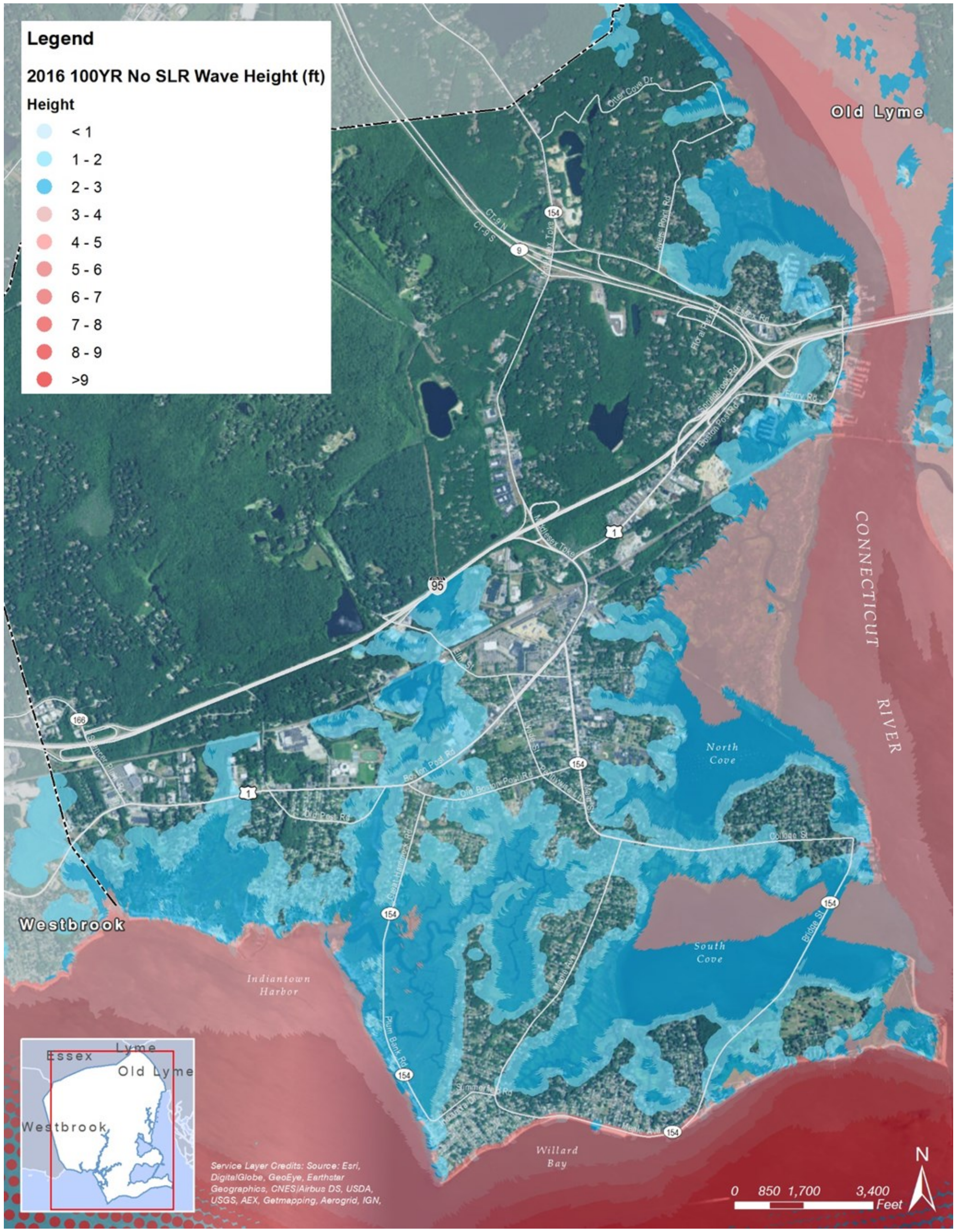


Figure 2-26: 100-year Recurrence Interval Wave Heights

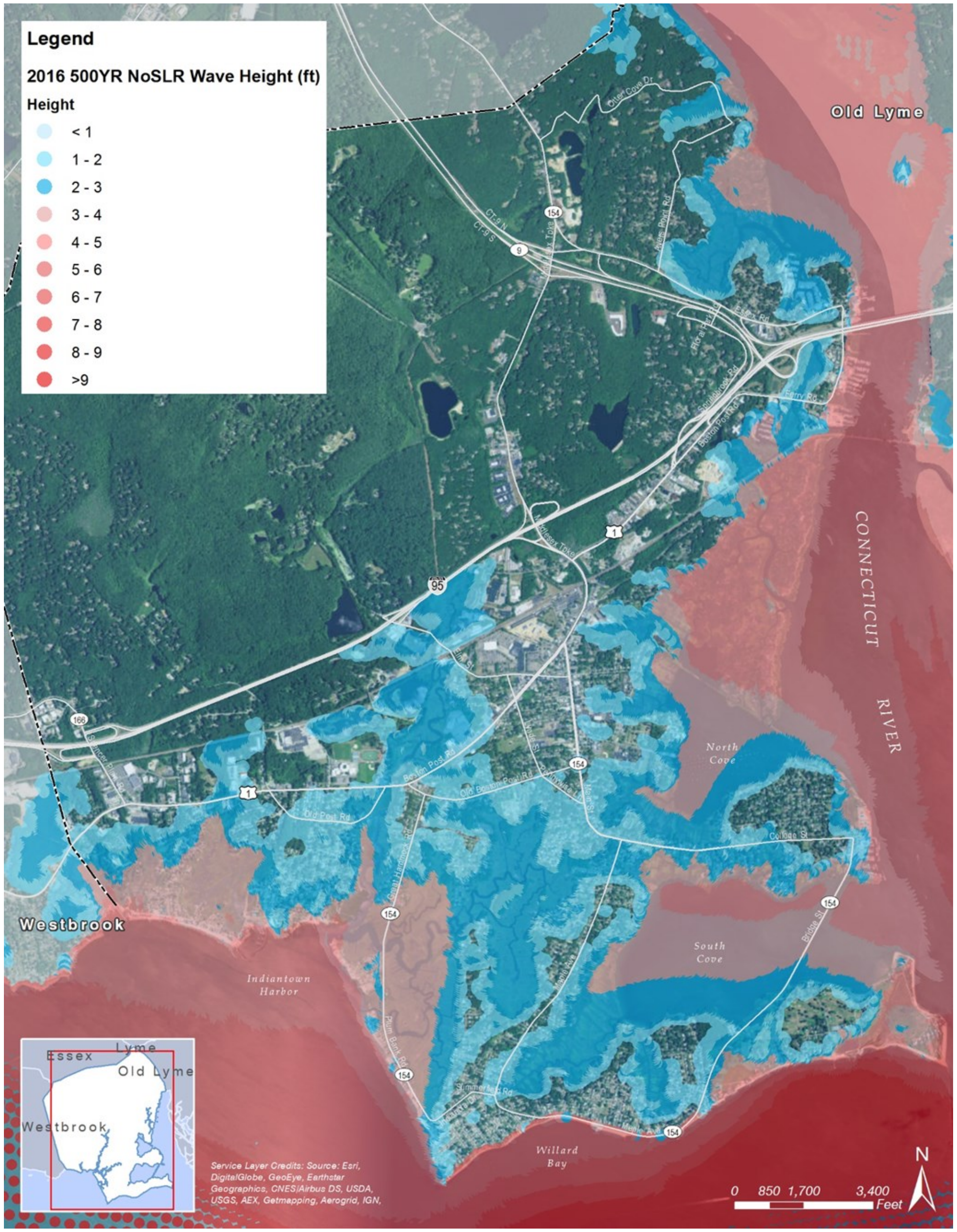


Figure 2-27: 500-year Recurrence Interval Wave Heights

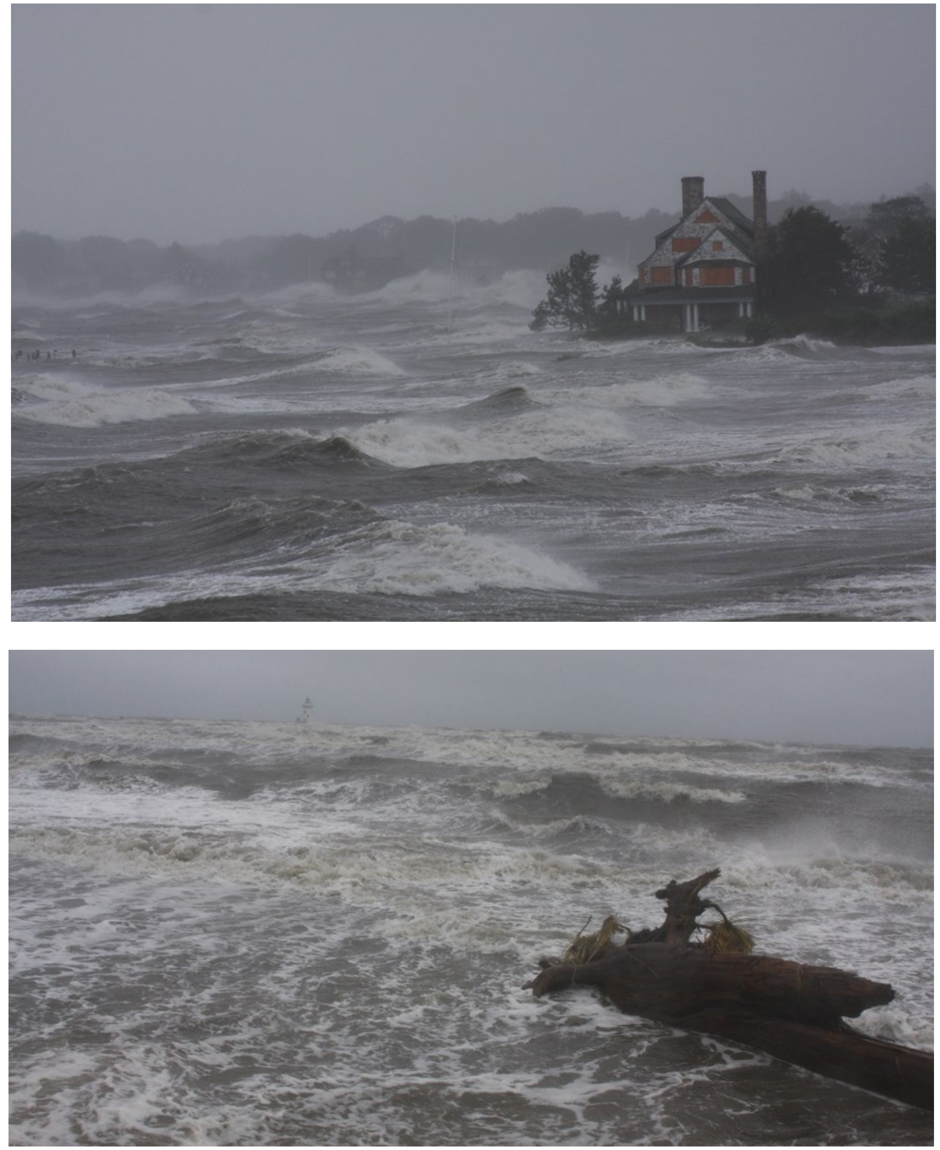


Figure 2-28: Photographs of Tropical Storm Irene (+/- 10-yr recurrence interval) at Fenwick. Wave heights about 3 to 4 feet.

Prevailing Wind-Generated Waves

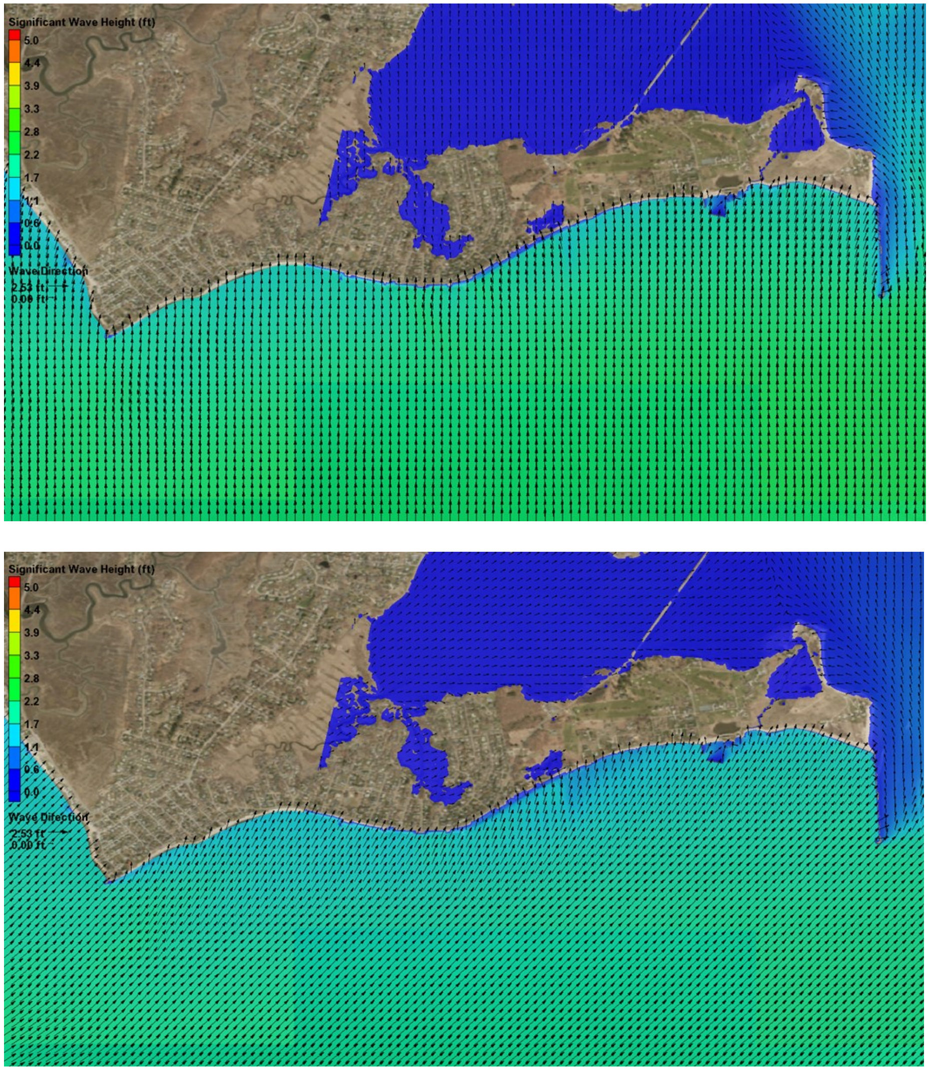


Figure 2-29: Prevailing Wave Vectors and Heights – South Wind (above) and Southwest Wind (below); South Facing Shore

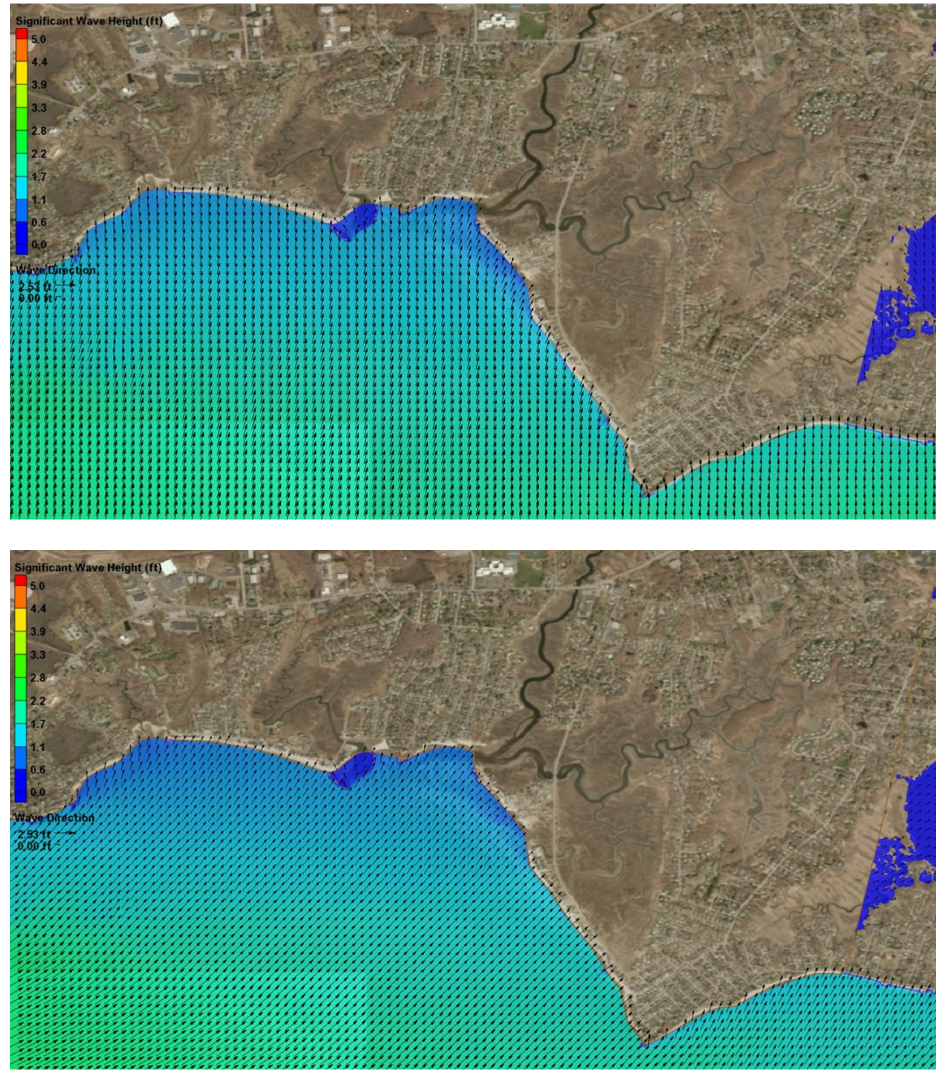


Figure 2-30: Prevailing Wave Vectors and Heights – South Wind (above) and Southwest Wind (below); Low Beach Communities

Precipitation

Precipitation probability point data is available from NOAA's National Weather Service Atlas 14. Data is presented in tabular and graphical form in **Table 2-10** and **Figure 2-26.**

The predicted trend for the Northeast US is for an increase in the frequency of intense precipitation events. Detailed climate-related precipitation change predictions have not been developed for Connecticut; however, increase in the frequency of intense rainfalls in Connecticut of 200% to 300% are likely by the end of the century. The predicted trend is also for wetter winters, springs and summers.

PDS-based precipitation frequency estimates with 90% confidence intervals (in inches)[1]

Duration	Average recurrence interval (years)									
	1	2	5	10	25	50	100	200	500	1000
5-min	0.341 (0.260-0.445)	0.409 (0.311-0.535)	0.521 (0.395-0.682)	0.613 (0.462-0.806)	0.740 (0.543-1.00)	0.838 (0.604-1.16)	0.936 (0.658-1.33)	1.06 (0.709-1.52)	1.22 (0.790-1.80)	1.35 (0.852-2.01)
10-min	0.483 (0.368-0.631)	0.580 (0.441-0.758)	0.738 (0.559-0.966)	0.868 (0.655-1.14)	1.05 (0.769-1.42)	1.19 (0.856-1.64)	1.33 (0.933-1.88)	1.50 (1.00-2.15)	1.73 (1.12-2.55)	1.91 (1.21-2.85)
15-min	0.568 (0.433-0.742)	0.682 (0.519-0.891)	0.868 (0.658-1.14)	1.02 (0.771-1.34)	1.23 (0.905-1.68)	1.40 (1.01-1.93)	1.56 (1.10-2.21)	1.77 (1.18-2.53)	2.04 (1.32-3.00)	2.24 (1.42-3.35)
30-min	0.792 (0.603-1.03)	0.951 (0.723-1.24)	1.21 (0.917-1.58)	1.42 (1.07-1.87)	1.72 (1.26-2.34)	1.95 (1.40-2.69)	2.18 (1.53-3.09)	2.46 (1.65-3.53)	2.84 (1.84-4.18)	3.13 (1.98-4.66)
60-min	1.02 (0.774-1.33)	1.22 (0.927-1.59)	1.55 (1.18-2.03)	1.83 (1.38-2.40)	2.21 (1.62-3.00)	2.50 (1.80-3.45)	2.79 (1.96-3.96)	3.16 (2.11-4.53)	3.64 (2.35-5.36)	4.01 (2.54-5.98)
2-hr	1.32 (1.01-1.72)	1.59 (1.22-2.07)	2.03 (1.55-2.64)	2.39 (1.81-3.12)	2.89 (2.13-3.91)	3.28 (2.38-4.50)	3.66 (2.60-5.18)	4.18 (2.81-5.96)	4.87 (3.16-7.11)	5.39 (3.42-7.98)
3-hr	1.54 (1.18-1.98)	1.85 (1.41-2.39)	2.35 (1.80-3.05)	2.78 (2.11-3.61)	3.36 (2.48-4.52)	3.80 (2.77-5.21)	4.25 (3.03-6.00)	4.87 (3.27-6.91)	5.69 (3.70-8.28)	6.31 (4.01-9.31)
6-hr	1.95 (1.51-2.51)	2.35 (1.81-3.02)	2.99 (2.30-3.85)	3.53 (2.69-4.56)	4.26 (3.17-5.70)	4.83 (3.53-6.57)	5.39 (3.86-7.57)	6.19 (4.17-8.72)	7.23 (4.71-10.4)	8.03 (5.12-11.8)
12-hr	2.43 (1.88-3.10)	2.92 (2.26-3.72)	3.72 (2.87-4.75)	4.38 (3.36-5.62)	5.29 (3.95-7.03)	5.99 (4.40-8.09)	6.70 (4.80-9.32)	7.66 (5.19-10.7)	8.94 (5.85-12.8)	9.91 (6.34-14.4)
24-hr	2.85 (2.22-3.61)	3.45 (2.68-4.37)	4.43 (3.43-5.63)	5.24 (4.04-6.68)	6.35 (4.77-8.40)	7.21 (5.33-9.69)	8.07 (5.83-11.2)	9.30 (6.32-12.9)	10.9 (7.16-15.5)	12.1 (7.79-17.5)
2-day	3.18 (2.49-4.00)	3.90 (3.05-4.91)	5.07 (3.95-6.39)	6.04 (4.68-7.65)	7.37 (5.58-9.70)	8.40 (6.25-11.3)	9.43 (6.88-13.1)	11.0 (7.51-15.2)	13.1 (8.61-18.5)	14.7 (9.45-21.0)
3-day	3.45 (2.71-4.32)	4.22 (3.31-5.30)	5.49 (4.29-6.90)	6.53 (5.08-8.24)	7.98 (6.05-10.5)	9.09 (6.78-12.1)	10.2 (7.46-14.1)	11.9 (8.14-16.4)	14.2 (9.34-19.9)	15.9 (10.3-22.6)
4-day	3.70 (2.92-4.63)	4.51 (3.55-5.64)	5.83 (4.57-7.31)	6.93 (5.40-8.72)	8.43 (6.41-11.0)	9.60 (7.17-12.8)	10.8 (7.87-14.8)	12.5 (8.58-17.2)	14.9 (9.82-20.8)	16.6 (10.8-23.6)
7-day	4.42 (3.50-5.50)	5.29 (4.18-6.58)	6.71 (5.28-8.36)	7.88 (6.17-9.86)	9.50 (7.24-12.3)	10.7 (8.04-14.2)	12.0 (8.77-16.3)	13.8 (9.48-18.8)	16.2 (10.7-22.5)	18.0 (11.7-25.4)
10-day	5.12 (4.06-6.35)	6.03 (4.77-7.47)	7.50 (5.92-9.32)	8.72 (6.85-10.9)	10.4 (7.94-13.4)	11.7 (8.77-15.3)	13.0 (9.49-17.5)	14.8 (10.2-20.0)	17.1 (11.4-23.8)	18.9 (12.3-26.6)
20-day	7.25 (5.78-8.93)	8.23 (6.55-10.1)	9.82 (7.79-12.1)	11.1 (8.79-13.8)	13.0 (9.91-16.5)	14.4 (10.8-18.5)	15.8 (11.5-20.9)	17.4 (12.1-23.4)	19.6 (13.1-27.0)	21.3 (13.9-29.7)
30-day	9.04 (7.23-11.1)	10.1 (8.03-12.3)	11.7 (9.34-14.4)	13.1 (10.4-16.2)	15.0 (11.5-19.0)	16.5 (12.4-21.1)	18.0 (13.0-23.5)	19.5 (13.6-26.1)	21.6 (14.4-29.5)	23.1 (15.1-32.1)
45-day	11.3 (9.04-13.8)	12.3 (9.89-15.1)	14.1 (11.3-17.3)	15.6 (12.3-19.1)	17.6 (13.5-22.0)	19.1 (14.3-24.3)	20.6 (14.9-26.7)	22.1 (15.4-29.3)	23.9 (16.0-32.5)	25.3 (16.6-35.0)
60-day	13.1 (10.6-16.0)	14.3 (11.4-17.4)	16.1 (12.9-19.6)	17.6 (14.0-21.5)	19.7 (15.1-24.6)	21.3 (16.0-26.9)	22.9 (16.5-29.4)	24.2 (16.9-32.0)	25.8 (17.4-35.1)	27.1 (17.8-37.4)

[1] Precipitation frequency (PF) estimates in this table are based on frequency analysis of partial duration series (PDS).

Numbers in parenthesis are PF estimates at lower and upper bounds of the 90% confidence interval. The probability that precipitation frequency estimates (for a given duration and average recurrence interval) will be greater than the upper bound (or less than the lower bound) is 5%. Estimates at upper bounds are not checked against probable maximum precipitation (PMP) estimates and may be higher than currently valid PMP values.

Please refer to NOAA Atlas 14 document for more information.

Table 2-10: NOAA Atlas 14 Precipitation

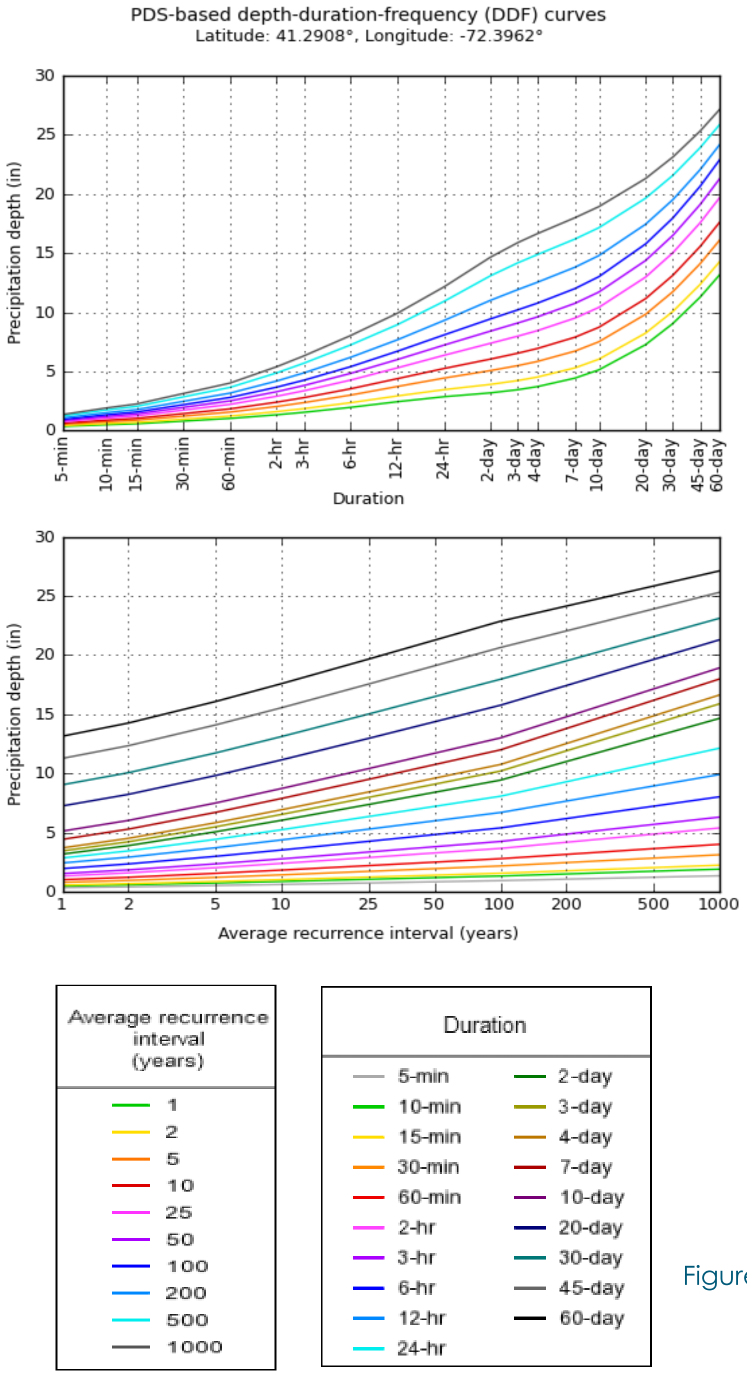


Figure 2-29: Precipitation Point Data

Additional Climate Considerations

Additional, relevant climate considerations include changes to temperature, precipitation and the water balance including snow water equivalent, runoff, soil water storage and evaporative deficit. Worldwide climate modeling centers participating in the 5th Climate Model Intercomparison Program (CMIP5) are providing climate information for the ongoing Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC).

Attachment 2 Appendix A presents a summary report for Middlesex County using the United States Geological Survey Climate Change Viewer (NCCV). The NCCV includes the historical and future climate projections from 30 of the downscaled models for two of the RCP emission scenarios, RCP4.5 and RCP8.5. RCP4.5 is one of the possible emissions scenarios in which atmospheric GHG concentrations are stabilized so as not to exceed a radiative equivalent of 4.5 Wm^{-2} after 2100, about 650 ppm CO_2 equivalent. RCP8.5 is the most aggressive emissions scenario in which GHGs continue to rise unchecked through the end of the century leading to an equivalent radiative forcing of 8.5 Wm^{-2}, about 1370 ppm CO_2 equivalent. The climate and water balance data are averaged into four climatology periods: 1981-2010, 2025-2049, 2050-2074, and 2075-2099.

United States Geological Survey Climate Change Viewer (NCCV). The NCCV includes the historical and future climate projections from 30 of the downscaled models for two of the RCP emission scenarios, RCP4.5 and RCP8.5. RCP4.5 is one of the possible emissions scenarios in which atmospheric GHG concentrations are stabilized so as not to exceed a radiative equivalent of 4.5 Wm^{-2} after 2100, about 650 ppm CO_2 equivalent. RCP8.5 is the most aggressive emissions scenario in which GHGs continue to rise unchecked through the end of the century leading to an equivalent radiative forcing of 8.5 Wm^{-2}, about 1370 ppm CO_2 equivalent. The climate and water balance data are averaged into four climatology periods: 1981-2010, 2025-2049, 2050-2074, and 2075-2099.

The output from the CMIP5 models is typically provided on grids of ~1 to 3 degrees in latitude and longitude (roughly 80 to 230 km at 45° latitude). To derive higher resolution data for regional climate change assessments, NASA applied a statistical technique to downscale maximum and minimum air temperature and precipitation from 33 of the CMIP5 climate models to a very fine, 800-m grid over the contiguous United States (CONUS). The full NEX-DCP30 dataset covers the historical period (1950-2005) and 21st century (2006-2099) under four Representative Concentration Pathways (RCP) emission scenarios developed for AR5.

The USGS used the air temperature and precipitation data from the 30 CMIP5 models as input to a simple water-balance model to simulate changes in the surface water balance over the historical and future time periods on the 800-m CONUS grid. Combining the climate data with the water balance data in the NCCV provides further insights into the potential for climate-driven change in water resources.

Air Temperature: The seasonal average Summer, 2-meter air temperature is predicted to increase (from historical averages of around 80°F) to about 85°F (RCP4.5) to about 92°F by the year 2100. The seasonal average Winter, 2-meter air temperature is predicted to increase (from historical averages of around 40°F) to about 45°F (RCP4.5) to about 50°F by the year 2100. The annual number of extreme heat days is predicted to increase significantly in Connecticut.

Water Temperature: In general, over the last 45 years there has been a steady, but slight increase in Long Island Sound water temperature, with average winter temperatures at around 41°F (5°C). Winter water temperatures appear to be increasing more rapidly than spring, summer or fall temperatures, and winter 2012 is the warmest since the inception of this record by a large margin. Increases in surface water temperatures have been linked to observed changes in the fish community. Cold-adapted fish have been observed less frequently in recent years, while warm-adapted fish have been observed more frequently. The combination of increasing water temperatures and changing fish community is believed to be indicative of climate change. The overall mean from 1976 through 2015 is 3.90°C (39.02 F) for winter, 11.22°C (52.20F) for spring, 20.07°C (68.13F) for summer, and 12.24°C (54.03F) for fall. (From Long Island Sound Study).

Spring Freshet: As temperatures rise in the spring, snow and ice that have accumulated throughout Long Island Sound's watershed begins to melt, which leads to high levels of runoff into small streams and rivers which, in turn, drain into the Connecticut River, which provides about 70% of the fresh water input into Long Island Sound, as well as other smaller rivers. This process is called the spring 'freshet'. Changes in the timing of the freshet may have implications for some aquatic species and human activities along the coast. Flooded fields and marshes along the river during the freshet provide critical feeding areas for migratory waterfowl. So if the freshet comes earlier, waterfowl could be impacted if they do not adjust the timing of their migration. Changes in the timing of flooding may also provide a competitive advantage to invasive plants (such as purple loosestrife and Phragmites) in the marshes since some of these species emerge earlier than the natives. In the past, these invasives were flooded in early spring and often rotted due to submergence for prolonged periods. So, if the flooding occurs earlier, the invasives (still emerging before the natives) will no longer rot in early spring and may gain a competitive advantage over natives.

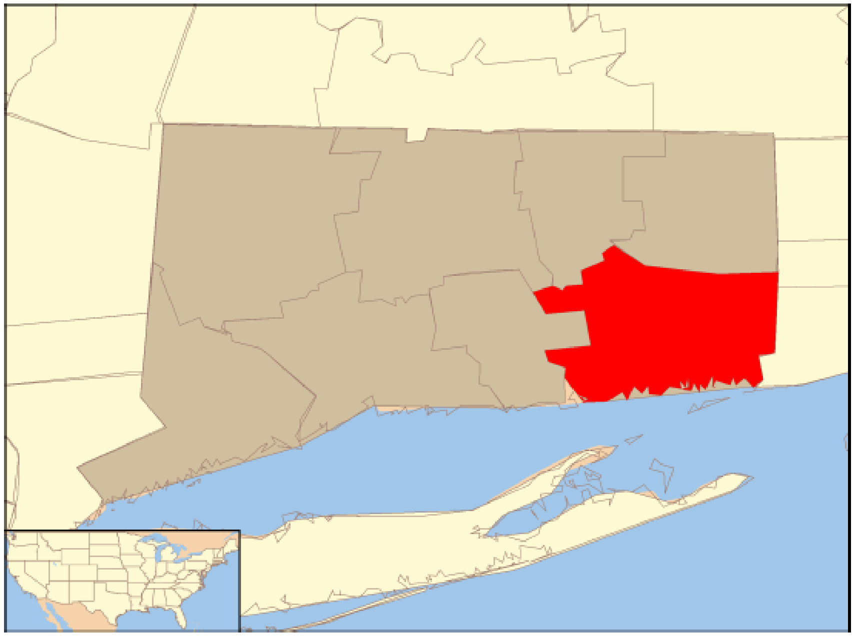
By looking at 80 years of river data, scientists at the US Geological Survey and UConn have determined that the spring freshet is occurring earlier in the spring. This indicator is derived from measurements of river flow at a gauge at Thompsonville, CT, near the Massachusetts border). The indicator is the date (we use Julian days, or # of days into the year, to account for leap years) that the total volume of water that has passed by the gauge exceeds half of the total for the year. The critical date is called the "winter-spring center of volume" or WSCV. While spring weather in New England is quite variable, the WSCV usually occurs in late March or early April. Despite large oscillations, the freshet is getting to Long Island Sound on average about 10 days earlier than it did a hundred years ago.

While the exact magnitude and timing of the freshet in any given year is highly dependent on local and regional weather patterns during the late winter/early spring period, the long-term shift towards an earlier center of volume is indicative of a general warming trend throughout the region. (From Long Island Sound Study)

Growing Season: The length of the growing season is the variation between the last frost of spring and the first frost of fall. This indicator uses air temperatures measured at Tweed-New Haven Airport in New Haven since 1973 and compares it to frost measurements from an 18th and 19th century datasets collected and published in 1866 by Yale College. The average length of the growing season over the past 40 years (1973-2015) is 26 percent higher than the average length of the growing season from 1788 to 1866, an increase from 126 days to 159 days. Over the past 11 years the length of the growing season has been equal to or exceeded the modern-era average every year, but two. (from Long Island Sound Study)

U.S. Geological Survey - National Climate Change Viewer

Summary of New London County, Connecticut



December 1, 2016

1 Maximum 2-m Air Temperature

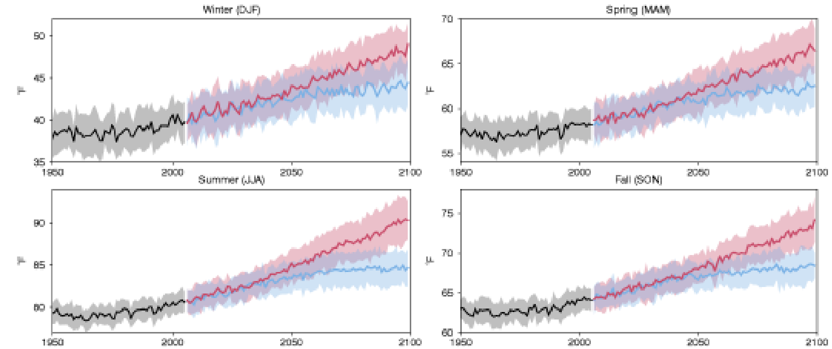


Figure 1: Seasonal average time series of maximum 2-m air temperature for historical (black), RCP4.5 (blue) and RCP8.5 (red). The historical period ends in 2005 and the future periods begin in 2006. The average of 30 CMIP5 models is indicated by the solid lines and their standard deviations are indicated by the respective shaded envelopes.

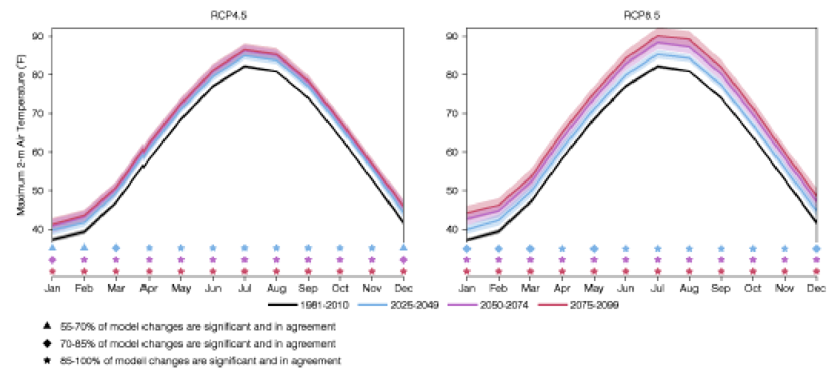


Figure 2: Monthly averages of maximum 2-m air temperature for four time periods for the RCP4.5 (left) and RCP8.5 (right) simulations. The average of 30 CMIP5 models is indicated by the solid lines and their standard deviations are indicated by the respective shaded envelopes. Triangle, diamond and square symbols indicate the percent of models that simulate future minus present changes that are of the same sign and significant. A two-sided Students t-test is used to establish significance ($p \leq 0.05$).

2 Minimum 2-m Air Temperature

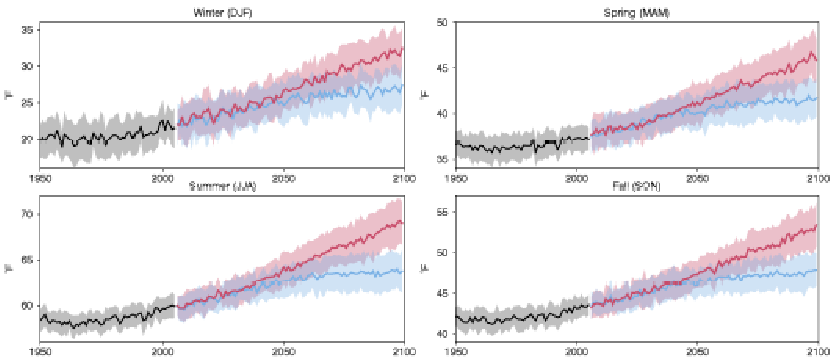


Figure 3: Seasonal average time series of minimum 2-m air temperature for historical (black), RCP4.5 (blue) and RCP8.5 (red). The historical period ends in 2005 and the future periods begin in 2006. The average of 30 CMIP5 models is indicated by the solid lines and their standard deviations are indicated by the respective shaded envelopes.

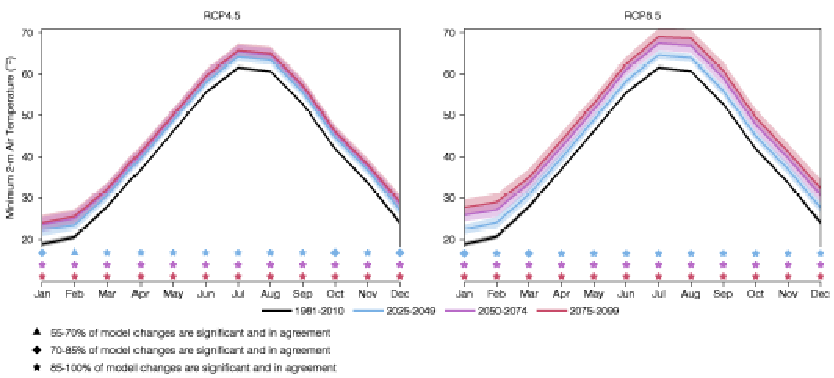


Figure 4: Monthly averages of minimum 2-m air temperature for four time periods for the RCP4.5 (left) and RCP8.5 (right) simulations. The average of 30 CMIP5 models is indicated by the solid lines and their standard deviations are indicated by the respective shaded envelopes. Triangle, diamond and square symbols indicate the percent of models that simulate future minus present changes that are of the same sign and significant. A two-sided Students t-test is used to establish significance ($\rho \leq 0.05$).

3 Precipitation

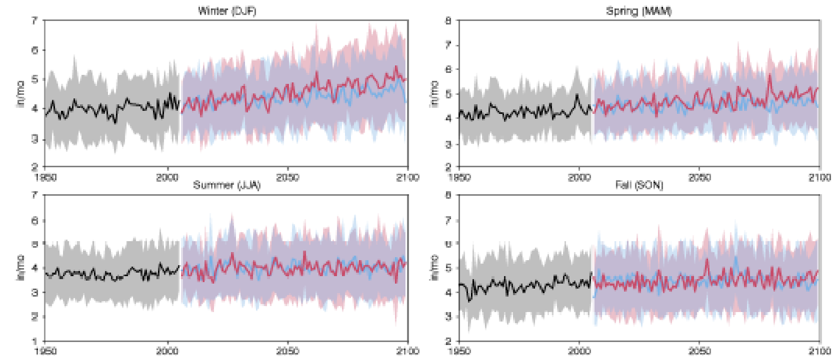


Figure 5: Seasonal average time series of precipitation for historical (black), RCP4.5 (blue) and RCP8.5 (red). The historical period ends in 2005 and the future periods begin in 2006. The average of 30 CMIP5 models is indicated by the solid lines and their standard deviations are indicated by the respective shaded envelopes.

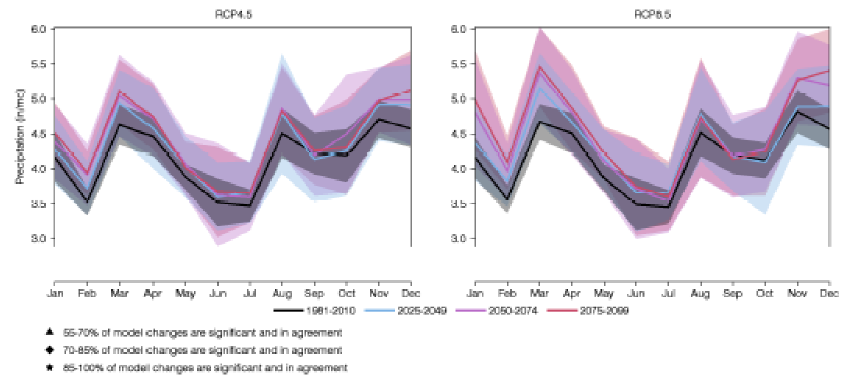


Figure 6: Monthly averages of precipitation for four time periods for the RCP4.5 (left) and RCP8.5 (right) simulations. The average of 30 CMIP5 models is indicated by the solid lines and their standard deviations are indicated by the respective shaded envelopes. Triangle, diamond and square symbols indicate the percent of models that simulate future minus present changes that are of the same sign and significant. A two-sided Students t-test is used to establish significance ($\rho \leq 0.05$).

4 Snow Water Equivalent

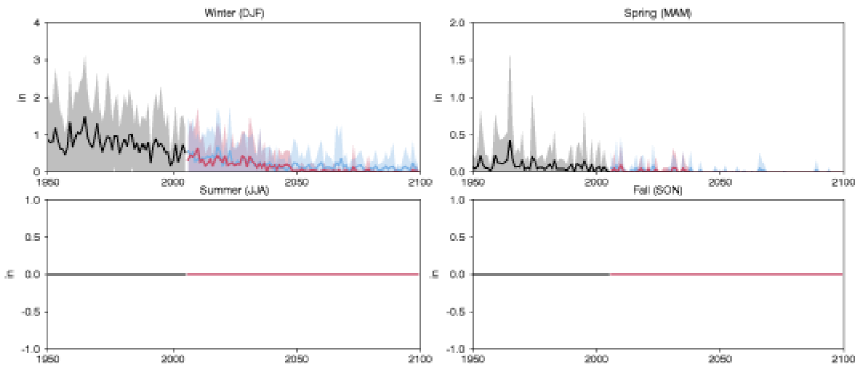


Figure 7: Seasonal average time series of snow water equivalent for historical (black), RCP4.5 (blue) and RCP8.5 (red). The historical period ends in 2005 and the future periods begin in 2006. The average of 30 CMIP5 models is indicated by the solid lines and their standard deviations are indicated by the respective shaded envelopes.

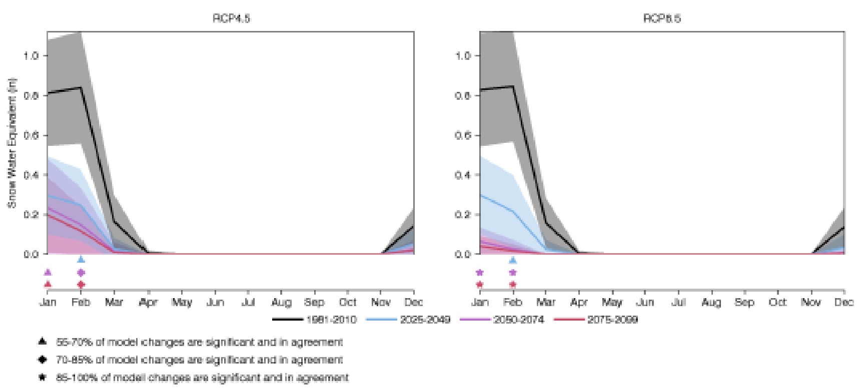


Figure 8: Monthly averages of snow water equivalent for four time periods for the RCP4.5 (left) and RCP8.5 (right) simulations. The average of 30 CMIP5 models is indicated by the solid lines and their standard deviations are indicated by the respective shaded envelopes. Triangle, diamond and square symbols indicate the percent of models that simulate future minus present changes that are of the same sign and significant. A two-sided Students t-test is used to establish significance ($\rho \leq 0.05$).

5 Runoff

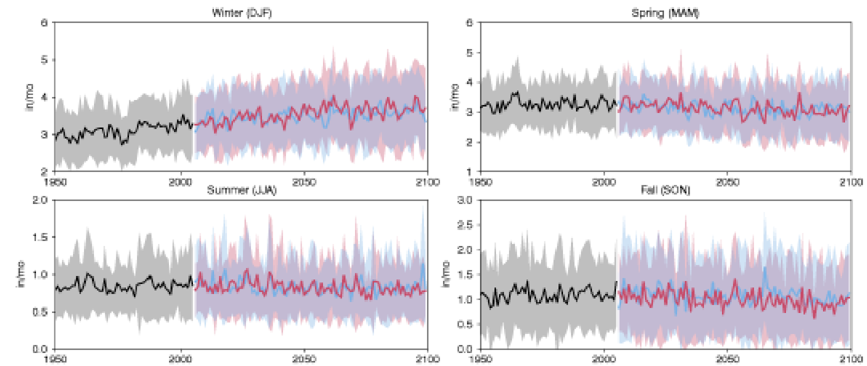


Figure 9: Seasonal average time series of runoff for historical (black), RCP4.5 (blue) and RCP8.5 (red). The historical period ends in 2005 and the future periods begin in 2006. The average of 30 CMIP5 models is indicated by the solid lines and their standard deviations are indicated by the respective shaded envelopes.

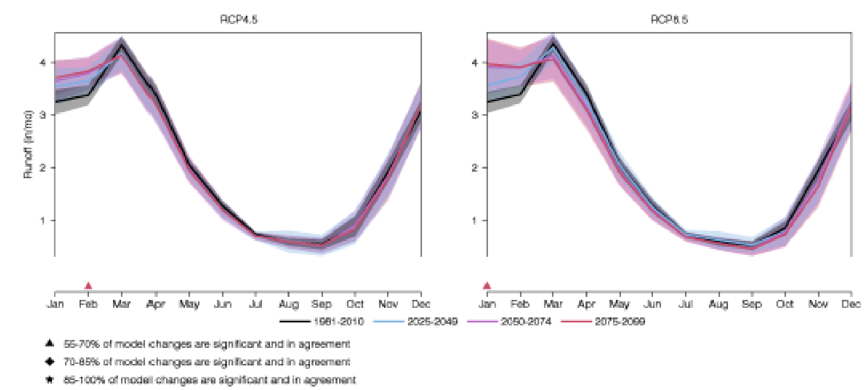


Figure 10: Monthly averages of runoff for four time periods for the RCP4.5 (left) and RCP8.5 (right) simulations. The average of 30 CMIP5 models is indicated by the solid lines and their standard deviations are indicated by the respective shaded envelopes. Triangle, diamond and square symbols indicate the percent of models that simulate future minus present changes that are of the same sign and significant. A two-sided Students t-test is used to establish significance ($\rho \leq 0.05$).

6 Soil Water Storage

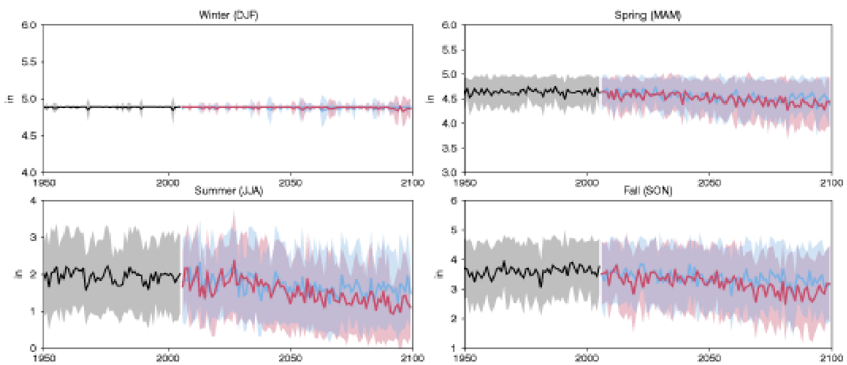


Figure 11: Seasonal average time series of soil water storage for historical (black), RCP4.5 (blue) and RCP8.5 (red). The historical period ends in 2005 and the future periods begin in 2006. The average of 30 CMIP5 models is indicated by the solid lines and their standard deviations are indicated by the respective shaded envelopes.

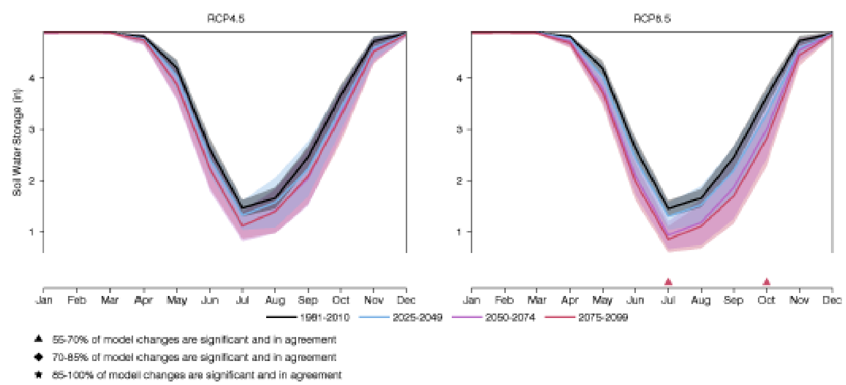


Figure 12: Monthly averages of soil water storage for four time periods for the RCP4.5 (left) and RCP8.5 (right) simulations. The average of 30 CMIP5 models is indicated by the solid lines and their standard deviations are indicated by the respective shaded envelopes. Triangle, diamond and square symbols indicate the percent of models that simulate future minus present changes that are of the same sign and significant. A two-sided Students t-test is used to establish significance ($\rho \leq 0.05$).

7 Evaporative Deficit

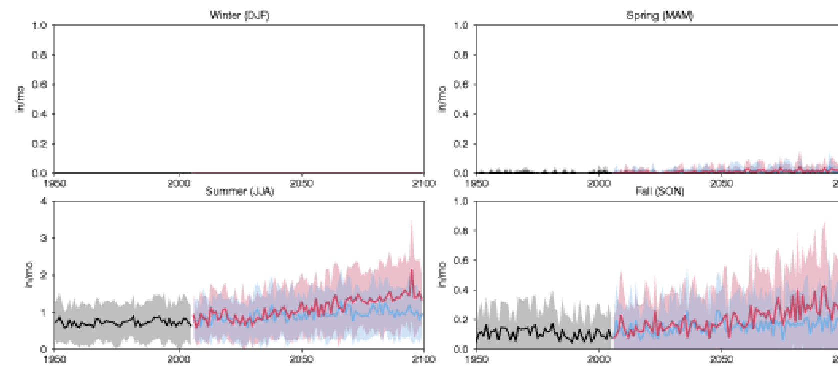


Figure 13: Seasonal average time series of evaporative deficit for historical (black), RCP4.5 (blue) and RCP8.5 (red). The historical period ends in 2005 and the future periods begin in 2006. The average of 30 CMIP5 models is indicated by the solid lines and their standard deviations are indicated by the respective shaded envelopes.

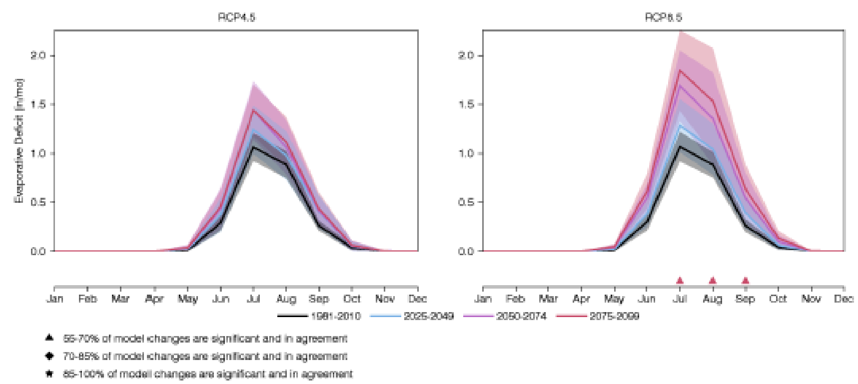


Figure 14: Monthly averages of evaporative deficit for four time periods for the RCP4.5 (left) and RCP8.5 (right) simulations. The average of 30 CMIP5 models is indicated by the solid lines and their standard deviations are indicated by the respective shaded envelopes. Triangle, diamond and square symbols indicate the percent of models that simulate future minus present changes that are of the same sign and significant. A two-sided Students t-test is used to establish significance ($\rho \leq 0.05$).

8 Data

The temperature and precipitation summaries are created by spatially averaging the NASA NEX-DCP30 data set (Thrasher et al., 2013). The water-balance variables snow water equivalent, runoff, soil water storage and evaporative deficit are simulated by using the NEX-DCP30 temperature and precipitation as input to a simple model (McCabe and Wolock, 2007). The water-balance model accounts for the partitioning of water through the various components of the hydrologic system, but does not account for groundwater, diversions or regulation by impoundments.

9 Models

ACCESS1-0	bcc-csm1-1	bcc-csm1-1-m	BNU-ESM	CanESM2	CCSM4
CESM1-BGC	CMCC-CM	CNRM-CM5	CSIRO-Mk3-6-0	FGOALS-g2	FIO-ESM
GFDL-CM3	GFDL-ESM2G	GFDL-ESM2M	GISS-E2-R	HadGEM2-AO	HadGEM2-CC
HadGEM2-ES	inmcm4	IPSL-CM5A-LR	IPSL-CM5A-MR	IPSL-CM5B-LR	MIROC5
MIROC-ESM	MIROC-ESM-CHEM	MPI-ESM-LR	MPI-ESM-MR	MRI-CGCM3	NorESM1-M

10 Citation Information

Alder, J. R. and S. W. Hostetler, 2013. USGS National Climate Change Viewer. US Geological Survey http://www.usgs.gov/climate_landuse/clu_rd/nccv.asp doi:10.5066/F7W9575T.

Hostetler, S.W. and Alder, J.R., 2016. Implementation and evaluation of a monthly water balance model over the U.S. on an 800 m grid. Water Resources Research, 52, doi:10.1002/2016WR018665.

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11 Disclaimer

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