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STORM TIDE FREQUENCY ANALYSIS FOR THE COAST OF GEORGIA

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A report on work for the Federal Insurance Administration, Department of Housing and Urban Development by the National Oceanic and Atmospheric Administration, Department of Commerce.

ABSTRACT

Storm tide height frequency distributions are developed on the Georgia coast for the National Flood Insurance Program by computing storm tides from a full set of climatologically representative hurricanes, using the National Weather Service hydrodynamic storm surge model. Tide levels are shown in coastal profile between annual frequencies of 0.10 to 0.002. This report is intended for use in estimating actuarial risk to buildings from coastal floods and in land use management.

1. INTRODUCTION

1.1 Objective and Scope

The Federal Insurance Administration (FIA), Department of Housing and Urban Development (HUD), requested the National Oceanic and Atmospheric Administration (NOAA) to study flood levels from storm tides on the open coast of Georgia. This study, designated type 8 by FIA, is part of the survey of the whole United States by FIA to delineate those areas and communities subject to flooding required by Section 1360(1) of the National Flood Insurance Act of 1968. A flood insurance rate-making study (Type 15) made for Chatham County, Ga., is included in a separate report.

1.2 Authorization

The National Flood Insurance Act of 1968, Title XIII, Public Law 90-448, enacted August 1, 1968, authorizes and directs the Secretary of Housing and Urban Development to establish and carry out a National Flood Insurance Program. The Secretary is authorized to secure the assistance of other Federal Departments or other agencies on a reimbursement basis in identifying flood plain areas, including coastal areas. Authorization for this particular study is Project Order No. 6, dated May 2, 1973, under Agreement No. IAA-H-5-73 between the Federal Insurance Administration and NOAA.

1.3 Study Method

The technique used in the tide frequency analysis for the open coast of Georgia is basically the same as that developed earlier for the New Jersey coast [1] and applied to Long Beach Island and adjoining mainland of Ocean County, N.J. [2]. Updates and revisions from the 1970 procedure are explained in a report in preparation [3].

First, the behavior of hurricanes along the coast was assessed from past records. Factors analyzed included depression of the atmospheric pressure at the storm center below the surrounding area, forward speed and direction of motion of the storm, and distance from the storm center to the band of maximum winds. All these factors relate to a storm's potential to produce high tides.

The second step in the tide frequency analysis is to calculate the coastal tide levels that each of a number of hypothetical but representative hurricanes would produce from various combinations of the hurricane parameters. For this, a dynamic calculation method is used that has been demonstrated to reproduce observed surges of past hurricanes within acceptable tolerances.

Finally, the computed storm surges were combined with the astronomical tide variation by using the joint probability method to obtain a frequency distribution of the resulting total tide.

Open-coast tide frequencies were computed at several selected points on the Georgia coast. Frequency profiles along the coast were constructed by interpolation between these selected points taking into account variations in water depths ("shoaling factor," defined in par. 4.2) and hurricane climatology parameters.

Nonhurricane storms cause tide levels on the Georgia coast up to the 15-yr return period magnitude. These are not analyzed explicitly. Their effects are taken into account by statistical analysis of the tide gage records and the 10-yr return period frequency curve is adjusted accordingly.

2. SUMMARY OF HISTORICAL HURRICANES

2.1 Hurricane Tracks

This section summarizes the hurricanes that have moved across the coast of Georgia from the Atlantic since 1800. A few of the lesser storms are omitted. The tracks of hurricanes since 1871 are shown in figure 1, and dates are given along the respective tracks with dates of major hurricanes underlined. A dashed line track indicates that the intensity had decreased to that of a tropical storm. The information on hurricane tracks is taken from the charts of North Atlantic tropical cyclones compiled by Cry [4] for the years 1871-1963. For 1964-73, similar tracks were published in the Monthly Weather Review, then a NOAA publication.

2.2 Historical Notes

Brief notes on the history of hurricanes and damages caused by them are abstracted from published papers (for example, references [5] and [6]). Water levels for hurricanes of 1824-93 are based on data from the U.S. Army Corps of Engineers, either from a published report [7] or furnished directly by the Savannah District Office. Data furnished in terms of the "National Geodetic Vertical Datum of 1929" were adjusted to the local mean sea level (msl) reference datum of this report (par. 5.2.1) by subtracting 0.3 ft.

<u>September 3-9, 1804</u>

The destructive power of hurricane tides along the Georgia coast was first recorded during the passage of this major hurricane. The evidence of high storm tides was compiled by Ludlum from original sources and published in "Early American Hurricanes 1492-1870" by the American Meteorological Society. At Savannah the tide surged over the sand bars, into the bay, up the rivers, and over the wharves -- over everything that was less than 10 ft above sea level. This was purported to be the first hurricane to strike the coast near Savannah since 1752.

It so happened that Aaron Burr, that controversial figure in American history, was at St. Simon Island on the Central Georgia coast on the day the hurricane struck. In his celebrated correspondence with his daughter Theodosia, Burr has left a graphic description of the impact of the tide and winds which clearly imply that the eye of the storm passed over the island at 4 p.m. on September 7. He stated that the tide was about 7 ft above the height of an ordinary high tide. Excerpts from [8] follow. The first is from a letter written by Burr from Savannah on the 11th:
"The storm commenced on Friday night, and continued to increase until Monday morning, by which time every vessel in the harbor was either sunk, driven over the docks or dismasted. There is not a house in the lower part of the town but what has suffered very materially from the high tide which rose to the astonishing height of from twenty to thirty feet above the highest spring tides. Gun boat No. 1 was driven from anchorage 7 miles over marshes, through woods, and finally came to in a field."

Ludlum quotes a vivid description from Ramsay of the effect of the hurricane and storm tide at Fort Green at the entrance to the Savannah River and along the coastal plain.

"On Cockspur Island Fort Green was leveled, all the buildings destroyed, and thirty lives lost. Muskets were scattered all over the island. Cases of canister shot were carried from one hundred to two hundred feet, and a bar of lead of 300 pounds was likewise removed to a considerable distance. A cannon weighing 4,800 pounds is said to have been carried thirty or forty feet from its position. Broughton Island was covered with water; and upwards of seventy negroes, the property of William Brailsford, were drowned by the oversetting of a boat in which they attempted to escape from the island to the main. The barn on the island being raised on high land stood the storm, and in it the negroes would have been safe. At St. Simon Island great damage was done. The crops were generally covered with water, and several negroes were drowned. The like happened on St. Catherines, and on the other island on the coast. At Sunbury the bluff was reduced to a plain, and almost every chimney leveled to the ground.

"The rice swamps and low lands within the reach of the tides were generally overflowed. The crops of rice and provisions were greatly injured, and in some places totally destroyed or washed away. The fields of cotton along the seashore, which previously promised an abundant crop, were blasted and nearly destroyed by the violence of the wind and the spray of the sea!" Hurricane tides to the North of Georgia were also described [8]:

"At Beaufort, South Carolina, the seaport in the complex of islands and bays between Port Royal Sound and St. Helena Sound (about half way from Savannah to Charleston), the damage was immense. The Port Republic Bridge Company saw the efforts of the past seven years swept away in a few minutes when the rising tide, capped by a storm-tossed waves, smashed all the causeway close to the mainland and destroyed about half the structure on the island side. All dwellings on Bay Point were swept away as the eye of the savage hurricane roared in from the Atlantic. Cotton fields around Beaufort were overflown to a depth of 4 to 5 feet by the immense water surge."

September 14-15, 1824

A memorable storm tide generated by a small, savage hurricane overwhelmed the Georgia coastal area on September 14-15, 1824, as the center of the storm struck somewhere between Jacksonville, Fla. and Savannah, Ga. This storm was reported earlier (on the 11th) near Turk Island some 600 miles southeast of the Georgia Coast. On St. Simon Island, Ga., nearly all property was destroyed and the whole island overflowed by the inrushing water driven by the hurricane. The tide went over the wharves at Savannah, but was not high enough to do any damage to goods in the stores. The Savannah Georgian of September 16, 1824 states that "The tide rose upward of 3 feet above the wharves at Savannah, which was 7 feet higher than ordinary high water." The corresponding tide level is computed at 13.1 ft msl. Heavy rains accompanying the storm caused the worst flood along the Savannah River since the memorable high water of January 1796.

September 7-9, 1854

Just 50 years after the "great Gale of 1804," coastal Georgia and South Carolina experienced a close repetition of the disaster. During the intervening years there had been several substantial storms that had seriously affected some part of the coastal area, but none of these approached the intensity of the 1804 storm. The 1854 hurricane was first encountered by a ship located some 60 miles northwest of Abaco Island (Bahama Islands) on September 7. The center of the hurricane entered the coast somewhere between Brunswick and Savannah on the 8th. The Smithsonian observer at Savannah reported a low pressure of 973.2 mb (28.74 in) and an estimated maximum wind of about 80 kt. Houses, churches, wharves and shipping at Savannah were extensively damaged. There were no reports on damage due to flooding as the storm arrived at low tide. Highest tide observed was estimated to reach elevation 11.2 ft msl at Fort Pulaski, near the mouth of the Savannah River.

August 21-29, 1881

This major storm reached hurricane intensity northeast of Puerto Rico on August 22. The lowest pressure reading was 984.8 mb. Its center entered the coast, south of Savannah on August 27. Damage in Savannah was estimated at $1.5 million. About 335 people were killed in and near the city. Nearly 100 vessels were wrecked along the coast. Damage was very heavy on Tybee and other coastal islands near Savannah. Highest tide observed was estimated to reach 16.2 ft msl at Savannah Beach.

August 21-26, 1885

This storm, which was discovered in the Bahamas, moved inland north of Savannah on August 25. Its center moved northward, passing to the west of Wilmington, N.C. It caused heavy damage in the Carolinas. Total damage was estimated at $1.7 million. As a result of this destructive storm, it was proposed that a weather reporting network be set up in the West Indies and Mexico. Damage inflicted by this storm in Georgia was light.

August 15-September 2, 1893

This major hurricane, which originated in the Cape Verde Islands, reached the Georgia coast on August 27. It was accompanied by a very high storm tide which submerged the islands along the Georgia and South Carolina coasts. Between 2,000 and 2,500 people lost their lives on the coastal islands and in the lowlands between Tybee Island, Ga. and Charleston, S.C. Property damage along the coast was estimated at $10 million. Damage in Savannah was placed at more than $1 million. Nearly every building on Tybee Island was damaged and the railroad to the island was wrecked. The highest tide known to have occurred in the county was estimated to have a range of 17.0 to 19.5 ft msl at Savannah Beach (18.2 ft given in reference [7]).

August 30-September 1, 1898

This hurricane entered the Georgia-South Carolina coast on August 30, its center passing over Tybee Island, Ga. Winds on Tybee Island were estimated at 87 kt, but the storm surges were not high enough to cause extensive damage. However, the hurricane was accompanied by very heavy rains and the countryside was flooded for 100 miles around Savannah. Most roads and railroads were impassible because of high water. Damage on Tybee Island was estimated at $50,000.

September 25-October 6, 1898

This storm first appeared to the east of the Leeward Island on September 25. Its center moved northwestward and entered the Atlantic coast near Brunswick, Ga. on October 2. Storm tides of about 8 ft inundated Brunswick. Nearly 200 people lost their lives in the vicinity of Brunswick and on the islands near the mouth of the Altamaha River. No extensive damage was reported near Savannah in the storm. Highest tide observed was estimated to reach elevation 12.1 ft msl at Isle of Hope near Savannah.

August 23-30, 1911

The center of this hurricane entered the coast between Savannah, Ga. and Charleston, S.C. on August 28. Maximum winds of 76 kt from the northwest were recorded at Savannah. Damage in the Savannah area was slight. Property on Tybee Island was heavily damaged. Excessive rains accompanied the storm and caused considerable damage to roads, crops, and other property throughout south Georgia.

August 5-15, 1940

This was the first hurricane to affect Georgia since August 1911. Its center entered the South Carolina coast to the north of Savannah, Ga. on August 11. It was more damaging in adjacent South Carolina than Georgia. The wind at Savannah reached 63 kt and damage in the Savannah area was estimated at $850,000. High tides of 7.4 ft msl were recorded at Fort Pulaski, Ga. near the mouth of the Savannah River and 6.4 ft at Fort Jackson, Savannah Harbor, Ga. The tide overtopped the sea wall along Beaufort River and flooded the entire business area of the town of Beaufort, S.C. to a depth of 2 to 3 ft. The waterfront portion of the town suffered the greatest damage and every wharf was either destroyed or ripped from its piling. The National Ocean Survey found high water marks up to 14.2 ft msl in the area (3). The outlying islands of St. Helena, Hilton Head, Daufuski, and Pinkney, S.C. suffered considerable damage due to the storm tide which inundated some of the low areas to depths of up to 10 ft and destroyed many small homes. Wells, which are the only source of water supply, were flooded with salt water. Several handred people were left homeless and 25 people died on these outlying islands.

October 12-23, 1944

This hurricane entered the Gulf coast of Florida and moved northeastward across the peninsula. Its center crossed the east coast near Jacksonville in a north-northeast direction and moved inland again near Savannah. The intensity had decreased to that of a tropical storm by the time it reached Georgia. The highest tide of 5.9 ft msl along the Georgia coast was observed at Fort Pulaski. Estimated damage in Georgia was about $500,000.

October 9-16, 1947

The center of this hurricane entered the Georgia coast just south of Savannah on October 15. At Savannah, maximum wind speed was 67 kt and the lowest pressure was 974.3 mb (28.77 in). Heavy losses were sustained at Savannah and Savannah Beach where more than 1,500 buildings were substantially damaged. Total damage in the coastal area was estimated at more than $2 million. A high tide of 7.9 ft msl was recorded at Fort Jackson, Savannah Harbor, Ga. High water mark data collected by a recent survey by the National Ocean Survey show 10.9 ft msl near the Savannah River entrance, 10.0 ft msl at Tybee and 11.0 ft msl near Wilmington Island, Ga.

September 20-October 2, 1959

Hurricane GRACIE moved inland on September 29, its center passing over the South Carolina coast near Beaufort. Wind gusts of hurricane force were felt in the Savannah area, and damage was inflicted over the northern Georgia coastal area. Total damage inflicted by the storm was estimated at about $14 million with damage in Georgia estimated at more than $500,000. High water marks ranged from 7.3 to 11.9 ft msl near Edisto Beach, S.C.

3. CLIMATOLOGY OF HURRICANE CHARACTERISTICS

This section describes important characteristics of hurricane parameters that are needed for calculating tide levels on the coast. Basic parameters of hurricanes affecting the U.S. coast, including central pressures, radius of maximum winds, speed of forward motion, and other factors affecting the storm tide producing capability of hurricanes were published in 1959 [9]. This compendium of hurricane characteristics has been updated through 1973 by the National Weather Service and adapted to the needs of the Flood Insurance Program, including specification of probability distributions of the individual parameters. The data used in this and other flood insurance studies by NOAA are being prepared for publication in a separate report [10]. The specific values adopted for tide frequency computations in the present study are presented in par. 5.1.

3.1 Frequency of Hurricane Tracks

The overall frequency of hurricane occurrences is basic to calculating the resulting tide frequencies. The tide frequency analysis treats three classes of storms separately, i.e., landfalling, exiting, and alongshore storms. Because the dynamic model described in the following section is set up to handle these separately, it is logical to examine frequency of hurricane occurrences separately according to these three categories. The frequency with which hurricanes and tropical storms have entered the coast or moved parallel to the coast (alongshore) was assessed by counting tracks and a smoothing process was then applied to the data along the coast. The resultant frequency is given in [10]. Exiting storms are weak and contribute little to the frequency of high storm tides for the area under study; they are not considered further in this report.

3.2 Probability Distribution of Hurricane Intensity

Storm surges vary directly with the strength of the wind that is putting stress on the water surface. A measure of this wind stress in hurricanes is the intensity of the storm as measured by the depression of the storm's central pressure below a representative peripheral pressure. The probability distribution of hurricane central pressures near Brunswick, Ga. based on storms from 1900-73 and smoothed along the coast as shown in figure 2. The diagram shows only the fraction of all hurricanes with intensities below certain levels and makes no reference to the number of events per year. Frequencies are treated separately. For storm tide computation this continuous distribution is divided into eight class intervals, each represented by the central pressure at the midpoint of the class interval. This computational probability distribution is indicated by the dashed line.

3.3 Probability Distribution of Radius of Maximum Winds

In all hurricanes, proceeding from the storm center outward, winds increase from low values at the center of the eye to their most intense velocity just beyond the edge of the eye, then decrease more slowly. The average distance from the storm center to the circle of the maximum wind speed is called the radius of maximum winds and is adopted as a convenient single number to be used as an index of the size or lateral extent of the hurricane, a factor which affects the surge profile along the coast. The probability distribution of this parameter is divided into three class intervals for computation.

3.4 Probability Distributions of Speed and Direction of Forward Motion

The probability distributions of the speed and direction of forward motion of hurricanes are discussed in [10]; these factors also affect computed surge height. The height of the surge on the coast increases with increasing storm speed up to a celerity higher than that of any recorded hurricane in the study area. Thus, the occasional fast-moving storms, especially if they are large, pose the greatest hazard (Jelesnianski 1972). Six class intervals of the probability distribution for the speed of motion and four for the direction were adopted in the frequency computations.

4. HURRICANE SURGE

4.1 Surge Model

The National Weather Service has developed a two-dimensional hydrodynamic model for calculating the water levels induced by hurricanes on the continental shelf [11], [12]. The objective of this work was to develop a tool to forecast coastal inundations when hurricanes were approaching. The model has become the backbone of NOAA's tide-frequency studies for the flood insurance program. The development of the model is described in [11] and operational applications in [12]. Both limitations and verification of the model are described in the references. Water-depth contours are input at a series of grid points. The model computes the surge, the difference between the local storm-induced water level and the normal water levels for the area. Thus, the computed storm surge must be added to the predicted astronomical tide.

Running this model requires a large computer. The model program is at present in residence at NOAA's computer complex at Suitland, Md. Inputs to a computer surge calculation are hurricane central pressure, radius of maximum winds, vector storm motion, and ocean depth at a series of grid points. Thus, the hurricane climatology just described is oriented toward providing these parameters. The computer program generates the needed moving sea level pressure field and moving wind field from the basic parameters by predetermined wind and pressure relations.

4.2 Shoaling Factor

The capacity of a hurricane of given characteristics to produce a coastal surge depends on the profile of water depth. The shallower the coastal water the higher the surge. This variation along the Atlantic coast is depicted in figure 2b of [12], showing the ratio of the surge that would be produced at each coastal point by a standardized hurricane compared to that over a continental shelf of average or standard slope. This ratio is called the shoaling factor. The Georgia portion of this diagram is reproduced in figure 3. The shoaling factor profile is generated by computing surges by the model that has been described at the various coastal points and over the "standard basin" and taking ratios of the peak surges. The study area has the highest shoaling factor along the Atlantic coast because here the Continental Shelf slopes seaward most gradually. The water depth off the Georgia coast is shown in figure 4. The shoaling factor is implicit in calculations of hurricane surge by the model at selected coastal points, since the corresponding water depths are input data to the calculation. The shoaling factor curve of figure 3 reveals that a maximum factor is reached at Sapelo Island, Ga. where the highest surge would be produced by a hurricane striking the coast a few miles to the south.

5. TIDE FREQUENCY ANALYSIS BY JOINT PROBABILITY METHOD

5.1 The Method

The first step in the joint probability method is to divide the hurricane parameters into class intervals and read out the midpoint value of each class interval, as indicated on figure 2. These parameters used in the computations are listed in tables 1 to 4 for the Florida-Georgia Border, Brunswick, Sapelo Island, and Savannah, respectively. The parameters adopted in the tables are eight pressure depression categories (six in table 4; see par. 5.2), four R categories, six forward speed categories and four direction-of-approach categories. These factors were considered independent in the statistical sense, except that the four Rs were not the same for all pressure depression categories, smaller values being used with the more intense pressure depressions in line with the discussion in [10] of inter-correlation. Thus, table 1 defines 576 different hurricanes (8X3X6X4 = 576), which in aggregate represent the range of climatological probabilities in the vicinity. The probability (fraction of all hurricanes) of each of these is the product of the respective parameter probabilities in the table. The sum of the probabilities of the 576 hurricanes, of course, equals 1.0. The frequency of all landfalling storms is 0.00101 to 0.00122 per n mi of Georgia coast per year (par. 3.1).

Use of more pressure depression categories at the intense end of the scale is a slight refinement in technique introduced since earlier preparation of a flood frequency study for Chatham County by NOAA. Table 4 for Savannah is carried forward from the Chatham County study. Comparing test calculations at Savannah with the full range of categories shows that the earlier calculated 100-yr tide level is not affected. This refinement is more important at lower latitudes where the spectrum of central pressure includes those of more intense hurricanes.

As the second step, calculations are made with a preprepared computer program to give the coastal surge profile for each selected hurricane. Most of the surge profiles are obtained by adjustment of other profiles rather than by complete surge calculations. Each storm is programmed to strike the coast not only at the point most critical for the point of interest but also at points to the north and south, and the storm surge profiles shifted along the coast accordingly. All 576 profiles at each coastal point were added to low astronomical tide, high tide, and two intermediate tide levels. Further discussion on astronomical tides is included in sec. 5.2. Since each surge profile has a prescribed frequency, all the profiles may be amalgamated into a single tide frequency curve for a fixed coastal point.

As the third step, storm tides were computed in a similar way for the alongshore storms from the data in tables 1 to 4.

Finally, summing all the possibilities yields the total tide frequency graph of figure 5. It should be emphasized that these frequency values are still-water levels on the open coast that would be measured in a tide gage housing or other enclosure, excluding wave action. The destructive effects of waves on the beach front must be taken into account separately. In insurance rating this is taken into account by the ocean front "velocity zone."

5.1.1 Adjustment Along Coast

The estimated tide frequencies for locations other than those selected for computation along this stretch of the coast were obtained by interpolation. The interpolation was based on consideration of the frequency of storms, the variation in the offshore bathymetry or shoaling factor, and trend in the hurricane climatology parameters along the coast.

Legend for Tables 1 to 4

D = Central Pressure deficit (mb).

P_i = Proportion of total storms with indicated D value.

f = Forward speed of storm (kt).

P_f = Proportion of storms with indicated f value.

R = Distance from center of storm to principal belt of maximum winds (n mi).

P_r = Proportion of storms with indicated R value.

P_{rD} = Proportion of storms in D class with indicated value.

θ_c = Orientation of coast, measured clockwise from north (deg.).

θ_L = Direction of entry, measured clockwise from the coast (deg.).

P_θ = Proportion of storms with indicated θ_L value.

L = Effective distance perpendicularly outward from coast to storm track (n mi).

F_b = Average number of storms per year that pass at distance L.

F_n = Frequency of landfalling storm tracks crossing coast (storm tracks per n mi of coast per year).

Note: Alongshore storms have the same value of D and P_i as those for landfalling.

Table 1.--Tropical storm parameters - Georgia-Florida Border

Landfalling storms

F_n = .00101 θ_c = 008

D	P_i	P_{rD} R- 14	17.5	21	28	f	P_f	θ_L	P_θ
82.5	.01	.5	.25	.5	.0	5.3	.1	85	.25
77.4	.03	.5	.25	.5	.0	7.1	.2	105	.25
68.0	.06	.4	.0	.4	.2	8.8	.2	120	.25
56.5	.10	.3	.0	.4	.3	11.2	.2	147	.25
41.8	.20	.3	.0	.4	.3	13.7	.2		
27.9	.20	.3	.0	.4	.3	16.2	.1		
20.8	.20	.3	.0	.4	.3				
16.8	.20	.3	.0	.4	.3				

Alongshore storms

L	F_b	R	P_r	f	P_f
4	.0095			5.4	.1
13	.0107			6.4	.2
22	.0109	17	.5	9.5	.2
30	.0145	24	.5	12.1	.2
43	.0367			15.5	.2
61	.0546			19.9	.1

Table 2.--Tropical storm parameters, Brunswick, Ga.

Landfalling storms

F_n = .00101 θ_c = 017

D	P_i	P_{rD} R=14.6	17.9	21.3	28.4	f	P_f	θ_L	P_θ
83.2	.01	.5	.25	.25	.0				
77.2	.03	.5	.25	.25	.0	5.3	.1		
67.1	.06	.4	.0	.4	.2	7.1	.2	074	.25
55.0	.10	.3	.0	.4	.3	8.9	.2	090	.25
40.1	.20	.3	.0	.4	.3	11.3	.2	104	.25
27.6	.20	.3	.0	.4	.3	13.8	.2	127	.25
20.1	.20	.3	.0	.4	.3	16.5	.1		
16.4	.20	.3	.0	.4	.3				

Alongshore storms

L	F_b	R	P_r	f	P_f
4	.0096			5.8	.1
13	.0114			7.5	.2
22	.0133	18.0	.5	9.7	.2
30	.0162	24.6	.5	12.1	.2
43	.0408			15.8	.2
61	.0462			20.3	.1

Table 3.--Tropical Storm Parameters - Sapelo Island, Ga.

Landfalling storms

F_n = .00110 θ_c = 017

D	P_i	P_{rD} R=15.1	18.4	21.6	28.7	f	P_f	θ_L	P_θ
83.2	.01	.5	.25	.25	.0				
77.2	.03	.5	.25	.25	.0	5.3	.1		
67.1	.06	.4	.0	.4	.2	7.1	.2	076	.25
55.0	.10	.3	.0	.4	.3	8.9	.2	096	.25
40.1	.20	.3	.0	.4	.3	11.3	.2	116	.25
27.6	.20	.3	.0	.4	.3	13.9	.2	142	.25
20.1	.20	.3	.0	.4	.3	16.8	.1		
16.4	.20	.3	.0	.4	.3				

Alongshore storms

L	F_b	R	P_r	f	P_f
4	.0118			5.8	.1
13	.0132			7.5	.2
22	.0160	18.0	.5	9.7	.2
30	.0190	24.6	.5	12.1	.2
43	.0430			15.8	.2
61	.0550			20.3	.1

Table 4.--Tropical Storm Parameters - Savannah, Ga.

Landfalling storms

F_n = .00122 θ_c = 030

D	P_i	P_{rD} R 16	22	29	f	P_f	θ_L	P_θ
71.7	.1	.4	.4	.2	5.2	.1	063	.25
56.6	.1	.3	.4	.3	7.2	.2	088	.25
42.2	.2	.3	.4	.3	9.1	.2	110	.25
29.5	.2	.3	.4	.3	11.5	.2	134	.25
21.1	.2	.3	.4	.3	14.4	.2		
16.2	.2	.3	.4	.3	17.6	.1		

Alongshore storms

L	F_b	R	P_r	f	P_f
4	.0120			6.3	.1
13	.0157	19	.5	8.1	.2
22	.0174	26	.5	10.2	.2
30	.0216			12.8	.2
43	.0561			16.7	.2
61	.0648			22.0	.1

5.2 Astronomical Tides

5.2.1 Reference Datum

"Mean sea level" in this report refers to the locally observed average height of the sea during the 1941-59 epoch, the current 19-yr reference epoch for published National Ocean Survey tide data. Measured tide levels have been adjusted to this reference. The "National Geodetic Vertical Datum of 1929," a geodetic surface to which land elevation contours are normally related, is 0.3 ft lower than the locally defined msl at Savannah.

5.2.2 Astronomical Tide

Most of the combinations of forces producing the astronomical tide are experienced during a 19-yr cycle. There is also a seasonal variation in the mean water level with a maximum in September-October. The month of September is taken to represent the hurricane season. Astronomical high tides for the base epoch were recalculated and summarized. Low tides were estimated indirectly. The frequency distribution of all astronomical tide levels with which hurricane surges might combine in a random manner is comprised of the frequency distribution of high tides just described, of low tides and, for this study area, of the frequency distributions of two intermediate values.

5.3 Tide Frequencies

Figure 5 shows the resultant total tide frequency curves on the open coast at the Florida-Georgia border for Brunswick, Sapelo Island, and Savannah, Ga. Figure 6 shows the variation of the total tide heights along the Georgia coast for the 10-, 50-, 100-, and 500-yr return periods, scaled from these diagrams and interpolated between by reference to the shoaling factor (par. 4.2) and the hurricane climatology. The 10-yr level is smoothed to agree with a direct statistical analysis of maximum annual water levels (par. 5.4).

5.4 Comparison of Frequency Curves with Observed Tides and High Water Marks

Figure 7 shows some representative observed high water marks to present a general view of storm surges observed along the coast. Except for the 1824 storm tide of 13.1 ft msl estimated at Savannah, other tide values were reported near the open coast. Figure 7 also includes the total tide values with a 100-yr return period estimated for the open coast of Georgia in this study. As expected, during the period of observed data some coastal points experienced hurricane tides higher than the "100-yr" level, while others either did not reach this level or it was not observed. The 100-yr level is to be construed as the tide level having a probability of occurrence each year of 0.01.

The 8 highest open coast tides (produced by hurricanes of 1854, 1881, 1893, 1898, 1940, 1944, 1947 and 1949) observed near Savannah Beach, Ga., with return period calculated by the formula proposed by Beard [13], are plotted and shown in figure 8. The length of the data series was taken as 150 years, from 1824 through 1973, for this plot. The tide value for the 1824 hurricane is omitted since the specific tide level near the coast is not known. The highest tide report in 150 years was 18.5 ft msl during the passage of the 1893 hurricane. Does this highest observed value in 150 years have a 150-yr return period or, as is conventionally done, twice that, or somewhere in between? Using Beard's plotting position formula, return periods of about 200 and 95 years would be ascribed to the tide levels of the 1893 and 1881 hurricanes (18.2 and 16.2 ft msl), respectively. The adopted frequency curve (curve A in fig. 8 reproduced from the "Savannah" curve of fig. 5) assigns 18.2- and 16.2-ft return periods of about 400 and 200 years, respectively. The difference is due primarily to the length of coast implicitly considered in the two analyses.

Yearly highest tides from the NOS tide gage data recorded at Fort Pulaski, Ga. were plotted using the same statistical formula and analyzed to yield curve B (fig 8). These data begin in 1935, and only a few of the higher values pertain to hurricanes. Their principal purpose here is to influence the adopted 10-yr return period tide level. Computed frequencies are blended smoothly into curve B at the 10-yr return period. Similar analyses were made at available tide gages in northern Florida to adjust the 10-yr level on the southern part of the Georgia coast.

5.5 Relation of This Report to Disaster Planning

A potential high tide on the coast would attain a substantially much higher elevation than either the highest observed 1893 level or the 500-yr curve of figure 6, if a hurricane of the same intensity as hurricane Camille of 1969 were to strike at any point of the Georgia coast. (Hurricane Camille of 1969, having a central pressure of 908 mb, generated a peak surge of 24.4 ft msl near Pass Christian, Miss.) The probability of such a hurricane striking a point of the coast cannot be precisely estimated. It is, however, prudent to take into account the magnitude of possible exceptionally high tides in assessing flood hazards for purposes other than those of this report.

This report is intended for use in estimating actuarial risk to buildings from coastal floods and in land use management. Hurricane evacuation route planning should be based on studies made for that particular purpose and should take into account the possibility of a severe storm whose frequency is small. A direct strike at any point of the coast of Georgia from a hurricane of the intensity of Camille could produce a tide level of over 25 ft msl at the coast. This has been estimated with the same surge model described in chapter 4. The annual frequency of such an event somewhere on the Georgia coast is several times as great as the frequencies of figure 6 which apply to individual points.

5.6 Coordination

The resultant tide frequency values (figs. 5 and 6) of this report have been coordinated with the Savannah District Office of the U.S. Army Corps of Engineers, who are revising a preliminary report on "Tidal Flood Information" for the coastal area of Chatham County, Ga. prepared in 1968 [7]. The tide frequencies on the open coast at the state borders are the same as reported in the Nassau County, Fla. and Beaufort County, S.C. reports prepared by NOAA for the Federal Insurance Administration [14], [15].

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15. Department of Commerce, NOAA, "Flood Insurance Study, Beaufort County, South Carolina," Study for Federal Insurance Administration, HUD, April 1972, revised 1974.

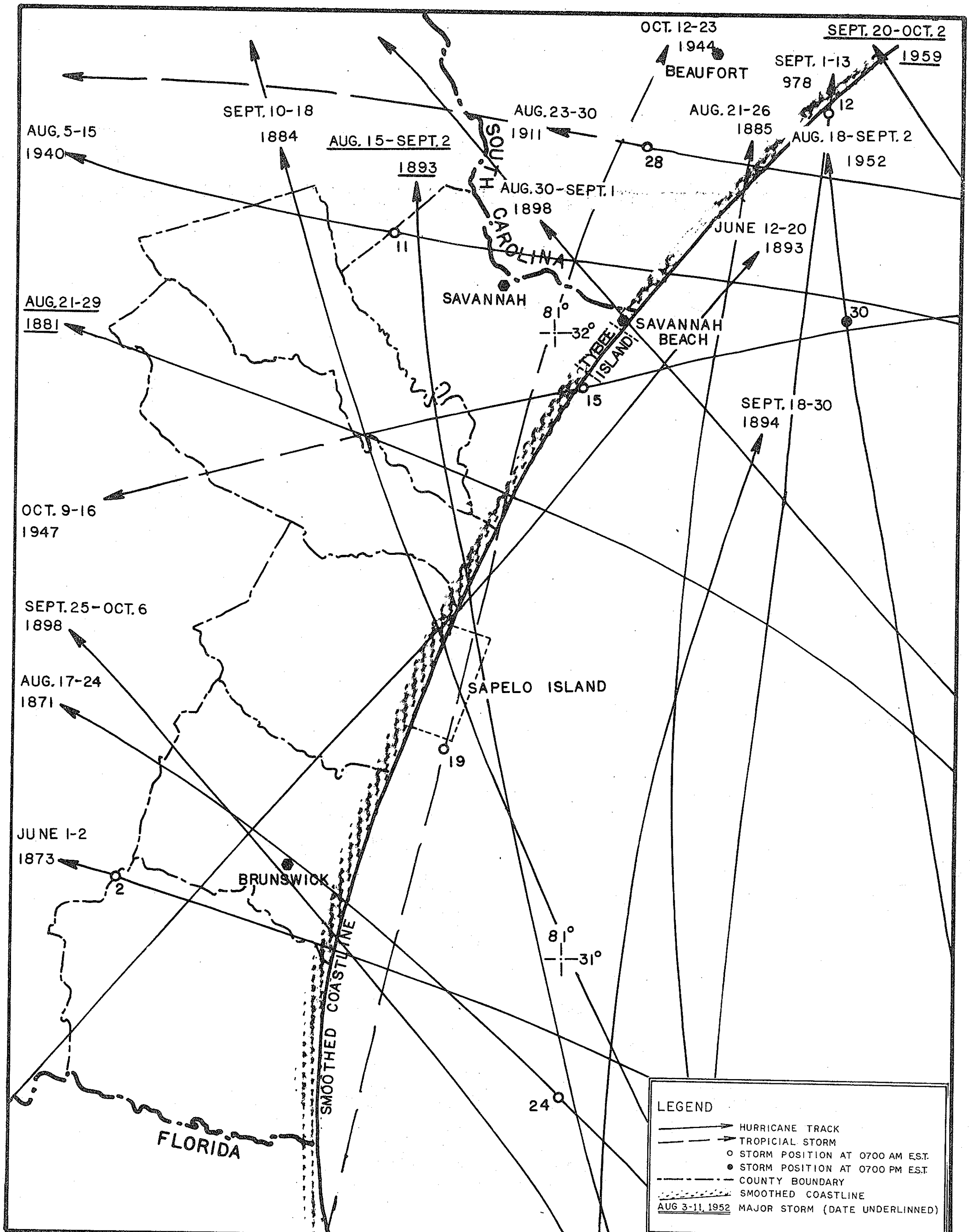

Figure 1.--Tracks of hurricanes affecting Georgia coast, 1871-1973.

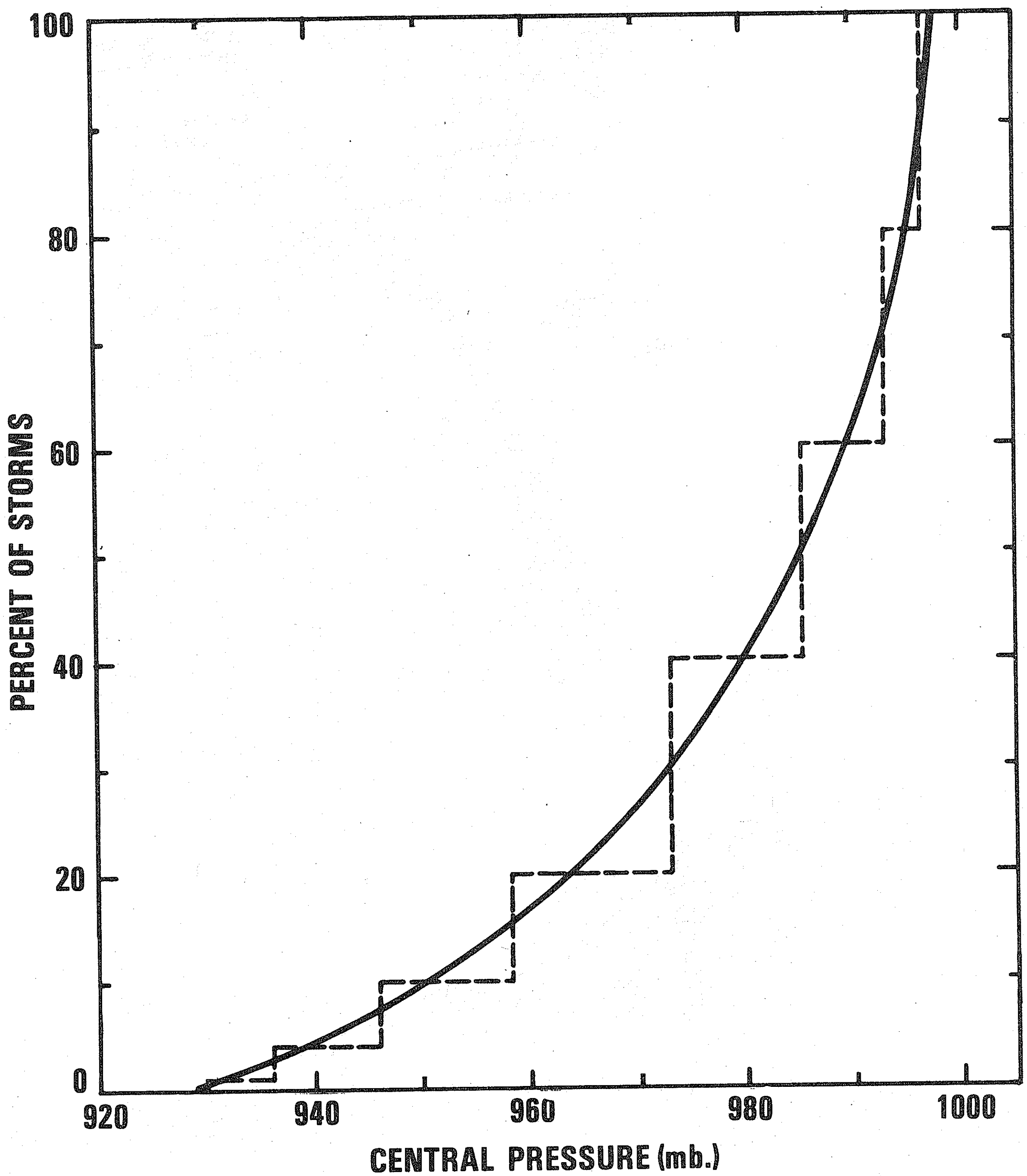

Figure 2.--Probability distribution for central pressure adopted for Brunswick, Ga., with class interval values (dashed line).

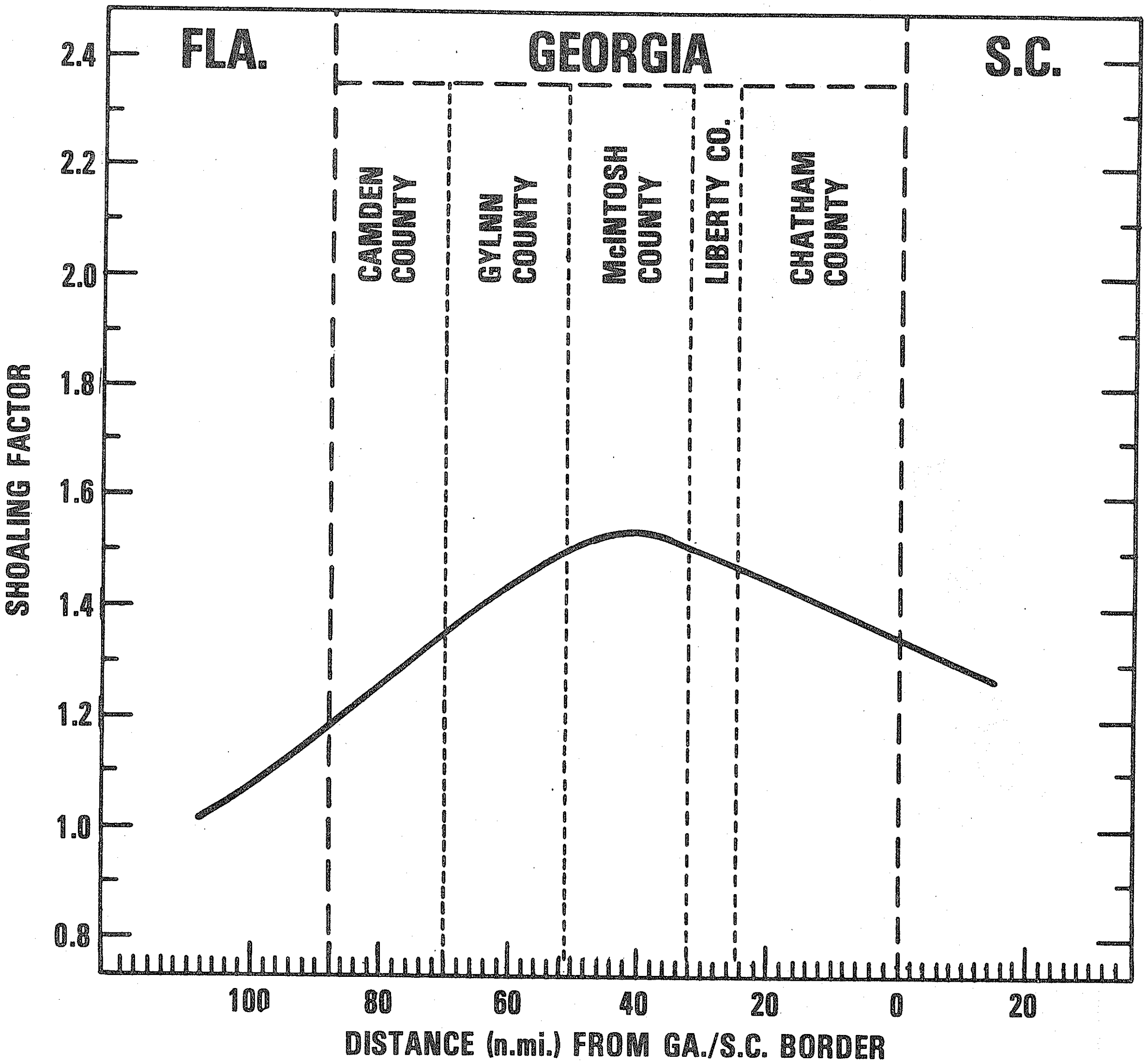

Figure 3.—Shoaling factor curve along Georgia Coast, after [10].

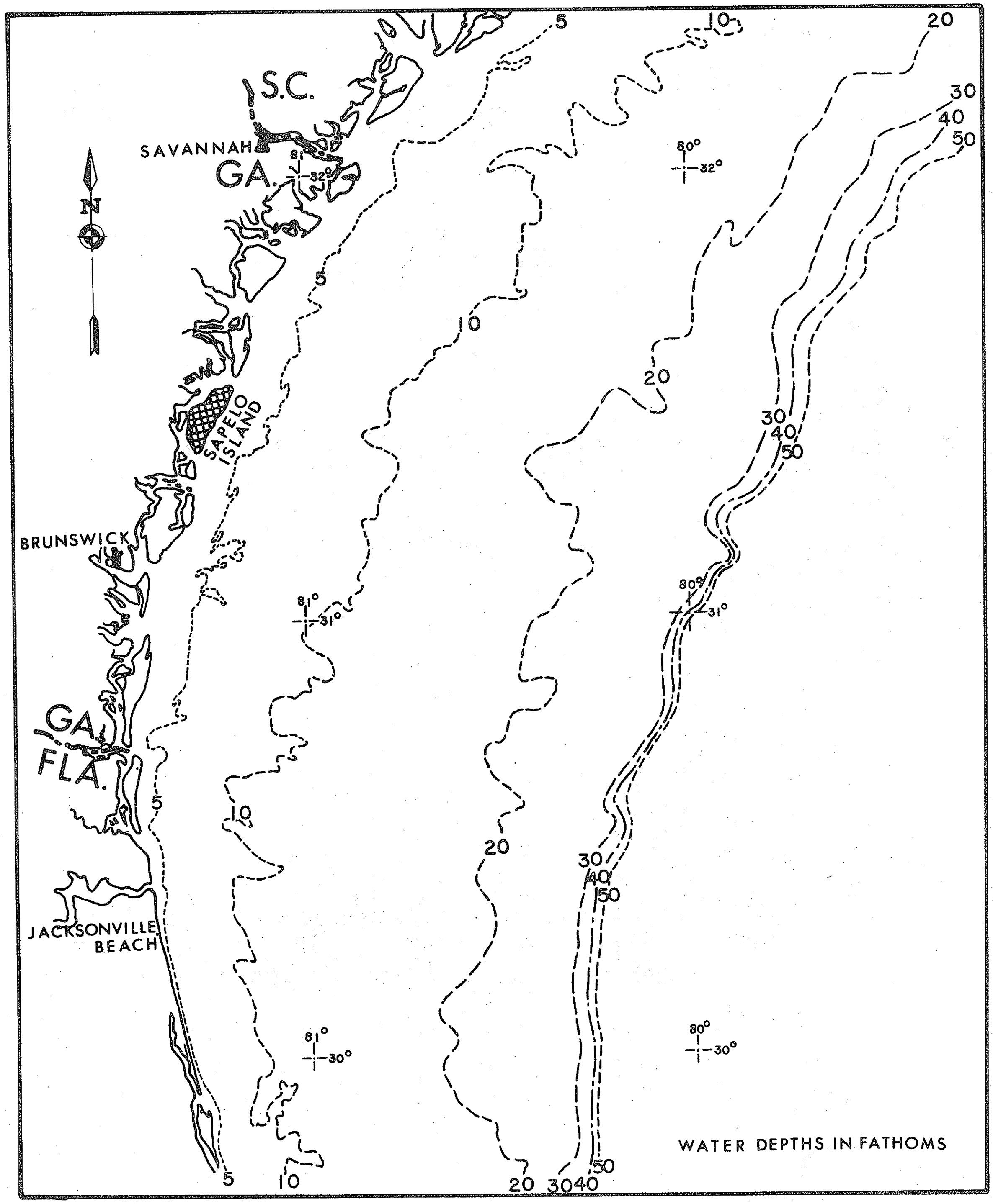

Figure 4.--Water depths off Georgia coast.

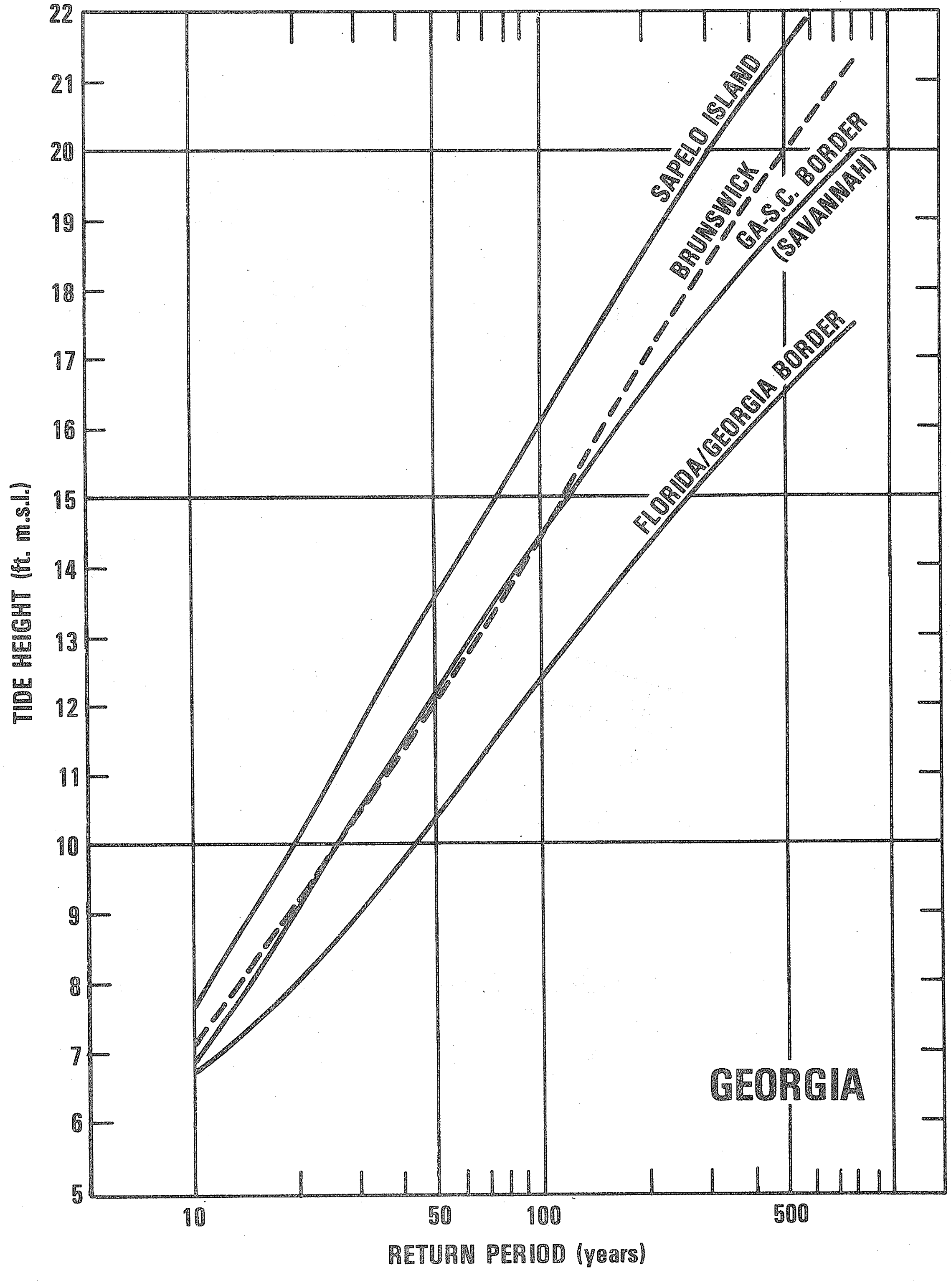

Figure 5.--Total tide frequency curves on the open coast at Florida-Georgia border, Brunswick, Sapelo Island, and Savannah, Ga.

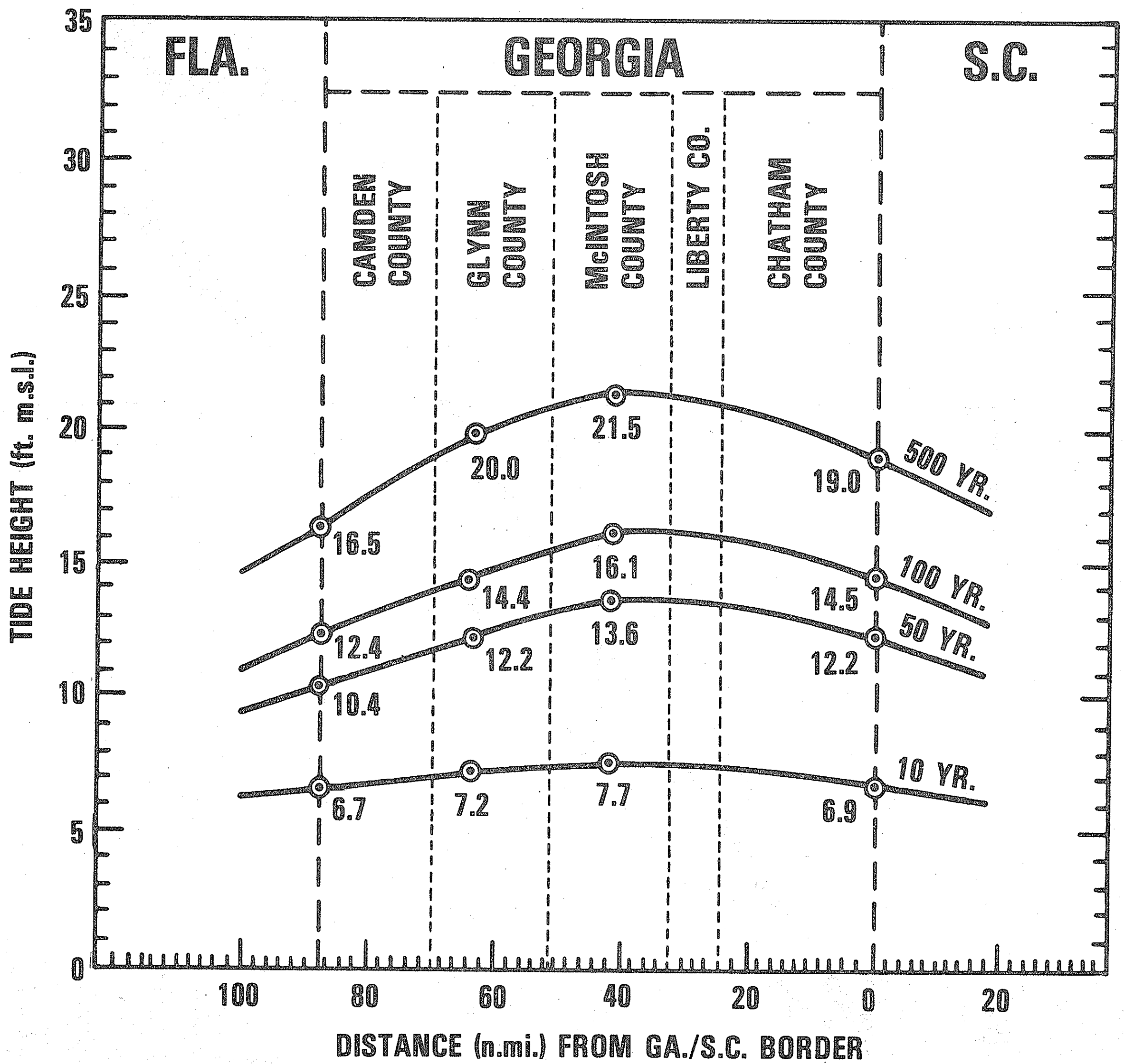

Figure 6.--Tide frequency profile along Georgia coast.

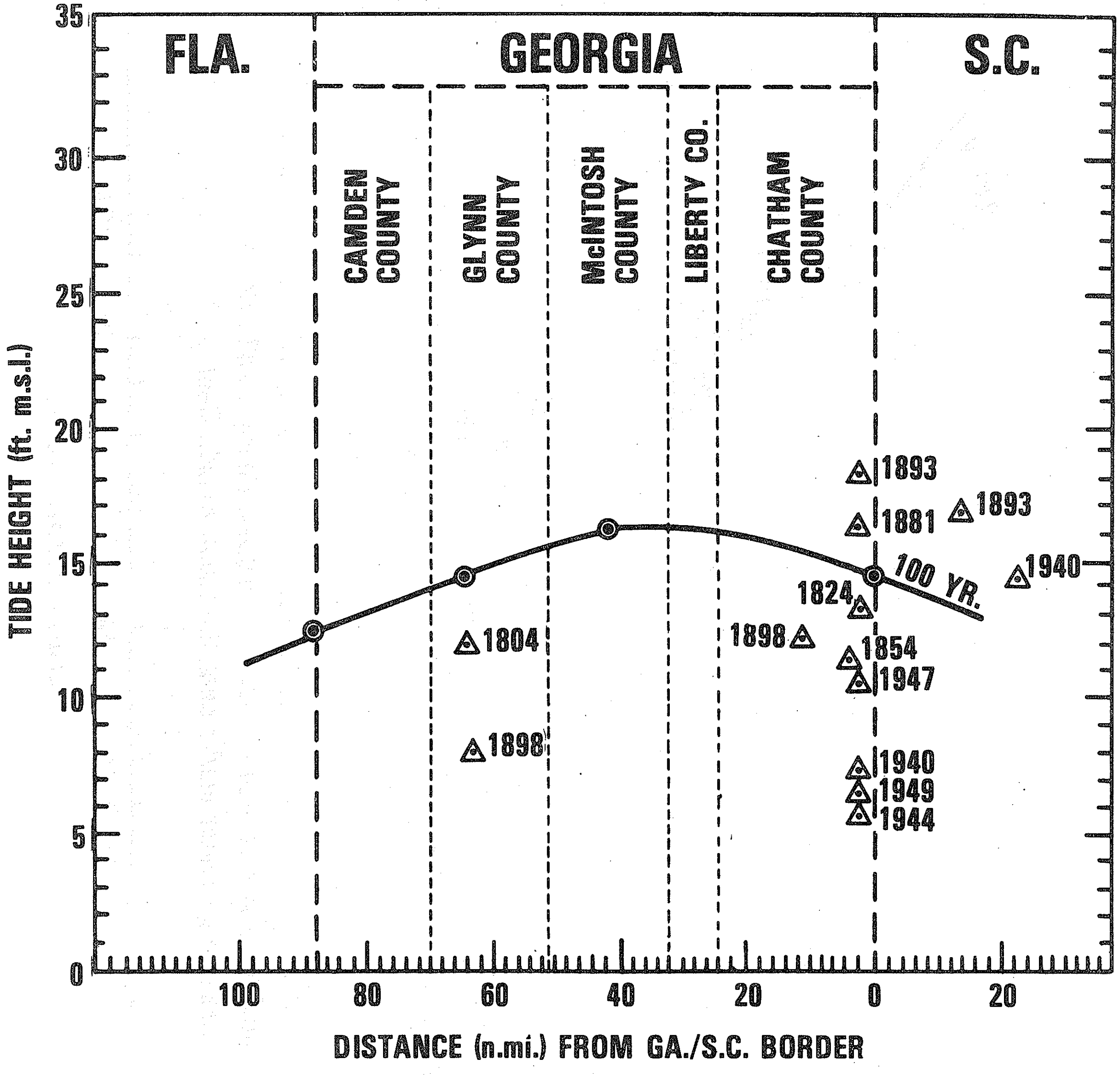

Figure 7.--Some representative high water marks (△) with storm dates and total tide frequency profile for 100-yr return period (from figure 6).

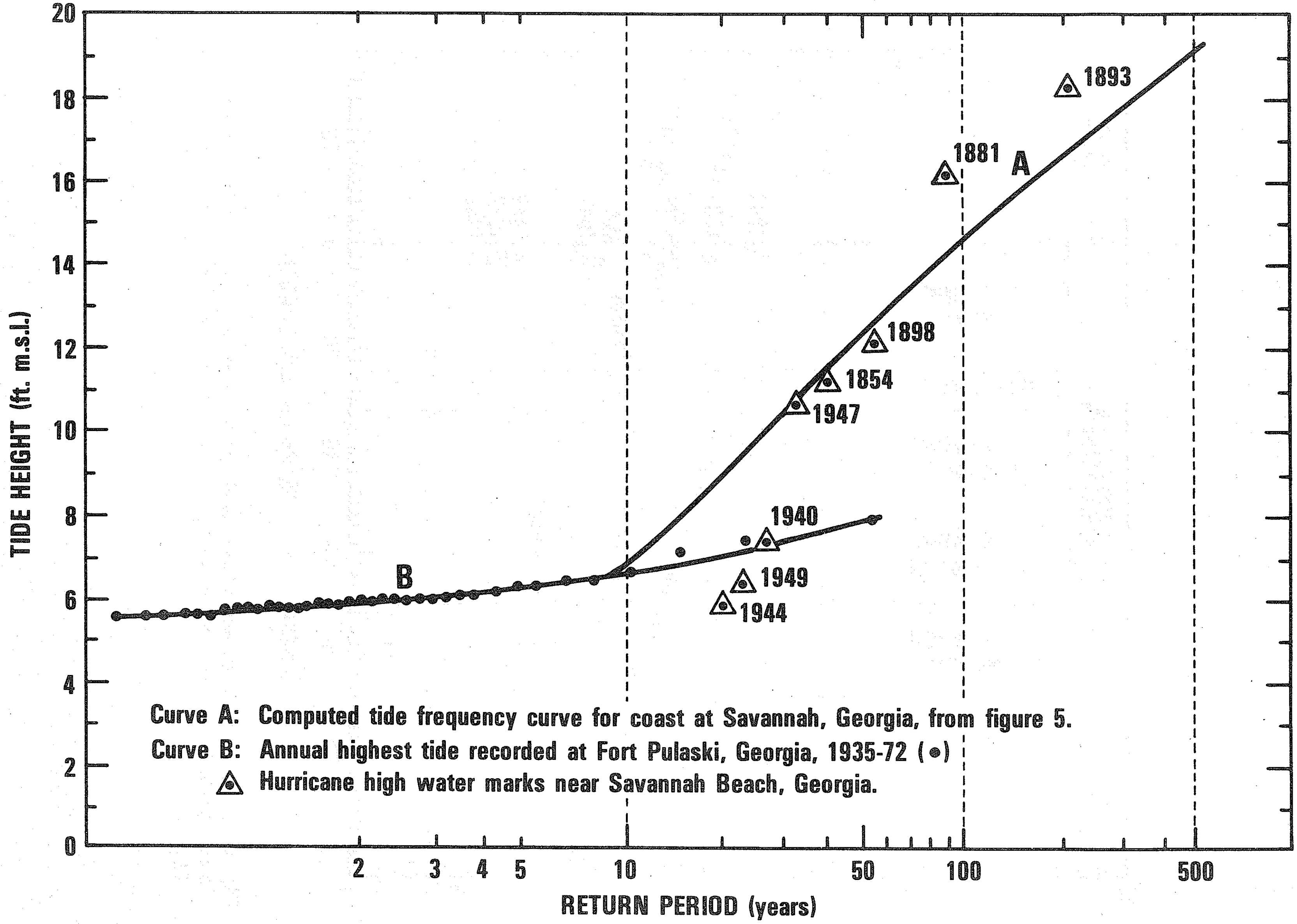

Figure 8.--Comparison of tide frequency curve.