ENGINEER MANUAL

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ENGINEERING AND DESIGN

STORM SURGE ANALYSIS

DEPARTMENT OF THE ARMY
CORPS OF ENGINEERS
OFFICE OF THE CHIEF OF ENGINEERS

CHAPTER 4

RELATED EFFECTS

4-1. General. This chapter presents methods and procedures for estimating the effects of direct rainfall, direct surface runoff, fluvial inflows, astronomical tide, initial water level and wave setup in water level determinations. Direct surface runoff is defined herein as the rainfall excess that drains off the land (non channelized) into the adjacent water body. Rainfall and wave setup effects were identified in Chapter 1 as two of the processes associated with storm surge generation, however, all of these effects can contribute to the total rise of water level in coastal waters during storm periods. The total rise at maximum stage is, of course, of paramount importance since it is this water level that is used in planning and design of coastal projects.

4-2. Direct Rainfall and Direct Surface Runoff.

a. As previously indicated, rain falling on the open sea usually has a minimal effect on the surge produced along the open coast. However, in estuaries and in areas where low-lying terrain landward from the coast is flooded, rain may cause a rather substantial rise in the local water level. Water levels may be increased either from direct rainfall over the water body or inundated area, or as a result of direct surface runoff from adjacent land areas. Prediction of probable rainfall amounts and their distribution is thus essential in estimating design water levels for many coastal regions. Rainfall information is also important in design of pumping facilities and gravity drainage structures in connection with hurricane flood protection projects.

b. Rainfall associated with severe landfalling tropical storms has been studied by a number of investigators. Item 13 of Appendix A (published in 1926) was among the first studies concerned with mapping the areal distribution of hurricane rainfall. This study revealed that in a moving hurricane rainfall was asymmetrically distributed with the heaviest amount being in front (60 to 80 miles) and to the right of the storm center. It was also found that relatively little rain falls to the rear of the storm. Furthermore, it was noted that when the storm motion ceases the rainfall pattern becomes more symmetrical with respect to the storm center. Subsequent investigations of hurricane rainfall have in general substantiated these findings.

c. The methodolgy presented for estimating rainfall associated with hurricanes is based on a study conducted in 1968 as discussed in item 21 of Appendix A. In this study, frequency and areal distributions of rainfall were developed from 46 tropical storms that crossed the Gulf Coast between Apalachicola, Florida and Brownsville, Texas. Unfortunately, no investigation similar to the latter has been carried out for the Atlantic Coast of the United States. Inasmuch as the methodology presented is strictly applicable to the coastal region in the Gulf of Mexico, it is possible to estimate the tropical rainfall along the east coast of the United States by using a modified version. The necessary modification to the methodology is discussed later in this section.

d. Although item 21 of Appendix A provides frequency and areal distributions of rainfall in zones from 25 miles offshore to 100 miles inland, only one zone (Zone A) is considered herein. It extends from the coastline to 25 miles inland--an area that is usually of primary concern in storm water level determinations. Point rainfall depth for a given frequency and a given distance from the left or right of the storm track is considered to vary uniformly along the coast far any given storm. Also, the rainfall depths are considered uniform, along any line parallel to the storm track extending across the 25 mile wide zone. Point rainfall for selected frequency levels at either 6 and 12 hour intervals before landfall and after landfall is shown in Figures 4-1 to 4-6. Hours indicated as negative values in the figures signify hours before landfall. Figure 4-7 is used to transform point rainfall for 6 and 12-hour intervals for the various frequency levels to area rainfall (areas up to 1000 square miles.)

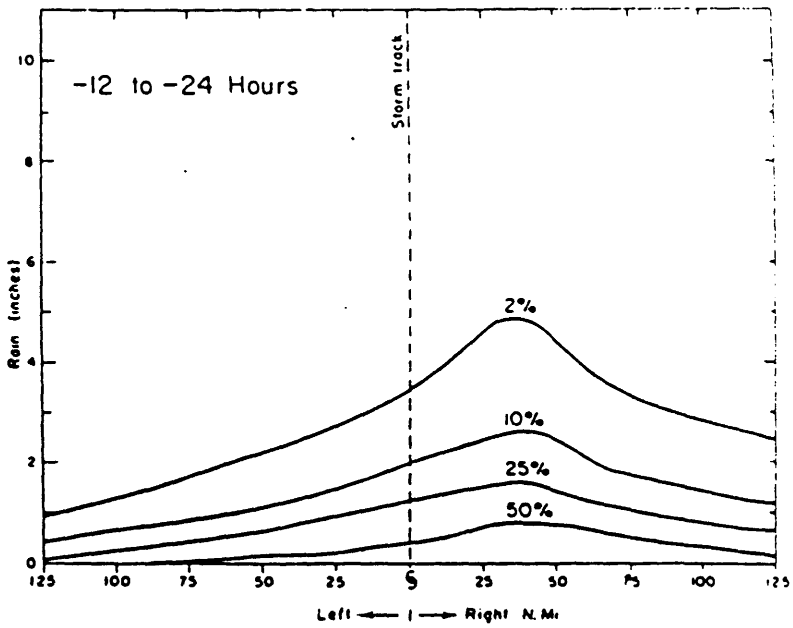

Figure 4-1. Rainfall for selected frequency levels for 12 to 24 hours before landfall. (item 21 of Appendix A)

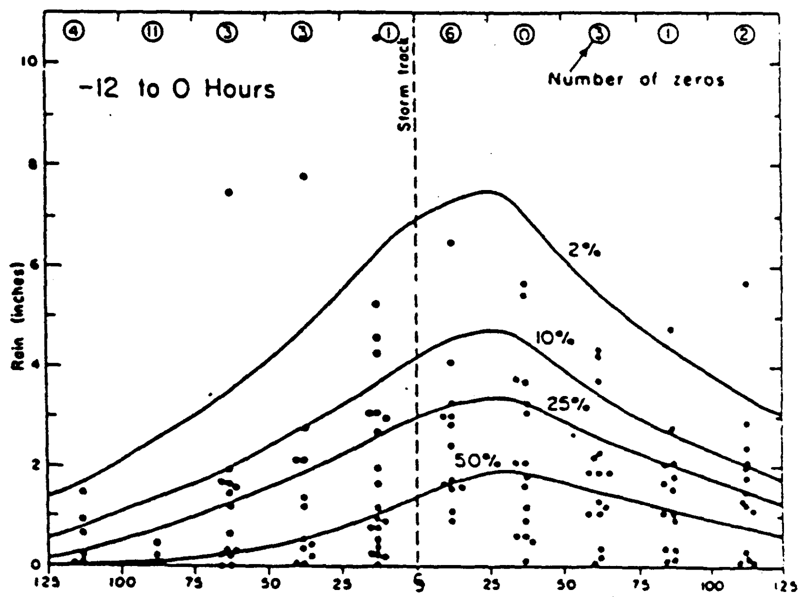

Figure 4-2. Rainfall for selected frequency levels for 12 hours before landfall. (item 21 of Appendix A)

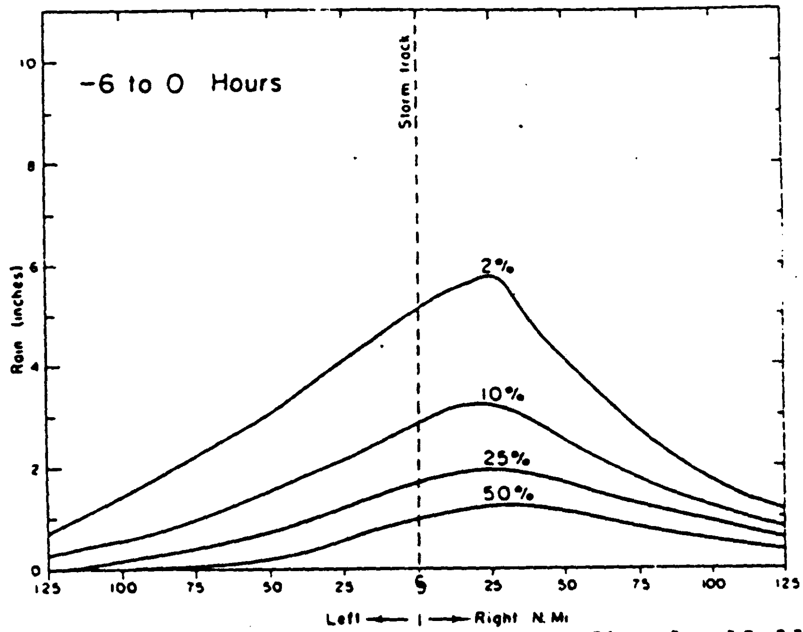

Figure 4-3. **Rainfall for 6-hour period preceding landfall for selected frequency levels. (item 21 of Appendix A)**

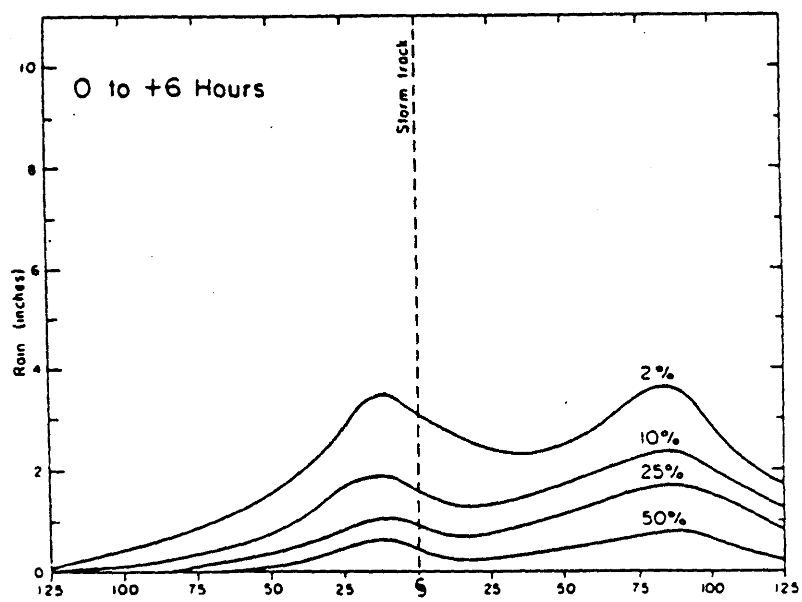

Figure 4-4. Rainfall for 6-hour period after land fall for selected frequency levels. (item 21 of Appendix A)

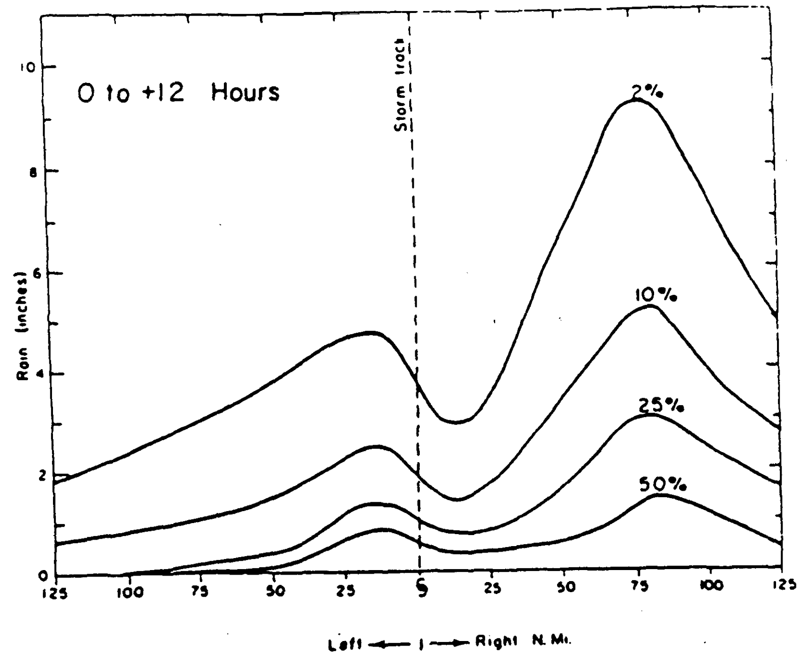

Figure 4-5. Rainfall for the first 12-hour period after landfall for selected frequency levels. (item 21 of Appendix A)

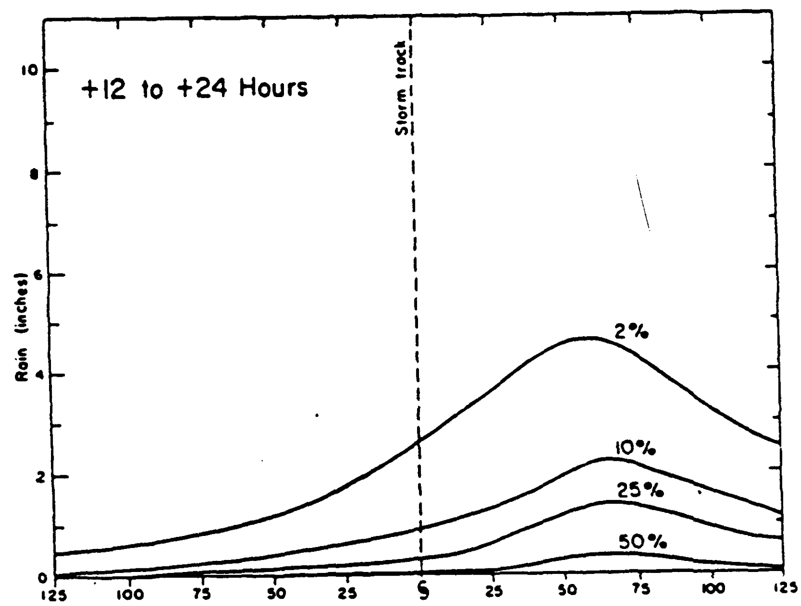

Figure 4-6. Rainfall for the second 12-hour period after landfall for selected frequency levels. (item 21 of Appendix A)

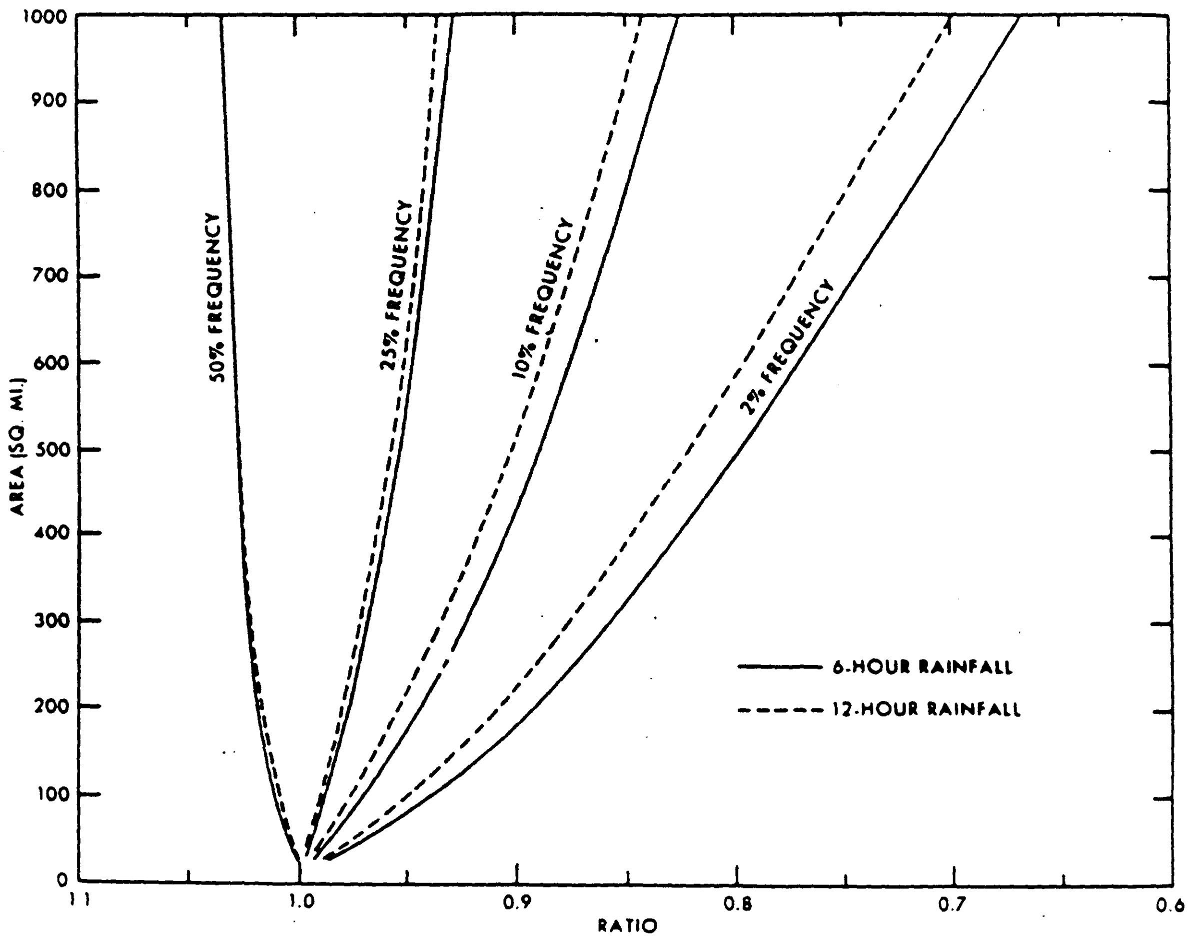

Figure 4-7. Ratios of areal rainfall for selected frequency levels. (item 21 of Appendix A)

e. For design purposes, the rainfall duration within the selected zone is presumed to be a function of the speed at which the tropical storm moves through the zone. At a given point within the zone, rainfall duration is assumed to be directly related to the forward speed of the storm, regardless of the path prescribed for landfalling storms. It is further assumed that rainfall duration is related to the storm translation speeds in accordance to the Standard Project Hurricane Criteria as high translation speed (HT), moderate speed (MT) and slow speed (ST). On this basis the rainfall duration for a HT storm is taken as 12-hours (6-hours before landfall and 6-hours after landfall), for a MT storm 24-hours (12 hours before landfall and 12-hours after landfall) and for ST storm 48-hours (24-hours before landfall and 24-hours after landfall). The basis for the later assumption is that a high speed storm will pass over the zone rather rapidly while a slow speed strom will subject the zone to a much longer rainfall duration.

f. Point rainfall data as exhibited in Figures 4-1 to 4-6 depict curves for the 2-, 10-, 25- and 50-percent levels of occurrence. The 2-percent curve implies that 98 percent of the expected rainfall depths on the average corresponds to the curve or below and 2-percent are above for a given period and distance from the storm track. Because the 2-percent curve will usually provide a conservative estimate of the rainfall, it is recommended for approximating the design rainfall.

g. The following problem will illustrate the procedures required to determine the average expected rainfall coincident with a tropical storm moving over a coastal zone.

************************* EXAMPLE PROBLEM *************************

Given: A moderate speed design hurricane enters a coast and moves over the zone along a path perpendicular to the coast.

Find: The average rainfall expected over an area of 500 square miles centered 50 miles to the right of the projected storm path.

Solution: Because the storm is moving at a moderate speed, the point rainfall must be determined 12-hours before landfall and 12-hours after landfall. From Figure 4-2 the point rainfall depth 12-hours before landfall is about 6.1 inches at the distance 50 miles to the right of the storm track; and according to Figure 4-5 the point rainfall 12-hours after landfall is about 6.3 inches. The adjustment ratio from Figure 4-7 for a 500 square mile area and a 12-hour rainfall period is approximately 0.82. Upon multiplying the ratio times the point rainfall amounts, it is found that the average rainfall in the period 12-hours before landfall is about 5 inches and 12-hours after landfall about 5.2 inches.

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h. With a knowledge of the rainfall rates, it is possible to include this effect directly as part of the mathematical model simulations via the continuity relation in Equation [1-8]. Thus by using an appropriate interpolation procedure, it is possible to add a quantity of rainfall at each time step. This applies to both direct rainfall over water bodies and inundated areas and rainfall runoff from adjacent land areas. Provisions for including surface runoff in the model require that the model be formulated such that moving boundaries can be treated and the adjacent land areas are incorporated into the modeled system. Direct surface runoff amounts prescribed will require adjustment to account for the effects of initial losses and infiltration during the course of the storm.

i. The problem of accounting for direct rainfall and rainfall surface runoff from adjacent land areas was first treated in connection with studies of storm surges in Galveston Bay (item 54 of Appendix A).

j. The method described for specifying rainfall over coastal areas along the Gulf Coast of the United States is considered applicable to the Atlantic Coast provided that the point rainfall depths are adjusted to reflect the probable depths characteristic of the region under consideration. These expected rainfall amounts can be estimated based on those tropical storms that have occurred in the study area and general vicinity. In applying the method to the Atlantic Coast, it is assumed that the distribution of the rainfall and area correction factors as given on Figure 4-7 are identical to those estimated for the Gulf Coast.