Shrewsbury River Basin, Sea Bright, New Jersey Coastal Storm Risk Management Feasibility Study

Draft Integrated Feasibility Report & Environmental Assessment

Appendix A: Engineering

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Chapter 1: Introduction

1.1 Description of the Study Area

The Borough of Sea Bright is located in northeastern Monmouth County, New Jersey. The Shrewsbury Project area covers about 1.5 square miles, and is bounded by the Shrewsbury River Bridge to the north, the Atlantic Ocean to the east, the Shrewsbury River to the west, and Sandpiper Lane to the south. Figure A1 below shows the location map.

Figure A1: Sea Bright project location; Shrewsbury, New Jersey.

1.2 Characteristics and Problem Identification of Study Area

The Sea Bright area is low-lying, with a shoreline that has been stabilized by a relatively low bulkhead. The majority of the area west of Ocean Avenue is at elevations that are at or below +4 feet North American Vertical Datum of 1988 (NAVD88). There is a slight rise in elevation along Ocean Avenue, with an elevation generally between +4 feet and +5 feet NAVD88. East of Ocean Avenue, the elevations rise. Landward of the beach and dune, elevations generally vary between +6 feet to +12 feet NAVD88, and generally average +10 feet NAVD88. Along the Atlantic Ocean shoreline, the beach conditions vary, but are generally at an elevation of +10 feet NAVD88. The beach is backed by an existing seawall through a portion of the study area, with heights up to elevation +16 feet NAVD88. There are portions of the area where the highest elevation is +10 feet NAVD88.

Most of the community is within the one percent floodplain of the Shrewsbury River. The mean tidal range on the riverside at Sea Bright is 3.15 feet (oceanside range is 5.08 feet). Depending on the tides, runoff and tidal flow from the river can produce significant currents through the narrows at Sea Bright. Flooding in the Shrewsbury River Basin is most severe during nor'easters and hurricanes.

In response to recurrent flooding, some Sea Bright residents and businesses have elevated their buildings. The Borough granted permits for at least 46 structures in the study area to be elevated after Hurricane Sandy in 2012. However, many structures remain at or near grade, and this project seeks to provide flood damage risk reduction from hurricanes for these homes and businesses.

1.3 Other Federal Studies

Prior USACE Reports:

- Optimization Report, "Shrewsbury River, Flood Risk Management Study; Sea Bright, New Jersey, Optimization of Preliminary Nonstructural Plans" (May 2012)
- Draft Preliminary Alternatives Analysis Report, "Shrewsbury River Basin, New Jersey, Flood Risk Management Study Preliminary Alternatives Analysis Report" (January 2011)
- ERDC/CHL Letter Report, "Shrewsbury River Flood Control Modeling" (February 2006)
- "Shrewsbury River Basin, New Jersey, Reconnaissance Study for Flood Control & Ecosystem Restoration, Section 905(b) (WRDA 86) Preliminary Analysis" (July 2000)
    - The Reconnaissance Study recommended further Federal investigation into the feasibility of reducing flood risks along the Shrewsbury River at Sea Bright, and the feasibility of aquatic habitat restoration.
    - Based upon local sponsor preferences, the Feasibility Cost Sharing Agreement that was entered into between USACE and NJDEP focused on the flood risk management aspects of the study.
- General Design Memorandum, "Atlantic Coast of New Jersey from Sandy Hook to Barnegat Inlet Beach Erosion Control Project" (January 1989)

Existing Water Resource Projects:

- Borough of Sea Bright's ocean-facing seawall, , including an extension currently under construction
- Riverfront bulkheads built and maintained by homeowners
- Riverfront bulkheads built and maintained by the Borough of Sea Bright
- Stormwater outfalls
- Atlantic Coast of New Jersey, Sandy Hook to Barnegat Inlet Beach Erosion Control Project (Section 1 – Sea Bright to Ocean Township, New Jersey)

- Shrewsbury & Navesink Rivers Federal navigation projects
- Shrewsbury & Navesink Rivers state navigation projects

Chapter 2: Existing Conditions

2.1 Flooding Sources

Flooding in the Shrewsbury River Basin is the result of complex interactions. The basin receives about 45 inches of precipitation per year. Flooding in the Shrewsbury River Basin is most severe during nor'easters, which typically occur during the late fall, winter, and early spring. These storms can deposit significant amounts of precipitation in the watershed and produce strong onshore winds. When high onshore winds are sustained over several tidal cycles, the resultant storm surge can combine with runoff to produce severe flooding along the coast and in back bay areas, including the Shrewsbury River.

Hurricanes also cause major flooding in the basin. A hurricane surge pushes its way into the Shrewsbury and Navesink Rivers, and into surrounding communities. Hurricane Sandy in 2012 flooded many municipalities in the basin. Relatively low-lying communities such as Sea Bright experience major flooding and associated damages. Communities with higher elevations generally fair better during storms.

2.2 Future Water Surface Elevations Due to Sea Level Change

NACCS Stage Frequency and Wave-Frequency

Stage-frequency curves for the start year for the period of analysis (2020) were acquired from the North Atlantic Coast Comprehensive Study (NACCS) for the project location. The stage-frequency curves for the entire region were developed through surge and wave modeling of a suite of synthetic design storms. The stage frequency data were taken without manipulation, although an adjustment was made to get the stage data into the NAVD88 datum. The stage-frequency curves are referenced to the MSL datum, so a shift to the NAVD88 datum was necessary for this particular project. The datum conversion from the Mean Sea Level (MSL) datum to the NAVD88 datum was calculated to be 0.24ft. This conversion factor was used since the Sandy Hook gauge is located relatively close to the project site. Table A1 contains the datum information for the Sandy Hook Gauge.

Table A1: Datum for the Sandy Hook gauge.

Elevations on Station Datum

Station: 8531680, Sandy Hook, NJ
T.M.: 75 W
Status: Accepted (Apr 17 2003)
Epoch: 1983-2001
Units: Feet
Datum: STND

Datum	Value	Description
MHHW	7.74	Mean Higher-High Water
MHW	7.41	Mean High Water
MTL	5.06	Mean Tide Level
MSL	5.09	Mean Sea Level
DTL	5.13	Mean Diurnal Tide Level
MLW	2.71	Mean Low Water
MLLW	2.51	Mean Lower-Low Water
NAVD88	5.33	North American Vertical Datum of 1988
STND	0.00	Station Datum
GT	5.22	Great Diurnal Range
MN	4.70	Mean Range of Tide
DHQ	0.33	Mean Diurnal High Water Inequality
DLQ	0.19	Mean Diurnal Low Water Inequality
HWI	0.29	Greenwich High Water Interval (in hours)
LWI	6.64	Greenwich Low Water Interval (in hours)
Maximum	12.60	Highest Observed Water Level
Max Date & Time	09/12/1960 13:00	Highest Observed Water Level Date and Time
Minimum	-2.20	Lowest Observed Water Level
Min Date & Time	02/02/1976 16:00	Lowest Observed Water Level Date and Time
HAT	9.11	Highest Astronomical Tide
HAT Date & Time	10/16/1993 12:48	HAT Date and Time
LAT	1.14	Lowest Astronomical Tide
LAT Date & Time	01/21/1996 19:36	LAT Date and Time

Tidal Datum Analysis Periods

01/01/1983 - 12/31/2001

STND: station datum, an arbitrary, vertical reference point at a given location

The raw output, which includes peak surge elevation and associated significant wave heights and mean wave periods, was processed to estimate statistical wave parameters. Figure A2 displays the results of a regression analysis which determines the flood wave parameters for fifteen events ranging from 0.1 to 99 percent annual exceedance probability. The peak surge elevation for each of the synthetic storms is plotted against the associated significant wave height and peak wave period. From this trend, we can estimate the wave heights for different surge elevations. The results of this regression analysis give the required wave-frequency information at the project site. The location of the project site can be seen on the map in Figure A3. Table A2 contains the resulting stage and wave frequency curves for the project site.

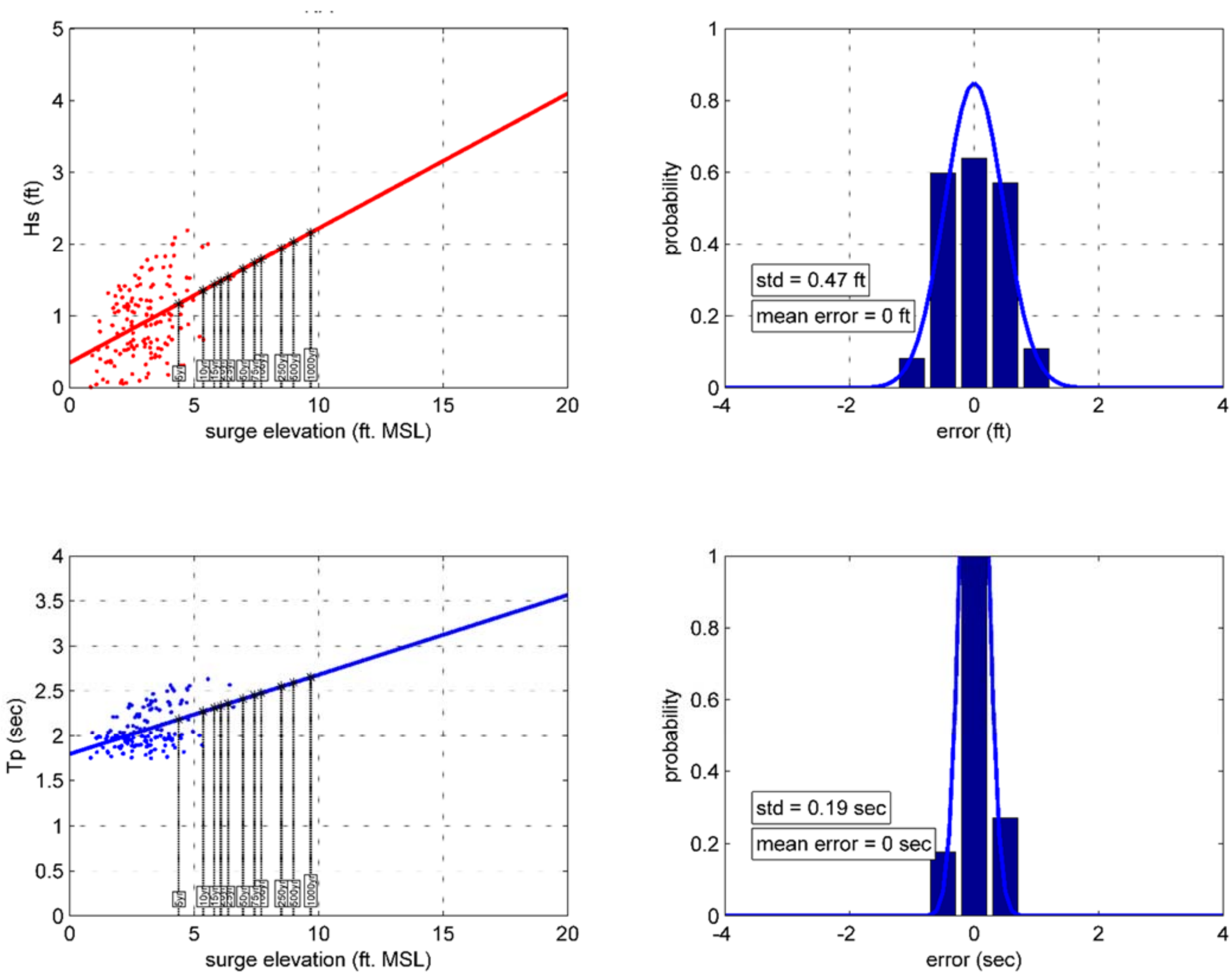


Figure A2: Regression analysis of peak surge and associated significant wave height (Hs) and peak wave period (Tp) for the ADCIRC Node 162137, at Sea Bright.

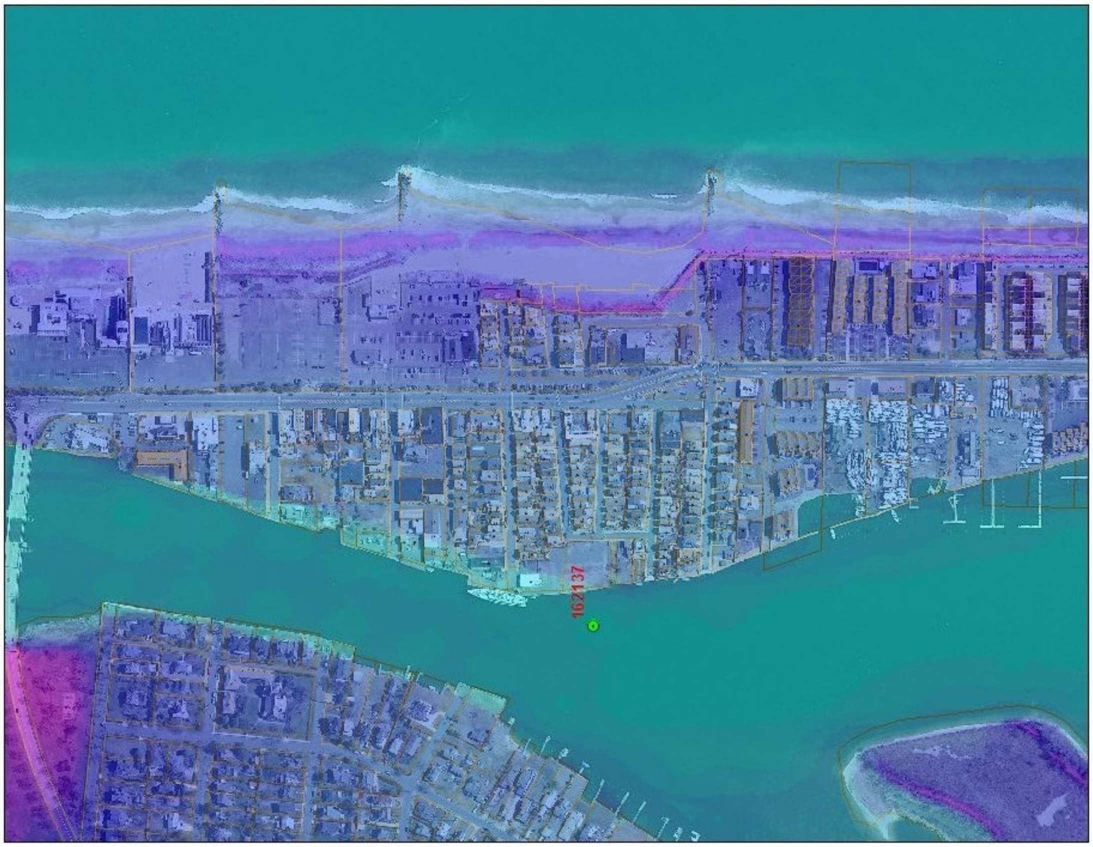


Figure A3: Location of Node 162137 in ADCIRC model in project area.

Table A2: Existing Conditions NACCS stage and wave frequency curves.

Condition	Annual Exceedance Probability, %	Mean Surge Elevation (ft NAVD88)	Significant Wave Height (feet)	Peak Wave Period (Sec)
2020 Existing	99	2.1	0.9	2.0
2020 Existing	50	2.7	1.0	2.0
2020 Existing	33	3.5	1.3	2.0
2020 Existing	25	4.2	1.5	2.1
2020 Existing	20	4.7	1.6	2.1
2020 Existing	10	5.6	1.8	2.1
2020 Existing	6.7	6.1	2.0	2.1
2020 Existing	5	6.4	2.0	2.2
2020 Existing	4	6.6	2.1	2.2
2020 Existing	2	7.2	2.3	2.2
2020 Existing	1.3	7.7	2.4	2.2
2020 Existing	1	8.0	2.5	2.2
2020 Existing	0.4	8.8	2.7	2.3
2020 Existing	0.2	9.2	2.8	2.3
2020 Existing	0.1	9.9	3.0	2.3

USACE Stage Frequency and Wave-Frequency for Future Conditions (2070)

Stage and frequency data for future conditions were not available from the NACCS. To determine future hydraulic boundary conditions, Sea Level Change (SLC) rates were determined using the methodology outlined in the USACE Engineering Circular on SLC. A website tool was used to estimate the SLC rates at the Sandy Hook gauge, which is located near the project site. The website tool can be found at: http://www.corpsclimate.us/ccaceslcurves.cfm.

The three curves displayed in Figure A4 give rates for the low, intermediate and high estimates of SLC. Table A3 contains the tabular SLC data for the Sandy Hook gauge. Assuming construction is complete in 2020 and the period of analysis ends in 2070, the incremental SLC value is +0.7 feet for the low estimate, +1.1 feet for the intermediate estimate, and +2.5 feet for the high estimate. To determine future condition stage-frequency data, the incremental SLC rates are added directly to the base condition curve. For example, if the 25-year 2020 stage is 6.6 feet NAVD88, the future 2070 low-SLC 25-year stage would become 7.3, which is a 0.7-foot increase. Significant wave heights and peak wave periods for future conditions were developed by plugging in the future condition surge values into the same trendlines developed for 2020 conditions. The higher future condition surge elevations produce large waves. **Tables A4** through **A6** contain the stage-frequency and wave-frequency data for the project site for the 2070 condition, for low, intermediate, and high SLC rates.

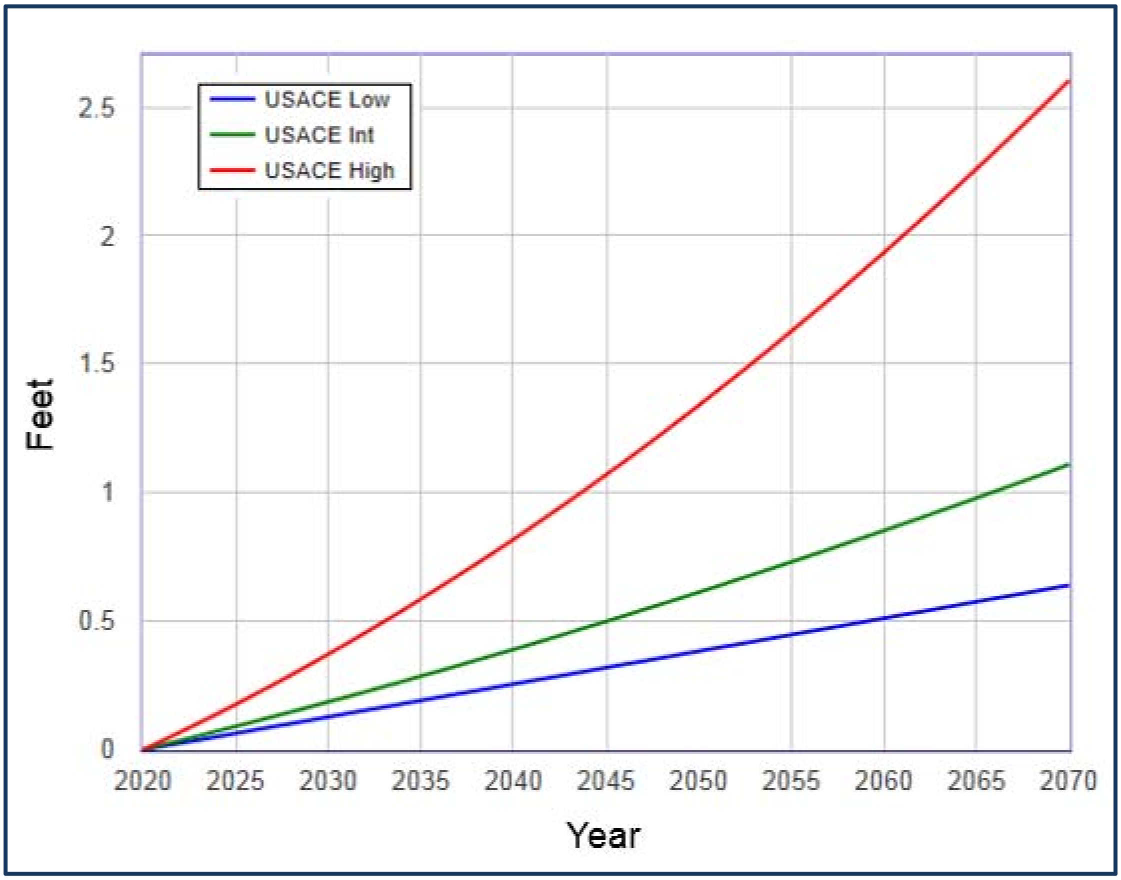


Figure A4: Low, intermediate, and high SLC rates at the Sandy Hook gauge.

Table A3: Low, intermediate, and high SLC data for the Sandy Hook gauge.

Year	USACE Low (feet change since 2020)	USACE Intermediate (feet change since 2020)	USACE High (feet change since 2020)
2020	0.00	0.00	0.00
2025	0.06	0.09	0.18
2030	0.13	0.19	0.37
2035	0.19	0.29	0.59
2040	0.26	0.39	0.82
2045	0.32	0.50	1.07
2050	0.38	0.61	1.34
2055	0.45	0.73	1.63
2060	0.51	0.85	1.94
2065	0.58	0.98	2.26
2070	0.64	1.11	2.61

Table A4: Summary of future condition surge & wave conditions for Low SLC.

Condition	Annual Exceedance Probability, %	Mean Surge Elevation (ft NAVD88)	Significant Wave Height (feet)	Peak Wave Period (Sec)
2070 Low	99	2.8	1.1	2.0
2070 Low	50	3.3	1.2	2.0
2070 Low	33	4.1	1.4	2.1
2070 Low	25	4.9	1.6	2.1
2070 Low	20	5.3	1.8	2.1
2070 Low	10	6.3	2.0	2.2
2070 Low	6.7	6.7	2.1	2.2
2070 Low	5	7.0	2.2	2.2
2070 Low	4	7.3	2.3	2.2
2070 Low	2	7.9	2.5	2.2
2070 Low	1.3	8.3	2.6	2.3
2070 Low	1	8.6	2.7	2.3
2070 Low	0.4	9.4	2.9	2.3
2070 Low	0.2	9.9	3.0	2.3
2070 Low	0.1	10.6	3.2	2.4

Table A5: Summary of future condition surge & wave conditions for intermediate SLC.

Condition	Annual Exceedance Probability, %	Mean Surge Elevation (ft NAVD88)	Significant Wave Height (feet)	Peak Wave Period (Sec)
2070 Intermediate	99	3.2	1.2	2.0
2070 Intermediate	50	3.8	1.3	2.0
2070 Intermediate	33	4.6	1.6	2.1
2070 Intermediate	25	5.3	1.8	2.1
2070 Intermediate	20	5.8	1.9	2.1
2070 Intermediate	10	6.7	2.1	2.2
2070 Intermediate	6.7	7.2	2.3	2.2
2070 Intermediate	5	7.5	2.3	2.2
2070 Intermediate	4	7.7	2.4	2.2
2070 Intermediate	2	9.3	2.6	2.3
2070 Intermediate	1.3	8.8	2.7	2.3
2070 Intermediate	1	9.1	2.8	2.3
2070 Intermediate	0.4	9.9	3.0	2.3
2070 Intermediate	0.2	10.3	3.1	2.3
2070 Intermediate	0.1	11.0	3.3	2.4

Table A6: Summary of future condition surge & wave conditions for high SLC.

Condition	Annual Exceedance Probability, %	Mean Surge Elevation (ft NAVD88)	Significant Wave Height (feet)	Peak Wave Period (Sec)
2070 High	99	4.6	1.6	2.1
2070 High	50	5.2	1.7	2.1
2070 High	33	6.0	1.9	2.1
2070 High	25	6.7	2.1	2.2
2070 High	20	7.2	2.3	2.2
2070 High	10	8.1	2.5	2.2
2070 High	6.7	8.6	2.6	2.3
2070 High	5	8.9	2.7	2.3
2070 High	4	9.1	2.8	2.3
2070 High	2	9.7	3.0	2.3
2070 High	1.3	10.2	3.1	2.3
2070 High	1	10.5	3.2	2.3
2070 High	0.4	11.3	3.4	2.4
2070 High	0.2	11.7	3.5	2.4
2070 High	0.1	12.4	3.7	2.4

2.3 Historical Storm Events

Sea Bright has a history of being impacted by both Hurricanes and Extratropical Storms. This section provides a general description of each storm type and how they affect the project area, followed by a list of specific events and their impacts.

Hurricanes. Hurricanes that develop in tropical latitudes are the most destructive storms affecting the Atlantic Coast. Hurricanes approaching the project area often are reduced in intensity from overland travel and a cooler environment. Even with reduced storm intensity, property damage and loss of life has been caused by hurricanes along the New Jersey coast.

Only two hurricanes have directly hit the New Jersey coast between 1899 and 1977. Both hurricanes hit the coast in September, the first in 1903 and the second the following year in 1904. Although no recent hurricanes have made landfall over the study area, they have physically affected this area by causing high winds, waves, and tides. The closer the path of the storm to the coast, the greater the resulting damages.

Prior to 1933, nine recorded hurricanes impacted the project area: August 1635; August 1788; September 1815; September 1821; September 1869; October 1878; August 1893; September 1930. Although this list is undoubtedly incomplete, the above dates, along with the more recent storms to be described below, serve as an indication of frequency.

Extratropical Storms. Extratropical storms, especially those from the northeast, are second in their destructive force only to hurricanes. If these storms occur during periods of higher astronomical tidal events, they can cause extensive damage to shorelines and coastal structures.

Significant Storms to Affect Sea Bright

The following is a list of some of the most significant coastal storms to affect Sea Bright:

Hurricane of September 1944. The storm center passed 30 miles east of the study area. The storm passed the New Jersey coast at about the time of high tide. The highest tide recorded at Sandy Hook was 7.7 feet above sea level datum. Gusts of up to 99 mph were recorded at New York City, while at Sandy Hook a sustained wind velocity of 68 mph from the northwest was recorded. Damage was severe throughout the study area. Several waves were reported to have reached a height of 15 feet over the top of the seawall in Sea Bright. A portion of the seawall was damaged and a section of railway which traversed the area at that time was destroyed. Boardwalks along almost every municipality in the study area were destroyed or badly damaged.

Storm of November 1950. The storm formed over Eastern North Carolina and moved northerly towards the study area. Wind gust velocities of 72 mph were recorded at New York City, and the average attained hourly wind velocity was 47 mph. Tides at Sandy Hook reached a height of 7.2 feet above sea level datum. The peak tide for this storm was only 0.5 feet below the greatest of previous record (September, 1944). The strong easterly winds resulted in high waves along the study area. Waves of up to 20 feet in height were observed to have swept across the barrier island at Monmouth Beach. Extensive damage to beaches, shore protection structures and homes in the study area resulted from the high tides and waves. Most of Sea Bright and a portion of Monmouth Beach were flooded to depths ranging up to 4 feet.

Storm of November 1953. This storm originated in the Gulf of Mexico and traveled easterly to a position off the Georgia coast where it assumed a more northerly course. The storm intensified when a high pressure system that was centered over the upper Great Lakes region brought cold air into the southeastern portion of the country. The storm center passed within 60 miles of the New Jersey coast, moving inland in the vicinity of New York City. The maximum sustained wind velocity was 55 mph with gusts up to 74 mph. Wave heights observed by US Coast Guard personnel at Sandy Hook were estimated at 30 feet.

The passage of the storm at the time of the predicted high tide resulted in high tidal levels within the study area. The tide reached a record 7.9 feet above sea level datum at Sandy Hook. The extreme tidal conditions together with the severe wave action, resulted in extensive damage to beaches, as well as public and private properties adjacent to the ocean and to shore protection structures. This storm was the storm of record for the authorizing project.

Storm of March 1962. The storm of March 6-8, 1962 resulted from the joining of two storms, one moving easterly from the Midwest, the other moving northerly up the coast. These storms combined off the mid-Atlantic Coast and remained nearly stationary. For a period of three days, strong onshore winds over a long fetch of ocean influenced the entire Atlantic Coast. The maximum wind of one-minute duration recorded at Long Beach, New Jersey was 68 mph from the northeast. The storm occurred at the time of astronomic high tides. At Sandy Hook five exceptionally high tides occurred above sea level datum that were 7.1 feet and 7.6 feet on the 6th, 7.3 feet and 6.6 feet on the 7th, and 5.7 feet on the 8th of March.

This storm has been described as one of the most destructive extratropical cyclones ever to hit the United States coastline. At Sea Bright, inundation of residential sections required evacuation of the area. Heavy seas and high tides resulted in beach and dune erosion and inflicted structural damage to buildings, the seawall and many groins. At Monmouth Beach the seawall was damaged and the highway protected by the seawall was completely blocked by sand and flooding. The Monmouth Beach pavilion and other buildings were completely destroyed. At Long Branch, the beach and bluffs were eroded, and the seawall and groins were damaged. The boardwalk was extensively damaged with complete destruction at the north and south ends. Throughout the entire study area major damage resulted to the beaches and adjacent structures.

Hurricane Agnes, June 1972. Hurricane Agnes developed off the Yucatan Coast, traveled north across the Gulf of Mexico making landfall near Panama City, Florida. Once ashore, Agnes weakened to a tropical depression as it moved northward across the southeast. The storm rejuvenated as it moved back out to sea off the Virginia Capes then proceeded up the east coast and inland again across western Long Island. The storm center passed within 40 miles of the study area. Wind gusts up to 46 mph were recorded at Sandy Hook. Seas recorded at the Ambrose light tower were less than ten feet. The greatest damage associated with this weather system resulted from rain, which caused flooding. Storm damage within the study area was minimal.

Hurricane Belle, August 1976. This Hurricane moved north at 25 to 35 mph to within 40 miles of the study area. Highest winds near the center were 100 mph. The highest winds recorded at Manasquan Inlet Coast Guard station were 60 mph from the north. Beach erosion was relatively minor.

Extratropical Storm of March 28-29, 1984. This northeaster's near hurricane force winds raised tides 10 feet above normal and deposited nearly three inches of rain in Monmouth County. The storm damaged parts of the seawalls, destroyed two stop logs and caused up to 3 feet of flooding, predominantly from surges in Raritan Bay which flanked the seawalls through the Shrewsbury River. The storm caused more than $200 million in damage to both public and private property throughout the County.

Hurricane Gloria, September 27, 1985. Light damage was reported along most of the New Jersey Coast, due to the offshore path and arrival of this hurricane at low tide. The hurricane passed by the County at more than 40 miles per hour, with winds up to 70 mph and a storm surge of 5-6 feet. Sea Bright and Monmouth Beach experienced up to three feet of flooding due to high tides following rains. The boardwalk at Long Branch was damaged slightly, and a small corner of the amusement pier collapsed. Overall damage was far less than expected and considerably less than damage sustained from the extratropical storm of March, 1984.

The Perfect Storm, October – November, 1991. The nor'easter was absorbed Hurricane Grace and ultimately evolved back into a small unnamed hurricane late in its life cycle. The storm lashed the east coast of the United States with high waves and coastal flooding before turning to the southwest and weakening. In Sea Bright, New Jersey, waves washed over a seawall, forcing 200 people to evacuate. Further inland, the Hudson, Passaic, and Hackensack rivers experienced tidal flooding.

Hurricane Isabel, September 8, 2003. Hurricane Isabel produced slightly above normal tides and rough surf along the Jersey shore, killing one surfer off of Wildwood Crest. The combination of gusty winds and the heavy surf produced moderate beach erosion along much of the coastline, primarily to beaches facing southeastward. Most coastal areas of Monmouth County reported eroded beaches by up to 4 feet (1.2 m), with Union Beach losing about 5,000 sq. feet (465 sq. m) of sand.

Hurricane Irene, August 28, 2011. Hurricane Irene was a long-lived Cape Verde-type Atlantic hurricane during the 2011 Atlantic hurricane season. The storm formed near Cape Verde on August 4 and crossed the Atlantic, turning northward around Bermuda before being absorbed by an extratropical while situated southeast of Newfoundland. The storm caused beach erosion and flooding in Monmouth County, notably in Sea Bright.

Hurricane Sandy, October 30, 2012. Hurricane Sandy was the deadliest and most destructive hurricane of the 2012 Atlantic hurricane season, and the second-costliest hurricane in United States history. While it was a Category 2 storm off the coast of the Northeastern United States, the storm became the largest Atlantic hurricane on record (as measured by diameter, with winds spanning 1,100 miles (1,800 km)). Hurricane Sandy devastated Sea Bright, with storm surge inundating the Borough from both the Shrewsbury River and Atlantic Ocean. As of 2015, the Borough continues its recovery.

2.4 Regional Geology

The study area lies within the Coastal Plain Province, which forms the eastern margin of the State of New Jersey. Its surface has a gentle slope to the southeast, generally not exceeding 5 or 6 ft to the mile. The surface of the plain extends eastward with the same gentle slope beneath the Atlantic Ocean for about 100 miles to the end of the continental shelf, where the depth is approximately 100 fathoms. At this point, the ocean bottom drops abruptly to greater depths. The moderate elevation of the Coastal Plain, which rises to 400 ft in some areas, but is generally lower than 200 ft, has prevented the streams from cutting valleys of any considerable depth. Throughout the greater portion of the plain, the relief is insignificant and the streams flow in open valleys that lie at only slightly lower levels than the broad, flat divides.

The study area, which is contained in Monmouth County, lies in the area that is above the sea level. This sub aerial portion is generally a dissected plain that rises gradually from sea level at the coast to nearly 400 ft in central New Jersey. It then declines to a broad shallow depression less than 100 ft above sea level extending to the Delaware River at Trenton. Some conspicuous features of the sub aerial portion of the plain are the marshes, which border the stream courses and the submerged or drowned valleys, which were formed by erosion when the land was at a higher elevation than at present. During the geologic history, the sea level fluctuated to a large extent. The rise and fall of the water resulted in wide migration of the shoreline across the Coastal Plain. The sub aerial region was especially influenced by these fluctuations during the Cretaceous Period.

The Cretaceous Period resulted in many successive sedimentary formations, each of which was subject to erosion, deposition, submersion, and emergence. Realizing that weathering and its associated agents determined all of New Jersey's geomorphology; this geological period had great influence on the study area. The resulting Cretaceous formations are composed of unconsolidated sand, clay, and greensand marl (glauconitic), which dip 25 ft to 60 ft per mile to the southeast and having a thickness in places of 500 ft to 1,000 ft. The sediments rest on a sloping formation of deep-seated hard rocks. The present surface features were most recently determined during the glacial Pleistocene Period and by subsequent erosion.

The subsurface geology of the Coastal Plain has been determined by study and correlation of well logs and by interpretation of seismic profiles. The Coastal Plain consists of Cretaceous to Recent sediments lapping on the basement material, which is composed of crystalline rock with locally infolded or infaulted Triassic sediments. The basement surface slopes at about 75 ft per mile, reaching a depth of more than 6,000 ft near the coast. The soils overlying the bedrock are of considerable thickness exceeding several hundred ft., and are of the Upper Cretaceous and Tertiary Period. The oldest and therefore the deepest formation, which rests unconformably on the bedrock is the Raritan (Magothy) formation. It consists of dark lignitic sand and clay containing some glauconite at the top overlying light colored sands and clays.

The Merchantville and Woodbury clay formations overlay the Raritan formation discomformably. Both formations are black, glauconitic, micaceous clay, the former being slightly more plastic and firmer than the latter. To the southeast of Waycake Creek (the western boundary of the Keansburg project area), the upper formation, the Englishtown sand, outcrops at the surface along Creek Road, and extends southeastward to Highlands under the recent swamp deposits at Pews Creek (the eastern boundary of the Keansburg project area). It reaches its maximum thickness at the Highlands where some of the beds have been cemented by iron oxide. This material overlays the Woodbury clay formation and it represents a period of emergence. The Englishtown sand consists of a white and yellow quartz sand, slightly micaceous.

With the final uplift of the land and withdrawal of the Cretaceous sea, streams established themselves across the emerging sea bottom. This ushered in the Cenozoic Era. Periods of submergence and emergence were the dominating geological force, but with the exception of a very shallow deposit of sand referred to as the Cape May formation, no other soil material from this era is found in the project area. The Cape May formation is an interglacial formation deposited by streams and overland deposition at the close of the last glacial period. The sea again invaded the area and created valleys, which have been filling with recent swamp material and sediment.

Considering the age of the Cretaceous materials, estimated by geologists to be 120 to 150 million years old and all the intervals of submergence and deposition, and emergence and erosion, one would expect these soils to be very firm on the basis that they have been subjected to relatively high prestresses. However, the clay materials were found to be nominally consolidated and very soft.

Chapter 3: Development of Alternatives

Structural and nonstructural alternatives were considered for the Shrewsbury River study. Structural measures are those which alter the nature or extent of a hazard, such as flooding. For example, a floodwall is a structure measure, as it alters (prevents the inundation from) the hazard (flooding) in a community. Nonstructural measures are defined as those that reduce human exposure or vulnerability to a flood hazard without altering the nature or extent of that hazard. For example, elevating a structure is a nonstructural measure because it doesn't alter (prevent the inundation from) the hazard (flooding) in a community, but rather removes the structure away from the hazard. Though elevating or modifying a structure involves construction activities, they are inherently nonstructural measure because they reduce human exposure or vulnerability without altering the nature or extent of flooding.

Descriptions and layouts of the alternatives can be found in the main report. The initial development of the alternatives utilized USACE stage-frequency data from 1998. Stage-frequency curves from the NACCS have been adopted as the stage-frequency data for the study.

3.1 Structural Alternatives

The following structural alternatives were considered for flood damage risk reduction:

- Alternative F1 – Floodwall built to 2 percent flood event water surface elevation (WSE)
- Alternative F2 – Floodwall built to 1 percent flood event WSE
- Alternative F3 – Floodwall built to 0.5 percent flood event WSE
- Alternative F4 – Floodwall built to 0.3 percent flood event WSE
- Surge Barrier Alternative – Off-shore breakwater across Sandy Hook Bay at Shrewsbury River

The alternatives were compared to the planning objectives to determine which features should be considered for more detailed analysis. **Table A7** shows the major advantages and disadvantages of each of the structural alternatives.

Table A7: Advantages and disadvantages of structural plans.

Alternative	Description	Major Advantages	Major Disadvantages
Alternative F1	+7.0-foot NAVD88 floodwall	Decreases flood risk Consistent with current waterfront use	Provides limited risk reduction High residual risk
Alternative F2	+8.5-foot NAVD88 floodwall	Decreases flood risk Consistent with current waterfront use	Potential for viewshed impacts Lack of sponsor support Provides limited risk reduction High residual risk
Alternative F3	+9.5-foot NAVD88 floodwall	Decreases flood risk Consistent with current waterfront use	Potential for viewshed impacts Lack of sponsor support Provides limited risk reduction High residual risk
Alternative F4	+11.5-foot NAVD88 floodwall	Decreases flood risk Consistent with current waterfront use	Potential for viewshed impacts Lack of sponsor support
Surge Barrier	Surge barrier at the Shrewsbury River at Highlands, NJ	Provides regional risk management solution Does not impact viewshed	Potential negative environmental impacts

The Surge Barrier Alternative was analyzed as part of a study for Highlands, New Jersey, and it was found that the cost of such a project would not be justified by the benefits gained throughout the Shrewsbury River basin. In addition, all floodwall alternatives were found to be not cost effective. Therefore, all of these structural alternatives were dropped from further consideration.

3.2 Non-Structural Alternatives

Different nonstructural scenarios were developed, each affecting an incrementally greater number of structures. The scenarios were formulated by grouping structures with different main floor elevations (MFE). The groupings that were used were structures with a MFE less than or equal to the 10-year, 25-year, and 1 percent still water surface elevations. The nonstructural alternatives are:

- Nonstructural Alternative 1: structures with a MFE less than or equal to the 10 percent flood water surface elevation (+4.5 feet NAVD88)
- Nonstructural Alternative 2: structures with a MFE less than or equal to the 4 percent flood water surface elevation (+6.0 feet NAVD88)
- Nonstructural Alternative 3: structures with a MFE less than or equal to the 1 percent flood water surface elevation (+8.2 feet NAVD88)

Table A8 shows the major advantages and disadvantages of each of the nonstructural alternatives.

Table A8: Advantages and disadvantages of nonstructural plans.

Alternative	Description	Major Advantages	Major Disadvantages
Alternative NS 1	Elevations only for structures with MFE below 10 percent flood WSE, 4.5 ft NAVD88	Decreases flood risk Consistent with Sea Bright rebuilding strategy No impact to viewshed No O&M requirements Public support of plan	Temporary inconvenience to residents and businesses No risk management provided for evacuation route Limited to 10 percent floodplain
Alternative NS 2	Elevations only for structures with MFE below 4 percent flood WSE, 6.0 ft NAVD88	Decreases flood risk Consistent with Sea Bright rebuilding strategy No impact to viewshed No O&M requirements Public support of plan	Temporary inconvenience to residents and businesses No risk management provided for evacuation route Limited to 4 percent floodplain
Alternative NS 3	Elevations only for, 1 percent flood WSE, 8.2 ft NAVD88	Decreases flood risk Consistent with Sea Bright rebuilding strategy No impact to viewshed No O&M requirements Public support of plan	Temporary inconvenience to residents and businesses No risk management provided for evacuation route Limited to 1 percent floodplain

Chapter 4: Evaluation of Alternatives

After developing and verifying the inventory of structures in the Sea Bright project area, a nonstructural measures engineering tool developed by the USACE National Nonstructural Floodproofing Committee was used to determine the appropriate treatment for each structure. A flow chart was developed for the Fire Island to Montauk Point, NY study, and it was also used for the Leonardo, New Jersey Feasibility Study. The flow charts follow this Appendix in Figures A5 through A8. The tool identified elevations and ringwalls as the most appropriate treatments in the study area, given the amount of inundation and structure types involved. To identify the most efficient and cost effective nonstructural plan, structure elevations and ringwalls were considered separately. For the initial array, nonstructural plans that included only structure elevations were used for comparison and screening of the initial array of alternatives. Ringwalls that were economically justified on their own, or incrementally justified, were added to the plan later in the planning process. Of the alternatives, Alternative NS 2 is the only one with positive net benefits. Using the main floor elevation as the basis for inclusion into each alternative, initially three alternatives were developed, based on the main floor elevations at or below the 10 percent, 4 percent, and 1 percent flood water surface elevations

The plan includes the elevation of 34 structures with a MFE at or below the 4 percent WSEL of +6.0 feet NAVD88. Ringwalls were individually considered in a last-added analysis to reduce residual risk. Many different ringwall designs were considered. Considering current land uses, deployable ringwalls are the most appropriate for the study area. Permanent ringwalls would impede the operation of businesses and potentially impact Ocean Avenue, a major evacuation route. The ringwalls were designed to a height of +11.2 feet NAVD88, which is equal to the height of the elevated structures (the 1 percent flood level of +8.2 plus 3 feet). Detailed ringwall design will be developed prior to construction, in coordination with the NJDEP and Borough of Sea Bright. Costs and benefits were calculated for individual ringwalls identified in Table 6, and were compared. Of the ringwalls in Alternative NS 2, one ringwall had positive annual net benefits of $42,000. Ringwall #10 is located around two attached structures. The ringwall was added to Alternative NS 2.

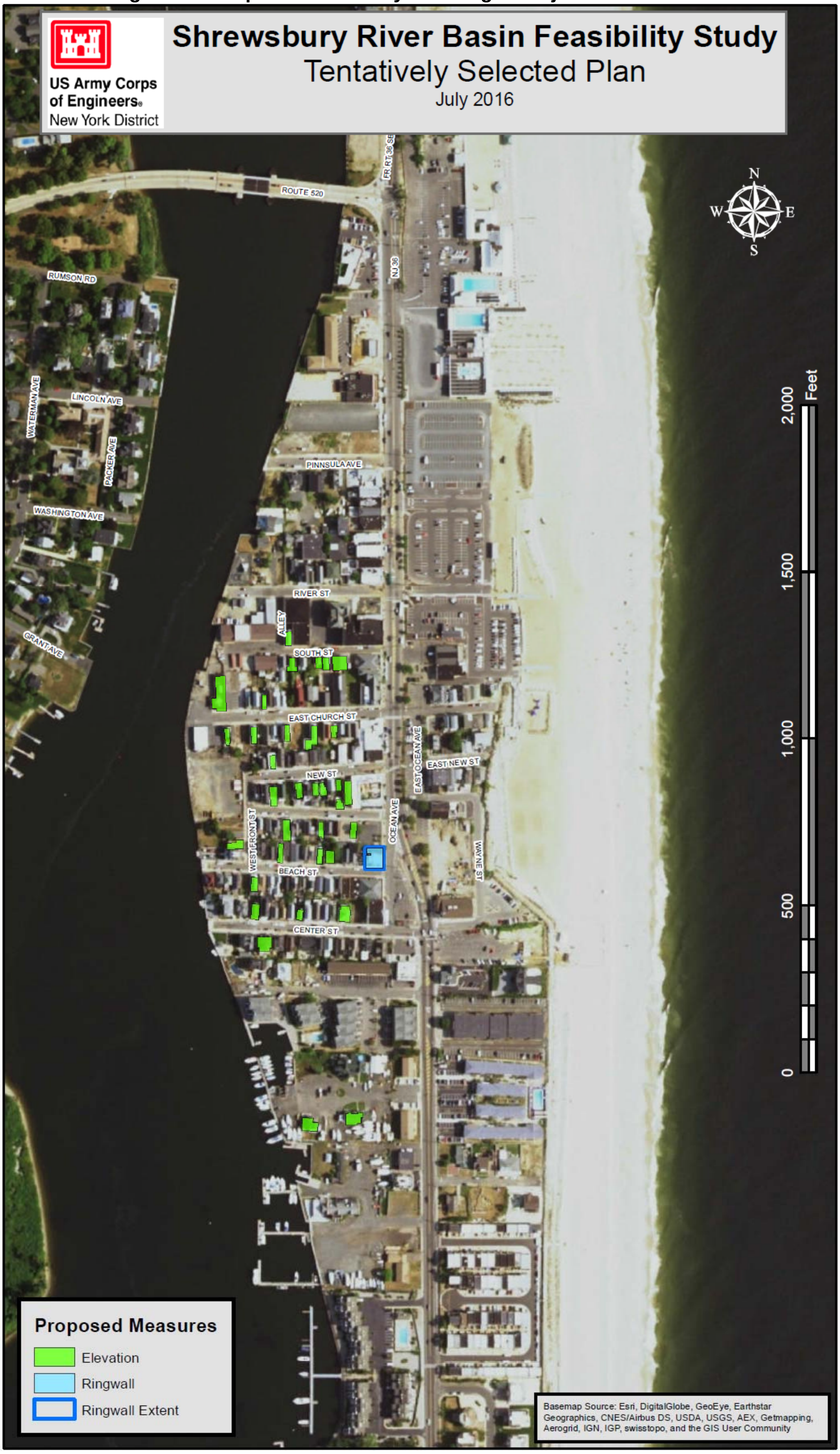
Chapter 5: Tentatively Selected Plan

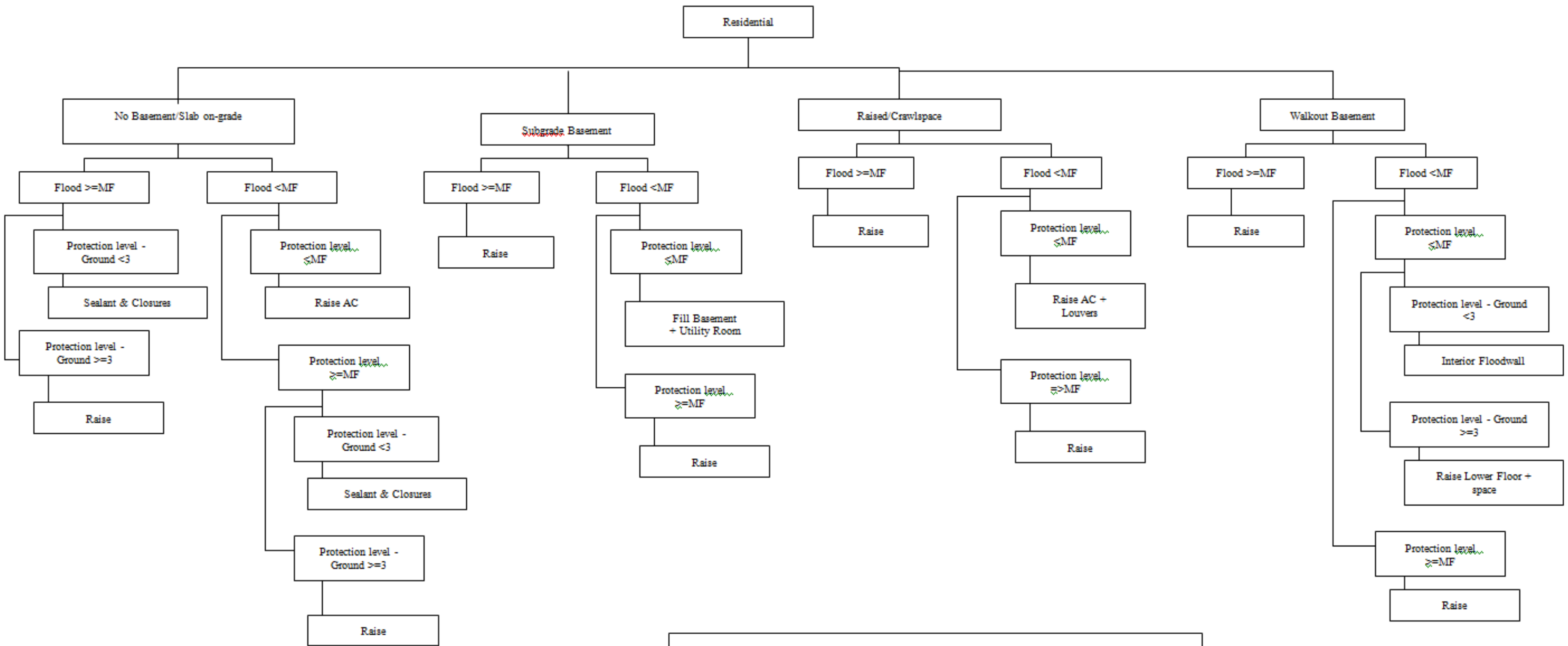
Alternative NS 2 (elevation of structures with a main floor elevation at or below the 4 percent flood water surface elevation of +6.0 feet NAVD88), including the one ringwall with positive annual net benefits has been identified as the TSP. Table A9 shows the selected nonstructural treatment for each structure that is included in the plan. Figure A5 is a map of the project area indicating the location of all proposed structure raises, as well as the location of the structure with the deployable ringwall solution. All mapping products utilize the NAD83 Horizontal Datum and were referenced to the New Jersey State Plane projection.

Table A9: Summary of nonstructural treatments for the tentatively selected plan.

Structure ID#	Structure Type	Main Floor Elevation (ft NAVD 88)	Recommended Plan	Area (sqft)
28.03	Residential	5.77	Elevate	750
30	Residential	5.62	Elevate	660
31	Residential	5.78	Elevate	740
32	Residential	5.50	Elevate	1840
41	Residential	5.63	Elevate	590
44	Residential	5.74	Elevate	3630
46.01	Residential	5.59	Elevate	700
47	Residential	5.85	Elevate	840
51	Residential	4.86	Elevate	800
53	Residential	4.91	Elevate	1170
56	Residential	5.65	Elevate	600
66	Residential	5.62	Elevate	650
70	Residential	4.97	Elevate	1250
72	Residential	5.71	Elevate	930
74	Residential	4.93	Elevate	660
75	Residential	5.34	Elevate	710
77	Residential	5.94	Elevate	550
78	Residential	4.45	Elevate	1560
80	Residential	5.66	Elevate	500
81	Residential	5.32	Elevate	860
84	Residential	5.58	Elevate	740
86	Residential	5.17	Elevate	1350
90	Residential	4.80	Elevate	1110
93	Residential	5.17	Elevate	1490
97	Residential	5.12	Elevate	760
98	Residential	5.28	Elevate	980
101.01	Nonresidential	4.26	Ringwall	1420
101.02	Nonresidential	4.26	Ringwall	1160
106	Residential	5.27	Elevate	810
117	Residential	4.92	Elevate	1510
122	Residential	4.53	Elevate	590
127	Residential	5.11	Elevate	1020
132	Residential	5.13	Elevate	1720
156	Residential	5.75	Elevate	1670
157	Residential	5.48	Elevate	1630

Figure A5: Map of Shrewsbury Sea Bright Project Area with TSP





Typical Structures
(Structures are defined by foundation type)

1. RAISED (crawl space)
2. SLAB-ON-GRADE
3. BASEMENT (Subgrade (Traditional) and Walkout)
4. BI-LEVEL/RAISED Ranch
5. SPLIT-LEVEL

Assumptions for TYPICAL STRUCTURES

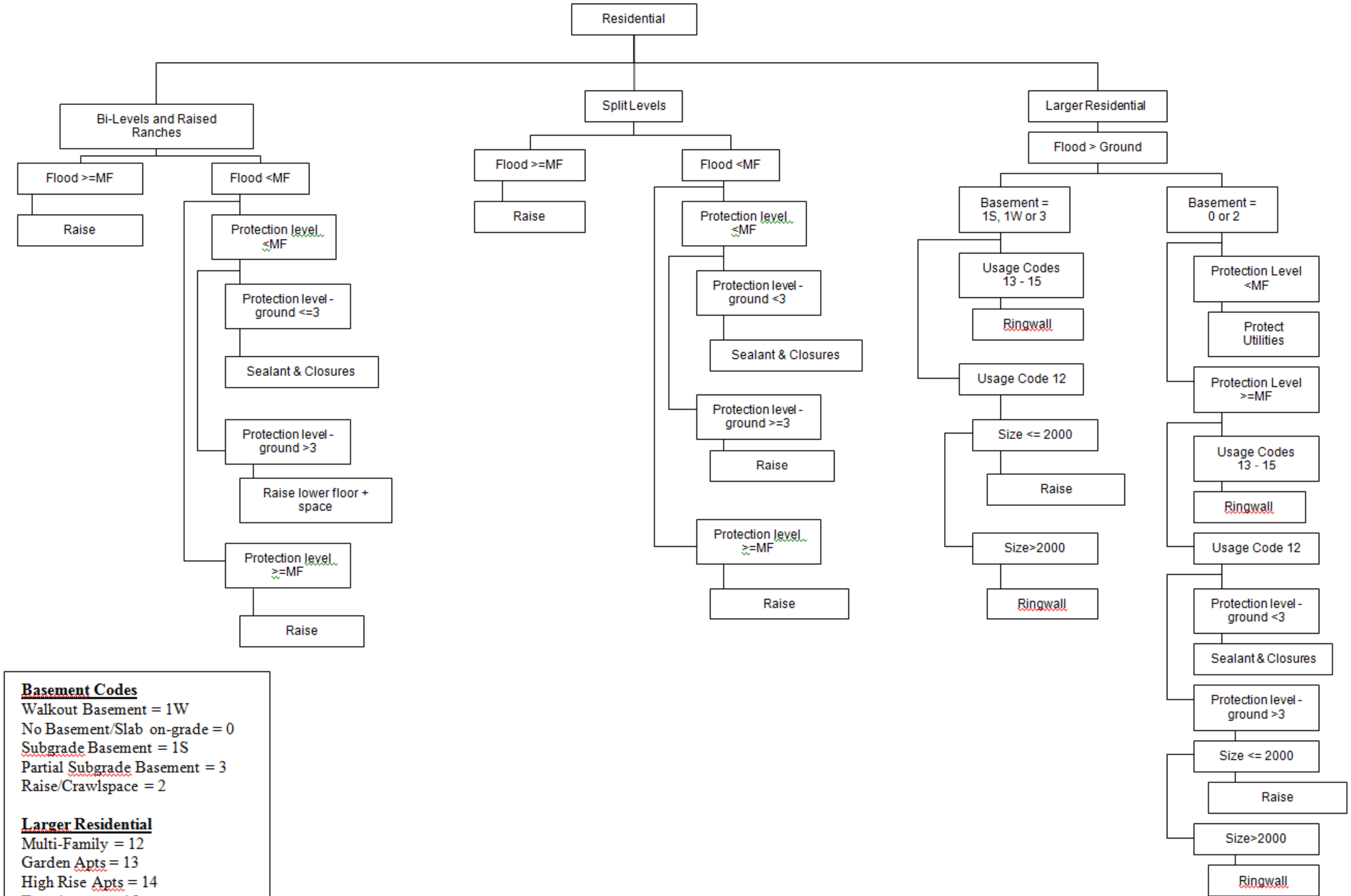
1. (a) Raised(Crawl Space): No utilities are located in the crawl space.
1. (b) Raised(Crawl Space): Wet Flood Proofing includes exterior utilities only.
2. (a) Slab: Wet Flood Proofing is possible when flood depth is below the MF (shallow flooding). Typically exterior utilities only (e.g. AC).
3. Basement: All basements are unfinished.
4. (a) Bi-level/Raised Ranch: The lower floor is a minimum of 4-ft of masonry wall
4. (b) Bi-level/Raised Ranch The lower level is slab on grade; walkout
5. (a) Split-Level: The lower level (LL) is slab on grade; the main floor is raised over a crawl space
5. (b) The Main Floor and the upper level can be separated from the lower level in order to raise the structure.

Larger Residential
Multi-Family = 12
Garden Apts = 13
High Rise Apts = 14
Townhouses = 15

Criteria for flood proofing TYPICAL STRUCTURES

1. Loss of living space due to flood proofing measures will be minimized or replaced.
2. No dry flood proofing for depths>2 feet

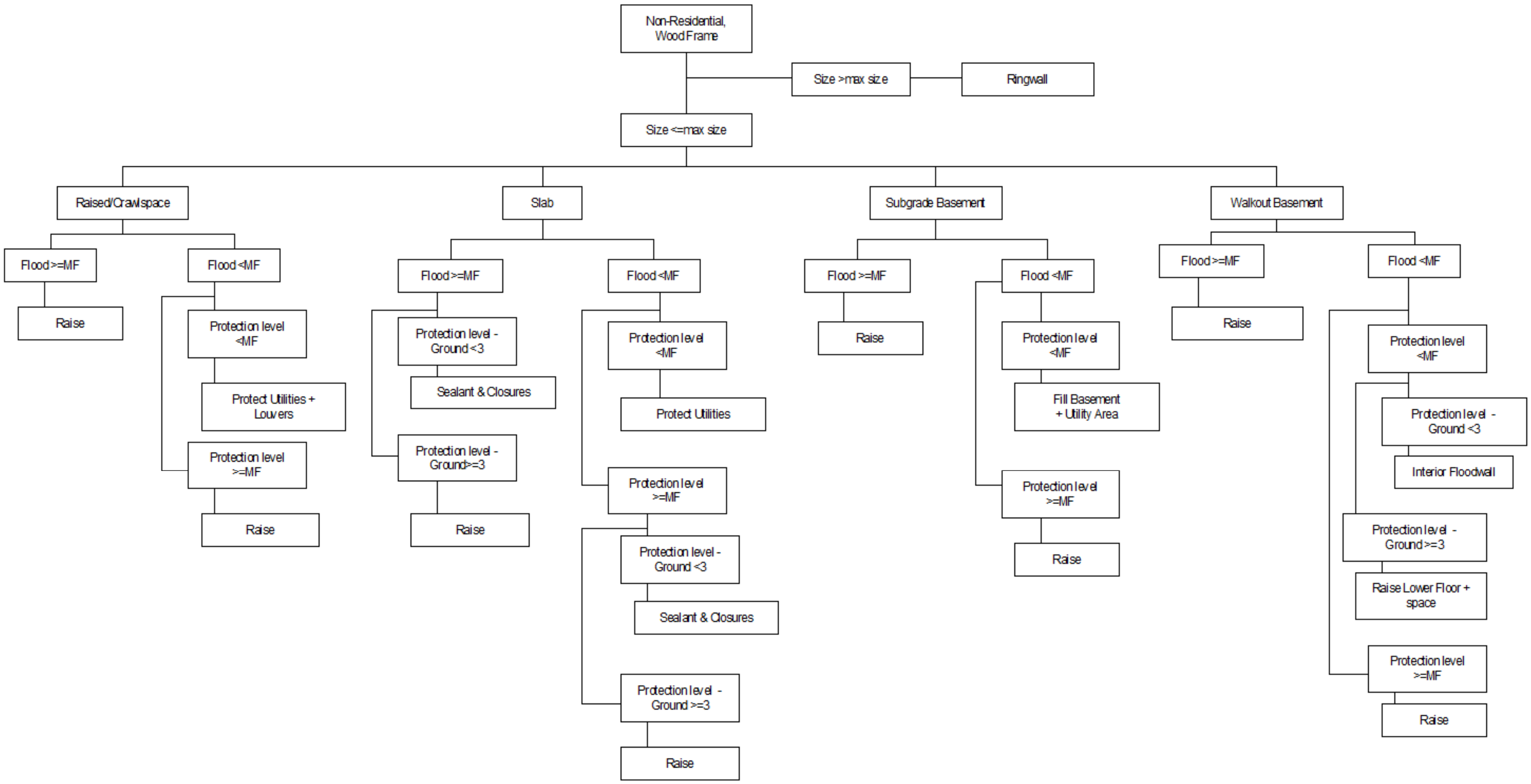
Figure A6: Residential flowchart.



Basement Codes
Walkout Basement = 1W
No Basement/Slab on-grade = 0
Subgrade Basement = 1S
Partial Subgrade Basement = 3
Raise/Crawlspace = 2

Larger Residential
Multi-Family = 12
Garden Apts = 13
High Rise Apts = 14
Townhouses = 15

Figure A6: Residential Flowchart (continued).



Basement Codes
Walkout Basement = 1W
No Basement/Slab on-grade = 0
Subgrade Basement = 1S
Partial Subgrade Basement = 3
Raise/Crawlspace = 2

Figure A7: Non-Residential flowchart.

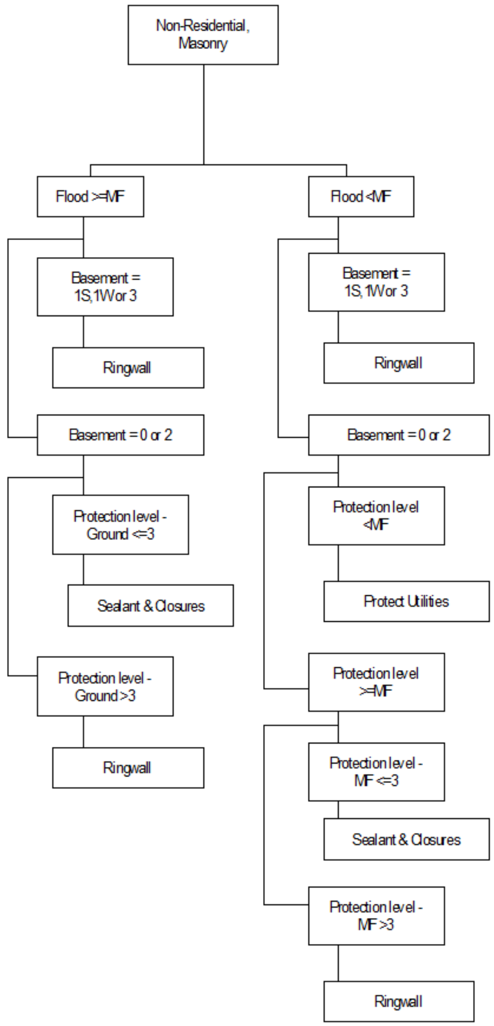


Figure A8: Non-Residential flowchart (continued).

Chapter 6 Proposed Nonstructural Treatments

The following sketches indicate generic elevation plans, and are intended for conceptual purposes only. Actual designs will be based on specific conditions at each site.

Deployable ringwall concepts and designs will be chosen based on appropriateness and feasibility. Pictures of conceptual designs can be found in Chapter 3 of the main report. Coordination with the non-Federal sponsor and Borough of Sea Bright will occur during feasibility-level design.

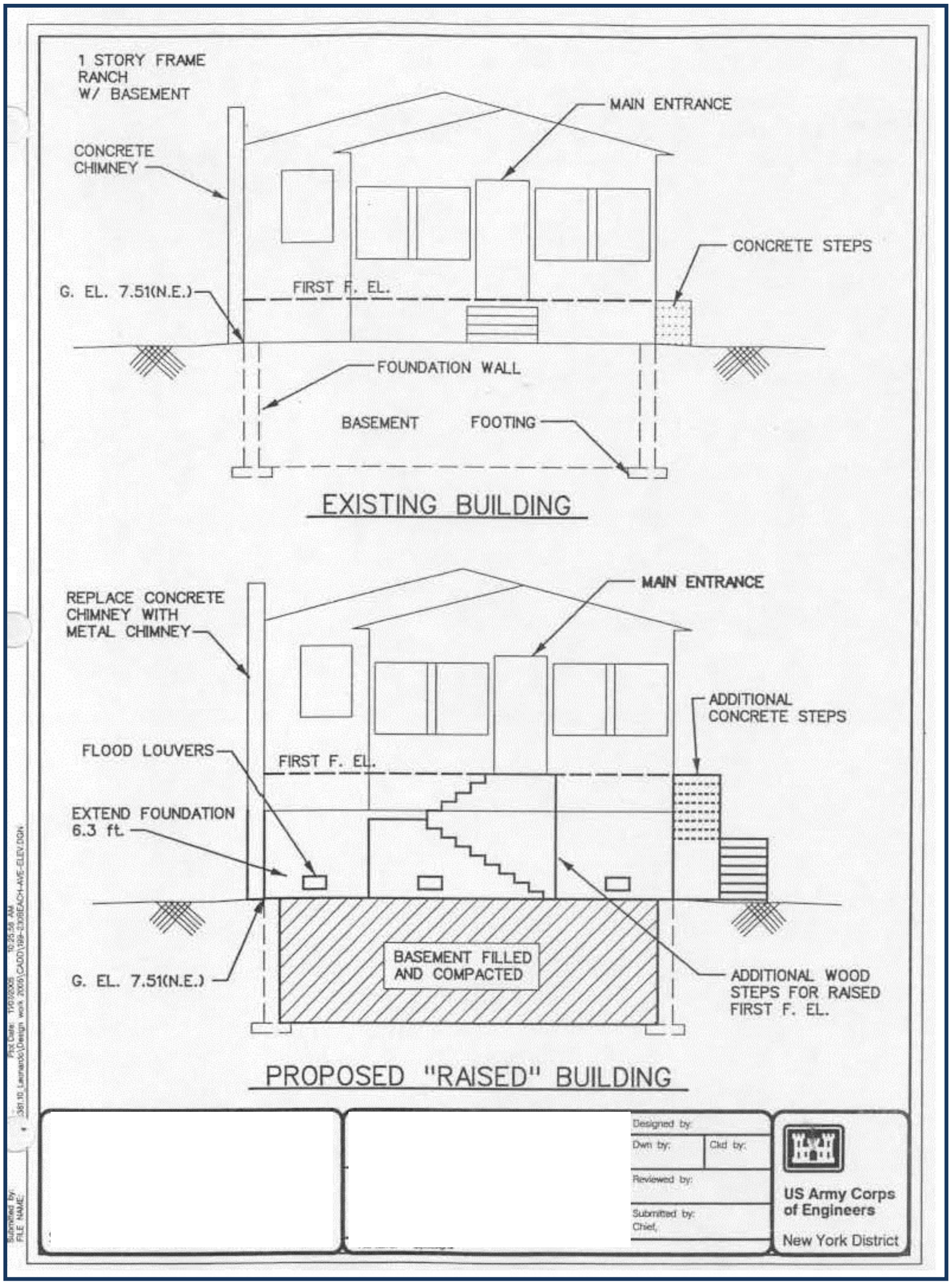


Figure A8: Type A proposed nonstructural treatment.

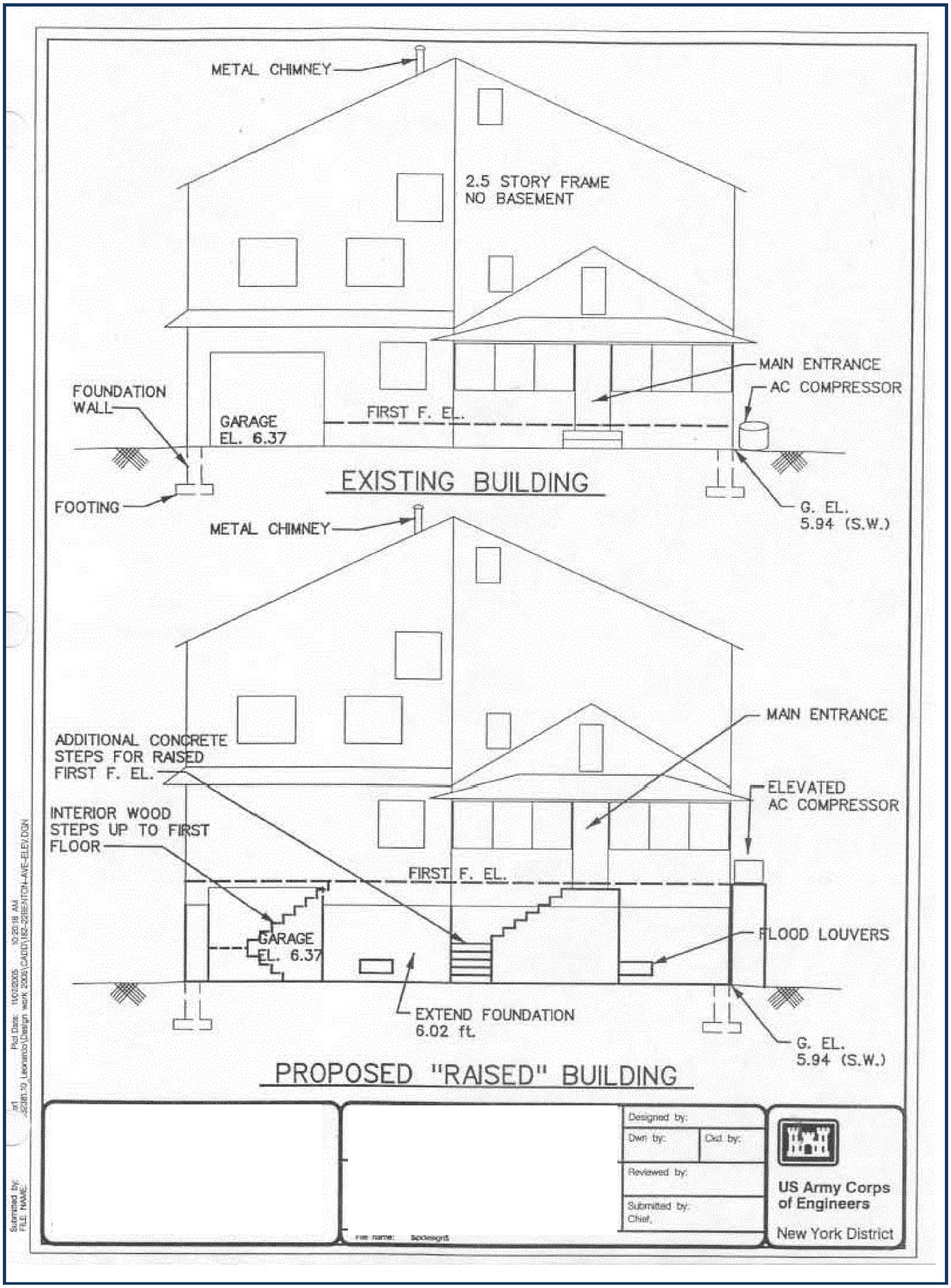


Figure A9: Type B proposed nonstructural treatment.

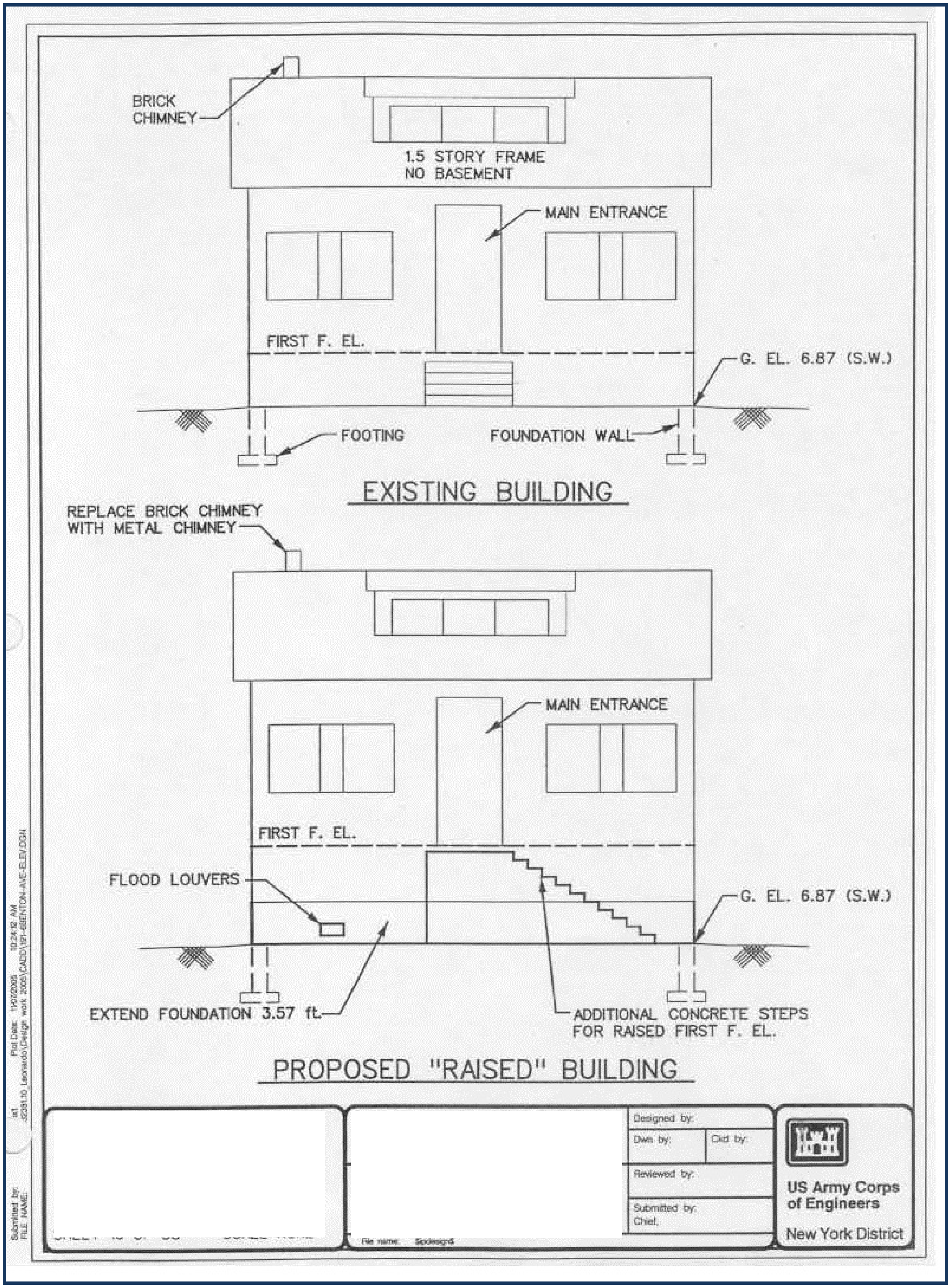


Figure A10: Type C proposed nonstructural treatment.