STORM SURGE OVER THE MISSISSIPPI RIVER DELTA ACCOMPANYING HURRICANE BETSY, 1965

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ABSTRACT

Selected tide water gage readings taken during hurricane Betsy, 1965, along the Mississippi River Delta and adjacent areas are graphically presented. The various processes involved in the change in tide water level associated with the passage of a hurricane are discussed. The data are divided into three main categories in order to show the storm surge response along the coast (Gulf Coast gages), on inland waterways (New Orleans area gages), and on an inland lake (Lake Pontchartrain gages). A discussion of surge elevation along the Mississippi River from the mouth upriver to New Orleans is also included.

The topography of the City of New Orleans is described and the extent and probable cause of the flooding in the City are discussed.

The storm surge elevations along the coast predicted by currently used methods are found to compare favorably with the actual readings during Betsy.

1. INTRODUCTION

The purpose of this report is to present a picture of the hurricane surge in Betsy, 1965, and an analysis of the resulting flood as disclosed by tide water gage recordings available over the affected area.

Severe hurricane Betsy struck the southeastern Louisiana coast [1] on the night of September 9. It was the most destructive, economically, ever to hit the United States. Winds reaching 125 m.p.h. or more caused extensive damage in the New Orleans metropolitan area, but the greatest loss of life and property was realized only after the strong winds had subsided. The flood [2], which inundated a large section of New Orleans, and most of the parishes in the Delta to the southeast of the City, was a direct result of the storm surge which moved across the low delta land with the hurricane.

2. BACKGROUND

At least five distinct processes, according to Harris [3], are involved in the change in tide water level associated with the passage of a hurricane. These are: pressure setup, wind effect, Coriolis effect, effect of waves, and rainfall effect. All five factors played some role in producing the tide water changes accompanying hurricane Betsy. The central pressure in Betsy at landfall was 28.00 in. at Grand Isle, La. (fig. 1). Since 1 in. of mercury is equivalent to about 13 in. in the water barometer, pressure setup was reasonably estimated at 2 ft. of water in the storm center. The strong east and southeast winds associated with Betsy over the Gulf of Mexico southeast of New Orleans drove water up into the marshes around Lake Borgne (figs. 1, 2, and 3) between the Mississippi River Delta and the Mississippi coast (wind effect). The high tides along the Mississippi coast were due in part to the Coriolis effect acting to turn shoreward the westward moving water just off the coast. The flooded marshes permitted waves to readily develop, thus further inhibiting the return of water to the Gulf. Betsy did not produce as much rainfall (3 to 7 in.) over the Lower Mississippi Valley as many hurricanes of the past. Nevertheless, some of the water rise over the affected area was attributable to rainfall runoff from the storm.

The storm surge associated with a hurricane begins to form while the storm is out at sea. The wave (or waves) then moves shoreward with a speed in shallow water equal to $(gD)^{1/2}$, where g is the acceleration due to gravity and D is the depth of the water. As the wave moves into shallow water near shore it is slowed because of decreasing depth, and its amplitude is increased by shoaling and by convergence of water near shore. The amplitude of the wave may then decrease as it moves inland by the spreading out of water over higher ground, or it may increase by convergence into an inlet or channel.

Both amplitude effects were evident in the gage readings from Betsy. One example of the amplitude effect was the increasing surge elevation in the Mississippi River to a point about 70 mi. upriver from the mouth (fig. 4). A decrease in amplitude occurred between the gage readings at Alluvial City (fig. 1, curve A), near the coastline, and the Paris Road Bridge gage (fig. 2, curve G) on the Mississippi River to Gulf Outlet.

3. NATURE OF DATA

The data used in this report include records of gage readings taken by the U.S. Army Corps of Engineers [5] during the hurricane period. Some of the records are incomplete because of storm damage. The available records, however, are sufficient to show a clear picture of the surge elevations accompanying the flood (fig. 6).

In an attempt to show individually the effects of the various storm surge producing processes reflected by the gage readings, the data were grouped into three main categories:

1) Gulf Coast gages (fig. 1), which include five coastal, or near coastal locations, and one river gage (Pointe-a-la-Hache), situated about 50 mi. from the mouth of the Mississippi River.

2) New Orleans area gages (fig. 2), which include five gages within the City.

3) Lake Pontchartrain gages (fig. 3), which include four gages surrounding the Lake and one on the causeway near the center of the Lake.

Maximum surge elevations along the Mississippi River (fig. 4) are included in a separate discussion and presentation of data.

4. GULF COAST GAGES

Probably the two most representative records of the coastal surge are curves A and E (fig. 1). Both are taken very near the Gulf Coast and show the effect of increased amplitude as the wave moved shoreward into decreasing water depths. Compare these with curve D, which is probably representative of the surge in the deeper Gulf. South Pass Bar (curve D) is not very far from deep water (see inset, fig. 1). An immediate increase in amplitude is evident as the wave moved to the Head of Passes gage (curve C).

Alluvial City (curve A) is about halfway between Biloxi (curve E) and the storm track, and shows a higher surge elevation than Biloxi. Most of the difference is due to direct wind effect. Note that gages A, E, and F lie in a nearly straight line abeam [1] of the storm at about 2300 CST, September 9. Curves A and E show the normal increase in tide prior to the storm, then reach peaks 2 to 3 hr. after the closest approach of the storm. This observation agrees with Jelesniański's [6] numerical calculation of storm tides. Pointe-a-la-Hache (curve F), however, reaches a maximum at or before closest approach of the storm. This effect was probably due to large quantities of water pouring over the east levee into the Mississippi River south of Pointe-a-la-Hache. The water was apparently driven from Breton Sound by the strong northeast and east winds prior to arrival of the storm center.

It is apparent that between 8 and 15 ft. of water swept across the area represented by these gages. Most of the Delta of southeastern Louisiana was inundated by at least 10 ft. of water above mean sea level. Almost every structure suffered severe wind damage, and all suffered water damage. Many fishing camps and homes were lifted by the flood waters and floated away. Many were totally demolished by the force of the wind and the water.

5. NEW ORLEANS AREA GAGES

The hurricane surge was approximately abeam of the storm with a direction of movement to the northwest, the same as that of the storm. The surge reached its crest just inland from Breton Sound along a northeast to southwest line about 25 mi. southeast of New Orleans. The low-lying marshes over which the storm surge traveled, and the existence of a wide, deep channel (the Mississippi River to Gulf Outlet), along the path of the surge, assisted in carrying the water far inland. The water borne by the Outlet and carried across the marshes was first recorded in New Orleans as a rapid increase in water level at the Paris Road Bridge gage on the Intracoastal Waterway (fig. 2, curve G). Shortly thereafter, the three gages on the River showed very rapid rises.

Curves I, J, and K are almost identical river records, showing surge peak just prior to closest approach of the storm. New Orleans was abeam of the storm at about midnight.

The high river levees in New Orleans easily contained the 10 ft. above normal low water in the River. The levees around the canals and waterways east of the River are not as high as the river levees and could not contain the water. On curve G, a decrease in the rate of water rise occurs at about 9 ft. m.s.l., just before 2200 CST. This represents overtopping of the levees surrounding the inland waterways. There were numerous levee breaks around the flooded area after overtopping occurred.

Curve H was recorded at the Seabrook Bridge on the Industrial Canal, very near Lake Pontchartrain, and shows little of the storm surge indicated on the other city records. Curve H is also included in the Lake Pontchartrain discussion, being more typical of the effect of the storm on the Lake.

6. LAKE PONTCHARTRAIN GAGES

By late afternoon on September 9, Lake Pontchartrain began showing the effects of hurricane Betsy (fig. 3). The closest approach of the storm center to the Lake was at about 0100 CST on September 10. Prior to that time, however, the strong northeast winds preceding the storm drove water toward the south and west shores and away from the opposite shores of the Lake. This apparent tilt of the lake surface is shown in the comparison of the gage readings at about 2200 CST on the 9th. The south shore gages (curves H and L) show an increase in water to near 6 ft. while the north shore reading (curve M) drops to about 1 ft. The gage near the center of the Lake (curve N) shows little change up to that time. A reading of 12.1 ft. (still water elevation at Frenier) on the west shore gives an

[1] Abeam of the storm here means a perpendicular to the storm track through the eye; also represents closest approach of the storm.

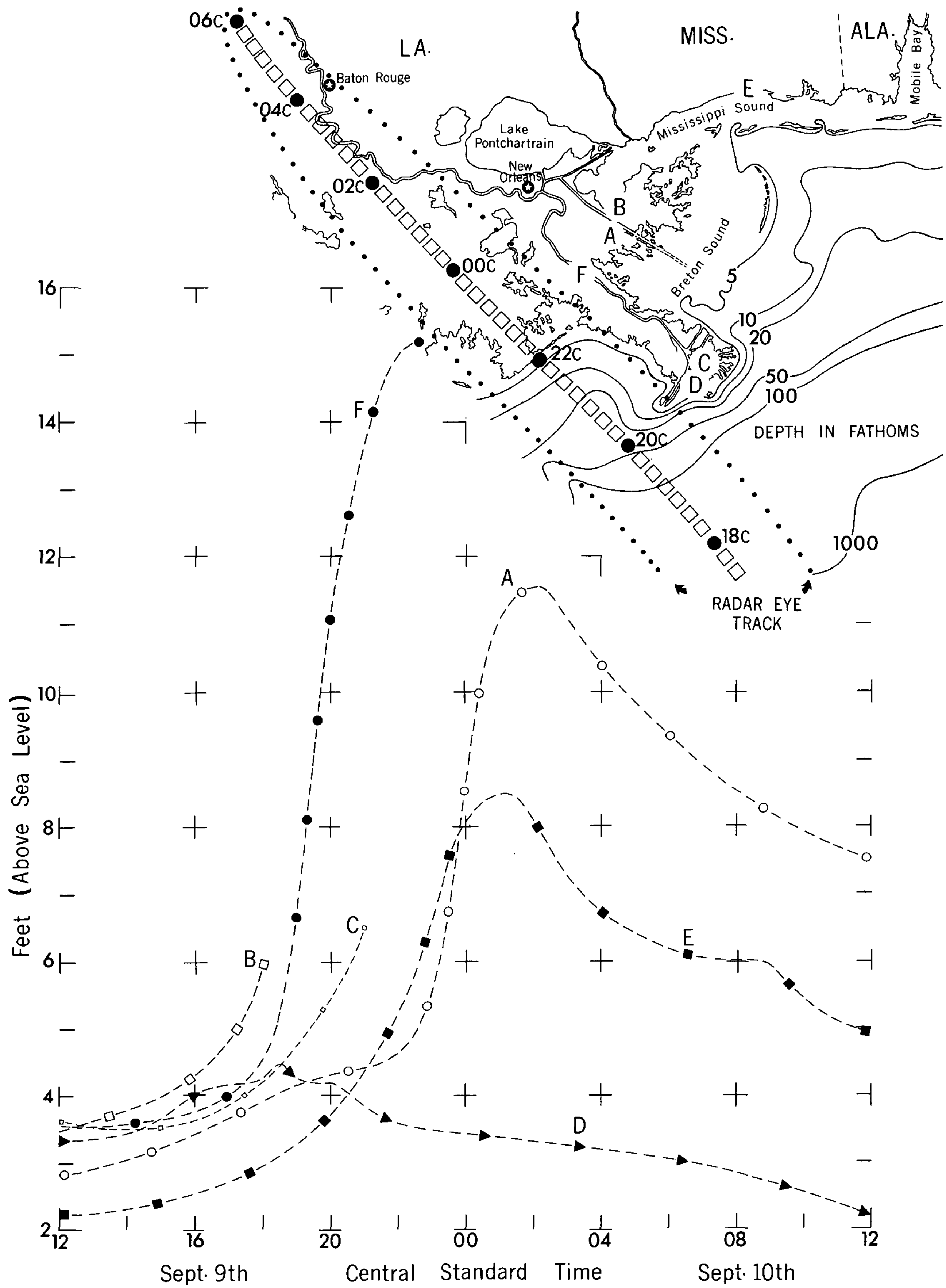

FIGURE 1.—Hurricane surge, Betsy, 1965, observed at gages along the Mississippi and southern Louisiana coasts. Location of gages, water depth (fathoms) of the Gulf of Mexico near the coast, and the radar eye track of the storm are shown.

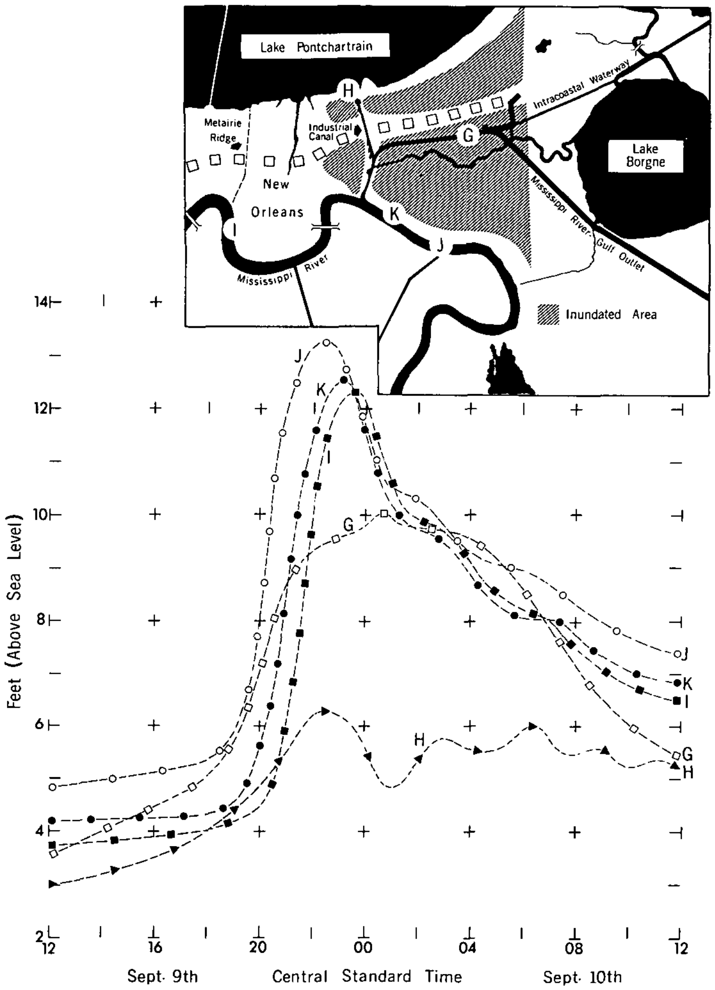

FIGURE 2.—Hurricane surge, Betsy, 1965, in New Orleans—observed on Mississippi River, Intracoastal Waterway, and Industrial Canal gages. Location of gages and the inundated sections (shaded area) of the City are shown.

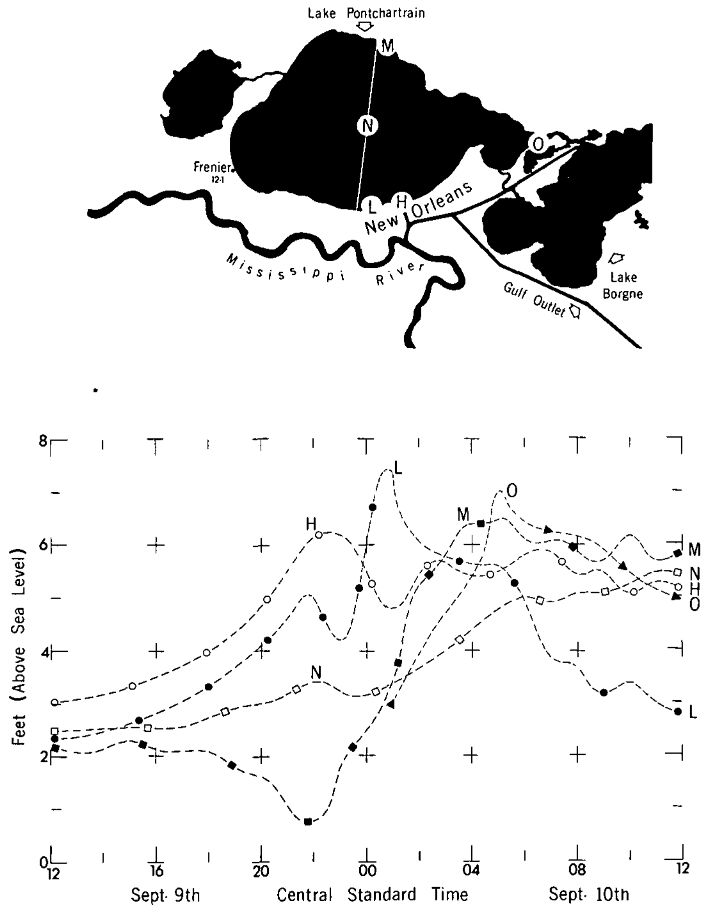

FIGURE 3.—Hurricane surge, Betsy, 1965, in Lake Pontchartrain. Location of gages are shown.

indication of at least a 10-ft. east to west tilt of the lake surface during the time of peak wind. This primary tilting of the Lake seems to have started an oscillation that looks remarkably like a damped sinusoidal curve at the Seabrook Bridge gage (curve H). There must have been an east to west, as well as a north to south component to the oscillation. Evidence to this effect is indicated in the out of phase relation between curves H and L, the two south shore gages. The natural low frequency resonance of Lake Pontchartrain was probably out of phase with the hurricane surge because there is little indication of the seiche phenomenon [2] in the lake records.

The gage readings show an increase in the average lake level after the closest approach of the storm. The additional water came from the coastal surge which flowed into the Lake through the Industrial Canal (curve H) and through the passes at the Rigolets (curve O) and Chef Menteur. The water level on the south shore of the Lake was about 6 ft. above sea level for several hours after midnight on the 9th. At the same time, the Gulf water at the Rigolets entrance to the Lake was near 10 ft. (averaging curves A and E), and the water in the Intracoastal Waterway was also near 10 ft. The Lake level dropped slowly during the first post-hurricane day as the surge water began to drain back into the Gulf. Few readings exceeded the 7-ft. level in the Lake and many remained below the 6-ft. level during the storm period. The greatest recorded acceleration in water level was at Mandeville (curve M) on the north shore where a 5½-ft. increase occurred between 2200 CST on the 9th and 0400 CST on the 10th.

7. MISSISSIPPI RIVER SURGE ELEVATIONS

The record of surge elevations along the Mississippi River below New Orleans (fig. 4) provides an excellent example of the manner in which a storm surge can build to a maximum. The first tide water gage on the Mississippi River is located at South Pass Bar, at the very end of the Pass in the Gulf of Mexico. Since the gage is very close to deep water, it effectively measures the Gulf tide at the mouth of the River. This gage would be expected to reflect the magnitude of the surge produced by the

[2] A standing wave oscillation of an inclosed water body that continues, pendulum fashion, after the cessation of the originating force.

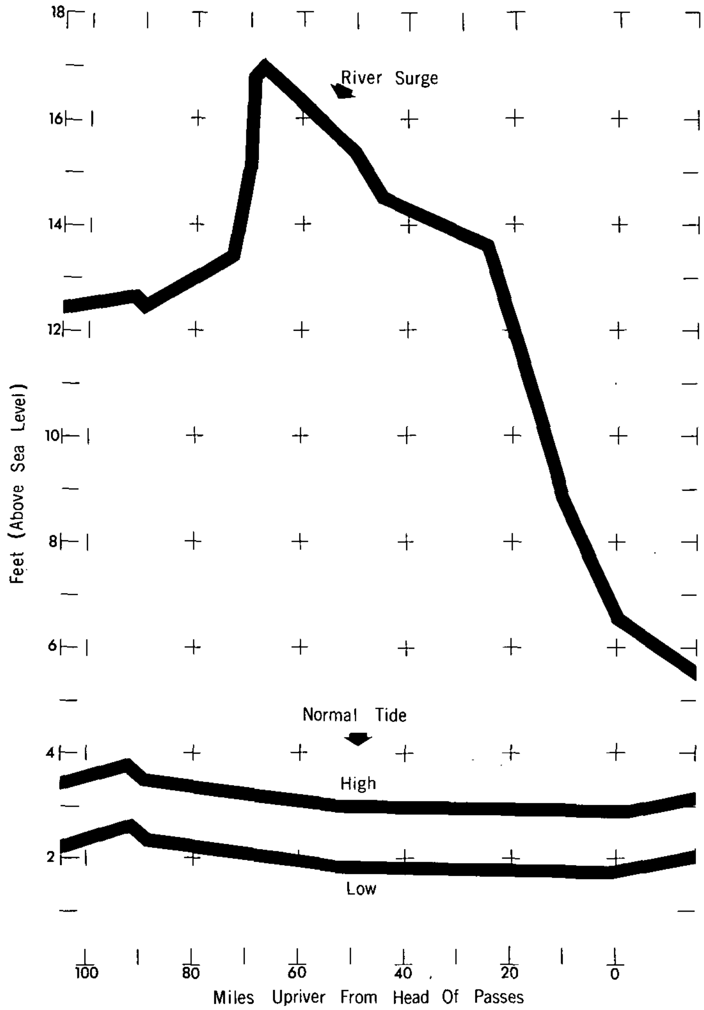

FIGURE 4.—Hurricane surge, Betsy, 1965, in the Mississippi River. Peak occurred about 70 mi. upriver from Head of Passes. Normal tides are shown.

storm in the deep Gulf waters. A few miles upstream, at the Head of Passes, the surge increased to 6 ft. or more above mean sea level. This is attributable to convergence of water to this point from the various passes to the south, and the fact that the water depth is less here than in the Gulf waters to the south (shoaling effect). Farther upstream, several high water marks attest to the increase in the surge maxima. Numerous reports were received concerning water flowing over the east levee into the River from Breton Sound. Along the east bank, south of Pointe-a-la-Hache, there is a section with only an alluvial levee formed by the River. The surge elevations continued to increase to a maximum of about 17 ft. at a point 70 mi. upriver from the mouth. Evidence of overtopping of the levees was found as far north as 54 mi. from Head of Passes. Maximum surge heights began to decrease to the north of the 17-ft. maximum, but still remained well above 12 ft. when the maximum reached New Orleans. This is an increase of about 10 ft. above normal low water level in the River at New Orleans. Because of the higher river levees near the City and the lessening of the maximum surge elevations, the water was contained in the river channel. The surge continued upstream and was felt as far north as 400 mi. from the mouth of the River.

8. THE NEW ORLEANS FLOOD

The topography of the City of New Orleans consists of several natural basins formed in the past by silt deposits from the Mississippi River. These basins are surrounded by alluvial ridges that rise to as much as 14 ft. above sea level in some places. One of the basins lies in the crescent of the River from which the City gets its slogan, "The Crescent City." Between Lake Pontchartrain to the north and the River to the south, a natural alluvial ridge, called the Metairie or Gentilly Ridge (fig. 2), runs from west to east and rises to 2 to 4 ft. above sea level. East of the Industrial Canal, between the Gentilly Ridge and the Lake, the ground elevation drops to more than 6 ft. below sea level. A similar basin lies between the Gentilly Ridge and the River. These two basins received most of the flooding from the storm.

The lower basin between the Ridge and the River is exposed to the marsh that runs into Lake Borgne to the east. There is a back protection levee surrounding the area, but it was easily overtopped by the 10- or 11-ft. surge. The water came into the City from the southeast over the marsh and up the Gulf Outlet. Overtopping occurred along the levees surrounding both the Industrial Canal and the Intracoastal Waterway. This overtopping is graphically shown on curve G (fig. 2) where the increase in water depth becomes less rapid at about 9 ft. around 2200 CST on the 9th. The overtopping caused numerous breaks in the levees surrounding the lower basin. The flood water extended to much of the low ground (below sea level) both west of the Industrial Canal and north of the Gentilly Ridge.

Gravity drainage is impossible in New Orleans because much of the City is below the level of the surrounding waters. A system of 286 mi. of drainage canals, with a total pumping capacity of 28,000 ft.^{3}/sec. drains the City of rain water. The system, the most powerful in the world, can handle 2 in. of rainfall during a 1-hr. period, and ½ in. each hour thereafter until 6 in. have fallen. Even such a system cannot cope with a storm surge that easily overtopped the levee system.

9. SURGE PREDICTION AND MODIFICATION

One method of predicting the storm surge (fig. 5), by Conner [7], gives a value of 11.5 at Alluvial City and 8.3 ft. m.s.l. at Biloxi. Actual readings were 11.72 and 8.56 ft. m.s.l., respectively. The maximum surge prediction, according to Conner, Kraft, and Harris [8], for a storm of Betsy's intensity is about 12 ft. The much higher value (about 17 ft.) of the maximum surge in the Mississippi River resulted from the funneling of great quantities of water into the river channel, and to additional water overtopping the east river levee as far upriver as Pointe-a-la-Hache.

Unusual terrain features of both land and sea bottom in the Mississippi River Delta region contributed to the modification of the storm surge. A refraction and focusing effect, suggested by Hubert and Clark [4] appears to have played a role in driving the maximum surge up through Breton Sound across the marsh between the Gulf Outlet and the Mississippi River. This effect is developed when variations in the sea depth cause various parts of the crest to travel at different speeds and to converge. An increase in surge height is experienced on a beach adjacent to convex bottom contours such as the areas off Breton Sound and around the River Delta.

10. AVENUES OF RESEARCH

It may be concluded from the data and resumé that the coastal surge, at least, was predictable. These prediction methods were developed for the hurricane surge on the immediate coast. It is evident that the extent of inland

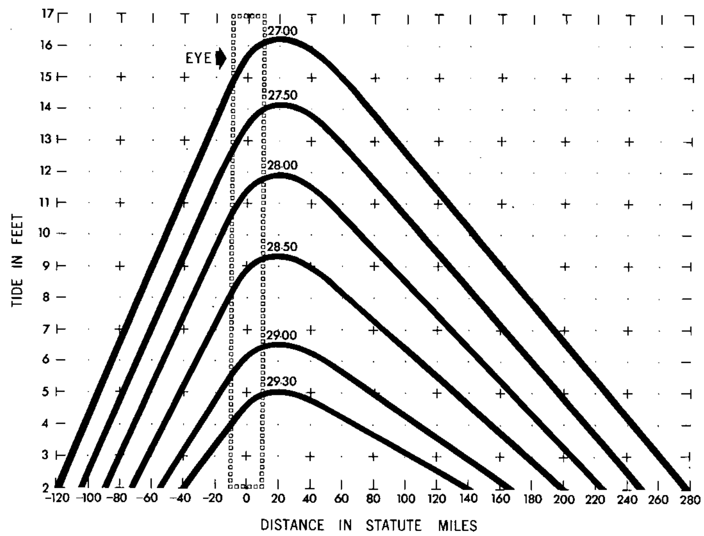

FIGURE 5.—Hurricane surge profile forecast chart for the Gulf of Mexico coast. Plus values for distance are to the right of point where center crosses the coastline; negative to left.

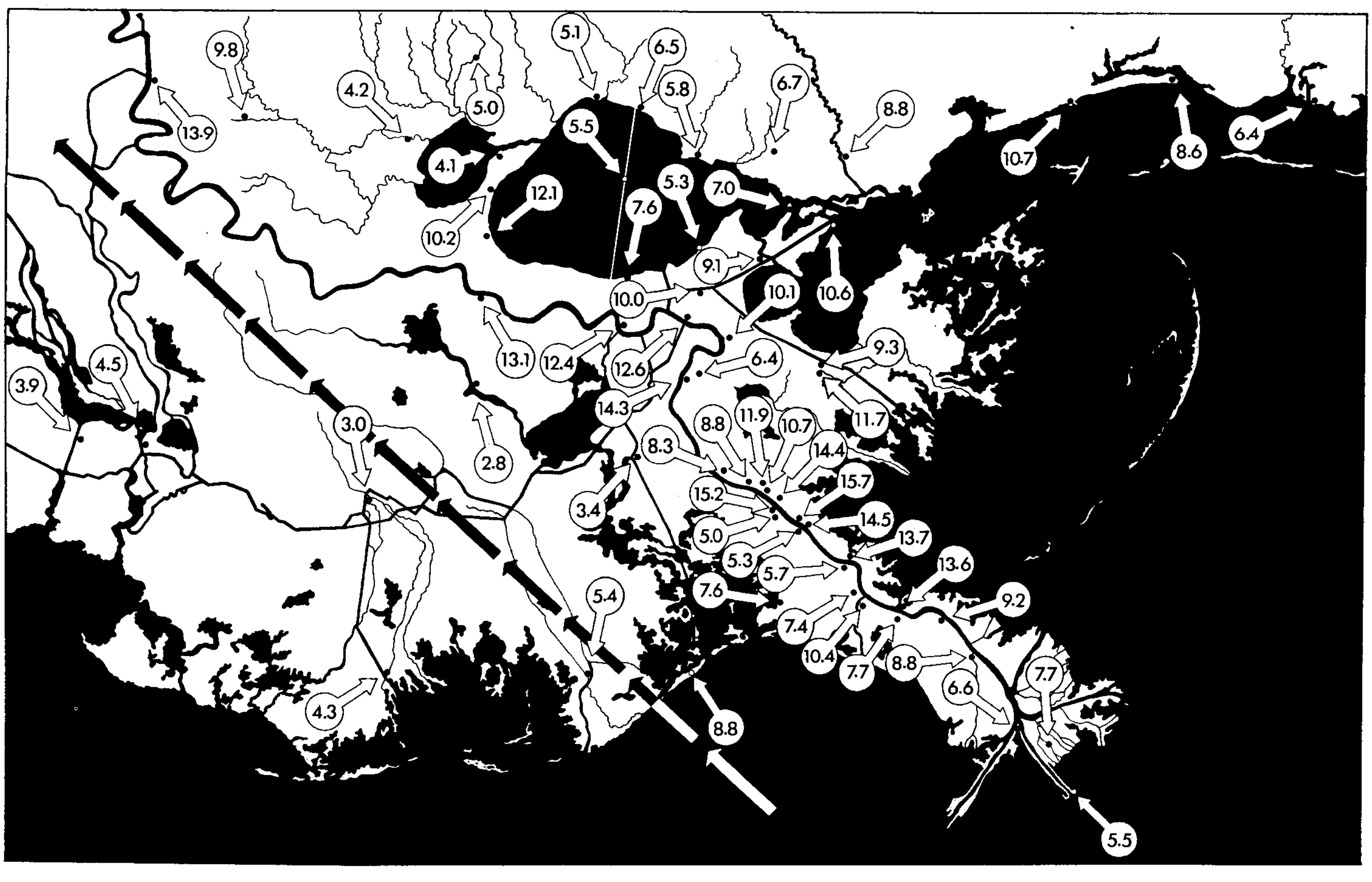

FIGURE 6.—Hurricane Betsy, 1965. High water marks Louisiana and Mississippi coastal areas (based on data obtained from the New Orleans District of the U.S. Army Corps of Engineers).

flooding from storm surges presents problems apart from the actual surge on the coast. The surge on inland waterways, as occurred on the Mississippi River, is also different in time and extent from the coastal surge.

In low coastal areas, such as the entire Louisiana coast, the surge is disposed of mainly by the sea water spreading over the lowlands, sometimes as far inland as 50 mi. The invasion of the surge water into the marshes creates and expands open bodies of water. The waves, generated by the wind over these bodies, help to transport greater amounts of water inland. The return of this water to the sea is a slow complicated process.

The tilting of water in inland lakes, such as occurred on Lake Pontchartrain, must be taken into consideration along with the surge to determine flooding possibilities.

As more industries and people continue to move into coastal areas subject to flooding, the determination of the extent of inland flooding becomes increasingly important for the protection of life and property. It is also becoming more difficult to determine the extent of the flooding. The continual construction or changing of levees, canals, navigable waterways, drainage, protective barriers, and other factors, contribute to the complexity of the inland inundation problem. Further complications arise by the changes which occur in the maze of levees. Natural changes, erosion and subsidence take their toll; also pilfering of the fill or actual cutting of the levees weakens the systems.

The loss of life, 57, in southern Louisiana, in hurricane Betsy occurred mainly from the inland flooding rather than from the actual surge on the immediate coast. A large part of the billion dollar loss was a result of inundation well away from the coastline. Except for the mass evacuation of 300,000 persons from the low coastal area, the loss of life in Betsy would have been appalling. Even when the storm surge on the coast can be adequately forecast, the problems of forecasting the extent of inland flooding must be resolved by extensive study and knowledge of the contributing factors for the area involved. Only when the extent of the flooding behind protective barriers for certain areas is reasonably anticipated can a major catastrophe be averted in some future storm.

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CORRECTION NOTICE

No. 1, January 1968, front cover, Contents, pp. 39–46: latter part of title of paper by Maunder should read "—A New Zealand Example."