CHAPTER 42

OPERATION OF HURRICANE BARRIERS IN NEW ENGLAND

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ABSTRACT

Construction of two hurricane barriers to protect the coastal communities of New Bedford and Fairhaven, Massachusetts and Providence, Rhode Island is nearly complete. The projects include navigation gates, pumping stations, street closures, cooling water canal, and numerous utility gates. Operation of these various features introduces many problems not generally encountered in flood control projects on rivers. Delineation of responsibilities, with close coordination and cooperation between governmental agencies and local interests is essential to assure full effectiveness of the structures during hurricane conditions.

INTRODUCTION

Historic records show that the coast of southern New England has been battered periodically by hurricanes. The earliest one of record occurred in August 1635. Since then there have been numerous accounts of damaging coastal storms, many of which were of hurricane intensity. The most recent major events with good meteorological data occurred in September 1938, September 1944, and August 1954 (Carol).

The 1938 hurricane took 500 lives in New England and caused damages estimated at $300 million. The August 1954 storm cost 60 lives and caused damages approximating those of 1938. The height of the tidal surge in the 1944 storm exceeded the other two. Fortunately, it occurred at low tide and damages were less severe.

Two large cities - Providence, capital of Rhode Island, and New Bedford, Massachusetts, see figure 1, - have been particularly vulnerable to tidal surges. Losses in lives and monetary damages in both cities have been very high. Following Congressional authorization in June 1955, studies were initiated to determine the feasibility of protective barriers at these two cities and at other coastal communities. Projects at Providence and at New Bedford-Fairhaven were determined to be structurally feasible and economically sound and subsequently were authorized for construction. Work started on the Fox Point Barrier at Providence in December 1960 and was followed by construction starting in New Bedford and Fairhaven in October 1962.

Numerous papers, written on the technical features of the investigations, are listed in the attached references. This paper is limited to the operational aspects of the two projects during hurricanes and severe coastal storms, the prescribed rules and procedures for operation, and the responsibilities and coordination of the local communities, the Corps of Engineers, the U. S. Weather Bureau and the U. S. Coast Guard.

NEW BEDFORD-FAIRHAVEN BARRIER

The New Bedford-Fairhaven Barrier (see figures 2 and 3) may be divided into three principal features: (1) the harbor barrier and dike across the

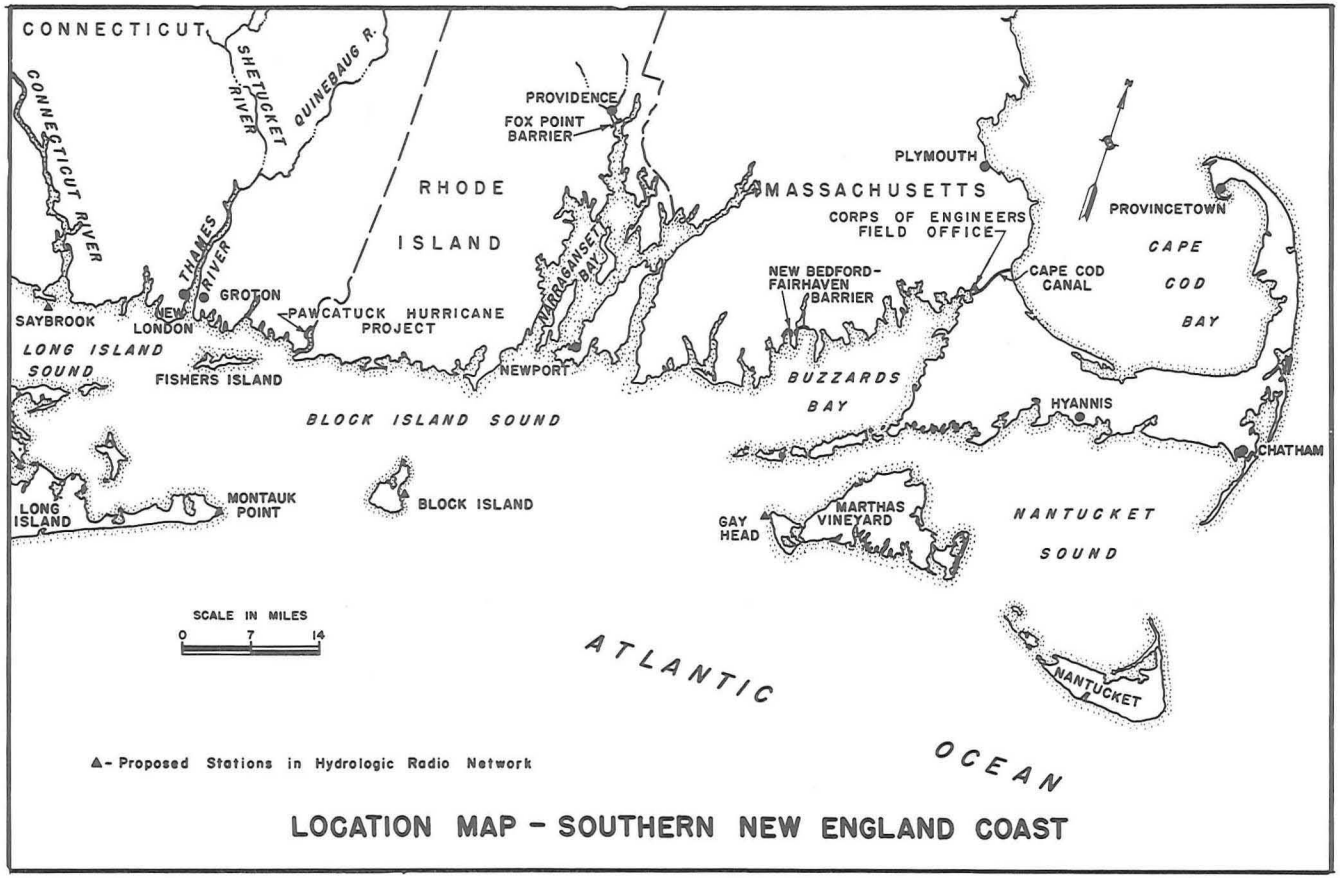

Figure 1. Location Map - Southern New England

entrance to New Bedford and Fairhaven Harbor, (2) the Clark Cove Dike which protects a low area at the head of the cove and prevents high tidal surges from flanking the harbor barrier from the west, and (3) the Fairhaven Dike which protects a low area in Fairhaven and prevents tidal flanking from the east.

The harbor barrier extends from Fort Phoenix at the southwestern tip of Fairhaven, westward across the harbor to New Bedford, a distance of 4,600 feet. A dike extension at the western end of the barrier is provided for 4,500 feet along the southeastern shore of Clark Point and return to high ground. Top of the harbor barrier, where the volume of wave overtopping during the design storm does not seriously affect the harbor stages, is elevation 20 feet above mean sea level. Top of the dike along the shore is elevation 22, 2 feet higher than the barrier in order to minimize the amount of wave overtopping onto the land area.

The navigation channel breaches the harbor barrier with an opening 150 feet wide. Two sector gates, with sills at elevation -39.0 feet and top at +20 feet, will close the channel during major storms and hurricanes. Two twin-barrel gated conduits are provided in the barrier section to insure circulation of water in the southwestern corner of the harbor during the normal tide cycles. Each conduit is 6 feet wide by 9 feet high. As this section of the project contains the navigation gates and appurtenances, both the harbor barrier and the gates will be maintained and operated by the Corps. Local interests contributed a lump sum payment to cover the non-Federal cost for this maintenance and operation, as required by law as part of their obligations.

The shore dike includes three gated conduits, 48, 36 and 24 inches in diameter, and a street gate on Rodney French Boulevard East. The street gate consists of two hinged sections, each 31 feet long and 14.5 feet high. The street and conduit gates will be operated by City personnel.

The Clark Cove area is protected by a dike 5,800 feet long around the north and east sides of the cove, with short flanking dikes returning to high ground (see figures 2 and 4). Top of the dike across the head of the cove is elevation 22.0, while the flanking dike along the easterly side, more exposed to wind and waves, is elevation 23. Operational structures in this section of the project consist of 2 street gates, 6 gates on utility conduits and a pumping station. The closure at Rodney French Boulevard West has two hinged swing gates, each 31 feet long and 12.5 feet high. The opening on Cove Road at the west end of the dike is closed with two gates, each 31 feet long and 13.5 feet high. The 6 utility gates range in size from a 24-inch diameter sea water intake conduit to a 96- by 84-inch main interceptor sewer.

The pumping station is for the evacuation of interior storm runoff and sewage. It contains 4 vertical propeller-type pumps driven by 350-horsepower motors. Each pump is designed to discharge 122 cfs against a head of 20 feet. A ponding area adjacent to the station provides about 10 acre-feet of storage for inflows that may exceed the pumping capacity. Before initiating pumping, the following operations are necessary: (1) closing a gravity outfall gate, (2) opening the intake gate to the sump, and (3) opening two gates to permit inflow from the ponding area. The Clark Cove dike, street gates, pumping station and utility gates will be maintained and operated by the City.

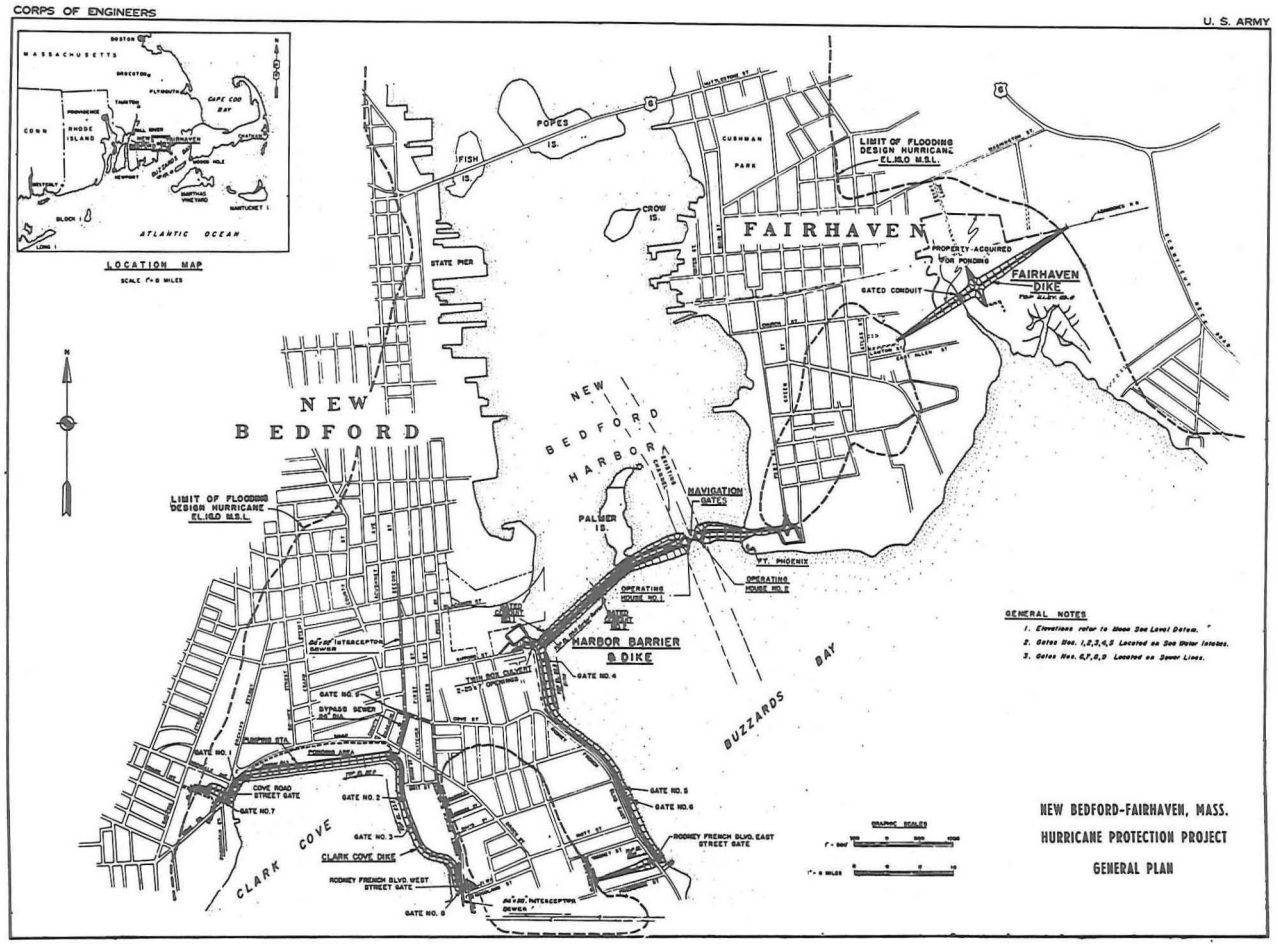

Figure 2. New Bedford-Fairhaven, Mass. Hurricane Protection Project General Plan

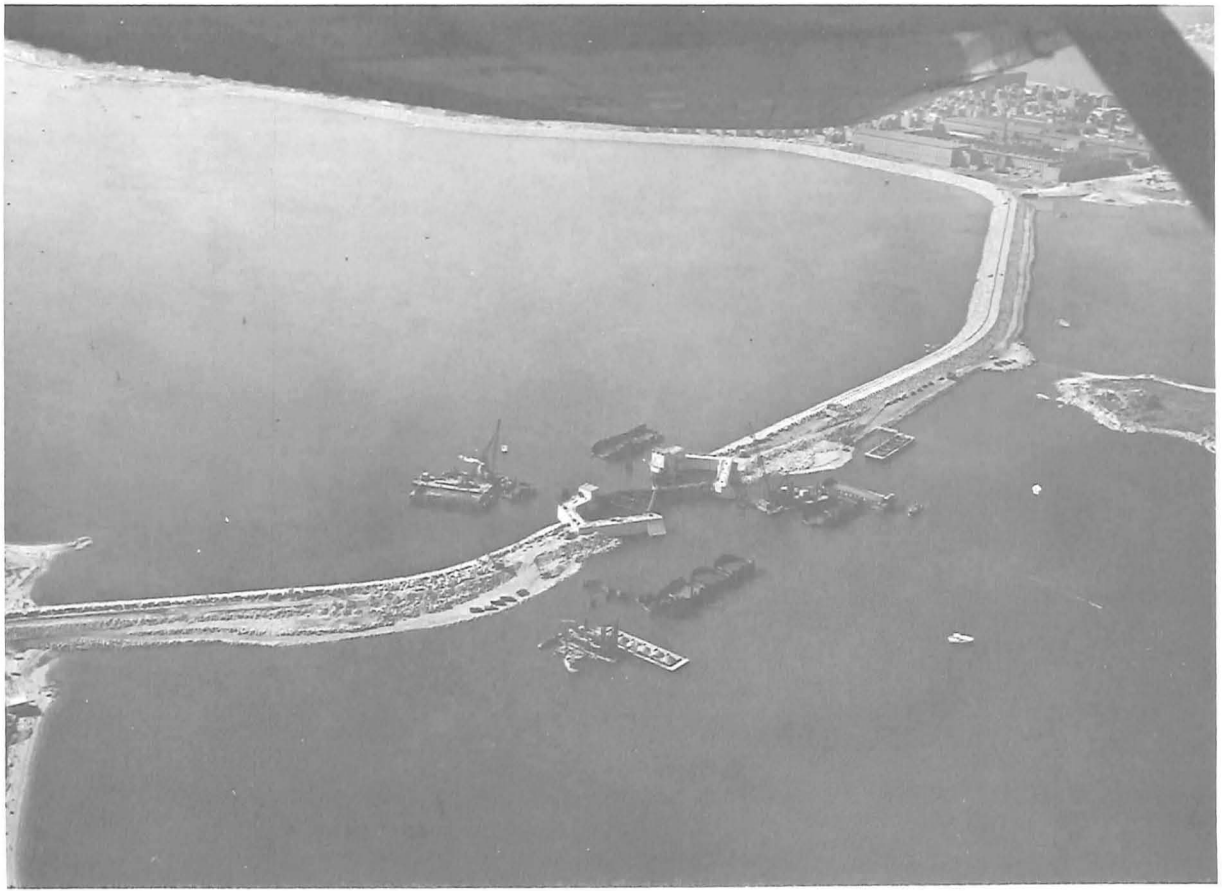

Figure 3. New Bedford-Fairhaven, Mass. Harbor Barrier and Navigation Gates

Figure 4. New Bedford, Mass. - Clark Cove Dike (Harbor Barrier in Background)

The southern portion of Fairhaven is protected by a dike 3,100 feet long, with top of dike at elevation 20. This portion of the project has a single 4 x 4 foot sluice gate in the drainage conduit that requires operation. There is sufficient ponding area for temporary storage of storm runoff during the few hours that gate closure is required. This dike and gate will be maintained and operated by the town of Fairhaven.

PROVIDENCE, FOX POINT BARRIER

The Fox Point Barrier, shown in figures 5 and 6, consists of 6 principal features as follows: (1) a concrete dam across the Providence River at Fox Point, (2) a pumping station to discharge interior runoff, (3) three tainter gates to close the river opening through the barrier, (4) a canal to provide cooling water to the Narragansett Electric Company, (5) street gates, and (6) utility gates.

The main barrier includes the pumping station, the three tainter gates and the cooling water canal intake. The pumping station, shown in figure 7, contains five 109-inch vertical propeller-type pumps, each driven by a 4,500 horsepower (3,600 KW) motor. Each pump has a discharge capacity of 1,400 cfs against a 20-foot head for a total of 7,000 cfs. The pumps are manually controlled during an operation.

The three tainter gates, shown in figure 8, are each 40 feet wide and 40 feet high. Each sill is at elevation -15 feet msl and the top of gate in closed position is +25 feet. The gates are normally in open position with the bottom of gate at about elevation +23 feet to permit passage of small boats and barges. The gates may be lowered 1.5 feet per minute for a total elapsed time of about 25 minutes from fully open to closed position. They open at a rate of 6 inches per minute. It takes 30 minutes to lift the gates 15 feet to provide a full waterway opening and an additional 46 minutes to open the gates to elevation 23.

The cooling water canal was required to offset the detrimental effect of the tidal barrier on water temperatures. The canal is formed by a panel wall along the west side of the river. It provides cool circulating water up to a rate of 1,000 cfs to be taken from downstream of the barrier through two gated openings in the pumping station. The two control gates, each 10 feet wide and 15 feet high are normally open. They will be partially or completely closed, as necessary, to control the rate of bay water inflow during a hurricane operation. The gates may be opened or closed at a rate of 12 inches per minute. The warm water from the powerplant discharges in conduits through the canal into the river.

Three street gates require closure during a hurricane. The largest gate, located at Allens Avenue, consists of two leaves each 35 feet long and 12.5 feet high. A smaller gate in the west embankment is located within the yard of the Narragansett Electric Company. The third gate closes the South Main Street opening in the east embankment (see figures 9 and 10).

Seven motorized sewer gates require operation during a storm. The two largest gates, each 72 x 60 inches, are located in a manhole in Allens Avenue to control tidal backwater in a 102-inch diameter trunk sewer.

More complete description of the project with data on design criteria is available in the reference material.

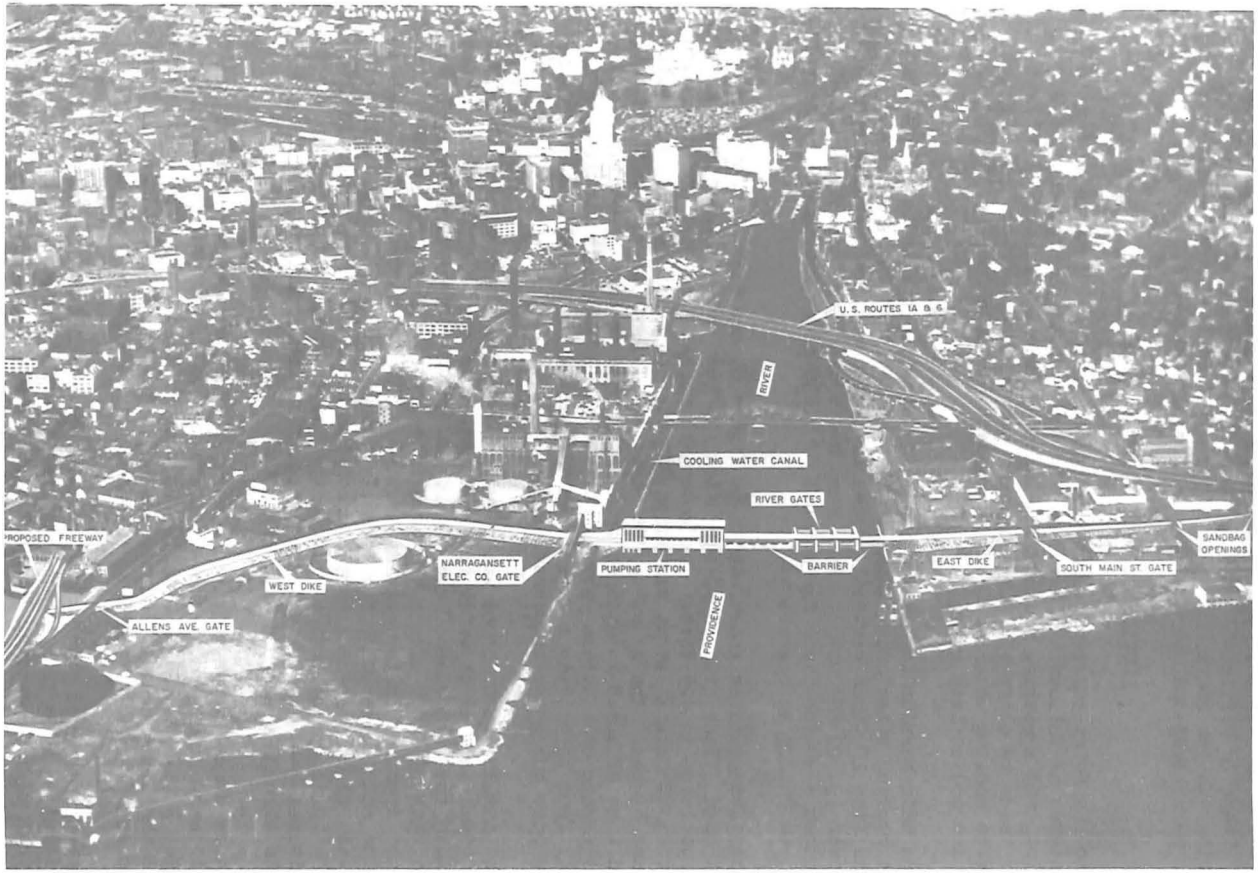

Figure 5. Artist's Conception of Fox Point Hurricane Barrier at Providence, R. I.

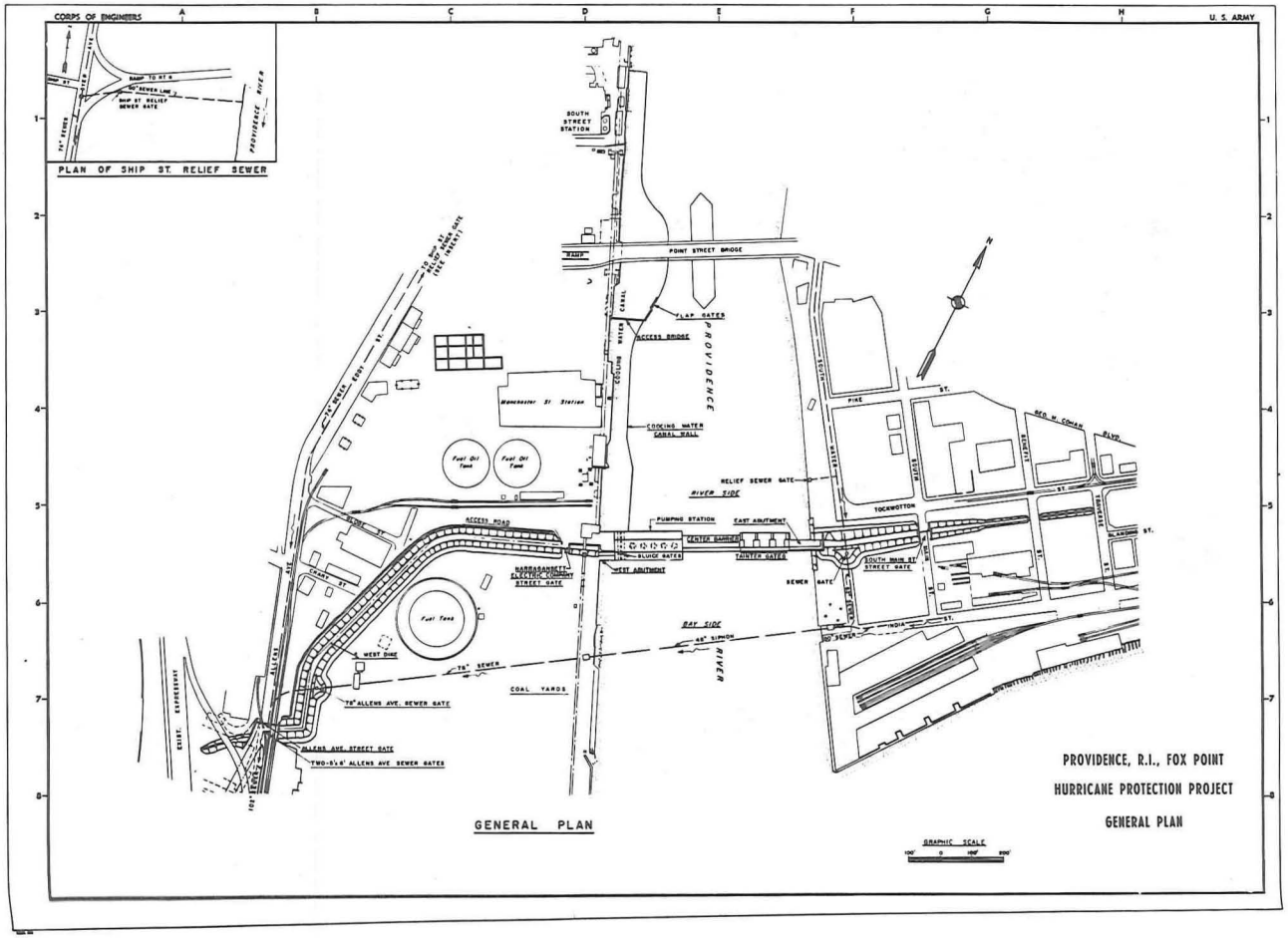

Figure 6. Providence, R. I. - Fox Point Hurricane Protection Project General Plan

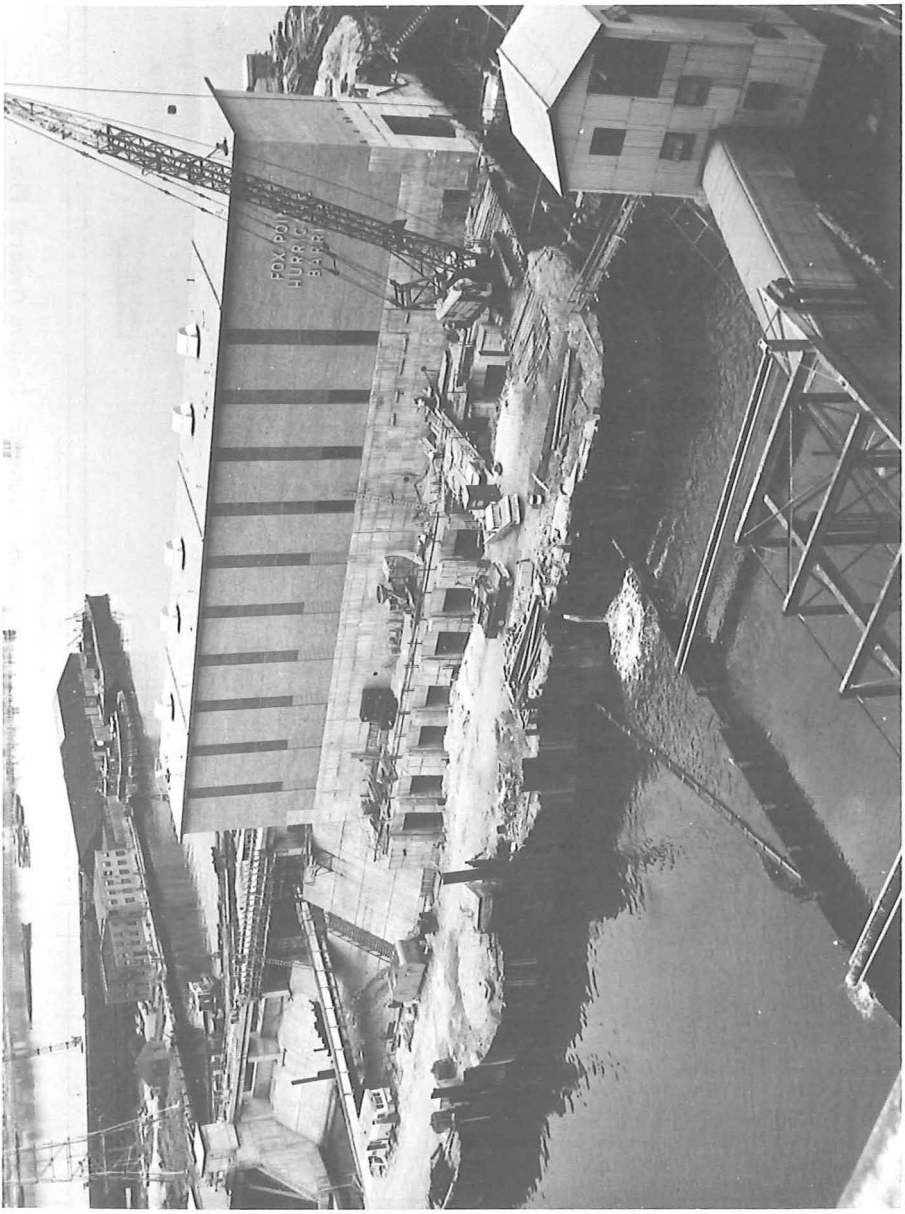

Figure 7. Providence, R. I. - Fox Point Hurricane Barrier Showing Pumping Station

Figure 8. Providence, R. I. - Fox Point Hurricane Barrier Showing Tainter Gates

Figure 9. Providence, R. I. - Fox Point Hurricane Barrier - Street Gate in Open Position

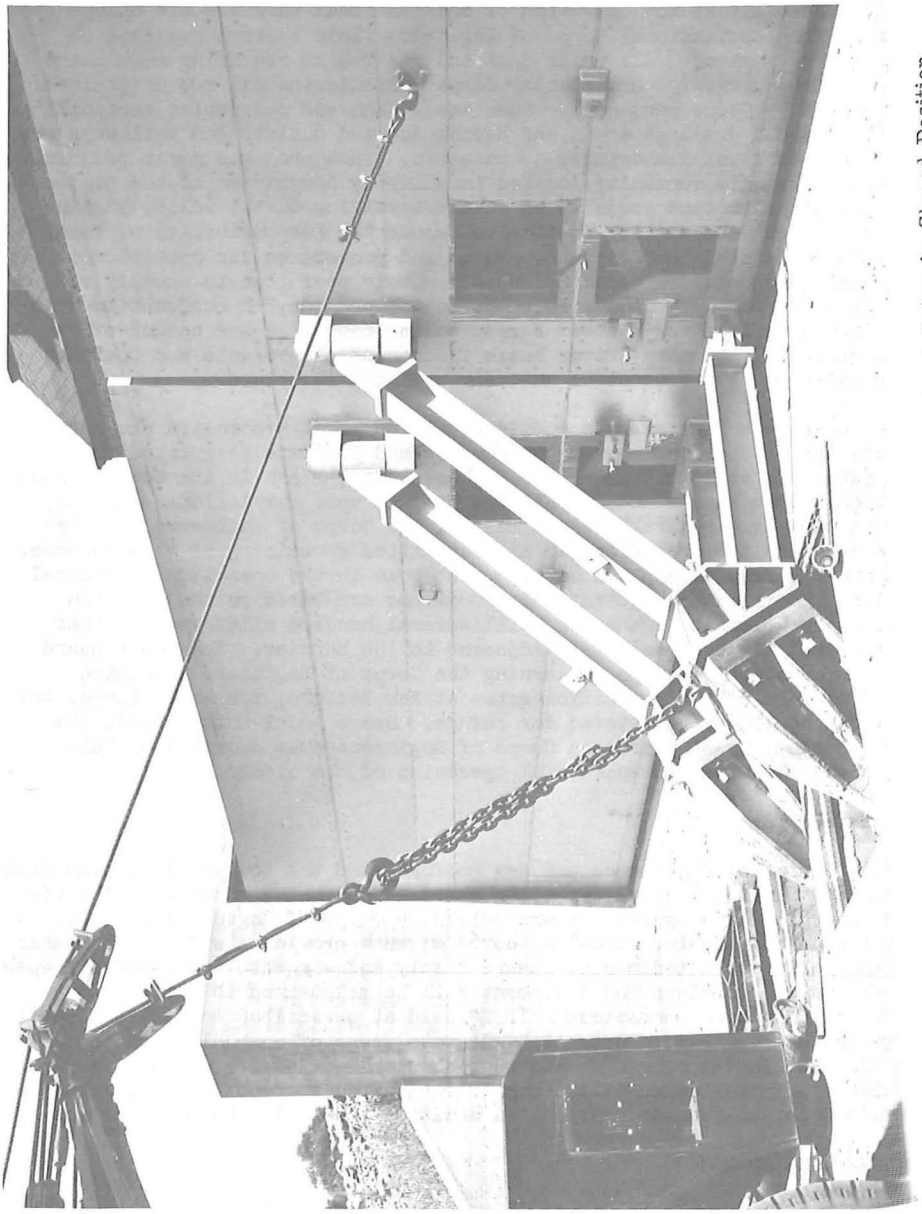

Figure 10. Providence, R. I. - Fox Point Hurricane Barrier - Street Gates in Closed Position

RESPONSIBILITIES AND COORDINATION

Responsibilities for operation of coastal tidal barriers are unique and different from conventional Corps of Engineers flood control projects on rivers in New England. All major dams and reservoirs requiring regulation during a flood normally remain under Corps jurisdiction and are maintained and operated by Corps personnel. Some small dams and reservoirs controlling relatively small drainage areas and having ungated outlets and spillways are turned over to local authorities to maintain. Such projects serve primarily to protect a single community located immediately downstream of the project site. Local protection projects on rivers involving dikes, walls, pumping stations, street and utility gates also become the responsibility of local interests to maintain and operate. Rules and procedures for operation of river basin projects are straightforward. Their operation is usually related directly to river stages adjacent to the project, in conjunction with river forecasts from the Weather Bureau to indicate time and height of expected crest. In summary, river basin flood control projects are operated either entirely by the Corps or entirely by local interests.

As hurricane barriers are considered to be local protection projects, Congressional authorization for the New England projects stipulated that local interests would provide lands and easements, share in the cost of construction, and maintain and operate the project upon completion. However, as navigation is a Federal responsibility, the Corps of Engineers will retain and direct the operations of all facilities pertaining to this purpose. The Weather Bureau also plays an important role in the operation of coastal projects. Mobilization and initial operations are based on the location and forecast movement of a storm still several hundred miles away, rather than on ocean stages immediately adjacent to the barrier. The Coast Guard radios information to ships concerning the Corps of Engineers predicted time of closure of the navigation gates at New Bedford, for when closed, the harbor can no longer be entered for refuge. Hence local authorities, the Weather Bureau, Coast Guard and Corps of Engineers must coordinate their activities to insure the successful operation of the tidal projects.

LOCAL INTERESTS

The cities of Providence and New Bedford, and the town of Fairhaven will operate and maintain their respective barriers and appurtenances in accordance with rules and regulations prescribed by Corps of Engineers operation and maintenance manuals. Local authorities must provide a sufficient number of technically qualified men to assure timely and adequate action on all operational items. Barriers and equipment will be maintained in satisfactory condition. Practice operations will be held at prescribed schedules. Local interests are required to establish adequate means of communication to receive Weather Bureau hurricane and coastal storm advisories promptly and dependably. Installation of equipment is required to receive the Weather Bureau's teletype weather service, in addition to public radio advisories.

U. S. WEATHER BUREAU

The Weather Bureau's role in the operation of the barriers is basically the continuing responsibility to forecast and keep the public informed on the progress and movement of hurricanes and coastal storms. In general, operational requirements of hurricane projects do not necessitate any

significant modification in the Bureau's past functions or responsibilities. Mobilization, closure of gates and activation of pumps by local interests normally will be related to specific terminology in the forecasts, such as "watch" and "warning."

The Weather Bureau has no specific responsibility or obligation to advise local interests or the Corps when or how to operate hurricane projects. The Bureau is not expected to provide personal forecasts or advisories to local interests in order to satisfy the particular operational requirements of specific projects. However, Bureau forecasters, in close liaison with the Corps, will divulge storm and tide conditions that might develop even though such conditions would not be noted in public forecasts. As hurricane movements are often erratic and unpredictable, it is essential that all projects be operated for the most adverse circumstances that might occur rather than the most probable. Although the issuing of "pessimistic" forecasts may result in some unnecessary operations, this is preferable to being caught unprepared.

CORPS OF ENGINEERS

The prime function of the Corps in hurricane projects is the operation of the navigation features. Corps responsibility in the two projects under discussion is limited principally to the two sector gates in the New Bedford-Fairhaven navigation opening. The Corps will also be responsible for operation of a navigation gate in the barrier now under construction at Stamford, Connecticut.

The Reservoir Regulation Section, serving a dual capacity as the Hydrology and Hydraulics Section in the Engineering Division, New England Division Corps of Engineers will issue instructions to field personnel for closure and opening of the navigation gates. The Reservoir Regulation Section will also maintain close liaison with the Weather Bureau for their latest advisories, and will furnish predicted time of gate closures to the Coast Guard. It is proposed to have engineers from the Corps monitor operations by local interests for several hurricanes to learn whether design criteria and regulation procedures are adequate.

As the Corps is responsible for the operation of the navigation gates, it is a departmental policy that the Corps should not be entirely dependent on information from other agencies to fulfill its own obligations. It is presently proposed to develop a hydrologic radio network off the southern New England coast from which data concerning tidal surge, wave height and barometric pressures may be received. "Read-out" from this coastal network will be received at the Corps office at Cape Cod Canal, which is open 24 hours a day, and at the New England Division headquarters in Waltham. It is anticipated the Weather Bureau may also have facilities to receive this hydrologic information for use in their own forecasts. The receipt of coastal data will not supercede the need for Bureau advisories on the position of storms as they move northward along the Atlantic coast, but will supplement Bureau data and provide a reliable one- or two-hour advance notice of the approaching tidal surge. The coastal network may also be of great value in spotting abnormal tidal conditions from unpredicted coastal storms developing just south of New England.

The Corps will furnish local interests all pertinent information

received from the coastal hydrologic network, or from any other source, that would affect their mobilization, preparedness or actual operation.

U. S. COAST GUARD

The Coast Guard will broadcast, by ship-to-shore radio, all advisories received from the Corps relative to predicted time of closing the navigation gates at the New Bedford-Fairhaven barrier. With completion of the barrier the harbor becomes a refuge in time of storm, and it is expected that more boats than ever will head for New Bedford-Fairhaven Harbor whenever hurricanes threaten New England. It is essential that mariners receive advance warning concerning the time the harbor gates may be closed. As the storm center moves north of Cape Hatteras, the day and approximate hour of closure will be estimated by the Corps, based on predicted positions by the Weather Bureau and knowledge of the astronomical tide cycles. Various bulletin scripts have been prepared describing predicted time of closure, notices of closure and opening, and termination of alerts should a hurricane miss New England. The Corps will select the appropriate bulletin for broadcast. The Coast Guard will broadcast the estimated time of closure at frequent intervals to all shipping interests.

OPERATIONAL CONSIDERATIONS

There are numerous items that must be carefully considered and weighed in prescribing operational procedures in a Manual of Operation and Maintenance. The principal considerations at these two projects are: (1) the forecasting problem, (2) the time needed by various personnel of the Corps of Engineers, New Bedford, Fairhaven and Providence to be mobilized and to operate gates, (3) the effect of closing the navigation gates on shipping at New Bedford, (4) the power required to operate the pumps at Fox Point and (5) the operation of the cooling water sluice gates at Fox Point.

FORECASTING

With the use of radar, reconnaissance planes and weather satellites, the Weather Bureau has continued to improve its techniques for locating and tracking hurricanes. However, the hurricane "girls" are capricious and temperamental. Their movement in terms of direction and speed are often uncertain, as those who followed Betsy's course this year will testify.

Besides determination of the size of the storms, wind velocities and barometric pressure, the two most important items affecting operations are the speed of the storm as it moves northerly towards New England, and the track of the storm center as it crosses land or veers eastward off Cape Cod and Nantucket. The speed of the storm, which often accelerates as it moves into the northern latitudes, affects the time permitted for mobilization, closure of gates and general preparation for the "big blow." The location of the storm track in passing a coastal community (for example, New Bedford) influences the magnitude of the surge. As all hurricanes and other low pressure systems in the Northern Hemisphere rotate in a counterclockwise direction, the winds will be highest, and southerly, if the projected area is eastward of the storm center. On the east side of the storm center, the components of the forward speed of the storm, the high circulating hurricane winds, and the tidal surge due to a low barometric pressure are additive. Such conditions may cause abnormally high tides and waves that are

often intensified at the heads of coves and bays. On the west side of the storm center, however, the counterclockwise rotation of the storm produces northerly winds which are generally offshore and in opposition to the storm movement. The resultant wind velocities are subtractive and usually smaller than those experienced on the east side where the components are additive. Offshore winds also tend to oppose the configuration effect of tidal surges within coastal coves and bays.

It is not yet possible to determine whether the track of a hurricane, still several hundred miles away, may hit or miss New England, or pass to the west or east of a project. Thus it is necessary, in operating a hurricane project, to assume that every hurricane threatening the north Atlantic will pass close enough to require mobilization of personnel and closure of gates. It is anticipated that over 50 percent of the storms, for which protective operations are fully completed, will veer away from one or both of the project localities and produce no appreciable tidal surge. Public reaction and apathy to these "false alarms" may become a problem.

MOBILIZATION

Construction of both projects has not been completed at the time of preparing this paper, so that actual time required to mobilize personnel and to prepare either project for a tidal surge is not known. Drilling of teams and periodic rehearsals are scheduled to assure that personnel will be familiar with their assigned duties and that equipment, gates and pumps are all functional. To provide sufficient time to overcome unforeseeable personnel or mechanical difficulties and allow for possible acceleration of the storm movement, it is presently proposed to initiate mobilization and closure of street gates when the Weather Bureau declares a "Watch." This will provide 12 hours or more for most hurricanes in advance of the predicted start of the tidal surge. The advance time for fast moving storms like September 1938 will approximate 7 hours. It may be possible to reduce this preparatory time in the future with more operating experience and scientific knowledge of hurricanes, but under present conditions, it is considered prudent to provide ample time for the operations and contingencies.

NAVIGATION GATES

Closing a navigation channel at the mouth of a harbor in anticipation of a tidal surge poses a problem. New Bedford-Fairhaven Harbor, covering 1,100 acres of water area, will be used temporarily for storing the flow from the Acushnet River and the local urban runoff. The total inflow could be considerable should the rainfall be heavy during a storm. To provide adequate storage for this flood runoff below damaging stages (elevation plus 6 msl) the navigation and sluice gates in the barrier will be closed when the incoming astronomical tide, antecedent to the expected arrival of the hurricane tidal surge, rises to elevation plus 2.0 msl. It takes approximately 15 minutes to either close or open the gates.

As the storm moves north along the Atlantic coast, the Coast Guard periodically will broadcast via radio to shipping interests, Corps bulletins on the estimated day and time of the gate closures. Mariners must heed the closing time if they wish to find shelter in the harbor, for once the large sector gates have been closed they will not be opened for mariners until the storm has passed and the tide has receded. The project is constructed

principally for the protection of the city of New Bedford and the towns of Fairhaven and Acushnet. Their safety cannot be jeopardized by opening the gates for late arrivals seeking refuge.

It is also anticipated that the existing Coast Guard cutters based at New Bedford would put to sea before the channel is closed so they may respond to distress calls during a storm.

POWER REQUIREMENTS AT FOX POINT PUMPING STATION

The power requirements at the pumping station (18,000 KW for the 5 pumps) are so large that the Narragansett Electric Company requires advance notice on the estimated number of pumps expected to be used. This permits the Company to plan their load distribution and if necessary to procure additional power from other producers in the New England power network.

The approximate number of pumps required is related to the flow in the Providence River. An estimate of the flow will be based on the discharge at an index gaging station on the Moshassuck River, located just upstream of tidewater and near the confluence with the Wonasquatucket River. An automatic telephone transmitter in the gaging station will permit frequent review of river stages and discharge data during the initial phases of a storm. This information will be used for making a quick estimate or revision of the number of pumps required and the corresponding powerload.

COOLING WATER CANAL GATES

Cool water from the bay side of the barrier flows into the canal through two gated passageways located in pumping station. Normally these gates are open and the passageways (with a total cross sectional area of 300 square feet) produce a negligible head loss between the bay and the canal.

When the barrier tainter gates are closed and the pumping station operated during a storm, the greater head differential between the bay and the canal makes it necessary to partially close the sluice gates to restrict the inflow to the amount required for cooling purposes. This will result in frequent gate changes as the bay rises rapidly during a tidal surge and the river stage fluctuates with the inflow and pumping. Discharge rating curves have been prepared to indicate the gate opening required to provide the desired cooling water flow for various head differentials between the bay and the canal.

The canal panel wall, consisting of steel H-piles and timber stop logs, is designed for a head differential of 2 feet between the canal and the river in either direction. To prevent excessive heads from developing, either by closure of the canal sluice gates or by too much inflow from the bay during a storm, 8 large flap gates, each 6 x 12 feet, are provided in the wall. Four of these gates open when a head differential exceeds 1 foot in either direction. Although it will be difficult to set the canal sluice gates to obtain a precise discharge, the automatic opening of the flap gates in the canal wall will compensate for either excessive or insufficient flow through the sluice gates.

All cooling water entering the canal during an operational period is

added to the interior runoff and has to be pumped back into the bay. The canal sluice gates will be closed to stop the canal inflow from the bay whenever 3 or more pumps are needed to evacuate the riverflow. During these periods when the sluice gates are closed, water for cooling purposes will enter the canal through the flap gates. The need for 3 pumps signifies a high rate of fresh water inflow which should provide an adequate source of water for cooling purposes during an operational period.

OPERATIONAL PHASES

Mobilization of personnel and operational functions as prescribed in the Manual of Operation and Maintenance are related to the position and movement of the hurricane. The operational functions have been divided into "phases" to assure clear delineation of responsibilities and actions to be taken as a storm approaches and strikes New England. These phases, as illustrated on figures 11, 13 and 16 are outlined as follows:

Phase	Designation	Approximate Position of Hurricane
1	Alert(1)	North of latitude 30° West of longitude 65°
2	Watch(2)	Latitude 35°, Cape Hatteras, Va.
3	Warning(2)	Latitude 38°, Cape May, N. J.
4	Surge(1)	Latitude 40°
5	Cessation(1)	Tidal surge has receded

(1) Corps of Engineers terminology
(2) U. S. Weather Bureau terminology used in hurricane advisories

The hurricane positions selected to delineate the various operational phases are based primarily on the 1938 and 1954 hurricanes which moved very rapidly up the Atlantic coast into New England (see figure 11). Other hurricanes, similar to Betsy in early September of this year, may move very slowly, stall several times, then reverse direction and no longer be a threat to New England. It is expedient, however, to be prepared prematurely rather than be caught unexpectedly with a fast moving storm.

Figure 12 shows the result of a study to determine whether there is correlation between the forward velocity of a hurricane as it moves across different latitudes, and the time in hours before tidal surges are experienced on the New England coast. The wide range in plotting positions for hurricanes of record illustrates the capricious characteristics of hurricanes, and the difficulty in forecasting. The minimum times indicated in the plotted data should be considered in preparation for an operation.

Hurricane positions will be carefully noted during future storms to evaluate the validity of existing operational procedures. Hindsight analyses may indicate desirable and necessary modifications in the present provisional regulations.

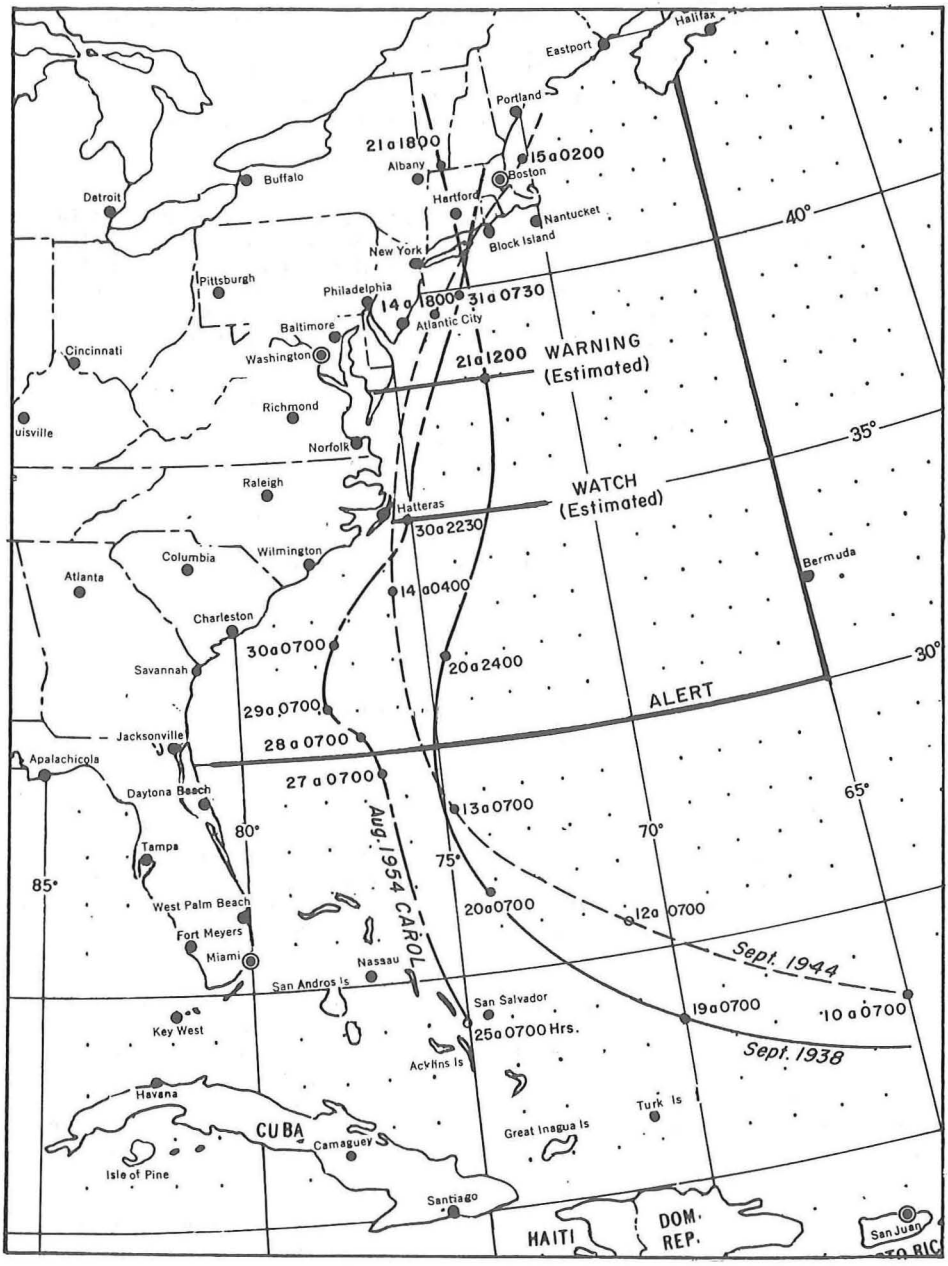

Figure 11. Tracks of Three Major Hurricanes and Areas of Operational Phases

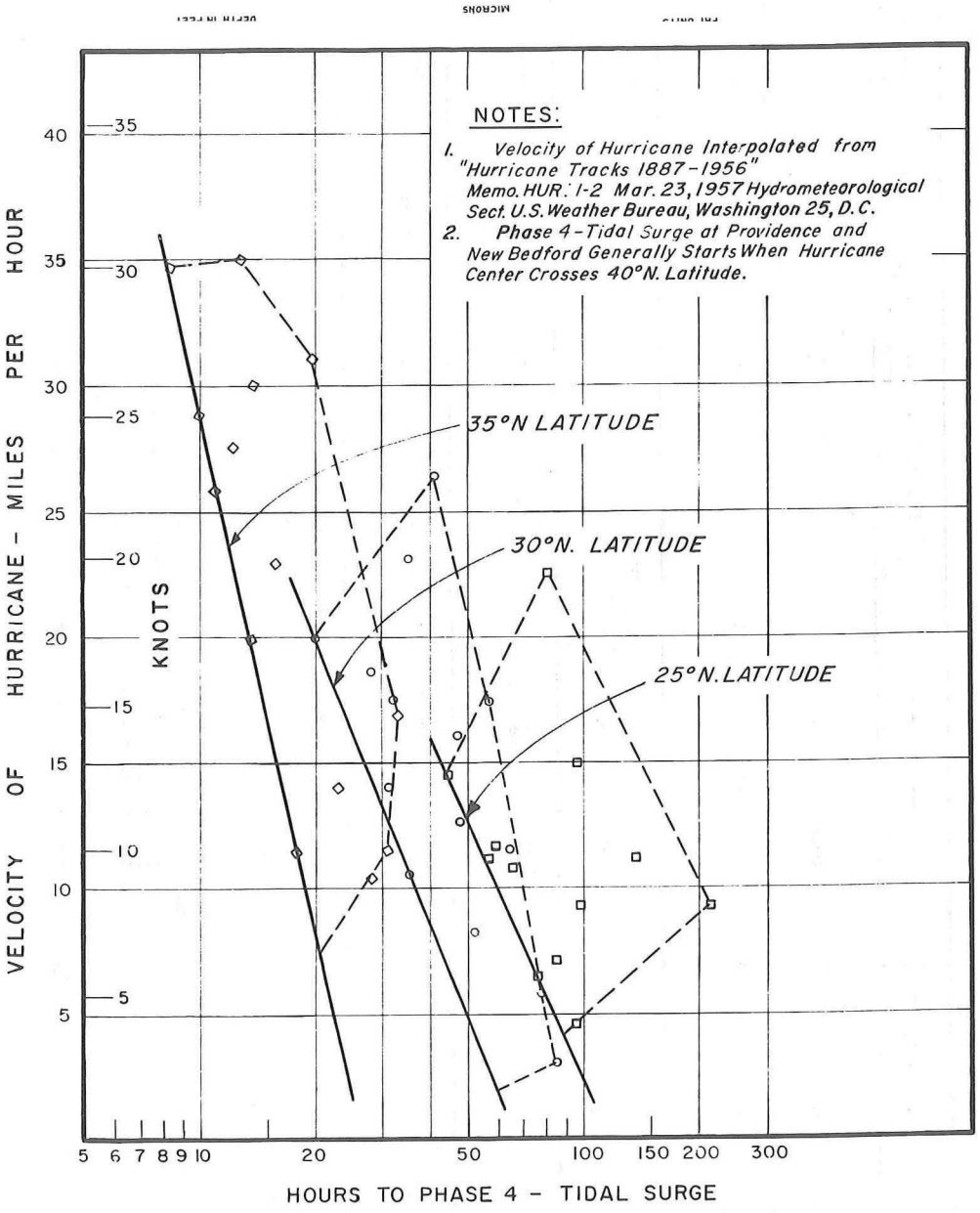

Figure 12. Operational Guide Curves

Phase	Condition	Corps of Engineers		City of New Bedford						Fairhaven
		Navigation Gates	Barrier Sluice Gates	Personnel	Street Gates	Sea Water Intakes	Sewer Gates	Pumping Station Gates	Pumping Station Pumps	Sluice Gate
	Normal	Open	Open	Inactive	Open	Open	Open Nos. 6,7,8 Closed No. 9	Outfall - Open Sump - Closed Pond - Closed	Idle	Open
1	ALERT Hurricane Crosses 30° Lat.	Open Advise USCG	Open	All Alerted	Open	Open	Normal	Normal	Idle	Open
2	WATCH Approx. Lat. 35°	Open Advise USCG	Open	Staff Pumping Station Mobilize Work Crew	Close: Rod.Fr.West Rod.Fr.East	Close Nos. 1,2,3,4,5	Normal	Normal	Test in Dry	Open (May Close in Daylight Hours)
3	WARNING Approx. Lat. 38°	Open Advise USCG	Close	Mobilized	Close Cove Road	Closed	Close Nos. 6,7,8 Open No. 9	Normal	Idle	Close
4	SURGE Tide - Plus 2.0' and Rising	Close Advise USCG,Cities	Closed	Mobilized	Closed	Closed	Closed Nos. 6,7,8 Open No. 9	Open Pond Close Outfall Open Sump	Operate By Schedule	Closed
5	CESSATION Tide Receding to Plus 2.0', Except As Noted	Open When Ocean Elevation Has Receded to Harbor Elevation	Open	Demobilize After Completion of Duties	Open	Open	Open Nos. 6,7,8 Close No. 9	Close Sump Open Outfall Close Pond	Stop By Schedule	Open

NOTES: All Elevations in Feet Above Mean Sea Level
See General Plan - Figure 2 , for Location of All Utility Gates
Gate Nos. 1,2,3,4,5 - Sea Water Intakes
Gate Nos. 6,7,8,9 - Sewer Gates

Figure 13. New Bedford-Fairhaven Hurricane Barrier. Standard Operating Procedure for Hurricanes

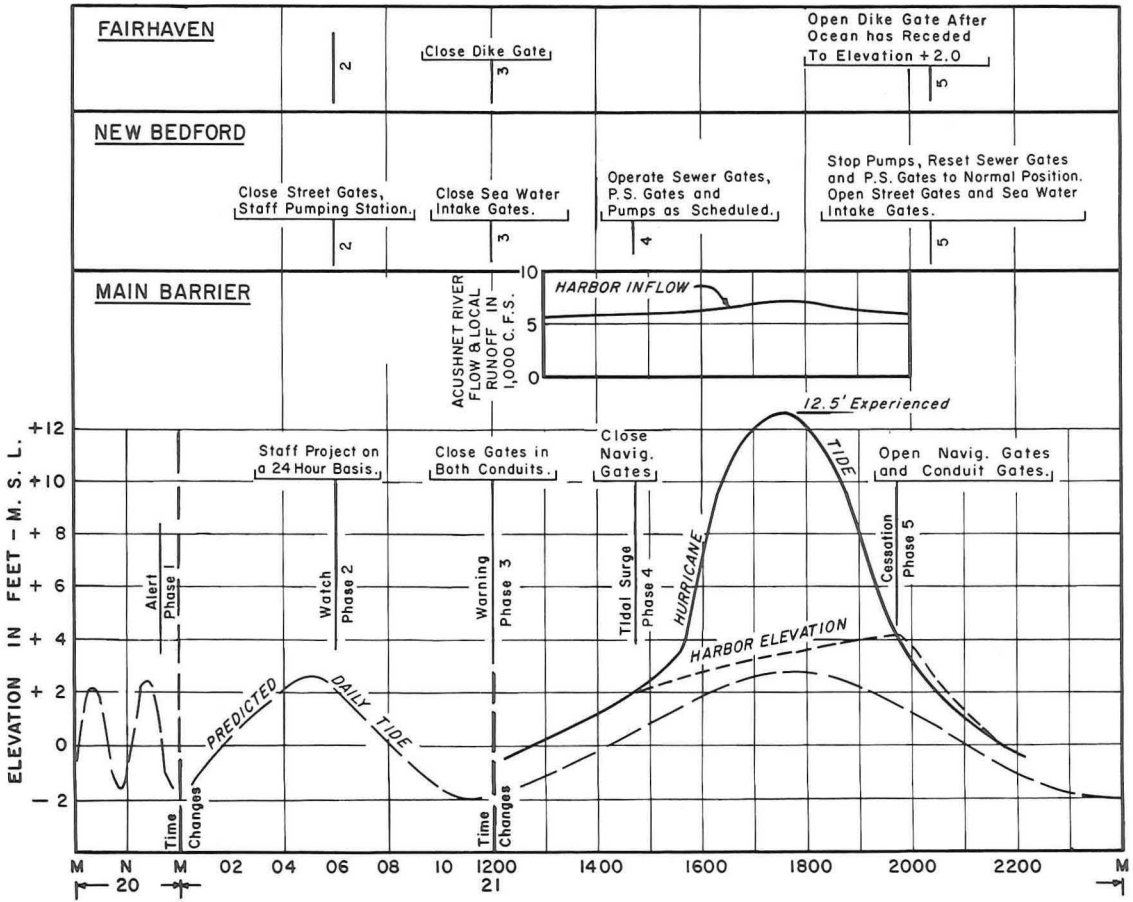

Figure 14. New Bedford-Fairhaven Barrier. Hurricane of September 1938

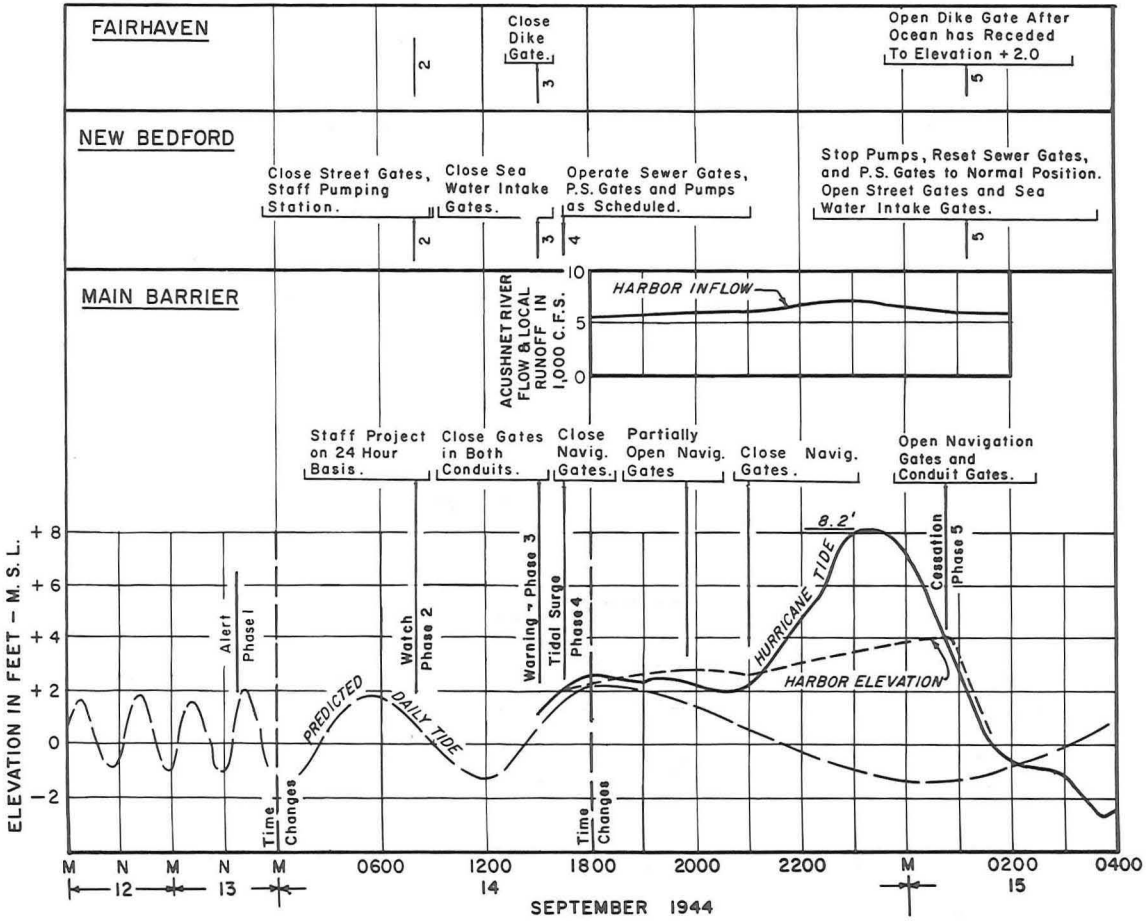

Figure 15. New Bedford-Fairhaven Barrier. Hurricane of September 1944

Phase	Condition	Personnel	Street Gates	Sewer Gates	Tainter Gates	Pumping Station	
						Pumps	Gates*
	Normal	Inactive	Open	Open Position South Water Street 78" Allens Avenue Two 5'x6' Allens Ave. Closed Position S. Water St. Relief Ship Street Relief	Open	Idle	Open
1	ALERT Hurricane Crosses 30° Lat.	All Alerted	Open	Normal	Open	Idle	Open
2	WATCH Approx. Lat. 35°	Staff Pumping Station Mobilize Work Crew	Close: So. Main St. Narragansett Elec. Co.	Normal	Open	Idle Advise Power Company per Schedule A	Open
3	WARNING Approx. Lat. 38°	Mobilized	Close: Allens Ave.	Close: 78" Allens Avenue Two 5'x6' Allens Ave. South Water Street Open: Ship Street Relief S. Water St. Relief	See Schedule B	Idle Advise Power Company per Schedule A	Close Each to 10-Foot Gate Openings
4	SURGE Rising Tide Antecedent to Expected Hurricane Tide	Mobilized	Closed	Closed Position 78" Allens Avenue Two 5'x6' Allens Ave. South Water Street Open Position Ship Street Relief S. Water St. Relief	Close per Schedule C	Operate per Schedule D	Operate per Schedule E
5	CESSATION Tide Has Receded to Plus 3.0 or to Elevation of River	Demobilize After Completion of Duties	Open	Return to Normal	Open	Stop 1 Pump Every 5 Minutes After Tainter Gates Have Started to Open	Open

Schedules

A

Moshassuck River Flow (cfs)	Probable Number of Pumps Required
to 800	1
800 to 1500	2
1500 to 2500	3
2500 to 3500	4
More than 3500	5

B

Moshassuck River Flow (cfs)	Gate Openings in Feet		
	#1	#2	#3
Less than 1500	0	12	0
1500 to 3500	12	12	0
More than 3500	12	12	12

C

Moshassuck River Flow (cfs)	Bay Elevation (feet msl)
Less than 200	+3
200 to 500	+2
More than 500	+1

D

River Elevation Limits (msl)		Number of Pumps
Start	Stop	
0.0	-3.0	1
+0.5	-2.5	2
+1.0	-2.0	3
+1.5	-1.5	4
+2.0	-1.0	5

E

Bay vs. Canal Head Differential in Feet	Gate Opening in Feet (Each Gate)
2	6
3	5
4	4
8	3
11	2.5
16	2

NOTES: *Sluice Gates to Cooling Water Canal
Elevations in Feet Above Mean Sea Level
See General Plan - Figure 5, for Location of All Gates

Figure 16. Providence - Fox Point Hurricane Barrier. Standard Operating Procedure for Hurricanes

STANDARD OPERATING PROCEDURES

Specific duties of the various governmental and municipal groups are described in standard operating procedures (SOP's). These procedures are described in detail in the text of the Manual of Operations and Maintenance and are summarized for ready reference, as shown on figures 13 and 16.

The basic duties to be performed in the various phases are as follows:

ALERT - All personnel concerned with projects alerted. Shipping advised that navigation gates may be closed.

WATCH - Pumping stations and gate control houses staffed. Equipment tested. Labor crews mobilized to close street gates on less heavily traveled highways. Advisories to shipping includes predicted closure time of New Bedford navigation gates.

WARNING - Full mobilization. Remaining street gates closed. Utility gates operated. Advisories to shipping continued. Tainter gates partially closed at Providence.

SURGE - Navigation closed at New Bedford. Shipping advised of gate closure. Tainter gates closed at Providence. Pumping stations started at both New Bedford and Providence.

CESSATION - Navigation gates opened. Shipping advised. Pumps stopped. Tainter gates opened. Utility gates operated. Personnel demobilized.

EXAMPLES OF OPERATIONS

Figures 14, 15, 17 and 18 illustrate examples of operation at the New Bedford-Fairhaven and Fox Point (Providence) projects in the event of a recurrence of the September 1938 and September 1944 hurricanes. The tidal surge in September 1938 coincided with the astronomical high tide and produced the highest stages of modern record. The tidal surge in September 1944 was even higher than 1938, but occurred during the astronomical low tide with resulting stages somewhat lower than 1938. The more recent August 1954 hurricane (Carol) has not been used to demonstrate an operation, as it was comparable to the September 1938 event.

Rainfall experienced during these two storms was relatively light at Providence and New Bedford. Providence measured about 3 inches in each storm while New Bedford received about 2 inches. Some inland areas received up to 17 inches in 1938 and over 5 inches in 1954. To illustrate greater use of the pumping stations, a synthetic storm has been assumed to produce a higher rate of interior runoff than was experienced. The stages of the predicted astronomical tides and the surges are shown as experienced. Closing the various gates in the two projects follow the procedures enumerated in figures 13 and 16.

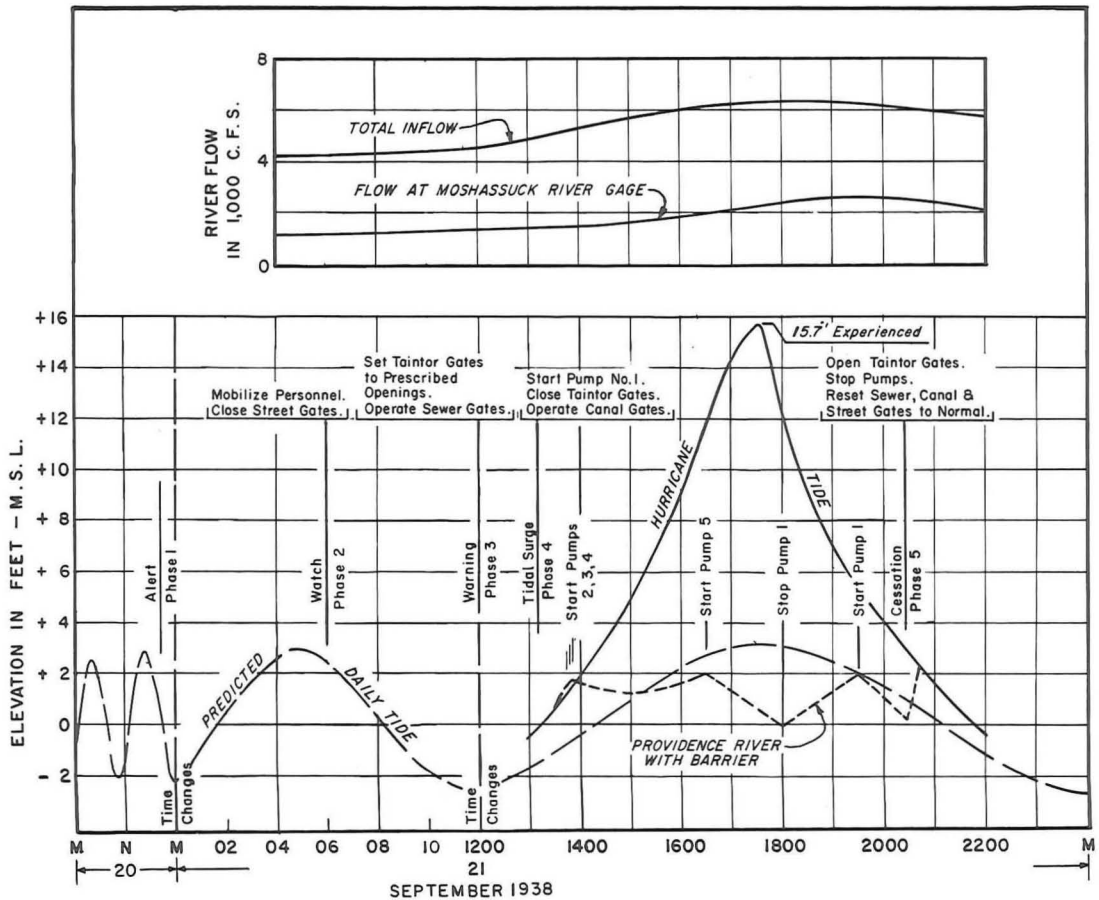

Figure 17. Providence - Fox Point Hurricane Barrier. Hurricane of September 1938

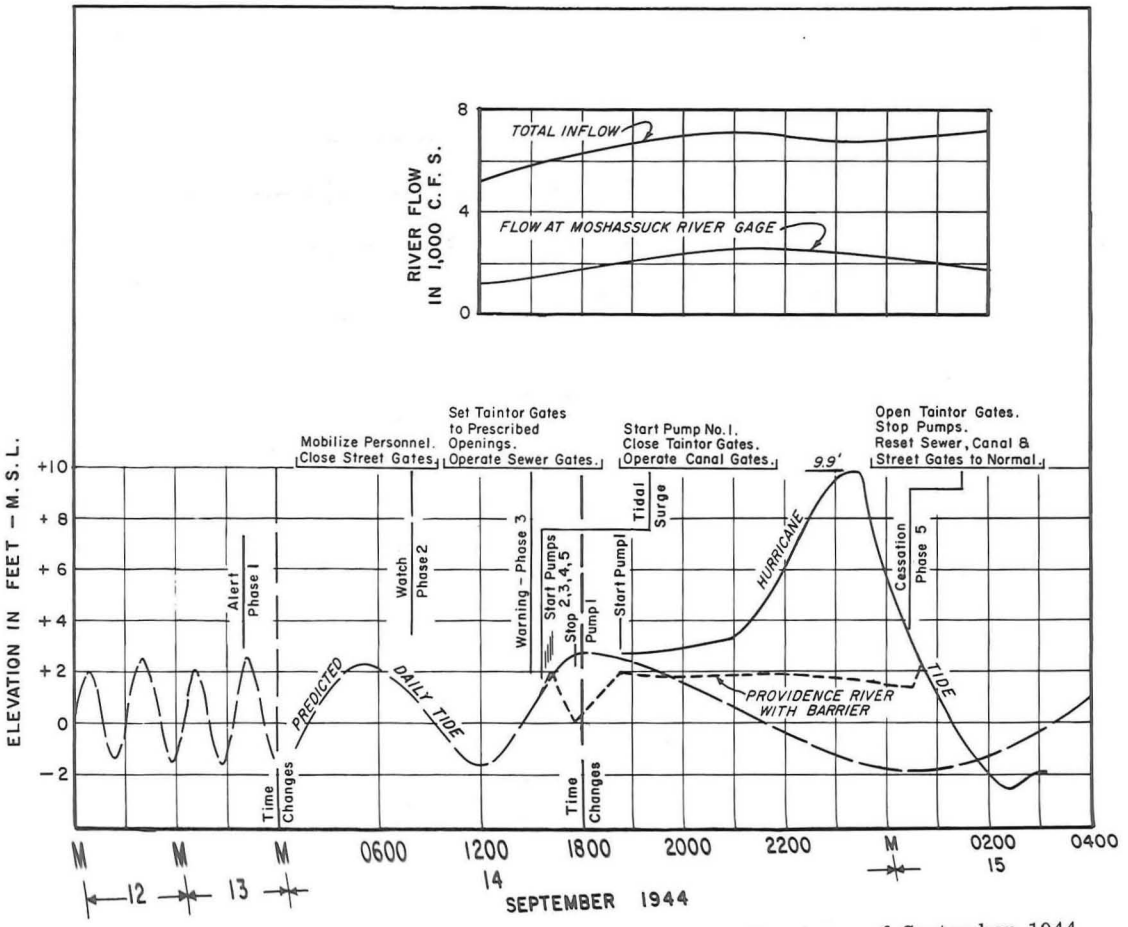

Figure 18. Providence - Fox Point Hurricane Barrier. Hurricane of September 1944

Time is an important factor in the regulation of the two projects. The elapsed time in hours for these two hurricanes are summarized as follows:

Phase	Designation	Elapsed Time in Hours Sept 1938	Sept 1944
1-2	Alert - Watch	10	16
2-3	Watch - Warning	6	7
3-4	Warning - Surge	1	1
4-5	Surge - Cessation	7	7

The 1938 and 1944 hurricanes were unusually fast moving. Although most other storms have moved much slower, it is essential in prescribing regulation procedures to plan for the shortest elapsed times.

OPERATION OF BARRIERS FOR COASTAL STORMS

The hurricane barriers at New Bedford-Fairhaven and at Providence will also be operated for coastal storms, not of hurricane intensity, that appear to be severe enough to produce abnormally high tides and exceed damage stages. Operations for coastal storms where tides may be 2 to 4 feet above normal will not require closure of street gates, but will require use of the other facilities.

Forecasting for coastal storms often presents a more difficult problem than for hurricanes. Some coastal storms originate in tropical areas similar to hurricanes and can be reasonably well tracked and predicted as they move northward. Sufficient warnings and preparation for these storms can be assured. Other disturbances, however, often develop over the ocean south of New England and strike the coastline without adequate warning. The need for mobilization and operation of gates could arise with only a few hours notice. It is possible that the navigation gates at New Bedford-Fairhaven may have to be closed with only 1 to 2 hours' notice to mariners. Duration of closure for the coastal storm tides would be relatively short and only for 1 or 2 hours before and after the predicted astronomical high tide.

The proposed coastal hydrologic radio network will be helpful in providing meteorological and tide data on the unpredicted storms developing just south of New England.

INSTRUMENTATION

Both projects are well instrumented to provide hydrologic data for operations and to maintain communications during hurricane conditions. The mechanical and electrical features are also well instrumented but these items are beyond the scope of this paper.

NEW BEDFORD-FAIRHAVEN BARRIER

Tide gages are installed at the navigation gate control house to record both the ocean and harbor water levels. Supplementary staff gages are located in the concrete abutments for calibration of the instruments and for

readings during fair weather. Meteorological instruments are provided to measure wind velocity and direction, barometric pressure and rainfall. The navigation gates and the barrier sluice gates are operated from a control panel located entirely within the shelter of the control house.

CLARK COVE PUMPING STATION

Gages are located within the pumping station to note the stages within the Cove, the temporary storage basin and the pumping station sump.

PROVIDENCE-FOX POINT BARRIER

Three water-level recorders are provided in the pumping station with level indicators mounted on the main control panel for ease in reading during an operation. These recorders and indicators show the levels of the bay, river, and the cooling water canal. Staff gages are located on the abutments to calibrate the instruments and for fair weather readings. Outside staff gages are of little value during darkness, waves, and stormy conditions.

Electrical controls for the tainter gates and cooling water canal sluice gates are located on the panelboard in the pumping station.

COASTAL HYDROLOGIC NETWORK

Development of a coastal hydrologic network is proposed in order to obtain more data on storm and tide conditions and to gain 1 or 2 hours' advance warning. The tentative station locations are shown on figure 1. A similar radio network is presently being installed in many inland river gages to improve communications for reservoir regulation. Installation of the coastal network will be initiated as soon as the river system has been completed and thoroughly tested.

COMMUNICATIONS

Radio facilities are available at the navigation gate control house at New Bedford for contact with the Division headquarters in Waltham, the Corps office at Cape Cod Canal, and for ship-to-shore radio contact with ships and boats. Walkie-talkie radio is also provided for communications between Corps personnel at the navigation gate control tower and City personnel operating the pumping station at Clark Cove. City of New Bedford public work vehicles are also radio equipped. Telephones will be installed in the control house and pumping station, but they cannot be depended upon during a hurricane.

As the city of Providence is responsible for the operation of the Fox Point project, the Public Works Department is planning to install equipment for direct receipt of weather forecasts via the Massachusetts Teletype Weather Service. Telephones are installed in the pumping station for contacts between city officials and the Narragansett Electric Company. City vehicles are equipped with radios which will be helpful during emergency conditions.

SUMMARY

This paper was prepared as the New Bedford-Fairhaven and the Fox Point

(Providence) projects were nearing completion. They have not yet experienced a hurricane, although full preparations were made for emergency use for hurricane "Betsy" which first appeared to head for the northern latitudes, then stalled, changed directions, struck southern Florida and Louisiana, and eventually deteriorated over land. Betsy was an excellent example of the difficulties in predicting the movements of hurricanes. Such course changes pose the most serious problem in formulating procedures for operating hurricane barriers. It must be understood and tolerated by all concerned that many alerts and initial preparations for an operation may prove unnecessary as the hurricane may change course and not affect New England. It is expedient, however, in providing reliable protection for the coastal communities to formulate plans for the fast-moving, destructive hurricanes that have been experienced in the past.

Successful and dependable operation of the many facilities at hurricane barriers requires the close coordination and cooperation of personnel of the municipalities, Corps of Engineers, Weather Bureau and the Coast Guard.

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