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Source: Journal of Coastal Research, 32(1) : 181-205

Published By: Coastal Education and Research Foundation

URL: https://doi.org/10.2112/JCOASTRES-D-14-00074.1

| Journal of Coastal Research | 32 | 1 | 181–205 | Coconut Creek, Florida | January 2016 |
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# Hurricane Barriers in New England and New Jersey: History and Status after Five Decades

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**ABSTRACT**

Morang, A., 2016. Hurricane barriers in New England and New Jersey: History and status after five decades. *Journal of Coastal Research,* 32(1), 181–205. Coconut Creek (Florida), ISSN 0749-0208.

Massachusetts, Rhode Island, Connecticut, and New Jersey suffered damage, flooding, and deaths from three major hurricanes in less than two decades during the mid-twentieth century. One of these, the Great New England Hurricane of 21 September 1938, caused unprecedented damage and flooded Providence, New London, and other urban areas. Following Hurricane Carol in 1954, the 84th Congress (1st Session, Public Law 71, 15 June 1955) authorized and directed the Secretary of the Army to conduct surveys and studies of damages, causes, and remediation measures with regard to hurricanes. After extensive studies during the late 1950s, Congress authorized and funded seven hurricane protection projects: (1) in Fox Point, Providence, Rhode Island, a barrier, navigation gates, and pumps; (2) in New Bedford, Massachusetts, a barrier, navigation gates, and pumps; (3) in New London, Connecticut, a barrier and navigation gate; (4) in Pawcatuck, Connecticut, earthfill and concrete walls; (5) in Stamford, Connecticut, a barrier and pump station; (6) in Raritan and Sandy Hook Bays, New Jersey, levees, beach fill, and pumps; and (7) in Charles River, Boston, Massachusetts, a dam with locks and pumps. Most of the projects have not been tested with storm-water elevations near their design elevation. Exceptions are the Charles River dam, which helped prevent flooding during the Blizzard of 1978, and Raritan Bay, during Hurricane Sandy. For lower levels, all projects have performed as designed. After the flooding caused by Hurricane Sandy in 2012, comprehensive hurricane barriers have been proposed for the New York area. Many major challenges would confront planners and designers of new hurricane barriers in the New York Bight area compared to the earlier projects: (1) Far more extensive environmental impact studies would have to be conducted now; (2) obtaining permits and negotiating property rights would be a challenging multiyear process; and (3) obtaining easements and construction access would be vastly more difficult now because of the substantially higher value of coastal real estate.

**ADDITIONAL INDEX WORDS:** *Hurricane surge, Fox Point, New Bedford, Pawcatuck, Stamford, New London, Raritan Bay, Charles River Dam, Boston, Providence, Great New England Hurricane, Hurricane Carol, Hurricane Sandy.*

## INTRODUCTION

Following the destruction caused by Hurricane Sandy in October 2012 to the New York Bight area, proposals have been raised to build hurricane dikes and barriers and enhance natural features to protect the area from future storms (City of New York, 2013; Hill, Bowman, and Khinda, 2013). Some of the proposals are for major projects, such as a three-part design, which would include closure gates at the Narrows, the Arthur Kill, and the upper reaches of the East River. City of New York (2013) estimates the cost could be $20–$25 billion and could cause extensive environmental and hydrodynamic problems, along with leaving many areas unprotected. More modest proposals include surge barriers to reduce flooding in small basins such as the Gowanus Canal (Brooklyn), Newtown Creek (Brooklyn), and Coney Island Creek (Coney Island).

In the mid-twentieth century, the U.S. Army Corps of Engineers (USACE) constructed seven hurricane protection projects in New England and New Jersey to prevent flooding during hurricanes and other unusually high water events. The projects in the U.S. Army Engineer District, New England (NAE), are in Boston and New Bedford, Massachusetts; Providence, Rhode Island; and Pawcatuck, New London, and Stamford, Connecticut (Figure 1). The U.S. Army Engineer District, New York (NAN), project is in Laurence Harbor (previously named Madison), Keansburg, and North Middletown (previously named East Keansburg) Townships, New Jersey, facing Raritan and Sandy Hook Bays. The gates and navigation portions of three of the projects—New Bedford, Providence, and Stamford—are currently operated by NAE, while the others are owned and operated by city agencies. The

*DOI: 10.2112/JCOASTRES-D-14-00074.1 received 26 March 2014; accepted in revision 26 June 2014; corrected proofs received 15 August 2014.*

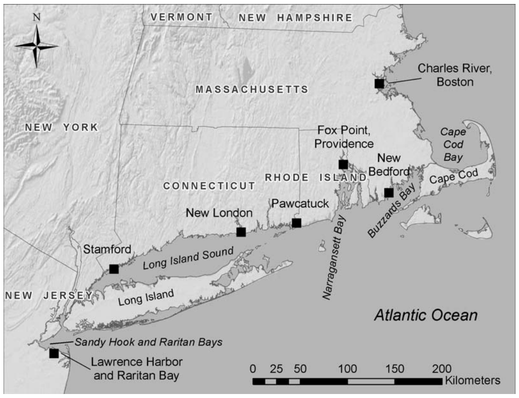


Figure 1. New England and New Jersey hurricane barriers (background from ESRI Maps and Data [ESRI, 2014]).

NAE (formerly New England Division) was a pioneer in the construction of hurricane barriers in the United States.

This purpose of this paper is to (1) describe the meteorological and historical conditions that led to the authorization and construction of hurricane barriers in the Northeast; (2) provide background information on the location and design of the barriers; (3) evaluate lessons learned after four decades of operation; (4) compare surge elevations from Hurricane Sandy with the older storms; and (5) make available design information that is hard to access.

This paper does not advocate for or against new hurricane barriers in the New York Bight area or for other protection schemes. Such new projects will require years of technical and economic studies.

## BACKGROUND TO PROJECT AUTHORIZATIONS AND CONSTRUCTION

The New England and New Jersey hurricane barriers were authorized in response to flooding, property damage, and loss of life that resulted from three highly destructive hurricanes. Powerful hurricanes or "gales" were not unprecedented in New England (Jarvinen, 2006; Minsinger, 1988; Perley, 1891), but they were rare compared to landfalls in Florida and the Gulf Coast. One of the earliest on record was the storm of 26 August 1635. Governor Bradford of the Plymouth Bay Colony wrote, "This year, ye 14. or 15. of August (being Saturday) was such a mighty storme of wind & raine, as none living in these parts, either English or Indeans, ever saw. Being like (for ye time it continued) to those Hauricanes and Tuffons that writers make mention of in ye Indeas" (Bradford, 1898). The surge at the head of Narragansett Bay may have exceeded 6 m. Governor Bradford's account was aptly graphic, "It caused ye sea to swell (to ye southward of this place) above 20. foote, right up & downe, and made many of the Indeans to clime into trees for their saftie." Donnelly *et al*. (2001) documented multiple New England landfalls in the geological record spanning 700 years.

### September 1938 Hurricane

The Great New England Hurricane of 21 September 1938 was one of the seminal meteorological events in New England's twentieth-century history. The storm caused unprecedented damage throughout New England and Long Island, killed over 600 people, and devastated coastal communities along the open Atlantic shore, Long Island Sound, Block Island Sound, Narragansett Bay, and Buzzards Bay (Allen, 1976; Federal Writers' Project, 1938; Minsinger, 1988). On Long Island alone, the death toll was 60. The damage was beyond anything that twentieth-century northeast residents had ever experienced or recorded. Throughout New York and New England, the wind and water felled 275 million trees, seriously damaged more than 200,000 buildings, knocked trains off their tracks, and beached thousands of boats (Haberstroh, 1998). Wind and rain damage extended as far north as Rutland, Vermont, entire city blocks burned in New London and other industrial towns, and downtown Providence, Hartford, and other cities were flooded.

Damage from the storm was estimated at $600 million in 1938 dollars by various writers. Pielke and Landsea (1998) estimated damage of $306 million for the affected coastal counties. They recalculated the loss to be $16.6 billion in 1995 dollars by normalizing the damage by inflation, personal property increases, and coastal county population changes. Therefore, if we double their base damage estimate to $600 million to include inland counties that experienced flooding, the normalization to 1995 dollars might be in the range of $32 billion. Based on the Consumer Price Index (CPI) inflation calculator (Bureau of Labor Statistics, 2014), this equates to $50 billion in 2014 dollars. In comparison, Hurricane Sandy in October 2012 caused approximately $18.75 billion in insured property losses, excluding flood claims covered by the Federal Flood Insurance Program (Insurance Information Institute, 2013).

The 1938 storm was first detected as a tropical depression off the Cape Verde Islands. On 15 September, east of Puerto Rico, it was upgraded to a hurricane. Florida residents began to make preparations, but by the 20 September, the system curved northward towards the Carolinas. A low-pressure trough moving out of the Great Lakes had enough strength to steer the hurricane away from the coast. Further out to sea, a Bermuda high was in place, with the result that the hurricane was squeezed between these two systems and accelerated north, but not out into the open Atlantic. The storm moved quickly up the Atlantic seaboard at over 80 km/h, therefore gaining the name "Long Island Express." On that day, seas and winds were not particularly high, and New England and Long Island coastal residents had little warning that severe weather was headed their way. The wind grew gradually during the morning of the 21 September, but by early afternoon, 130–160 km/h winds crushed houses, knocked down trees, stripped paint from cars, and lifted barges and boats onto land (Scotti, 2003). The eye of the storm made landfall near Bellport, New York, sometime between 1410 and 1440 EST as a category 3 storm (Figure 2; Landsea *et al*., 2014). Jarvinen (2006) lists the storm as a category 3.5 on the Saffir-Simpson scale. More detailed meteorological information can be found in Myers and Jordan (1956), Pierce (1939), Tannehill (1938), Vallee and Doin (1998), and Wexler (1939). Harris (1963) documented high water survey and tide data. Appendix A lists references on the 1938 hurricane, including social histories and memoirs.

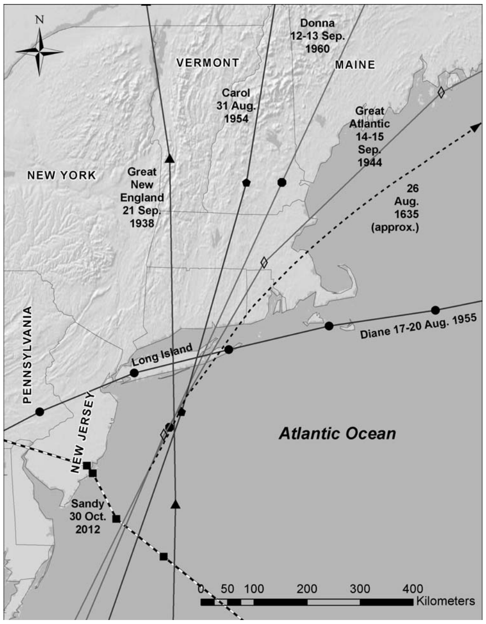


Figure 2. Tracks of prominent New England hurricanes. Modern tracks were downloaded from NOAA Coastal Services Center; 26 August 1635 track is from Jarvinen (2006). The 1815 and 1821 hurricane tracks are not available.

Hurricane-force winds were felt throughout New England, and a gust of 310 km/h was recorded at the Blue Hill Observatory in Milton, Massachusetts (10 km south of Boston). By 22 September, the storm had moved north into southern Canada and dissipated much of its energy, leaving a path of forest and coastal destruction (Figure 3).

Much of the inland flooding was not caused by the hurricane itself. Rainfalls of over 2.5 cm had fallen over broad areas of southern and central New England on both 12 and 15 September, causing a significant rise in river levels. On 17–20 September, another storm dropped more than 15 cm rainfall, sufficient to produce flooding over many tributary rivers throughout New England (NOAA, 2012). The stage was set for the hurricane on the 21 September, which dropped more than 15 cm of rain. The Thames drainage in Connecticut, where over 33 cm were recorded, was particularly hard hit, resulting in some of the worst flooding ever recorded. The Connecticut River, in Hartford, reached a level of 7.7 m, which was 5.9 m above flood stage. The author's father worked for the USACE Providence District at this time and was assigned to stream gauging in the Connecticut valley. He wrote in his diary that many roads in Connecticut were under water, washed out, or impassible because of fallen trees and debris.

Coastal residents suffered the greatest from the storm because the surge coincided almost exactly with the autumnal high tide. Long Island and southern Rhode Island residents reported that an 8–12 m wall of water overwashed the barrier islands with virtually no warning (Minsinger, 1988). Pore and Barrientos (1976) reported high water marks of only 1.6–4.1 m

Figure 3. Pawtuxet Village, near Providence, Rhode Island, 22 September 1938, was overwashed by a "breaker" (surge?) with a reported height of 9 to 12 m during the 1938 hurricane. From the NOAA National Weather Service Collection, Image ID: wea02398 (NOAA, 2013).

(National Geodetic Vertical Datum of 1929 [NGVD 1929]) in this area. It is unclear why survivors reported such dramatically higher water levels, unless their memories were exaggerated or all evidence in the most vulnerable area was totally destroyed. One of the enduring geological effects of the Great New England Hurricane was the cutting of the barrier beach south of Shinnecock Bay, which, after jetty construction, became the present Shinnecock Inlet (Morang, 1999). Another change is that the storm surge blew Sandy Point free of Napatree Point in Westerly, Rhode Island, thereby greatly changing tidal exchange and shoal migration in Little Narragansett Bay.

Along the southern Rhode Island shore, entire beach communities were washed away. I have seen remnants of chimneys and foundations exposed in the sand on East Beach, Rhode Island, after winter storms lowered the sand elevation. The surge funneled up Narragansett Bay, causing untold damage to East Greenwich, Barrington, Warwick, and Portsmouth (Providence Journal, 1938). The business district of Providence was flooded with over 4 m of water, submerging trolley cars, automobiles, and the ground floors of buildings. The incoming water entered the city so swiftly, within 10 minutes, that the downtown was engulfed, trapping people in the upper floors of buildings, and, tragically, in automobiles. It was almost 2 weeks before many stores and businesses could dig out debris, pump flooded basements, restore electricity, and resume business.

Viewing these events after six decades, we wonder, why were people caught so unawares by this storm? Along with the fact that the storm moved so quickly up the coast from Florida to New England, four factors may account for the tragedy. First, weather forecasters, without the benefit of satellites or storm-chasing aircraft, were unable to effectively track it.

Second, in that era, many forecasters discounted the possibility of a hurricane making landfall in New England, and the weather service was accused of underestimating the danger of the storm and not issuing adequate warnings (Burns, 2005; Scotti, 2003). This erroneous belief persisted despite numerous historical records of earlier major hurricanes, including ones in 1635, 1638, 1815, and 1869 (Ludlum, 1963) .

Third, radio stations and newspapers were unable to spread warnings to all the affected areas. The afternoon newspapers had not yet been distributed by the time the storm struck Long Island in midafternoon.

Finally, an intriguing historical note: Burns (2005) and Clowes (1939) stated that Long Island residents were distracted with other news. "However, reports received by the Weather Bureau indicate that owing to the general alarm over the European situation the public took little interest in news regarding the weather" Clowes (1939, p. 60). On 21 September 1938, the Czech parliament capitulated to Adolf Hitler and accepted cession of the territories with a German-speaking majority, the Sudentenland. The prime minister of the United Kingdom, Neville Chamberlain, flew to Munich to negotiate with Adolph Hitler about the partition of Czechoslovakia in an attempt to avert war (Churchill, 1948). Americans and Europeans, terrified that another world conflagration might break out, anxiously listened to wireless broadcasts from Germany hoping that Chamberlain might appease the German dictator.

### September 1944 Hurricane

The Great Atlantic Hurricane of 1944 followed a track very similar to the 1938 hurricane and two earlier events, in 1815 and 1821 (Brooks and Chapman, 1945). The storm pattern was first detected as a hurricane in the Atlantic Ocean on 4 September 1944. It strengthened to category 4 on 12 September and made landfall as a category 3 near Cape Hatteras. The storm made a second landfall on eastern Long Island on 14 September after causing significant damage in New Jersey. The storm progressed northeast, passing north of Boston and moving out into the Gulf of Maine (Figure 2). Of the 390 people who perished, 340 were lost on ships at sea. The storm was so powerful, it sank the U.S. Navy destroyer USS *Warrington* (DD-383) 700 km east of Vero Beach, Florida, with a loss of 248 sailors (Dawes, 1966). Low-lying areas of New Bedford and Buzzards Bay were inundated. The water level in New Bedford was recorded at 3.44 m. Coastal communities in Yarmouth and Dennis, on Cape Cod, suffered major damage. Buzzards Bay levels would have been higher if the Cape Cod Canal had not existed, which let water escape north to Cape Cod Bay.

The low death toll on land was due to well-executed warnings and evacuations, a result of the bitter lessons of 1938. However, thousands of houses and businesses were destroyed and damaged along the Jersey shore. Pielke and Landsea (1998) calculated the total damage in 1995 dollars to be $6.5 billion ($10.1 billion in 2014 dollars).

### Hurricane Carol

Hurricane Carol was first detected as a tropical storm near the Bahamas on 25 August 1954. After drifting northwest, it gained energy and accelerated to the north on 30 August. It struck Long Island as a category 3 on 31 August with wind speeds approaching 190 km/h (Figure 2). The eye passed over Groton, Connecticut, at 1000 h on 31 August (Jarvinen, 2006). Similar to 1938, a storm surge of 3–5 m was reported in many areas.

Because of Carol's rapid northward motion, residents had little warning. The Boston Weather Service did not issue a hurricane warning for New England coastal areas until 1030, and by then, it was too late for some Rhode Islanders. In Oakland Beach (Figure 4), water had already risen and flooded first floors by 0930 (local time), and by 1045, only 15 minutes after the official warning, 160 km/h winds were lashing the coast. By 1100, water was rising in downtown Providence, and at 1145, the flood rose within 0.3 m of the high-water mark from the 1938 hurricane. Carol's storm surge wiped out businesses and destroyed 3500 cars downtown (Carbone, 2004). In New Bedford, the fishing fleet and other coastal businesses sustained heavy damage for the third time in only two decades. Pielke and Landsea (1998) computed damage to be $9.0 billion in 1995 dollars ($14.1 billion in 2014 dollars). Some 20,000 residents were evacuated in front of the storm, just to be confronted by Hurricane Edna on 12 September (Davis, 1954). Appendix B lists additional references on Hurricane Carol.

## RESPONSE AND PLANNING FOR HURRICANE BARRIERS

It is unclear from the records if hurricane barriers were conceived or planned after the devastation of the 1938 hurricane. If plans were begun, political infighting and World War II put them on hold.

In the late 1930s, the federal government was embroiled in controversy over the construction of flood-control reservoirs for inland waters (Parkman, 1978). The winter of 1935–1936 was one of the most severe that New England had ever experienced. Intense storms lashed the eastern and central parts of the United States in March, causing unprecedented damage and disruption. Life in the Connecticut River Valley was essentially paralyzed with 77,000 people left homeless, railroads destroyed, and the National Guard occupying major cities to keep order. This led to widespread calls for aggressive federal action to prevent such tragedies in the future. The result was the Flood Control Act of 1936, which assigned new responsibilities to the federal government and new duties to the USACE. The 1936 act was the fundamental legislative authority that ultimately led to a vast program of public works costing billions of dollars throughout the nation (Arnold, 1988). After bitter debates concerning ownership and operation of reservoirs and dams, the Flood Control Act of 28 June 1938 stipulated that these structures, unless otherwise provided by law, would be constructed entirely at federal cost and would be owned, maintained, and operated by the federal government.

However, before any flood-control construction had begun, the 1938 hurricane pummeled Providence and other south shore communities. Parkman (1978, p. 179) wrote,

> Rather than hastening reservoir construction, the disaster led instead to further delay. The elections of 1938 were only weeks away, and the floods offered an irresistible issue. Though no reservoirs authorized in 1936 could have been completed in any event, Republican candidates blamed the delay in giving New England flood protection on the New Deal generally and on the

region's Democratic congressional opponents of the interstate compacts in particular. This was deadly campaign stuff at a time when thousands of people were still reckoning their losses, and Democratic leaders in Connecticut, New Hampshire, and Massachusetts made desperate appeals to Roosevelt for help.

Construction of some projects along rivers followed, but World War II soon siphoned funds from civil works projects, and many USACE engineers were reassigned to the war effort. By 1943, work on reservoirs and civil projects came to an end.

The 1944 hurricane again revealed how vulnerable New England coastal towns were to storm surges. The record is incomplete on whether there were calls for federal coastal flood protection at that time. The Flood Control Act of 1944 (public law [P.L.] 78–534) was enacted in the 2nd session of the 78th Congress and signed into law by President Roosevelt in December 1944. It authorized construction of numerous dams and levees across the United States and led to the establishment of the Pick-Sloan Missouri Basin Program. Pursuant to this law, the Secretary of War submitted a report to Congress on protection of the New Jersey coast due to tides and winds, but concluded that a project was not advisable at that time (New York District, 1963). It is unknown how many reports for other parts of the country were submitted to Congress in the mid-1940s.

Finally, after Hurricanes Carol and Edna in 1954 again demonstrated the vulnerability of coastal areas, Congress was compelled to act (Parkman, 1978). The 84th Congress (1st Session, Public Law 71, 15 June 1955) authorized and directed the Secretary of the Army, with cooperation of other federal agencies, to conduct surveys and studies of damages, causes, and remediation measures with regard to hurricanes in coastal and tidal waters of the eastern and southern United States.

To collect data on the water levels and damage caused by Hurricane Carol, the USACE conducted a major door-to-door survey of thousands of homes, industries, and other affected properties in 1955 and 1956 (Wiegel, 1993). They then estimated the extent of damage that could be expected to property and machinery at several project sites for various levels of flooding and prepared water stage–damage curves. The result was a series of interim studies for vulnerable coastal towns throughout southern New England and for areas along the south Atlantic and the Gulf Coast (Appendix C). These summarized storm conditions experienced in the towns, proposed a hurricane protection plan, and estimated the damages that might be avoided if a barrier were in place when a "Standard Project" hurricane struck. McAleer and Townsend (1958) summarized the findings and plans. Graham and Nunn (1959) described meteorological conditions pertinent to the Standard Project hurricane. Other USACE districts conducted studies in other parts of the country, especially Louisiana, which was highly vulnerable to hurricane surge because of its low-lying terrain (Secretary of the Army, 1965).

One of NAE's most ambitious proposals was to build barriers across the mouth of Narragansett Bay to prevent a surge (Figure 4). The dikes across West Passage and East Passage would have ungated openings large enough to allow ships to pass, but small enough to limit the quantity of water entering the bay during a hurricane. The Narragansett Bay studies were made over a 9 year period and involved the NAE, Coastal Engineering Research Center, Waterways Experiment Station, U.S. Weather Bureau, Coast & Geodetic Survey, U.S. Public Health Service, U.S. Fish & Wildlife Service, and several universities, including Texas A&M, the University of Rhode Island, and the Massachusetts Institute of Technology (MIT) (McAleer, 1963). The Waterways Experiment Station built a physical model of the bay in 1956 at 1:1000 horizontal and 1:100 vertical scale and tested flushing, salinity, hydraulic, and navigation conditions (New England Division, 1963; Pickering and Grace, 1965; Simmons, 1957, 1964; Waterways Experiment Station, 1959a, 1959b). The model, built within an aircraft hangar, was $40 \times 120$ m in size and included all of the bay and its tributary waters (Figure 5; Simmons, 1964). The modelers examined discharge characteristics of the navigation opening (with a base width of 450 m) for East Passage by means of both section and three-dimensional models. MIT researchers examined hydrodynamic and wave conditions at proposed barriers (McLaughlin and Anton, 1964). A more detailed model of East Passage at 1:150 undistorted scale was built on the request of the U.S. Navy to test fleet operations under various wave and tide conditions (Housley, 1967). The final plan estimated that the Narragansett barriers would prevent more than 90% of the design flood damages of $126 million in the area below the Fox Point barrier and that the construction cost would be about $90 million.

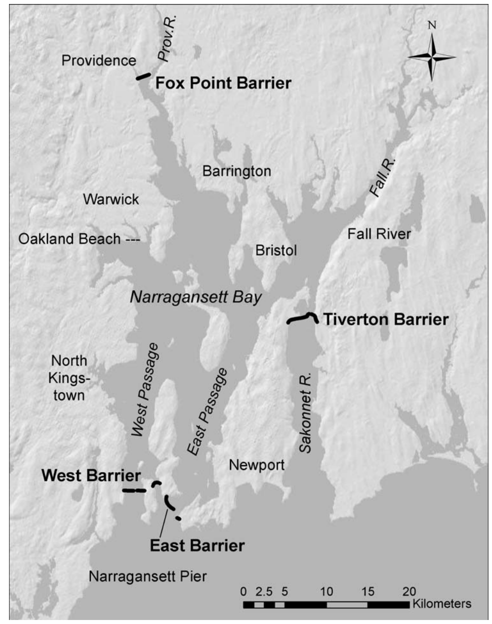


Figure 4. Proposed hurricane barriers in Narragansett Bay, Rhode Island (redrawn from New England Division, 1963). Only Fox Point was built, but barriers in other passages were model-tested (Simmons, 1957).

The USACE recognized the potential for environmental disruption and sponsored a series of studies on salinity, fisheries, pollution (Public Health Service, 1960), and tidal circulation (Hicks, 1956). These studies were unusually

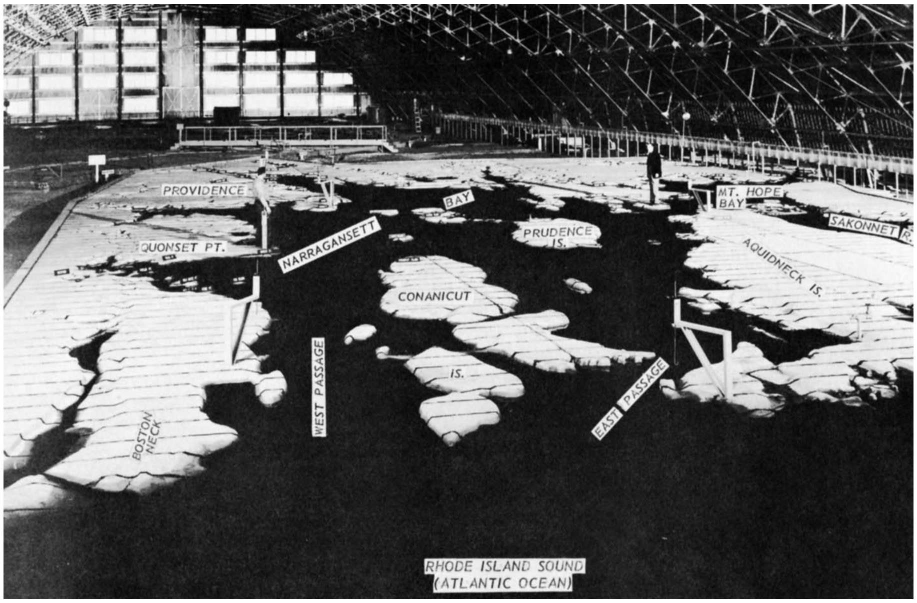


Figure 5. Hydraulic model of Narragansett Bay in Hangar 3, Waterways Experiment Station, Vicksburg, Mississippi, ca. 1963 (Simmons, 1964). The model and hangar are no longer extant.

comprehensive for that era. For example, the physical model in Vicksburg was of impressive scale, filling part of a hangar, and was operated for more than 4 years. University of Rhode Island fisheries experts studied fish populations and concluded that the barriers would not disrupt spawning or feeding (Saila, 1962).

Despite a decade of intensive study, the Narragansett Bay barriers were never built. I was unable to find documents stating the final reason the project never came to fruition, but several factors probably doomed the plan. First, the high cost of stone construction in deep water almost surely rendered the project uneconomical (Richard J. DiBuono, USACE, Headquarters [retired], *oral communication*, 27 November 2006).

Second, in this same era, NAE had been studying the feasibility of building massive stone structures across Passamaquoddy Bay, Maine, for the Passamaquoddy Tidal Power Project. Here, too, placing stone in deep water raised too many engineering and fiscal challenges (Parkman, 1978).

Third, politics and environmental concerns also played a role in stopping the Narragansett Bay project, as they did to a similarly ambitious Galveston Bay surge barrier (Richard Sager, USACE Hydraulics Laboratory, Waterways Experiment Station [retired], *oral communication*, 13 February 2007; Simmons and Boland, 1969).

Fourth, it was rumored that wealthy and well-connected yachtsmen from Newport feared they might be unable to sail their yachts through the barrier (although if an aircraft carrier could pass through the gap, it is unclear why a pleasure craft would not fit; Charles Brasfeild, USACE Hydraulics Laboratory, Waterways Experiment Station [retired], *oral communication*, 2007).

From among 14 proposed flood-protection plans in New England, five were authorized and funded: (1) Fox Point, Providence, Rhode Island, with a barrier, navigation gates, and pumps; (2) New Bedford, Massachusetts, with a barrier, navigation gates, and pumps; (3) New London, Connecticut, with a barrier and navigation gate; (4) Pawcatuck, Connecticut, with earthfill and concrete walls; and (5) Stamford, Connecticut, with a barrier and pump station.

It is unclear why Mystic and Fairfield, Connecticut, Point Judith and Narragansett Pier, Rhode Island, and other sites were rejected. Possibly the local partners were unable to generate their share of construction funds. Later, a project with levees, beach fill, and pumping station was authorized for Raritan and Sandy Hook Bays, New Jersey. Finally, in the early 1970s, another project was added to the group, a dam with pumps at the mouth of the Charles River in Boston (Figure 1).

In the early 1960s, the requirements for environmental permits and investigations prior to construction of major works were much less stringent than they are today. The USACE did coordinate with other agencies, but often the approval letter was little more than a single page included in the interim report and the *General Design Memorandum*. In New Bedford, the cleanup of the superfund site and brownfields area began in the 1970s, a decade after construction of the barrier. It is unknown if the presence of contaminated sediments in the harbor were factored into the design. By the time the Charles River project was conceived and built, times had changed, regulatory requirements had increased, and more extensive environmental studies were conducted.

## FOX POINT BARRIER, PROVIDENCE, RHODE ISLAND

The Fox Point Hurricane Protection Barrier was the first structure of its type in the United States to be approved for

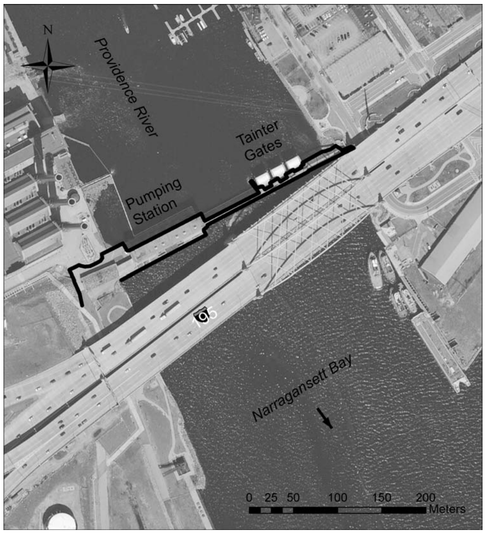


Figure 6. Fox Point barrier, Providence, Rhode Island (background aerial photography from ESRI® Maps and Data).

construction. The dam and gates were built across the Providence River about 0.25 km north of Fox Point and 2 km south of downtown Providence (Figure 6). The project cost $15 million ($120 million in 2014 dollars based on the first year of construction as converted by the CPI calculator; Bureau of Labor Statistics, 2014), with the federal portion about $11 million. The interim survey report (New England Division, 1957) stated a benefit/cost (B/C) ratio of 2.37 to 1 for Fox Point alone (the B/C ratio for the lower bay barriers, which were never built, would have ranged from 1.65 to 1 to 1.01 to 1). Construction began in December 1960 and was completed in January 1966, after delays caused by strikes and material supply problems. Construction was completed inside a series of circular sheet pile cofferdams. The dike, pump house, and gate

Figure 7. View of the Fox Point tainter gates from the Providence River (north side of the barrier; undated photograph from City of Providence).

Figure 8. Fox Point pump house, 4 November 2006 (photograph by A. Morang).

structures are supported on steel H-piles driven to bedrock (AEG, 2006).

The barrier itself is a 210 m concrete structure, 7.6 m high, that extends across the Providence River. The structure contains three tainter gates that permit passage of small vessels but can be closed to prevent entry of a surge from Narragansett Bay to the south. Each gate is 12 m high by 12 m wide (Figure 7). Originally, earthfill dikes with stone slope protection flanked each side of the barrier, but these were modified or replaced when the Interstate I-195 bridge was built just south of the barrier.

A pumping station and cooling water canal were integral parts of the project. The five pumps were designed to pump floodwaters of the Providence River through the barrier into the bay at times when the water level on the exposed (south) side was higher than the protected side. The five pumps were, at installation, the largest of their type ever built in the United States (Figure 8) and could transfer about 198,000 L/s out of the Providence River to the open harbor to the south. The pumps receive electricity from the Narragansett Electric Company at 11,000 V. There is no provision for on-site emergency generators, but the gates can be lowered manually.

## Hydraulic Design

Hydraulic conditions were based on a "design hurricane," established in cooperation with the U.S. Weather Bureau and the Beach Erosion Board (BEB). The BEB was a civilian research board of the USACE tasked to examine beach and coastal problems and advise on mitigation plans (Quinn, 1977). The basis for the design storm was the September 1944 hurricane. The transposed storm was moved northerly at a forward speed of about 38 m/s along a track moving northerly and producing sustained winds of 144 km/h from the SSE at the mouth of the Providence River. At the location of the proposed barrier, the storm surge associated with this storm was computed to be 5.3 m. This surge was added to the mean spring high water elevation of 0.70 m North American Vertical

Table 1. *Water levels, New England and New Jersey hurricane barriers*.

| | Providence | New Bedford | Pawcatuck | New London | Stamford | Boston | Sandy Hook |
|---|---|---|---|---|---|---|---|
| Tide stage (m, NAVD88) | | | | | | | |
| MHHW or MHW | 0.72 | 0.61 | 0.02 | 0.37 | 0.05 | 1.45 | 0.73 |
| Design hydraulics (m, NAVD88) | | | | | | | |
| Structure top elevation | 7.37 | 5.84 | 4.89 | 4.89 | 4.84 | 3.72 | 4.50 |
| Historical water levels (m, NAVD88) | | | | | | | |
| August 1635 Great Colonial Hurricane | 5.0 ± | 3.8 ± | | | | | |
| August 1638 hurricane | 5.3 ± | 4.1 ± | | | | | |
| 23 September 1815 hurricane ("Gale of 1815") | 4.10 | 3.25 | | | | | |
| 24 August 1893 hurricane | | | | | 3.14 | | |
| 21 September 1938 Great New England Hurricane | 4.64 | 3.56 | 3.10 | 2.66 | 3.35 | 1.59 | 1.30 |
| 14 September 1944 hurricane | 2.84 | 2.22 | 2.03 | 1.57 | | 1.73 | 1.98 |
| 7 November 1944 hurricane | | | | | 2.80 | 1.15 | |
| 30 November 1944 storm | | 1.82 | | 1.11 | 2.38 | 2.40 | 1.40 |
| 7 November 1953 storm | 1.81 | 1.64 | | 1.48 | | 1.99 | |
| 31 August 1954 Hurricane Carol | 4.31 | 3.37 | 2.88 | 2.15 | 3.14 | 2.26 | 1.55 |
| 12 September 1960 Hurricane Donna | 2.20 | 1.67 | | 1.54 | 2.53 | 1.81 | 2.16 |
| 6–7 March 1962 High-five storm | | | | | 2.56 | 2.30 | 1.97 |
| 30 November 1963 storm | 2.17 | | | | | 1.97 | |
| 12 November 1968 storm | | | | 1.37 | 2.86 | 2.10 | |
| 9 January 1978 storm | 2.23 | 1.67 | | | 2.44 | 2.39 | |
| 7 February 1978 Blizzard of '78 | | | | | 2.99 | 2.92 | |
| 27 September 1985 Hurricane Gloria | 1.99 | | | 1.26 | 2.50 | 1.54 | 1.75 |
| 2 January 1987 storm | | | | 1.38 | | 2.65 | |
| 19 August 1991 Hurricane Bob | 2.32 | 2.06 | | 1.20 | | 1.20 | 1.01 |
| 11 December 1992 Nor'easter | | | | 1.32 | 3.08 | 2.60 | 2.08 |
| 28 August 2011 Hurricane Irene | 1.76 | 1.45 | | 1.38 | 2.93 | 1.96 | 2.08 |
| 29 October 2012 Hurricane Sandy | 2.10 | 1.82 | | 1.88 | 3.38 | 2.26 | 3.18 |
| Conversion NGVD29 to NAVD88 (m) | | | | | | | |
| NOAA benchmark sheet | | −0.25 | | −0.29 | | −0.25 | −0.33 |
| VERTCON orthometric height conversion (Miller, 1999) | −0.25 | | −0.29 | | −0.34 | | |

Note: Elevations converted from English units and from NGVD or tidal datums in the original documentation. MHWW = mean higher high water, MW = mean high water.
Source: NOAA Tides and Currents, New England District (2013), New England Division (1959, 1961, 1962, 1965, 1972), and New York District (1963).

Datum 1988 (NAVD), resulting in a 6.0 m NAVD still-water elevation (note, elevations have been converted from the original datum of NGVD 1929). The top of the barrier was set to 7.37 m NAVD, allowing for wave overtopping in excess of 1.4 m. The 6.0 m still-water elevation was predicted to be approximately a 500 year surge level (Morang, 2007; New England Division, 1959).

Table 1 summarizes maximum water elevations during notable storms at Providence and the other New England barriers. Elevations were extracted from National Oceanic and Atmospheric Administration (NOAA) Tides and Currents online data if the tide stations existed at the time of the storm. For older data computed by the USACE, elevations were converted to metric units and adjusted from the original NGVD 1929 to NAVD using the National Geodetic Survey VERTCON methodology (Miller, 1999). Figure 9 plots Fox Point water elevations for the hurricanes of 1938, 1944, 1954, Bob, Irene, and Sandy.

Since construction, this project has not been tested with a flood near its design height. Hurricane Bob's (19 August 1991) maximum elevation at NOAA gauge 8454000 was 2.39 m, almost 2 m below the 1938 surge. Hurricane Sandy's (29 October 2012) peak was 2.1 m, similar to Bob's. The Sandy residual storm surge (measured water elevation minus predicted) was 1.64 m, which is less than the residual in Sandy Hook or the Manhattan Battery (Table 2). The pumps have been used at least 10 times since 1966, and the barrier prevented flooding during at least two hurricanes, Gloria and Bob (AEG, 2006). The Fox Point barrier prevented $600,000

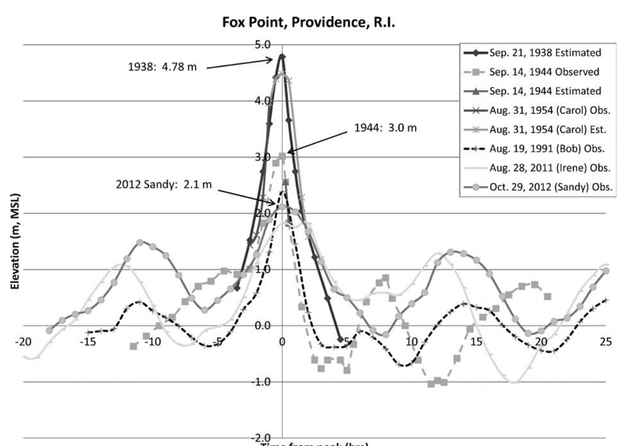


Figure 9. Observed water levels for hurricanes of 1938, 1944, Carol, Bob, Irene, and Sandy (from New England Division, 1959; NOAA Tides & Currents [NOAA, 2014]). Data for the Blizzard of '78 are not available.

Table 2. *Hurricane Sandy storm surge residual.*

| Station | ID | Date | Storm Elev. (m, MLLW) | Predicted Elev. (m, MLLW) | Storm Surge Residual (m) |
|---|---|---|---|---|---|
| Sandy Hook[ab] | 8531680 | 10/29/12 | 4.033 | 1.422 | 2.611 |
| New London | 8461490 | 10/30/12 | 2.436 | 0.634 | 1.802 |
| Providence | 8454000 | 10/29/12 | 2.854 | 1.215 | 1.639 |
| Boston | 8443970 | 10/29/12 | 3.939 | 3.147 | 0.792 |

Source: Fanelli, Fanelli, and Wolcott (2013). No data available for Pawcatuck (see New London, instead) or New Bedford. MLLW = mean lower low water.
[a] Instrument was damaged and did not record maximum water level.
[b] Recorded water level exceeded historical maximum value.

in flood damage during Hurricane Sandy (New England District, 2012). At 2.05 m NAVD, Sandy was not an exceptionally high water event in Providence or Narragansett Bay.

## Operation

After project construction, the barrier and all the equipment were transferred to the City of Providence, which operated the project until 2010. When a hurricane reached 38° N latitude and a hurricane watch was initiated, city work crews assembled and closed the vehicular gates. Once a storm entered Narragansett Bay, the floodgates were closed to prevent a surge from moving up the Providence River and entering the business district. It took about 30 minutes to lower the gates and 2 hours to raise them (AEG, 2006). During a 2006 site visit, City of Providence engineers told me that many of the control systems needed upgrading. The original electromechanical controls were increasingly unreliable, parts were unavailable, and the pumps were difficult to start. In December 2006, one of the pumps sustained serious internal damage and would be out of commission indefinitely (Mr. James Law, NAE, *personal communication*, 15 December 2006).

In May 2006, U.S. Senator Lincoln Chafee spearheaded language in the Senate version of the Supplemental Appropriations Bill (H.R. 4939) to provide authority for the USACE to operate and maintain the Fox Point Hurricane Barrier. In 2010, the USACE took over ownership of the facility, with day-to-day management of the Fox Point Barrier being the responsibility of the Cape Cod Canal Field Office. Overhaul of Pumps Nos. 1 and 5 was completed in 2012, and other rehabilitation is ongoing.

## NEW BEDFORD HURRICANE BARRIER, NEW BEDFORD, MASSACHUSETTS

The New Bedford barrier consists of a series of stone dikes and a movable gate across the mouth of New Bedford harbor (Figures 10, 11, and 12). The project is divided into three main features: a barrier extending across New Bedford harbor with extension dike on the mainland; Clark's Cove Dike in New Bedford; and the Fairhaven Dike. The project protects about

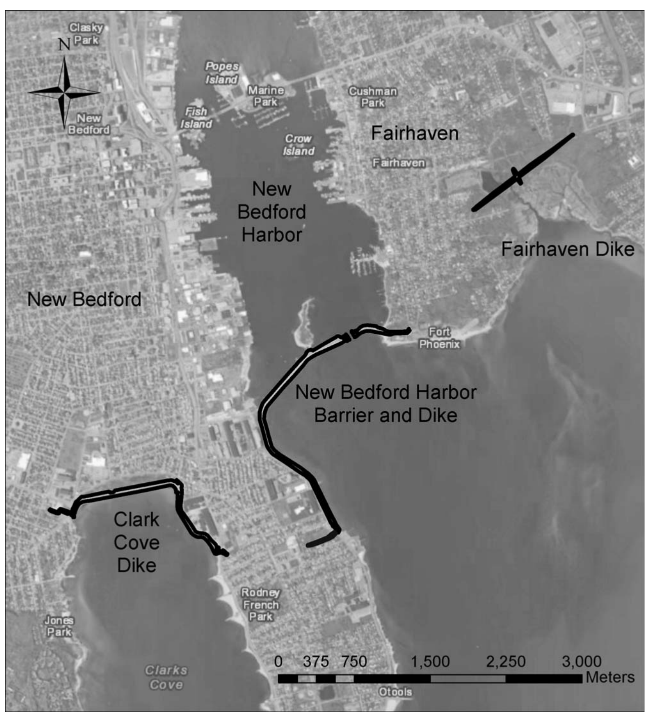


Figure 10. New Bedford, Massachusetts, dike and hurricane barrier (background photography from ESRI® Maps and Data).


Figure 11. New Bedford dike, view west from gate control house, 2 November 2006 (photograph by A. Morang)

1400 acres in New Bedford, Fairhaven, and Acushnet. This area is densely developed with industrial and commercial properties, particularly along the Acushnet River (Morang, 2007).

Construction began in October 1962 and was completed in January 1966, at a cost of $18.6 million ($147 million in 2014 dollars). The project required relocation and modification of power cables, sewerage, and drainage, and acquisition of land and buildings. Several web sites state the New Bedford barrier is the largest rock structure on the U.S. East Coast, but USACE documents do not make this claim.

## Hydraulic Design

For the New Bedford project, the same design hurricane was used as for Fox Point. Based on the transposed storm with


Figure 12. New Bedford hurricane barrier with gate open to allow passage of fishing boat, 2 November 2006 (photograph by A. Morang).

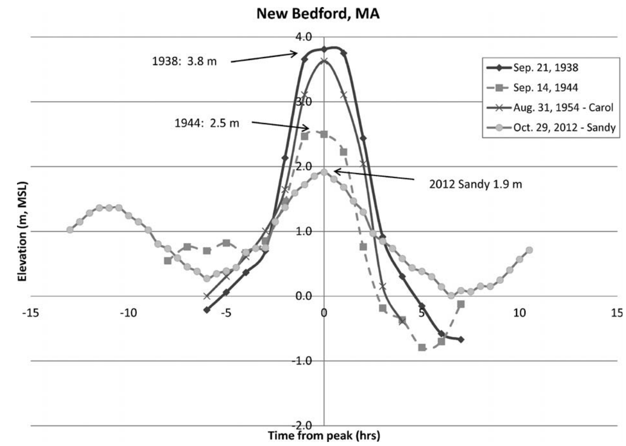


Figure 13. Observed storm-water levels, New Bedford, Massachusetts. Data from New England Division (1961) and New England District.

160 km/h winds, a surge of 4.05 m was predicted within New Bedford harbor. This was added to a mean spring tide of 0.57 m NAVD, resulting in a still-water elevation of 4.62 m. Wave heights for this storm were estimated to be 2.74 m for south-facing structures. The top elevation for the hurricane gates was set to 5.84 m NAVD. A still-water elevation of 4.63 m NAVD is slightly greater than a 500 year storm level (New England Division, 1961). Figure 13 shows surge levels for the 1938, 1944, and 1954 hurricanes and for Hurricane Sandy. NOAA data are not available at this location for comparison to other twentieth-century storms.

The rock-faced dike and concrete gate structure were built on a foundation of rock ledge. The site was isolated with coffer dams, dewatered, and excavated to rock basement (Figures 14 and 15). Stone for the dike came from Dartmouth, Massachu-

Figure 14. Sector gate foundation work within protective cofferdam, New Bedford harbor, Massachusetts, 5 May 1964 (photograph courtesy NAE).

Figure 15. Construction of the sector gatehouse, New Bedford barrier, 1964. The structure in the lower right is a guide for the gate rollers and also contains a tunnel through which the gate operators can walk under the channel (photograph courtesy NAE).


Figure 16. West side sector gate in rest position, New Bedford hurricane barrier, 2 November 2006. The pivot is at the upper center of the photograph, and the ship channel is to the right. Silt builds up in the basin and must be flushed with compressed air. The gate is operated by a 25 hp electric motor (photograph by A. Morang).

setts, a distance of only 5 or 6 km. The stone workmanship is among the finest that I have seen in coastal structures outside of Italy. The core of the dike is impermeable, and the crest is wide enough for a crane to use as a roadway (Figure 11). The dike has not needed maintenance since construction.

The main deep-draft channel to New Bedford has an authorized depth of 9.1 m. Most traffic now consists of fishing boats and barges, but some cruise ships and larger ocean-going freighters use the channel. If larger vessels need to enter the harbor in the future, the entire gate complex will have to be rebuilt. This will be very difficult because when the original gate was under construction within its cofferdam, the navigation channel was temporarily rerouted to the east. Now, the stone dike blocks this part of the harbor.

## Operation

All features except the navigation gate are operated and maintained by the City of New Bedford. The navigation gate is operated and maintained by the USACE. The Reservoir Control Center (RCC) of NAE is responsible for closure and opening of the navigation gates based on information from the National Weather Service, the U.S. Coast Guard, and local authorities (Wiegel, 1993). An operational and maintenance manual for the project describes the standard operating procedures, communications protocols, and other particulars. The gates are not operated automatically according to a set water level or other criteria. "Considerable discretion is necessary in initiating closure if approaching vessels are only a short distance from the barrier and will be passing through within 2 or 3 minutes. The ocean elevation and rate of rise must be considered in delaying closure for marine traffic. The project manager should be in communication with RCC during this sensitive phase of the operation if vessels are approaching" (quoted in Wiegel, 1993, p. 42).

During a site visit on 2 November 2006, the gate operator told me that the gates are used at least once or twice a month, whenever a high tide greater than +0.9 m coincides with a south or southwest wind. Tide predictions and closure instructions are transmitted from NAE's Cape Cod office, and operators must be on duty in the control house around the clock when a high-water stage is anticipated. In effect, this project has become a regular part of water-level control for New Bedford harbor. As of 2013, the barrier has never been used to hold back a surge anywhere near peak design height.

The control house is on the west side of the channel and contains the operators' quarters, machinery, a generator, and access steps to the tunnel, which passes under the channel. The gates are 400 ton steel structures, which swing horizontally across the 46-m-wide channel (Figure 12). Each gate fits into a well in its respective side of the channel (Figure 16) and is pivoted by a 25 horsepower (hp) electric motor via a gearbox. Electricity is normally supplied by the municipal power grid, but a diesel generator on site can provide power. There is no emergency means, such as a winch or pulleys, to move the gates if the electric motor, gearbox, or controls fail. This is in contrast to Providence, where the gates could be lowered into the channel by hand if necessary (although they could not be raised manually).

Technicians from NAE regularly perform tests and adjustments on the sector gates and tracks, wheels and trunnions, drive pins and sprockets, gate drive gear unit, sluice gates, diesel generator, traveling crane, sump pumps, and cathodic protection pieces. They have to sound within the gate pockets to determine the amount of shoaling. Sector gate wheels and other parts were renovated and replaced in the 2005–13 period. The gates are periodically painted, and zinc plates are used to reduce corrosion. Fishing boats have periodically hit the

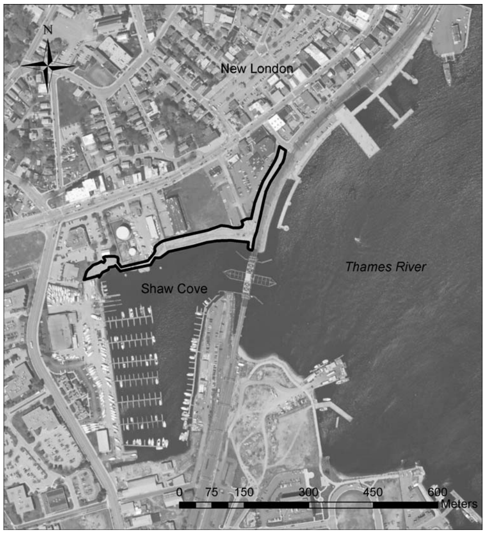


Figure 17. Shaw Cove, New London, Connecticut, hurricane barrier (background photography from ESRI® Maps and Data).

concrete walls, but these accidents did not cause structural damage. Cracks and spalling concrete have been repaired.

When the gates are moving across the channel, a roller runs in a channel cast into the top of the tunnel (Figures 15). Because the channel fills with silt, a compressed air system was installed with nozzles near the roller to clean out the channel. The air is also used to clear silt in the gate pockets, where the gates are parked in their open position. This air process has not been fully satisfactory, and a pump system to maintain a constant flow of water to flush the pockets has been proposed.

Along with the 5500 m of dike, the project includes two steel swing gates to seal off city streets and a pumping station at Clark Cove. These are operated by the City of New Bedford. At Clark Cove, a broad grassy area about the size of a soccer field serves as a catchment basin for storm-water runoff. The pump station was built by the USACE as part of the original project.

### Environmental Factors

New Bedford was an important industrial, whaling, and ship-building center for three centuries. The 18,000 acre New Bedford Harbor Superfund site extends from the northern reaches of the Acushnet River estuary south through the commercial harbor of New Bedford and into Buzzards Bay. The site contains sediment contaminated with polychlorinated biphenyls (PCBs) and heavy metals. An extensive body of literature discusses the cleanup (for example, see EPA, 2010) and ongoing attempts to bring new industry to the port and revitalize the city, but few researchers have addressed direct effects of the hurricane project. Sediment may be accumulating faster in some areas of the harbor inside the barrier, and less water is now being exchanged between the inner and outer harbors (Pesch *et al.*, 2001). Numerical modeling calculated that the residence time of water inside the barrier has increased up to 30%, with gyres recirculating water within the inner harbor (Abdelrhman, 2002).

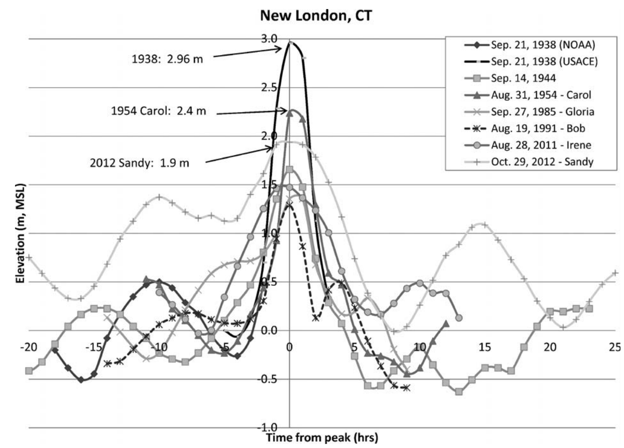


Figure 18. Observed water elevations for major storms at New London, Connecticut. Data from New England Division (1977) and NOAA Tides & Currents (NOAA, 2014).

Only one environmental document pertains directly to the hurricane barrier, the 1972 *Final Environmental Statement* (New England Division, 1972). This document states that the gate pockets were highly productive biologically and that temporary turbidity induced by the compressed air system did not have detrimental effects on marine life. The 1972 document also noted that rodent populations were a problem in some areas of the dike and that the USACE assisted the City of New Bedford with rodent control.

## NEW LONDON, CONNECTICUT, BARRIER

The New London Hurricane Protection Barrier is located at Shaw Cove on the Thames River waterfront (Figure 17). The barrier protects 173 industrial and commercial acres from hurricane and severe storm flooding and safeguards against interior flooding caused by overflows from Truman Brook. Construction was completed in May 1986 at a cost of $12 million ($44 million in 2014 dollars). The barrier is owned and operated by the City of New London.

The project consists of a 220-m-long earthfill dike with stone facing protection with maximum elevation of 4.13 m NAVD; a concrete flood wall, 240 m long with elevation of 4.13 m; two revetments; a 550-m-long gated concrete conduit to carry flow from Truman Brook into Shaw Cove; and a pumping station that discharges inflow through the dike during unusually high tide.

### Hydraulic Design

Table 1 lists water levels, and Figure 18 shows water-elevation curves for the 1938 and other major hurricanes. This barrier was designed for a 100 year still-water elevation of 2.91 m NAVD. This is equivalent to a surge of 2.6 m coincident with a mean spring high water tide of 0.29 m NAVD. Assuming maximum wave runup of 1.2 m, the resulting top elevation of the barrier was set at 4.13 m NAVD (New England Division, 1977). Hurricane Sandy was the third highest event to affect New London. The hurricane barrier was not overtopped, and

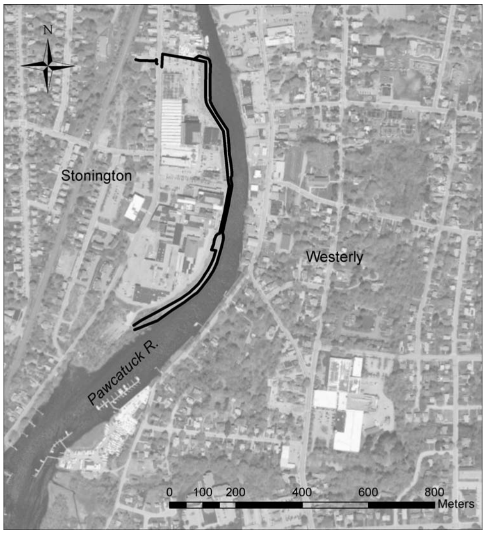


Figure 19. Pawcatuck River hurricane barrier, located on the Stonington, Connecticut, side of the river (background photograph from ESRI® Maps and Data).

there was no inundation or damage to buildings, roadways, and utility infrastructure (USACE, 2013).

Note that the protection level is for a 100 year storm, whereas the Providence and New Bedford projects were designed for a 500 year event. The original plan for New London was more comprehensive, to also include a dike around Bentley's Creek, located south of Fort Trumbull; this section was not constructed.

### Environmental Factors

The Shaw Cove dike enclosed an industrial area and did not affect any wetlands or enclose open water. It did not affect any known historic archaeology. The dikes were installed on land and therefore did not affect fish resources. A *Final Impact Statement* was filed with the Council of Environmental Quality on 25 August 1976 (New England Division, 1977).

In a comment letter filed with the *General Design Memorandum*, the U.S. Department of the Interior recommended that nonstructural alternatives be investigated as an alternative to building the dikes (New England Division, 1965). They recommended relocating the urban renewal area out of the flood zone. It is unclear if this was considered earlier in the planning phase for this project, and other entities were in favor of the dike project precisely because it would allow urban renewal, increase employment, and have other benefits to an economically depressed region.

Figure 20. Hurricane surge barrier, west bank of Pawcatuck River, Stonington, Connecticut (photograph by A. Morang, taken from Westerly, Rhode Island).

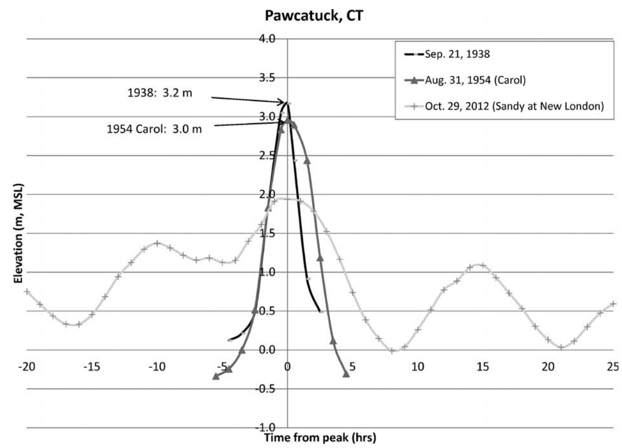


Figure 21. Observed storm-elevation curves at Pawcatuck for hurricanes of 1938 and 1954 (NAE data) and Sandy (NOAA Tides & Currents [NOAA, 2014], data from New London, Connecticut).

## PAWCATUCK, CONNECTICUT, HURRICANE PROTECTION DIKE

The Pawcatuck Hurricane Protection Barrier is located on the west bank of the Pawcatuck River in the town of Stonington (Figure 19). Pawcatuck suffered serious flooding from hurricanes in 1938, 1944, 1954, and 1960. Construction began in June 1962 and was completed in September 1963 at a cost of $859,000 ($6.8 million in 2014 dollars). The Town of Stonington operates and maintains the project (Morang, 2007).

The project consists of 580 m of earthfill dike and 285 m of concrete wall. Both have top elevation of 4.89 m NAVD (Figure 20). Two vehicular gates prevent street flooding. The protection begins 1.1 km south of the U.S. Route 1 bridge and extends 670 m north along the west bank of the Pawcatuck River, protecting about 34 acres of industrial land.

The lower portion of the river forms the border between Rhode Island and Connecticut and drains into Little Narragansett Bay, a bay partially sheltered from Long Island Sound by Napatree Point. The point was heavily settled before the 1938 hurricane, during which houses and

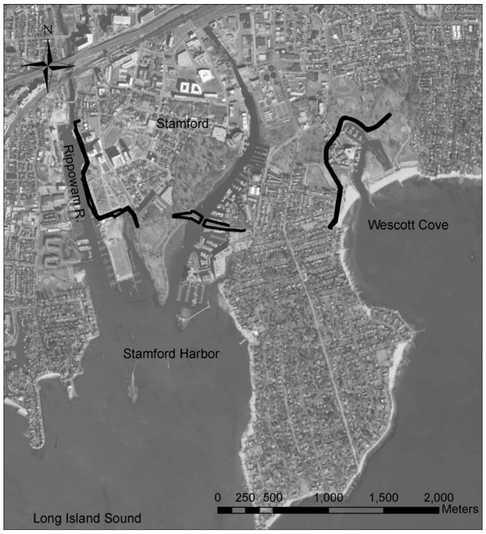


Figure 22. Project elements, Stamford, Connecticut (background aerial photography from ESRI® Maps and Data).

the decommissioned U.S. Army Fort Mansfield were destroyed.

## Hydraulic Design

The design hurricane was assumed to cross Long Island 60 km west of Montauk Point and move north directly over New Haven, creating sustained winds of 40 m/s. Within Little Narragansett Bay, at the mouth of the Pawcatuck River, the surge caused by this storm was computed to be 4.3 m. Added to the mean spring high water elevation of 0.10 m NAVD, this resulted in a 4.4 m NAVD still-water elevation. The transposition of this surge upriver to Stonington resulted in a design water elevation of 4.7 m NAVD, with no danger of wave action from Little Narragansett Bay. The 4.7 m level was approximately a 1 in 500 year event (Morang, 2007). Table 1 lists water levels, and Figure 21 shows the storm curves. A water elevation for Sandy was not recorded, and no significant impacts were listed (USACE, 2013).

## Environmental Factors

Similar to New London, this was also a land project that did not affect wetlands or open water. There appear to be no postconstruction environmental studies or reports.

# STAMFORD, CONNECTICUT, HURRICANE BARRIER

The Stamford Hurricane Protection Barrier is located in the harbor of Stamford (Figure 22). The area has been subjected to storm surges since 1635, and the 1938 and 1954 hurricanes caused significant damage to the town. The barrier now protects about 600 acres, which include factories, the town's main commercial district, residential neighborhoods, and a cemetery. Project construction began in May 1965 and ended in January 1969, costing $14.5 million ($110 million in 2014 dollars). The city operates the dikes and land facilities, while the USACE operates and maintains the navigation gate (Morang, 2007).

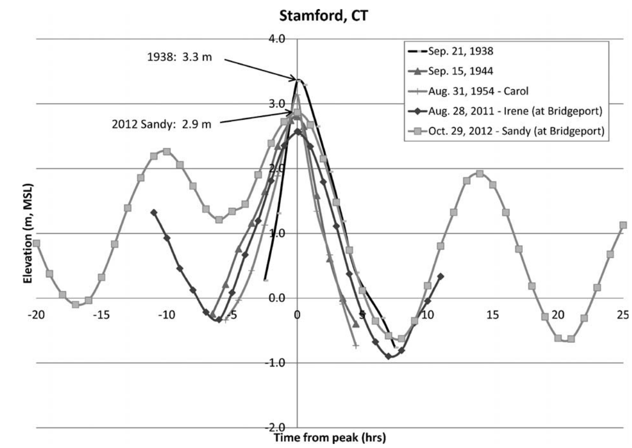


Figure 23. Observed storm-elevation curves at Stamford for hurricanes of 1938, 1944, and 1954 (New England Division, 1962) and Irene and Sandy (NOAA Tides & Currents [NOAA, 2014], data from Bridgeport Station 8467150).

Three elements comprise the project. The first is an 870-m-long earthfill dike with stone slope protection with top elevation of 4.8 m NAVD and a 27-m-wide opening for navigation on the East Branch Rippowam River. A pump station drains interior areas.

The second element provides protection along the east shore of the West Branch of the Rippowam River. It consists of 440 m of concrete wall and 590 m of earthfill dike with stone slope protection, both with top elevations of 4.8 m NAVD.

The third element is a 1.30-m-high earthfill dike with stone slope protection and top elevation of 5.1 m at Westcott Cove. Two pumping stations drain interior areas.

## Hydraulic Design

The September 1944 design hurricane was applied to Stamford. Within Long Island Sound, at Stamford, surge associated with this storm was computed to be 2.79 m NAVD. When added to the mean spring high water elevation of 0.96 m, the resulting still-water elevation would be 4.13 m NAVD. Wave heights associated with this storm would be about 0.6 m at peak surge, resulting in a top of barrier elevation of 4.8 m. The 4.13 m design still-water elevation was slightly greater than a 500 year level. Table 1 lists historic water levels, and Figure 23 shows water levels for five hurricanes. The 1938, 1944, and 1954 data are from the *General Design Memorandum* (New England Division, 1962). Note the elevations for Hurricanes Irene and Sandy are from NOAA Bridgeport station 8467150 and have not been projected (adjusted) to Stamford.

When Irene reached New England as a tropical storm on 28 August 2011, Stamford recorded its third highest water level since construction in 1969 (New England District, 2011). Hurricane Sandy's peak elevation on 29 October 2012, was about 0.4 m below the 1938 peak, the barrier was not

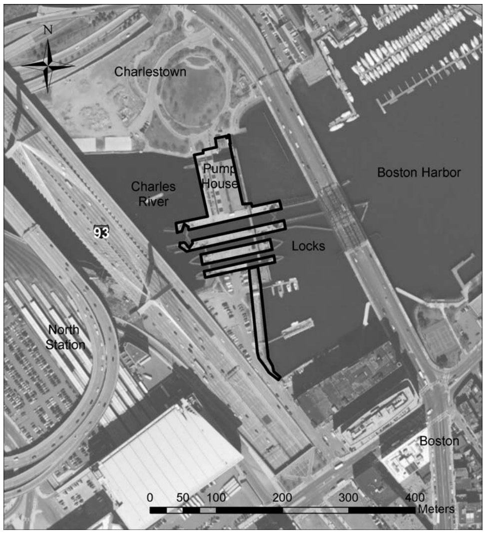


Figure 24. Charles River Dam and hurricane protection project, Boston, Massachusetts (background photography from ESRI® Maps and Data [ESRI, 2014]).

overtopped, and the barrier again proved its value in preventing widespread flooding. The USACE estimated that the barrier prevented about $25 million in damage to businesses and homes from Sandy (Navarro, 2012).

### Environmental Factors

There appear to be no postconstruction environmental studies or reports. No information is available on siltation, circulation, or other conditions.

Figure 25. Charles River Dam from Charlestown Bridge (Route 99), view looking south, 1 November 2006. The brick structure contains the pumps. The water in the foreground is the harbor side and is tidal. Downtown Boston is in the distance (photograph by A. Morang).

Figure 26. Diesel engines and pumps in Charles River Dam, 1 November 2006 (photograph by A. Morang).

## CHARLES RIVER DAM, BOSTON, MASSACHUSETTS

The Charles River Dam Local Protection Project was built across the Charles River, between Charlestown and the North End sections of Boston (Figure 24). It provides flood protection to 2440 acres of urban property in Boston, Brookline, Cambridge, and Boston's Back Bay.

The Charles River Project was initiated in November 1972 with removal of the Warren Street Bridge. Construction of the new dam began in 1974, and the project was completed in May 1978 at a cost of $61.3 million ($297 million in 2014 dollars). The benefit to cost ratio for the project was 1.7 to 1 (New England Division, 1973). The new dam is situated 0.9 km downstream of the older dam and is operated by the Massachusetts Department of Conservation and Recreation (formerly the Metropolitan District Commission [MDC]).

The project consists of an earthfill and concrete dam with stone protection (Figure 25). The dam is 120 m long with an elevation of 3.8 m above mean sea level. The pumping station is 58 m long and 37 m high and contains six pumps. The pumps are diesel-powered and independent of the municipal power grid (Figure 26). Three navigation locks provide transit for commercial and recreational vessels. Two of the locks measure $60 \times 6.7 \times 2.4$ m, while the third lock, measuring $91 \times 12 \times 5.1$ m, can accommodate commercial and large recreational vessels. The project also incorporates a boat facility for the Department of Conservation and Recreation Police, a park, a visitors' center, and a fish ladder to allow fish migration to the upper river (Morang, 2007).

### Background

The Charles River Dam is a more multifunction project than the other New England hurricane barriers. Not only was it designed to protect against unusually high tide or surge in Boston Harbor but also to maintain a restricted range of water level in the Charles River Basin. The basin between Boston and Cambridge was formerly an expanse of mudflats, which were

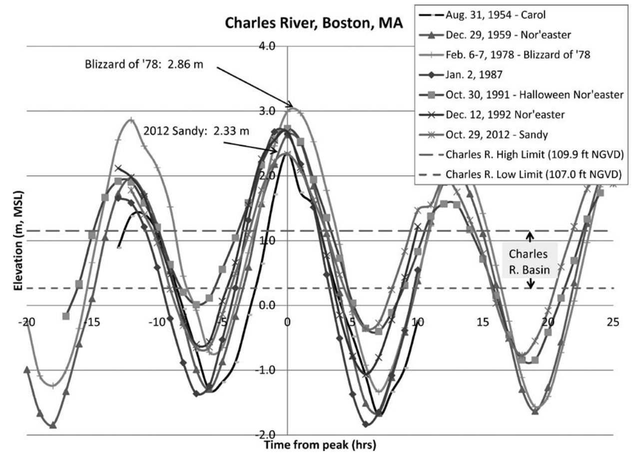


Figure 27. Observed storm-elevation curves at Boston for major storms, including Hurricane Sandy (NOAA Tides & Currents, data from Boston Station 8443970). Range of desired water levels for the Charles River Basin (dashed lines) was converted from MDC datum to MSL.

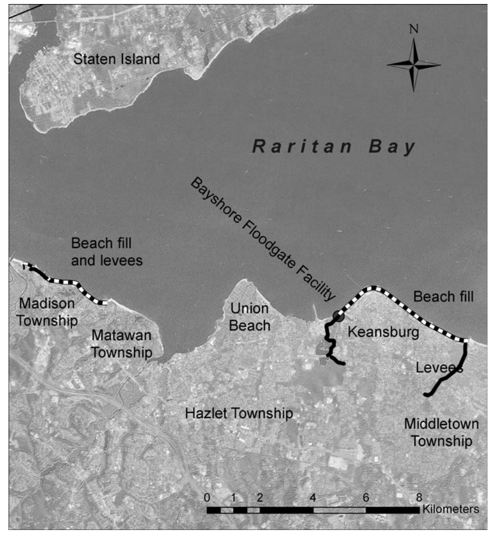


Figure 28. Raritan Bay, New Jersey, hurricane protection project. Dashed line shows beach fill (background photograph from ESRI® Maps and Data [ESRI, 2014]).

exposed twice daily and were renowned for mosquitoes and nasty aromas in summer. The original 1910 dam converted the basin into an agreeable freshwater body, along which fashionable homes, a landscaped esplanade, and institutions of higher learning were located (Whitehill, 1968). The dam greatly reduced saltwater influx by means of sluices, but the basin was never entirely free of a saltwater wedge because of leakage through the sluices and the lock (Hall, 1986). Little of the original dam can be seen because a busy highway crosses it, and the Museum of Science was built on the dam in 1950.

### Hydraulic Design

The Charles River Basin is highly sensitive to changes in water level and must be kept between 32.61 m and 33.50 m elevation, MDC datum (Mr. James Law, NAE, *personal communication*, 15 December 2006). At 32.6 m, boating problems occur, while at 33.5 m, low areas along the shore begin to flood. At spring tide, Boston Harbor water is higher than the Charles River level. The Charles River Dam is also unusual in that high runoff into the basin cannot be controlled by the six pumps alone. Additionally, the gates on the sluices must be manipulated, and the water in the basin must be lowered before a major storm in anticipation of the inflow of runoff and rain.

The water level of record occurred during the Blizzard of 1978 (Figure 27). Much of New England was enveloped in blizzard conditions from 5–7 February, causing snow drifts of 4 m in the Boston suburbs. Exceptional winds generated a powerful surge, which led to serious coastal flooding and beach erosion from New Jersey to Maine. Gusts of 35 m/s were recorded in Boston and 52 m/s in Chatham, on Cape Cod. The longevity of the storm led to four successive flooding high tides, which compounded the damage to beaches and property. In Massachusetts, 73 deaths were recorded, along with 26 in Rhode Island. Thousands of houses and businesses were destroyed or heavily damaged, with damage estimates exceeding $530 million in 1979 dollars (Strauss, 2008) or about $1.9 billion in 2013 dollars based on the Consumer Price Index inflation calculator (Bureau of Labor Statistics, 2014). Although the Charles River project had not been formally completed, the pumps and other equipment were operated and helped prevent significant flood damage in the Charles River Basin (Morang, 2007). The plot also shows that other nor'easters and storms have produced water levels only slightly lower. Hurricane Sandy's peak was 2.33 m mean sea level (MSL), 0.53 m below the 1978 peak. The residual for Hurricane Sandy (predicted minus storm-water level) was only 0.79 m (Table 2; Fanelli, Fanelli, and Wolcott, 2013). Other prominent storms clustered around the 2.3–2.5 m level.

### Environmental Factors

By the time the Charles River Dam was built in the mid-late 1970s, far more extensive environmental studies were required than for the earlier projects. New England Division (1973) issued a final environmental statement. The Charles River Dam was designed to not only prevent saltwater from entering the basin but also slowly flush saltwater out.

The dam contained an innovative fish ladder, designed with assistance from fisheries experts in the northwest (North Pacific Division, 1977). The ladder did not function as planned and was modified in the early 1990s (New England Division, 1992), but the other elements of the project have been a stellar success. Aelwives (*Alosa pseudoharengus*), blueback herring (*Alosa aestivalis*), American shad (*Alosa sapidissima*), and Atlantic rainbow smelt (*Osmerus mordax mordax*) simply pass through the locks with boats, and if large numbers of fish enter the locks when no boats are present, the operators lock them through (Hall, 1986). On 1 November 2006, I saw many cormorants (Phalacrocoracidae) swimming in the harbor next to the dam, attesting to the abundance of fish.

Figure 29. Bayshore pump station at Keansburg, New Jersey, 23 June 1972, 0955 h (photograph courtesy NAN). Levees and floodgate were under construction. The beach to the left had recently been nourished.

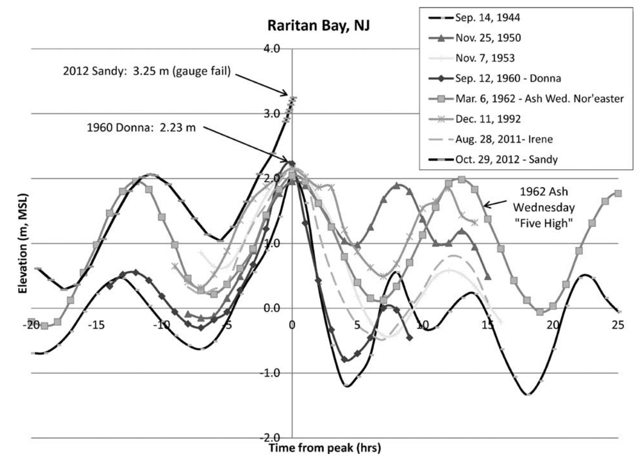


Figure 30. Observed water elevations for major storms in Raritan Bay, New Jersey (NOAA Tides & Currents [NOAA, 2014], data from Sandy Hook Station 8531680). The instrument failed at 1936 local time, and peak elevation may have been higher.

## RARITAN BAY AND SANDY HOOK BAY BEACH EROSION AND HURRICANE PROJECT

Section 203 of the Flood Control Act of 1962 authorized the project for hurricane-flood protection at Raritan Bay and Sandy Hook Bay, New Jersey. The project consisted of a combination of levees, walls, and beach nourishment along a 34 km stretch of shoreline in the communities of Madison Township, Laurence Harbor located in Old Bridge Township, and Keansburg and East Keansburg (now renamed North Middletown) located in Middletown Township (Figure 28; Christina Rasmussen, NAN, *personal communication*, 13 February 2007). Appendix D lists features of this project. The benefit to cost ratios were 1.9 to 1 for Madison Township, 1.9 to 1 for Keansburg, and 1.3 to 1 for East Keansburg.

### Hydraulic Design

Water-elevation data from the *Operations and Maintenance Manual* (New York District, 1970) refer to the "Authorized 1957 Design Event." The design stage used in the original Keansburg and Laurence Harbor beach fill cross sections consisted of the maximum recorded surge height during the 25 November 1950 nor'easter superimposed on a normal high tide (which was 0.69 m NAVD in 1950). The maximum surge recorded at Perth Amboy was 3.17 m, giving a design stage of +3.86 m MSL. The measurement was near land and therefore was assumed to include wave uprush (setup). At the toe of the fill, a design wave of 2.7 m was used for the original design, coupled with a design wave runup of 0.6 m (New York District, 1963, 1964).

This area was not flooded during the 1938 and 1954 hurricanes, but the 1944 hurricane caused significant damage along the Jersey shore. The hurricane generated a storm surge of up to 2.9 m and waves up to 12 m along the Atlantic shore, creating widespread flooding. In addition, winds gusting to 55 m/s destroyed hundreds of homes and damaged thousands, while the waves washed away fishing piers and boardwalks (Sumner, 1944). The extreme storm frequency curve was prepared in 1960 and predated the infamous Ash Wednesday storm of 1962 (Cooperman and Rosendal, 1963). Oddly, the frequency curve in the 1964 *General Design Memorandum* (New York District, 1963, 1964) was identical to the curve in the 1960 survey report and apparently not changed to reflect the Ash Wednesday storm.

The original design, as outlined in the *General Design Memorandum*, was for both beach restoration and hurricane protection. The project was modified over time. The shore protection at the west end of Madison Township (now Old Bridge Township) was built, but the protection at Matawan (east of Madison) was not. In east Madison Township, the beach cottage colony was destroyed before construction commenced, thereby negating the need for the beach fill and levee. The beach fill at Union Beach was also not built.

The Laurence Harbor levee and beach fill project was completed in October 1966. The Keansburg and East Keansburg beach fill was completed in December 1969, and the adjoining levee in June 1973 (Christina Rasmussen, NAN, *personal communication*, 8 January 2007). The project also included infrastructure improvements, installing floodgates at roads and railroads. Also included in the 1973 project was the Bayshore floodgate, which is located at the junction of Waackaack and Thorns Creeks (Figure 29). The facility consists of a floodgate and pump station as well as series of levees and dikes that hold back floodwaters during storms. The four pumps are rated at not less than 3500 L/s against a total dynamic head of 1.5 m. The New Jersey Department of Environmental Protection Bureau of Coastal Engineering operates and maintains the facility on a 24 hour basis. The gates are closed over 100 times a year, for every spring tide and whenever the tide stage in Raritan Bay reaches 1.4 m above MSL.

For most of its history, the project performed as designed. Before Sandy, the beach had not been comprehensively renourished, but the state had placed creek dredging material on the beach. The beach suffered erosion over three decades, but the dune had not failed. Because of increased urbanization, interior drainage from streets is now a serious problem after heavy rains. During Sandy, the dune was breached in two places near Keansburg and parts of the town near the breaches flooded (Christina Rasmussen, NAN, *personal communication*, 21 December 2013). In addition, a levee was breached near the crest in one location, but water did not go over the floodgate at the Bayshore station.

Hurricane Sandy was the storm of record in Raritan Bay. Unfortunately, the tide gauge at Sandy Hook failed during the storm, and the peak water level was not recorded (Figure 30; Fanelli, Fanelli, and Wolcott, 2013). The Hurricane Sandy surge residual was 2.61 m, the greatest residual of all sites examined in this paper (Table 2).

## CONCLUSIONS

The New England storm surge barriers were delayed for almost three decades from the time of the first disastrous twentieth-century hurricane in 1938 to their completion. Some of this delay was caused by geopolitical factors (World War II and the beginning of the Cold War), but much of this time was spent conducting studies, awaiting legislative authority, and securing local cooperation. It took a third major storm, Hurricane Carol in 1954, to spur Congress into authorizing a comprehensive investigation of hurricane damage potential. Also, and possibly just as important, by the mid-twentieth century, Americans had changed their attitude toward the role of the state. The U.S. government had brought us victorious through World War II, and more citizens than ever before felt that their government should also play an active role in mitigating and protecting against natural disasters. In response, Congress passed a series of Public Laws (*e.g.*, River and Harbor Acts, Flood Control Acts, Shore Protection Studies, Hurricane Studies) to authorize shore protection studies and projects (Hilyer, 2003). Table 3 summarizes design storm elevations and features of the northeast projects.

It is difficult to assess the dollar value of the protection afforded by the New England and New Jersey barriers. The cost analyses from the 1950s show values in the low tens of millions, but these numbers are irrelevant now. Five decades have passed, and the Northeast is much more extensively developed now. Not only is the coastal zone more densely inhabited, but the values of homes and industries are immensely greater (the former $5000 Rhode Island summer beach cottage is now a $300,000+ year-round home). With Hurricane Sandy damage mounting into the billions, we can safely say that an event of the magnitude and trajectory of the Great New England Hurricane of 1938 could cause tens of billions in damage in New York, Connecticut, and Rhode Island. Pielke and Landsea (1998) calculated the loss to be $16.6 billion in 1995 dollars for the affected coastal counties only.

Most of the projects have not been tested with storm-water elevations near their design elevation (Table 1). The Charles River project is one exception, because just before it was formally dedicated, the Blizzard of 1978 struck Boston. The pumps proved their worth by preventing flooding of the Charles River Basin. The Connecticut, Rhode Island, and Massachusetts projects were designed for a more significant storm event

Table 3. *Summary of hurricane barrier project features.*

| Project | Design Storm Elevation (m, NAVD) | Project Elevation (m, NAVD) | Total Levee, Dike, Wall Length (m) | Pump Capacity (L/s) | Other Features |
|---|---|---|---|---|---|
| Charles River, Boston, Massachusetts | 1.08 (Charles R. basin elev.) | 3.72 | 122 | 238,000 (6 @ 39,600 each) | Sluice gates, nav. locks. Operated to maintain Charles River Basin within restricted range |
| New Bedford, Massachusetts | 4.62 | 5.84 | 5500 | 6800 (Clark Cove) | 46-m-wide navigation channel (2 sector gates invert = 12.1 m NAVD) |
| Fox Point, Providence, Rhode Island | 6.00 | 7.37 | 670 | 198,000 (5 @ 39,600 each) | 213 m concrete dam with 3 tainter gates |
| Pawcatuck, Connecticut | 4.74 | 4.89 | 870 | 1400 | |
| New London, Connecticut | 2.91 | 4.13 | 460 | 5900 | 2.4-m-diameter pressure conduit from Truman Brook to Shaws Cove |
| Stamford, Connecticut | 4.17 | 4.8 and 5.1 (Wescott Cove) | 3200 | 22,600 (total for 3 locations) | 27.4-m-wide navigation channel (flap gate invert = −5.86 m NAVD) |
| Raritan and Sandy Hook Bays, New Jersey | 3.86 | 4.5 | 3300 | 13,900 (4 @ 3450 each) | 800 m of dune (4.7 m elev.) and beach fill |

Sources: New England District (2013), New England Division (1959, 1961, 1962, 1965, 1971), and New York District (1963).

than experienced during Hurricane Sandy. Nevertheless, the storm surge was significant and likely would have caused extensive damage in the absence of the storm surge barriers at New Bedford, Providence, New London, Stamford, and Stonington (USACE, 2013). In Raritan Bay, water elevations during Hurricane Sandy were the highest ever recorded, and flooding resulted from breaches in the dune and one levee. At Raritan Bay, the beach will need to be renourished after the damage from Sandy (Christina Rasmussen, NAN, *personal communication*, 21 December 2013).

There is little information in the literature regarding flushing, sedimentation, or other environmental effects of the New England barriers. All except the Charles River Dam were constructed in an era when environmental studies were minimal compared to today, and National Environmental Policy Act (NEPA) documents were not prepared for their construction. All were built to protect ports, industrial, and urban areas, which were already extensively developed and modified from their natural (preindustrial era) condition. New Bedford and Providence had serious pollution problems, but these were a legacy of two centuries of heavy industry. By the time the barriers were installed in the 1960s, the heavy industry was largely gone. The Charles River, once grossly polluted, was also already on the path to being cleaned when the new dam was completed in 1978. Upon NEPA authorization in 1969, NEPA documents were in fact generated for the federally run facilities for their operation and maintenance activities. New England streams in general have low sedimentation rates compared to streams in other parts of the country, therefore supplying little material to be trapped behind the barriers in Providence and New Bedford.

The gates at two of the projects, New Bedford and Raritan Bay, are not only in place for severe tropical storms, but are used regularly at spring tide and other high-water events to exclude water and prevent flooding of low areas. This insures that the machinery is used regularly and is maintained. If larger ships need access to New Bedford harbor in the future, the navigation gates would probably have to be totally rebuilt. This would be costly and disruptive. The gates in Providence will probably not be a limitation because they are upriver of the main commercial harbor and refineries. Plans for barriers in other locations should include options for expansion if there is a navigation component. Long-term maintenance requirements were underestimated for the projects with mechanical components. In particular, the 1960s electromechanical controls needed upgrading at Providence. The pumps at other sites are in similar condition: well-maintained but with electro-mechanical controls of mixed vintages.

For the New York Bight area, numerous hurricane protection concepts have been proposed, ranging from comprehensive dikes and floodgates, which would shield low-lying communities and barrier islands, to more local protection structures (City of New York, 2013). Regardless of which projects are finally selected and funded, planning, permitting, and environmental studies will be much more challenging than the projects of five decades ago because (1) far more extensive environmental impact studies would have to be conducted now; (2) obtaining permits and negotiating property rights would be a challenging multiyear process; and (3) obtaining easements and construction access would be vastly more difficult now because of the substantially higher value of coastal real estate. It is beyond the scope of this paper to discuss the feasibility of any of these plans as studies are still under way.

Many people are not aware that the USACE has built and efficiently operated hurricane barriers for more than 40 years. They are also unaware that these barriers have protected urban areas from flooding, although they have not been tested with severe storms of the magnitude of the 1938 and 1954 hurricanes. However, these were small-basin projects, designed for limited areas that benefited from topography. The New England and New Jersey barriers are excellent examples of cooperation and operational coordination between the USACE, state, and municipal agencies.

## ACKNOWLEDGMENTS

Christina Rasmussen, NAN, Linda Lillycrop and Tanya Beck, both Coastal and Hydraulics Laboratory (CHL), Charles N. Farris, NAE, Peter Crane, Mount Washington Observatory, and an anonymous reader reviewed this paper.

At CHL, work was performed under the general supervision of Tanya Beck, chief of the Coastal Engineering Branch, CHL; Jackie Pettway, division chief, Navigation Division, CHL; Edmond Russo, deputy director, CHL, and Jose Sanchez, director, CHL.

I wish to thank Richard J. DiBuono and Richard Sager, USACE (retired), Charles Brasfeild (deceased), James E. Law, Dubán Montoya, John Winkelman, and Abigail M. Clark, all NAE, and Christina Rasmussen, NAN, for information, historical data, and advice. Steven Fluegel, NAE, escorted me on a tour of the New Bedford project, including a walk under the harbor. Brittany Kolb, CHL, digitized historical paper plots. Susan Morang proofread the manuscript. Permission to publish this paper was granted by the chief of engineers, USACE. Maps throughout this paper were created using ArcGIS® software by Esri. ArcGIS® and ArcMap™ are the intellectual property of Esri and are used herein under license.

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[1] This list is not comprehensive; tens or hundreds of professional papers, articles, and memoirs have been written.

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## APPENDIX C. USACE HURRICANE AND FLOOD POTENTIAL REPORTS AND GENERAL DESIGN MEMORANDUMS FOR NEW ENGLAND AND NEW JERSEY COASTAL WATERS AND DISTRICT OF COLUMBIA

These documents are in the library at the Engineer Research and Development Center, Waterways Experiment Station, Vicksburg, Mississippi. Few are available in electronic format. Some of the reports are bound with screw posts and are not page-numbered. This list may not be comprehensive. Some of the hurricane survey interim reports were reprinted by the U.S. Government Printing Office if transmitted to Congress in the form of a "Letter from the Secretary of the Army," but it is unclear if all plates and appendices were included.

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## APPENDIX D. PROJECT ELEMENTS, RARITAN BAY AND SANDY HOOK BAY, NEW JERSEY, BEACH EROSION AND HURRICANE PROJECT

The following list of project features is an excerpt from New York District (1964) (note, English units were retained as per the original):

(1) Morgan Beach (Old Bridge Township). A beach berm to be constructed at a height of 15.0 ft M.S.L. (mean sea level) 25 ft wide with a slope of 1V:20H and length of 2300 ft. A levee was also to be constructed adjacent to New Jersey Route 35. This levee was to be built at a height of 15.0 ft M.S.L., width 25 ft and 900 ft long.
(2) Laurence Harbor (Old Bridge Township). A beach berm to be constructed at a height of 10 ft M.S.L., width 25 ft, with a slope of 1V:20H and length of 3800 ft.
(3) Seidler Beach (Old Bridge Township). A beach berm to be constructed at a height of 10 ft M.S.L., with a slope of 1V:20H, width 100 ft, and length of 2200 ft.
(4) Knollcroft (Old Bridge Township). A beach berm to be constructed at a height of 10.0 ft M.S.L., width 25 ft, with a slope of 1V:20H and length of 2850 ft.
(5) Union Beach. Beach fill was to be placed at a height of 5.5 ft M.S.L. and 100 ft wide with a slope of 1V:20H along 0.6 miles of shoreline.
(6) Keansburg and East Keansburg. A beach berm to be constructed at a height of 15.0 ft M.S.L., width 25 ft, with a slope of 1V:20H and length of 14,400 ft. Two closure levees, both in excess of 6000 ft in length were to be constructed, one at the west side of Thorns Creek and the other at the west side of Pews Creek. A closure gate and pumping station were to be constructed at Waackaack Creek. Three stone groins, each 285 ft in length were to be constructed at Point Comfort.
(7) Construction of the authorized project for Old Bridge Township (Morgan Beach, Laurence Harbor, Seidler Beach, and Knollcroft) was initiated in 1965 and completed in 1966. Construction of the shoreline portion of the authorized project for Keansburg and East Keansburg was initiated in 1968 and completed in 1969. During construction, a total of 3.4 million cubic yards of sand fill dredged from several offshore borrow areas was placed on the project area.
(8) Construction of the closure portion (levee and closure gate) of the authorized project for Old Bridge Township was initiated and completed in 1966.
(9) Construction of the closure portion (levees, closure gate, and pumping station) of the authorized project for Keansburg and East Keansburg was initiated in 1970 and completed in 1973.
(10) Cliffwood Beach and Union Beach were the only portions of the authorized project not constructed. These unconstructed portions of the Raritan Bay and Sandy Hook Bay project were deauthorized in January 1990, as noted in the Federal Register.

□ **RÉSUMÉ** □

En moins de deux décennies au cours du milieu du 20e siècle, trois ouragans majeurs ont causés des dégâts, des inondations, et des décès au Massachusetts, Rhode Island, Connecticut et au New Jersey. L'un d'eux, *The Great New England Hurricane* du 21 Septembre 1938, a causé des dommages sans précédent et a inondé la ville de Providence, de New London, ainsi que d'autres zones urbaines. Suite à l'ouragan Carol en 1954, le 84e Congrès (1re session, loi publique 71, 15 Juin 1955) a autorisé et chargé le Secrétaire de l'armée de mener des enquêtes et des études sur les dommages, les causes et les mesures de remédiations reliés aux ouragans. À la fin des années 1950, à la suite d'études exhaustives, le Congrès a autorisé et financé sept projets de protection contre les ouragans: (1) Fox Point, Providence, Rhode Island - barrières, portes de navigation et pompes; (2) New Bedford, Massachusetts – barrière, portes de navigation et pompes; (3) New London, Connecticut - barrière et portes de navigation; (4) Pawcatuck, Connecticut – remblaiement et murs en béton; (5) Stamford, Connecticut – barrière et station de pompage; (6) Raritan et Sandy Hook Bays, New Jersey – digues, rechargement des plages et pompes; et (7) Charles River, Boston, Massachusetts – barrage mobile à battant et pompes. La plupart des projets n'ont pas été testés avec des niveaux d'eaux pluviales à proche de leur élévation limite. Les exceptions sont le barrage *Charles River*, qui a permis d'éviter des inondations pendant la tempête de 1978, et *Raritan Bay*, lors de l'ouragan Sandy. Pour des niveaux inférieurs, tous les projets ont fonctionné comme prévu. Après les inondations causées par l'ouragan Ike en 2011, des barrières pour ouragan de grande envergure ont été proposés pour la région de New York. En comparaison des projets de protections des années antérieurs, les nouveaux projets de barrières contre les ouragan de la région de New York présenteront des défis majeurs pour les planificateurs et les concepteurs: (1) les études d'impacts environnementaux seraient de beaucoup plus grandes envergures maintenant; (2) L'obtention de permis et la négociation des droits de propriété serait un processus difficile qui s'étendrait sur plusieurs années; et (3) l'obtention de droit de passage et l'accès à la construction serait beaucoup plus difficile aujourd'hui en raison de la valeur nettement plus élevée de l'immobilier en région côtière.