CEWES-CR-O

MEMORANDUM FOR Commander, U.S. Army Engineer District, New Orleans,
ATTN: CELMN-ED-HC (Mr. Cecil Soileau)
P.O. Box 60267, New Orleans, LA 70160-0267

SUBJECT: LAKE PONTCHARTRAIN STORM SURGE PILOT STUDY

1. Representatives of the U.S. Army Engineer Waterways Experiment Station's (WES) Coastal Engineering Research Center (CERC) met with Mr. Jay Combe of the New Orleans District of the Corps of Engineers. The purpose of the meeting was to discuss the need for additional analyses of the Lake Pontchartrain and Vicinity Hurricane Protection plan. The primary subject of concern was whether the existing elevation of the protective levee system around Lake Pontchartrain and Lake Borgne provides adequate storm surge protection for the New Orleans area. This question stems from two concerns: 1) the design criteria for the Standard Project Hurricane (SPH) has been revised since the original (1966-1967) storm analysis used in the levee design, and 2) Relative changes in the Mean Sea Level (MSL) with respect to NGVD may have impacted the actual elevation of the levees with respect to a MSL related storm surge.

2. A broad scope of storm surge studies were discussed which included not only the Lake Pontchartrain area but also the entire coast of Louisiana. A new hydrodynamic model (ADCIRC), recently developed under the Dredging Research Program, was proposed as the model capable of resolving the complex shoreline and levee geometry in the study area and thus producing accurate storm surge predictions.

3. In order to both identify the need for a comprehensive storm surge study and demonstrate the versatility and accuracy of the model, it was decided that a pilot study be conducted using the ADCIRC model in conjunction with an existing computational grid of the Gulf of Mexico. It was recognized that the present model does not including a wetting and drying capability and that this feature would have to be developed for a comprehensive storm surge study of the area. The pilot study consists of the following tasks:

a. Improve resolution of the existing computational grid of the Gulf of Mexico in the area of Lake Pontchartrain to better resolve the connection between Lake Borgne and Lake Pontchartrain.

b. Examine model performance in reproducing tidal behavior in Lake Pontchartrain.

c. Develop storm data sets for the 1966 and present standard project hurricane (SPH) parameters along two critical tracks (A

Encl 5

and C) for simulation using the Planetary Boundary Layer (PBL) windfield model.

d. Determine the impact on flood stage in Lake Pontchartrain of using these different storm parameters by examining the difference between stages produced by the old and new SPH specification for each of the critical tracks.

e. Perform a desk study analysis of tidal behavior and datums (NGVD, mean sea level, etc.) for Lake Pontchartrain and recommend an approach for referencing flood stages to the project.

f. Provide a letter report of the study.

4. The following sections address each of the above items.

A: MODEL RESOLUTION

The ADCIRC model has been used in a pilot study of tidal elevations over the entire Gulf of Mexico and tidal currents within the Mississippi sound area. However, the computational grid used for this study contained a coarse representation of the Lake Pontchartrain and Lake Borgne regions. Therefore, a significant increase in grid resolution was provided for the areas of interest. Figure 1 shows the resulting computational grid of the entire Gulf of Mexico while Figures 2 and 3 show two levels of magnification of the grid in the study area. Note in both figures the inclusion of Chef Menteur Pass.

B: TIDAL VERIFICATION

The resolution of the numerical grid was progressively increased until the model satisfactorily reproduced prototype tidal water surface elevation data in the area of interest. Although a final grid would also require acceptable verification of tidal currents and storm surge elevations, the tidal elevation criteria was considered sufficient for this pilot phase of the study.

Two levels of tidal verification were performed for the model. First, the tidal elevation verification achieved by the pilot Gulf of Mexico (Westerink and Luettich 1991) study was reproduced in order to verify that boundary conditions were correctly implemented in the model. In this reverification effort, the model was driven by a tidal elevation time series at the Yucatan Channel and the Strait of Florida (Figure 4). Surface elevation time series were archived for 20 locations shown in Figure 4 within the Gulf of Mexico for which tidal constituent data were available. An acceptable verification of elevations was achieved at all locations, identical to the original study.

The prototype data time series used to drive the model and used to compare to computed time series at each gage location was reconstructed from published tidal amplitudes and epochs for the K_1, O_1, P_1, M_2, and S_2 tidal constituents. Example comparisons for the Southwest Pass and Bay St. Louis gages are shown in Figures 5 and 6.

The second phase of the tidal verification was to compare tidal elevations in the Lake Pontchartrain and Lake Borgne areas. Tidal constituent data for this purpose was available from the original Lake Pontchartrain study performed by WES (Outlaw 1982). Gages B-1, B-2, B-4, B-5, and B-6 in Lake Borgne and gages P-1, P-2, and P-7 in Lake Pontchartrain were selected for these model-to-prototype comparisons. Gages locations are indicated in Figure 7. An acceptable verification at all gage locations was achieved as shown in the comparisons of Figures 8 through 15.

C: DESIGN STORM TRACK CRITERIA

The third task of the study was to prepare storm track input data for the PBL model. Tracks selected for this input were the historical tracks A and C used in the 1966 and 1967 study conducted by the New Orleans District. These tracks are shown in Figures 16 and 17. Both storm tracks were derived from the 1915 hurricane of record. Input data for the PBL model were prepared by analyzing the National Hurricane Center HURRDAT tape which contains the track, central pressure and maximum velocity of all severe tropical storms along the east coast, Gulf of Mexico, and Caribbean Sea during the period of 1886 to present. The track of the 1915 event was shifted and the speed of the storm adjusted to correspond to the specified design tracks A and C. The total storm event for both tracks A and C are shown in Figure 18.

The original storm surge study conducted by the District specified the following hurricane parameters:

CPI Index:	27.6 inches (934.7 mb)
Radius to maximum winds:	30 nautical miles
Forward speed:	Track A - 6 knots
	Track C - 5 knots
Maximum wind velocity:	100 mph
Peripheral pressure:	29.91 inches (1013 mb)

The above criteria were extracted from the original design memorandum prepared by the New Orleans District (CE 1966, 1967). The Central Pressure Index (CPI) and maximum velocity values were based on 1959 SPH guidance (Dept of Commerce 1959). These criteria have since been updated and now indicate that a CPI index of 27.3 inches (925 mb) is a more representative central pressure criteria for the region. This updated criteria, published in EM 1110-2-1412 (CE 15 April 1986) is shown in Figure 19. Because the lower central pressure can produce a greater surge elevation, two additional updated storm tracks were prepared which reflected the reduced pressure of 925 mb. A far field pressure of 29.91 inches (1013 mb), corresponding to standard atmospheric pressure, was specified for all simulations. With the exception of the central pressure; the track location, forward speed, and far field pressure were unchanged. For both the historical (referred to as A66 and C66) and revised (A86 and C86) events, the CPI was increased by 1 mb per hour after the approximate time of landfall.

The purpose of developing historical and updated storm track data was to determine whether the new SPH criteria (27.3 mb) would produce a measurably larger surge elevation in the Lake Pontchartrain and Lake Borgne areas. The following section describes those comparisons.

D: FLOOD STAGE COMPARISONS

The storm event time history prepared in section C was input to the PBL windfield model and a time history of the pressure field and wind field distribution was computed for the entire event. Total duration of the storm was approximately 9 days, beginning in the eastern Caribbean Sea and terminating at the study area as shown in Figure 18.

In addition to the gage locations used in the tidal verification, four additional gages were located along the south shore of Lake Pontchartrain. These gages, shown in Figure 20, were included to provide surge level comparisons for the critical south shore area just north of New Orleans.

Water surface time series for all gages for tracks A66, C66, A86, and C86 are included at the end of this letter report. Figure 21 presents an overview of the peak water level results for all four simulations. A summary of the results is shown in Figure 22 in which the increase in storm surge resulting from the 1986 criteria is shown for both tracks A and C. As shown, the lower CPI produces a 1 to 2 foot higher surge elevation. Although some of these values would be reduced if the effects of flooding (i.e., wetting and drying) were accounted for, results are consistent in indicting a surge increase of a foot or more.

In order to test the sensitivity of the surge computations to water depth, a simulation was made in which the depth over the entire computational grid was increased by 0.5 m. The storm corresponding to track C86 was used for this simulation. Results are, in general, similar to the MSL computations with some reductions in peak elevation reflected at locations where high wind occurs over a large fetch, for example gages B-1, B-2, P-7, and P-8. This reduction may be due to a reduced shoaling effect. Table 1 provides a summary of the results for all simulations.

One additional simulation was requested by the District to test the accuracy of the model. This simulation represents the propagation and landfall of Hurricane Andrew which made landfall west of New Orleans in August 1992. The track of Hurricane Andrew is shown in Figure 23. A summary of the computed maximum surge elevation is shown in Figure 24.

Table 1 Maximum surge elevations for constant far field pressure criteria

Gage	A66 p_{far} 29.91 (ft MSL)	A86 p_{far}=29.91 (ft MSL)	C66 p_{far}=29.91 (ft MSL)	C86 p_{far}=29.91 (ft MSL)	C86+0.5 m p_{far}=29.91 (ft MSL)
B1	15.0	17.0	9.7	11.7	11.4
B2	13.0	14.7	10.0	12.0	11.9
B4	12.0	13.8	10.5	12.2	12.6
B5	15.1	17.4	11.5	13.5	13.7
B6	11.7	13.3	6.8	7.7	8.2
P1	7.9	9.5	4.2	4.9	5.3
P2	4.5	5.2	5.4	6.4	6.8
P7	2.0	>2.0	10.6	13.1	12.5
P8	2.0	>2.0	10.9	12.9	12.3
C1	10.8	12.4	11.9	13.9	13.1
C2	8.7	10.1	6.8	7.8	7.8
C3	6.6	7.7	3.5	4.0	4.1
C4	6.5	7.7	3.7	4.0	4.4

A final set of simulations was requested by the District to reflect differences in the far field pressure between the original study and the new criteria. Therefore, a far field pressure of 30.12 inches (1020 mb) and a central pressure of 27.6 inches (935 mb) was specified for the original storm criteria. The new storms tracks were specified to have a far field pressure of 29.77 inches (1008.2 mb) and a central pressure of 27.3 inches (925 mb). The resulting pressure deficit (far field minus central pressure) for the old and new criteria are practically identical. For example, δp_{old}=2.52 inches and δp_{new}=2.47 inches. Because hurricane winds, and therefore surge, are a function of pressure deficit, the computed surge elevations are nearly identical. A summary of computed surge levels are shown in Table 2. As discussed above, the computed elevations are equivalent due to the fact that the old and new pressure deficit criteria are nearly identical.

E: ANALYSIS OF TIDAL DATUMS

Three tidal datums in the Lake Pontchartrain area impact this pilot study. The first is the 1929 National Geodetic Vertical Datum (NGVD) which was established to provide a common

Table 2 Maximum surge elevations for revised far field pressure criteria

Gage	A66 p_{far} 30.12 (ft MSL)	A86 p_{far}=29.77 (ft MSL)	C66 p_{far}=30.12 (ft MSL)	C86 p_{far}=29.77 (ft MSL)
B1	16.4	16.0	11.1	10.8
B2	14.2	13.9	11.4	11.1
B4	13.4	13.1	11.7	11.4
B5	16.7	16.4	13.0	12.7
B6	12.8	12.5	7.4	7.3
P1	9.0	8.7	4.7	4.6
P2	5.0	4.9	6.1	5.9
P7	1.4	1.5	12.4	11.9
P8	1.5	1.6	12.4	12.0
C1	12.0	11.7	13.3	12.9
C2	9.7	9.5	7.5	7.3
C3	7.4	7.2	3.8	3.7
C4	7.4	7.2	3.9	3.8

reference datum across the United States. The 1929 NGVD is based on the assumption that mean sea level (MSL) and NGVD are equal and identically zero at 26 locations across the United States. The Biloxi, MS gage was one of those primary tide stations used in the establishment of the datum. Therefore, in 1929, the value of MSL and NGVD in the Lake Pontchartrain area was 0.0 ft. One important assumption concerning the NGVD datum is that it never changes, although the relationship of other datums to NGVD may change as a result of either sea level change, land subsidence, or both. The second datum of importance is MSL because tidal and storm surge computations are made relative to MSL.

A third datum is the Gulf Coast Low Water Datum (GCLWD) which was adopted by the NOAA in 1977. This datum is defined as mean lower low water (MLLW) in areas of mixed tide and mean low water (MLW) in areas where the tide is diurnal. The tides in the Lake Pontchartrain area are diurnal, therefore the GMLLW was originally set equivalent to MLW for the Lake Pontchartrain area. The GMLLW was used as the reference datum for bathymetry used on all NOAA charts in the Gulf of Mexico. These datums are used to determine the bathymetry for the numerical modeling effort. The relationship between the two is that GCLWD is 0.62 ft below MSL (at Mobile, AL, p. 65 Harris 1981; p. 2-37 CE 7 July 1989). The GCLWD has now been replaced by the MLLW datum (Combe 1993), therefore MLLW is 0.70 ft below MSL (Harris 1981, CE 7 July 1989).

The relationship between datums of concern to this study are as follows. Construction of the levee is referenced to NGVD however, because storm surges are referenced to MSL, the levee elevation should be referenced to MSL. The assumption used in the original flood protection project was that MSL was equal to NGVD. This assumption was correct according to the original concept of the 1929 NGVD datum, however, the relationship between sea level and NGVD in the Lake Pontchartrain area has been documented to be continuously changing. The relative sea level change values shown in Table 3 have been documented over the period of 1931-1977 (Penland 1989). Locations of the gages are shown in Figure 25.

Table 3 Relative Sea Level Change

Gage Location	Rel Sea Level Ch (MSL-NGVD)
Frenier	0.4 cm/yr
West End	0.4 cm/yr
Little Woods	1.0 cm/yr
South Shore	1.0 cm/yr
Mandeville	0.5 cm/yr

As indicated in Table 3, either sea level has risen with respect to NGVD or there has been subsidence in the land. In either case, the crests of the levee system are lower with respect to MSL than they were in 1929. If a change of 0.5 cm/yr is assumed average, the crest of the levee is approximately 1.0 foot nearer to MSL than it is to NGVD, i.e., NGVD is now approximately 1.0 foot below MSL. Therefore, if the design freeboard for the levee system is x-ft, then the levee should be constructed to x + 1.0 ft NGVD.

In response to the final question concerning recommendations for a reference datum, we would recommend the use of MSL because both tidal elevations and the storm surges are relative to this datum. For example, computationally, the ocean is assumed calm and the storm event perturbs the water surface from that equilibrium position. The relative sea level change data given in Table 3 can be used to relate MSL to NGVD for future design and construction criteria.

5. Conclusions of this study which relate to the two concerns stated in Paragraph 1 are that: 1) the new SPH pressure criteria produces (with equal far field pressures) an increase in surge of

approximately 1.0 - 2.0 feet for the design storm tracks A and C; 2) If the old and new pressure criteria is combined with a far field pressure such that the pressure deficit is equal, there is no difference in the computed surge elevations between the old and new criteria; and 3) MSL has increased with respect to NGVD by approximately 1.0 ft since 1929. Therefore, the overall conclusions of this pilot study are that the elevation of the levee system protecting the City of New Orleans should be reinvestigated. However, the design storm concept as a basis for the design of protective structures should be replaced by statistical procedures which make use of the full (over 100 yrs) data base of historical storms such as the joint probability approach described in EM 1110-2-1412 (CE 15 April 1986) or the empirical simulation technique recommended by CERC.

6. Storm surge propagation is a function of storm track, duration, forward speed and angle, pressure deficit, surface geostropic winds, radius to maximum winds, etc. All factors influence the propagation of the storm and the resulting maximum surge. By selecting a single storm as a design event, one risks the chance of being overly conservative and selecting an event which has a negligible chance of occurring. Conversely, a storm may be selected with a recurrence interval less than anticipated such that several 100-year events occur within a decade or two. Current approaches to design criteria are based on a statistical analysis of historical events, their respective descriptive parameters, and their resulting maximum storm surge elevations. The latter are computed through the use of numerical models such as ADCIRC. The data base of surge elevations and storm parameters are then statistically analyzed to compute local stage-frequency relationships. Because these relationships are based on multiple simulations, each stage-frequency relationship has a variability factor associated with it which provides a measure of risk. This statistical approach is recommended for this study. The methodology is based on the empirical simulation technique or bootstrap approach and has been successfully applied to a storm surge study of Panama City, FL region.

7. In conclusion, our recommendation is that a thorough statistical stage-frequency study of the Lake Pontchartrain and Lake Borgne area should be performed. If possible, a similar study of the entire Louisiana coast should be performed. If you have any questions concerning this report, please contact me at 601-634-3220.

Norman W. Scheffner

Norman W. Scheffner, PhD, PE
Research Division
Coastal Engineering Research Center

REFERENCES:

CE, 1966, "Lake Pontchartrain, Louisiana and Vicinity Design Memorandum No 1, Hydrology and Hydraulic Analysis, Part I - Chalmette," New Orleans District, Corps of Engineers.

CE, 1967, "Lake Pontchartrain, Louisiana and Vicinity Design Memorandum No 1, Hydrology and Hydraulic Analysis, Part II - Barrier," New Orleans District, Corps of Engineers.

CE, 1986, "Engineering and Design Storm Surge Analysis," EM 1110-2-1412 15 April 1986, U.S. Army Corps of Engineers, Washington, DC.

CE, 1989, "Water Levels and Wave Heights for Coastal Engineering Design," EM 1110-2-1414 7 July 1989, U.S. Army Corps of Engineers, Washington, DC.

Combe, Jay, 1993, Personnal correspondence on tidal datums in the Gulf of Mexico.

Dept. of Commerce, 1959, "Meteorological Considerations Pertinent to Standard Project Hurricane, Atlantic and Gulf Coasts of the United States," National Hurricane Research Project, Report NO. 33, November 1959, Washington, DC.

Harris, D.L., "Tides and Tidal Datums in the United States," Special Report No. 7, U.S. Army Corps of Engineers, Coastal Engineering Research Center, Kingman Building, Fort Bolvoir, VA.

Outlaw, D.G., "Lake Pontchartrain and Vicinity Hurricane Protection Plan, Report 1, Prototype Data Acquisition and Analysis," Technical Report HL-82-2, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Penland, Shea, Ramsey, Karen E., McBride, Randolph A., Moslow, Thomas F., and Westphal, Karen A., "Relative Sea Level Rise and Subsidence in Louisiana and the Gulf of Mexico," Coastal Geology Technical Report No. 3, Louisiana Geological Survey, Baton Rouge, Louisiana 1989.

Westerink J.J. and Luettich R.A., "Tide and Storm Surge Predictions in the Gulf of Mexico," Contractors Report prepared for U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

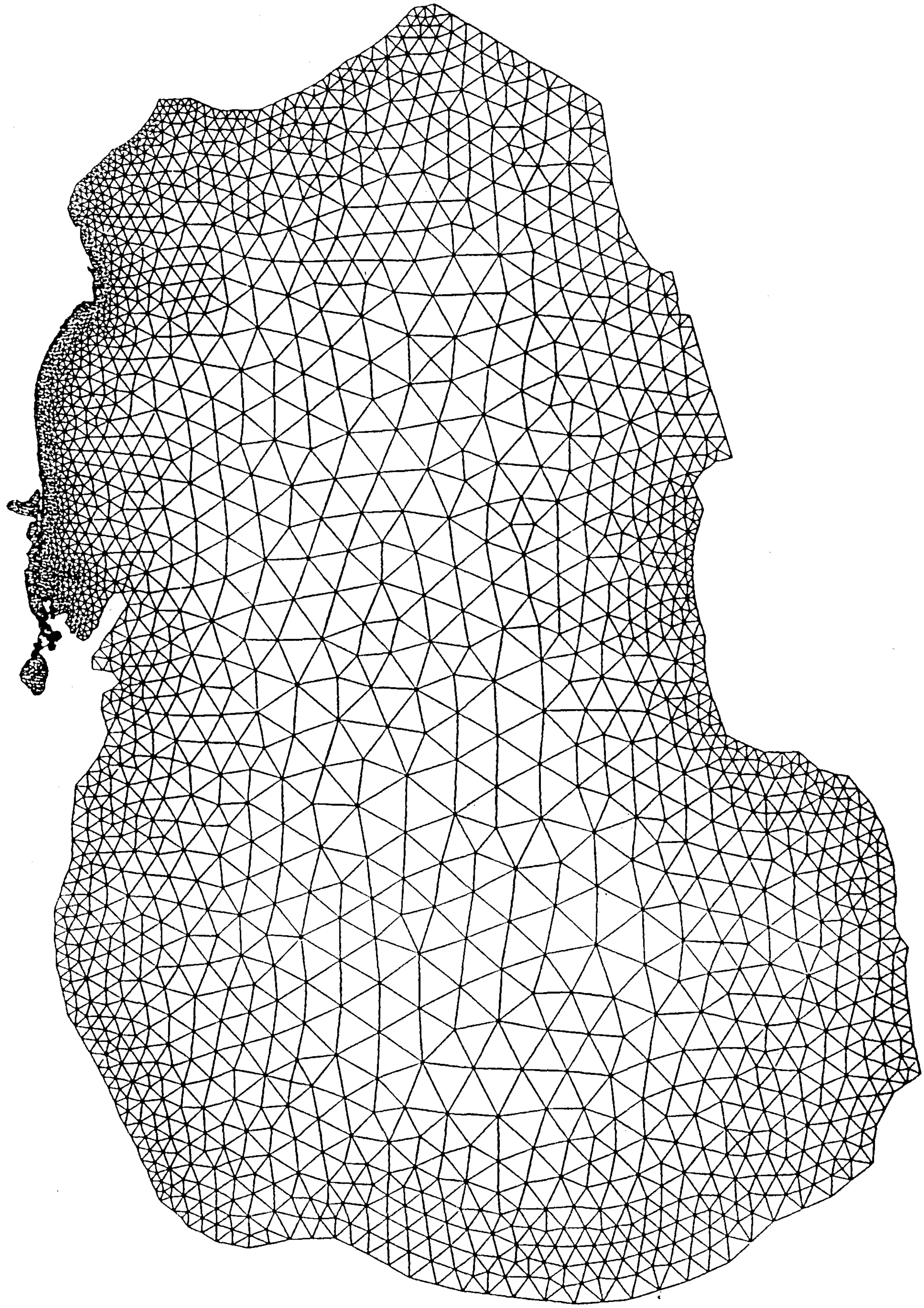


Figure 1 Computational grid

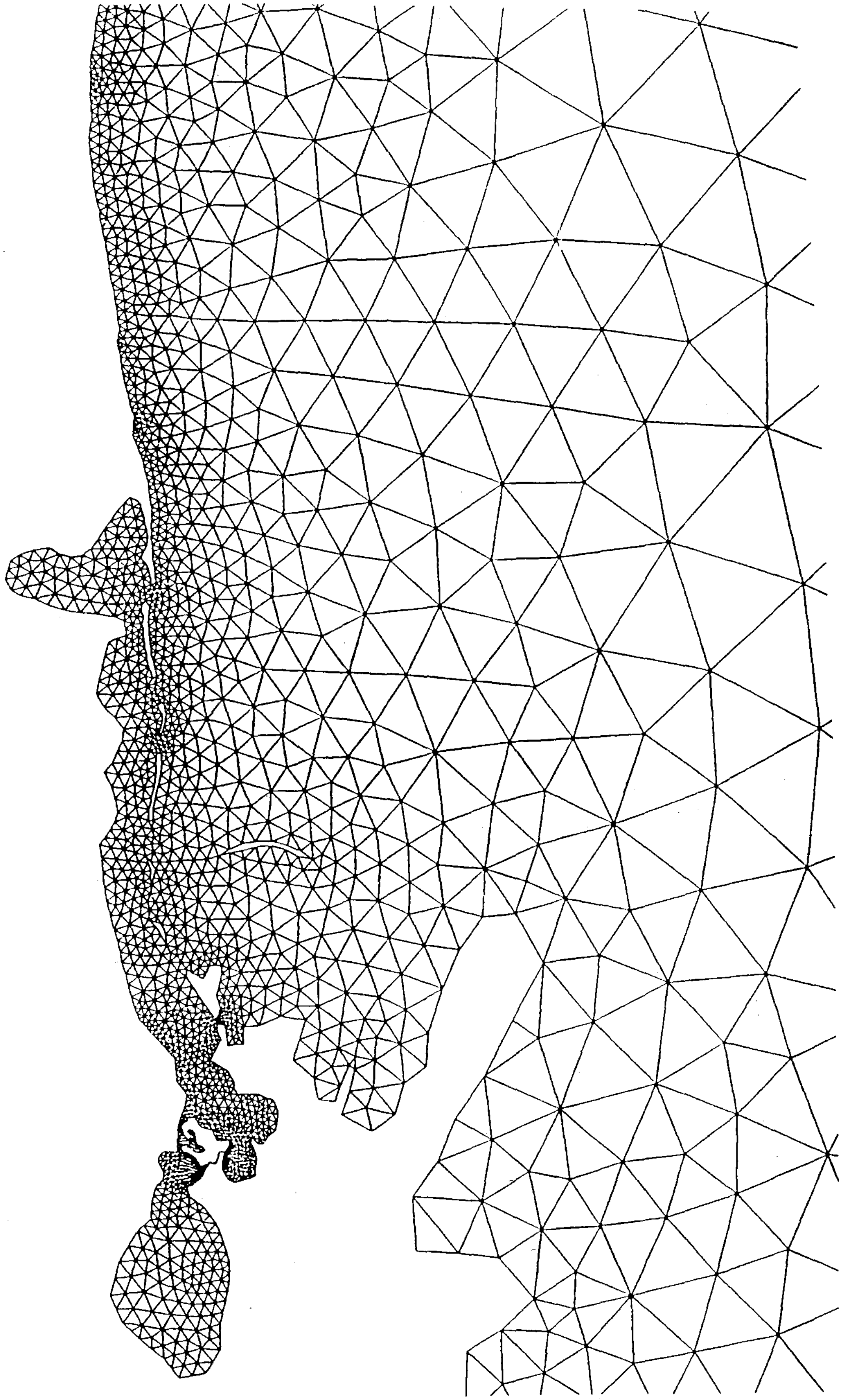


Figure 2 Computational grid - Mississippi Sound area

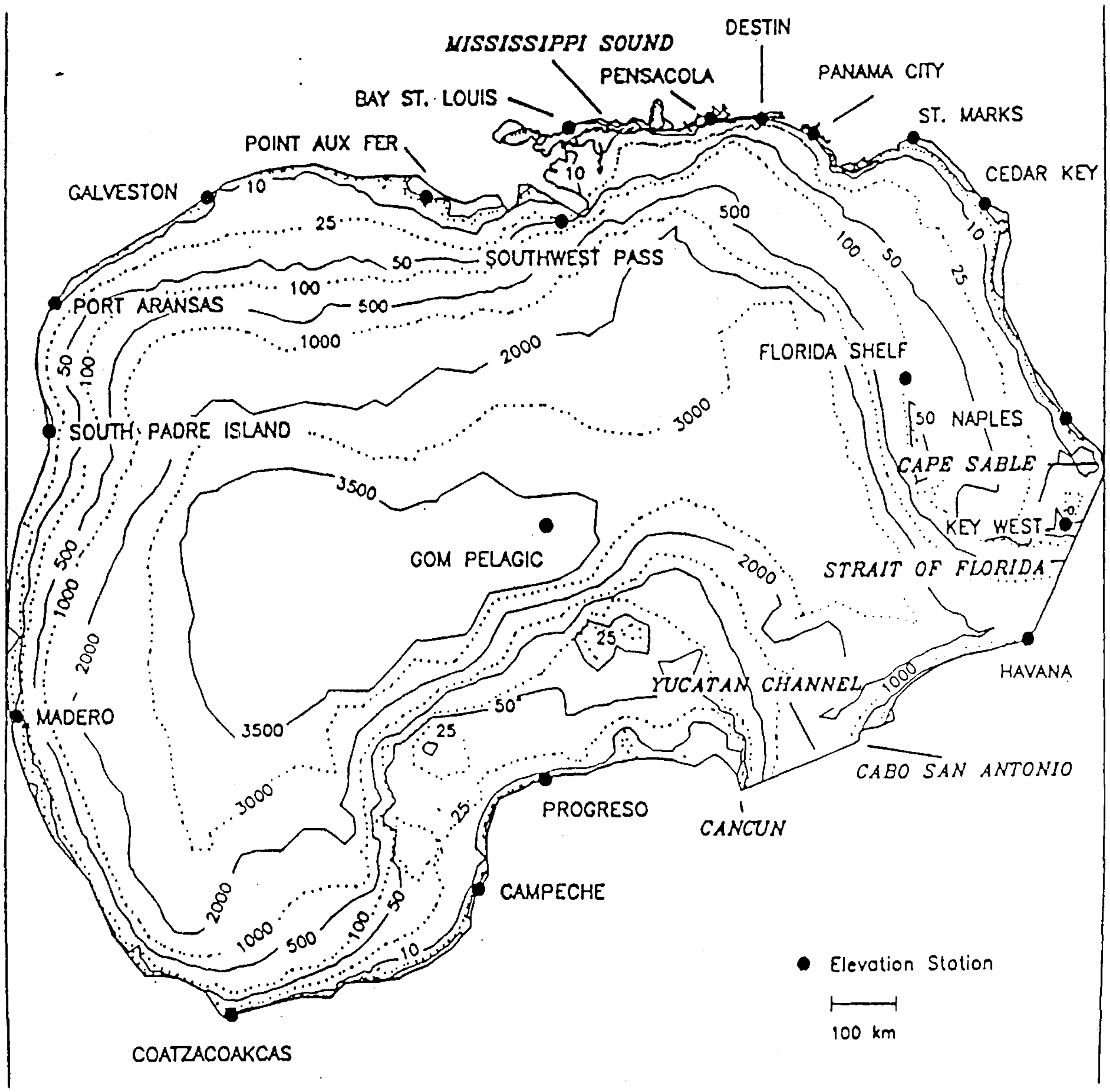


Figure 4 Gulf of Mexico tidal comparison stations

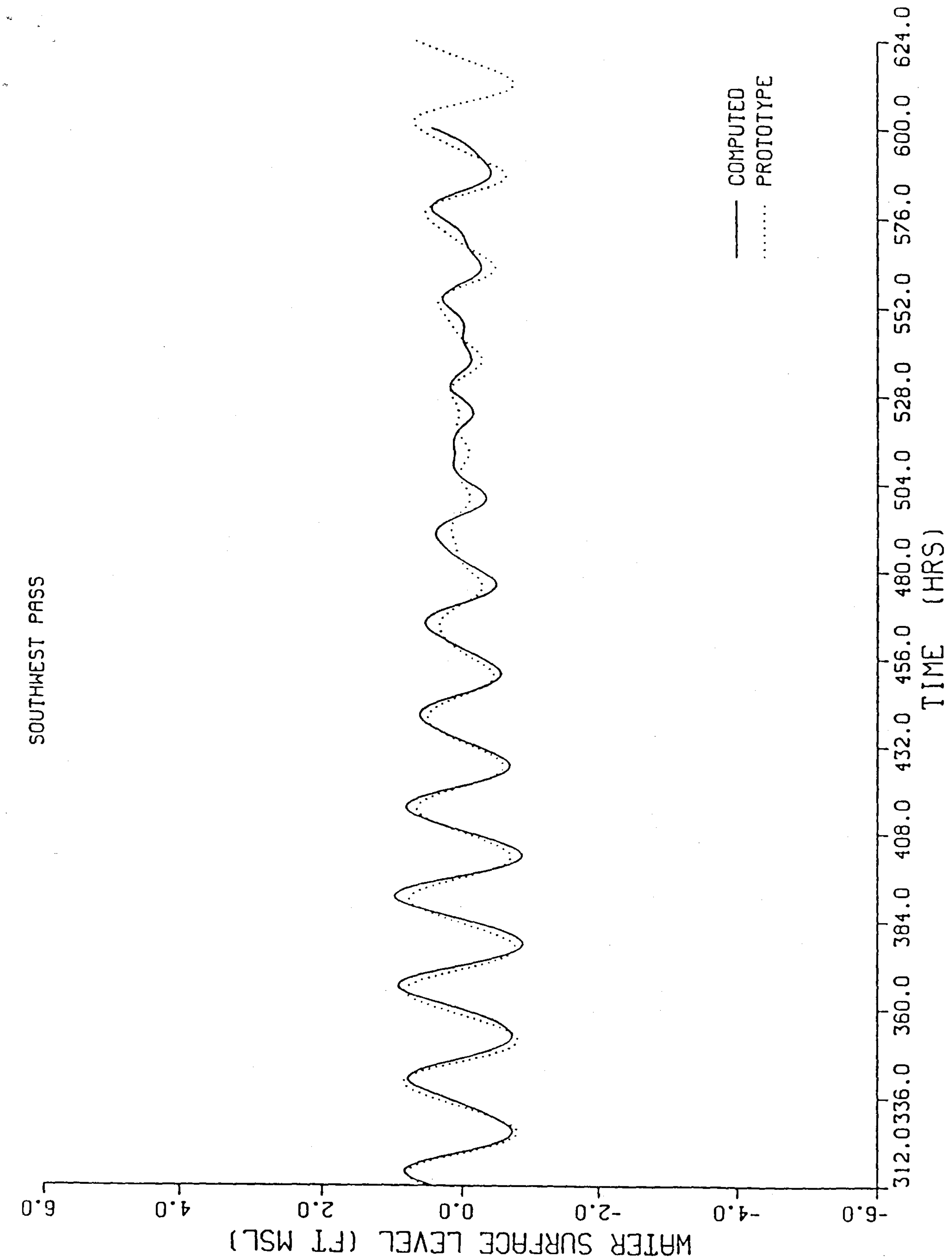


Figure 5 Southwest Pass tidal comparison

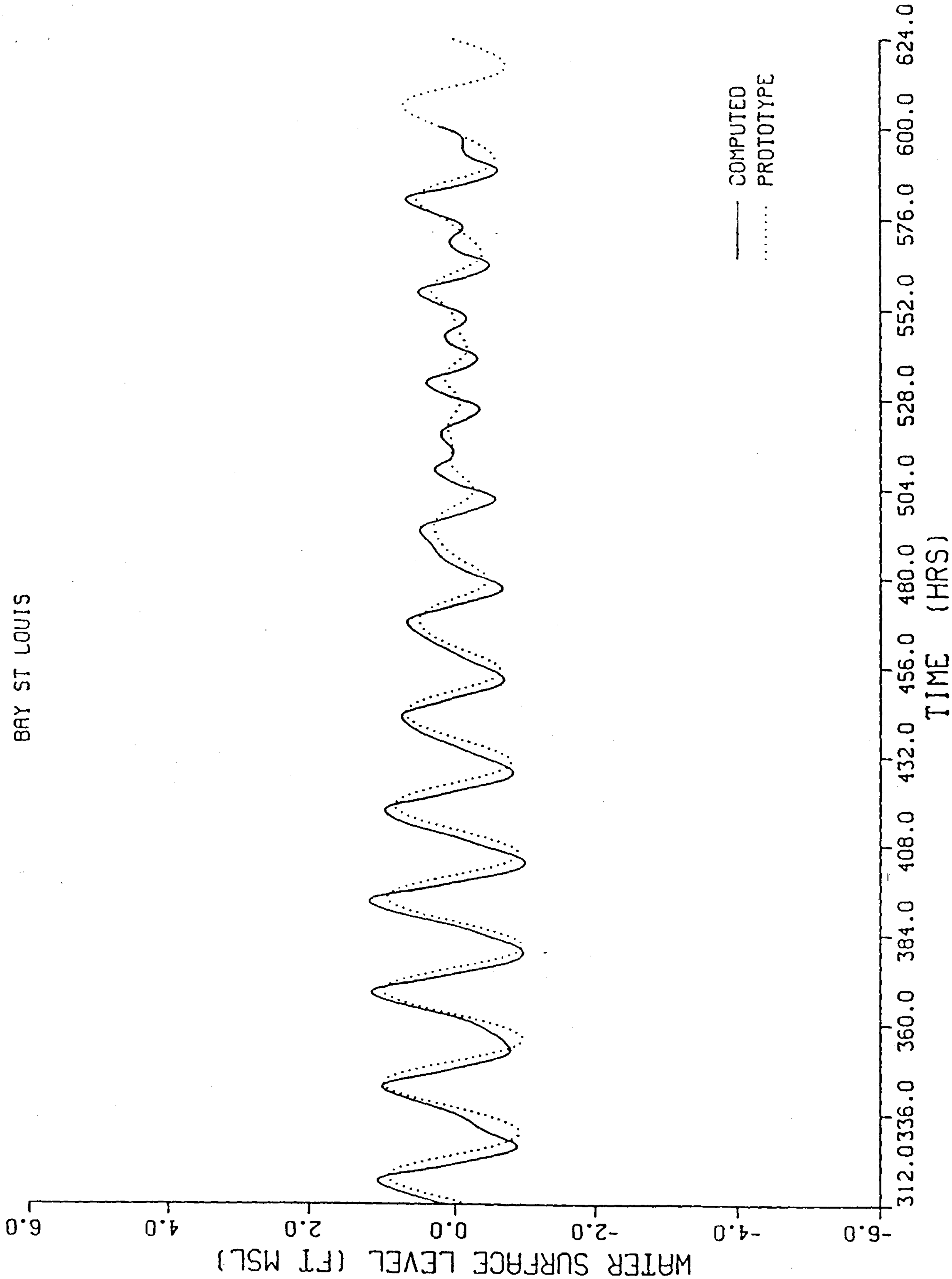


Figure 6 Bay St. Louis tidal comparison

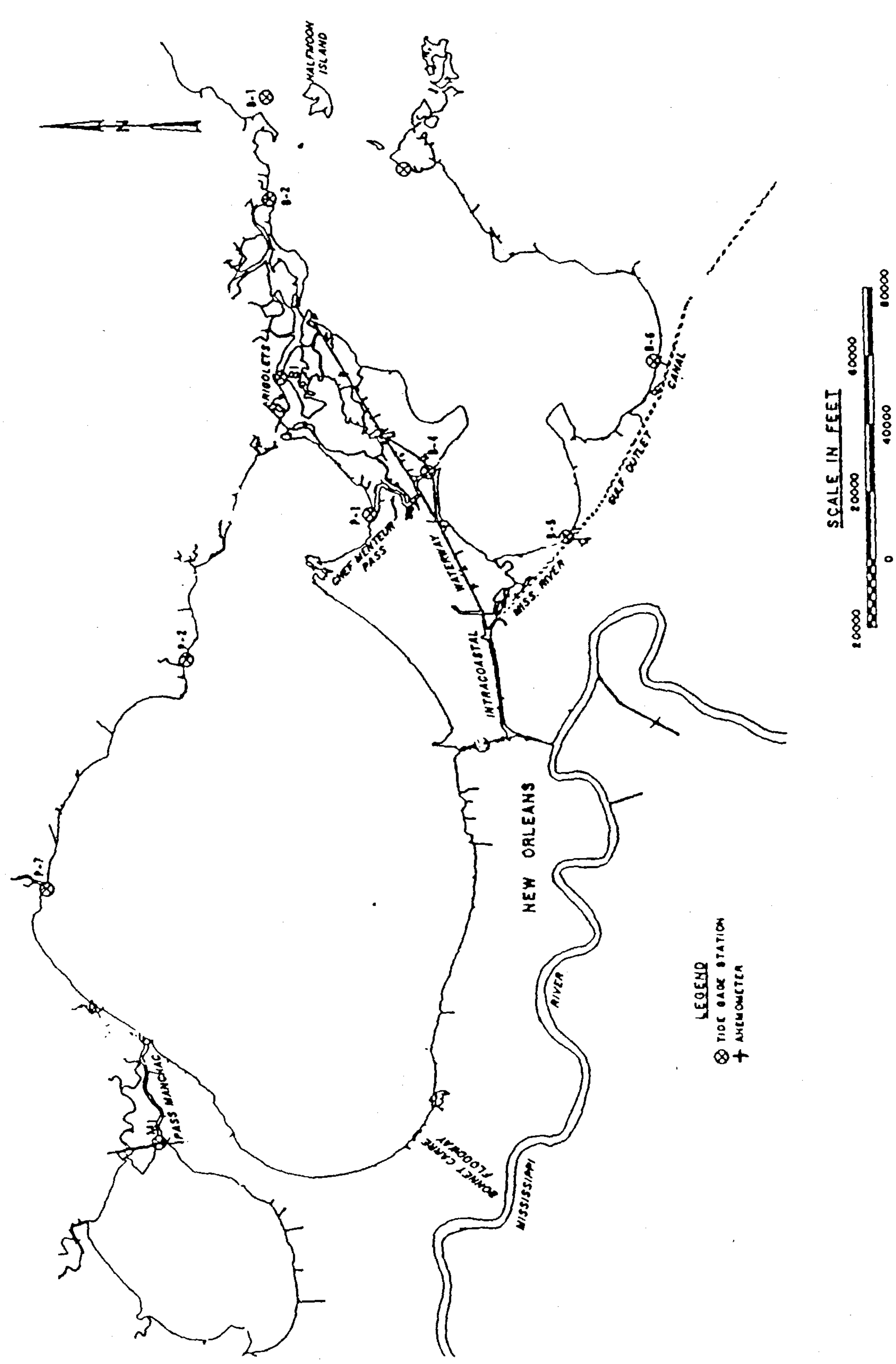
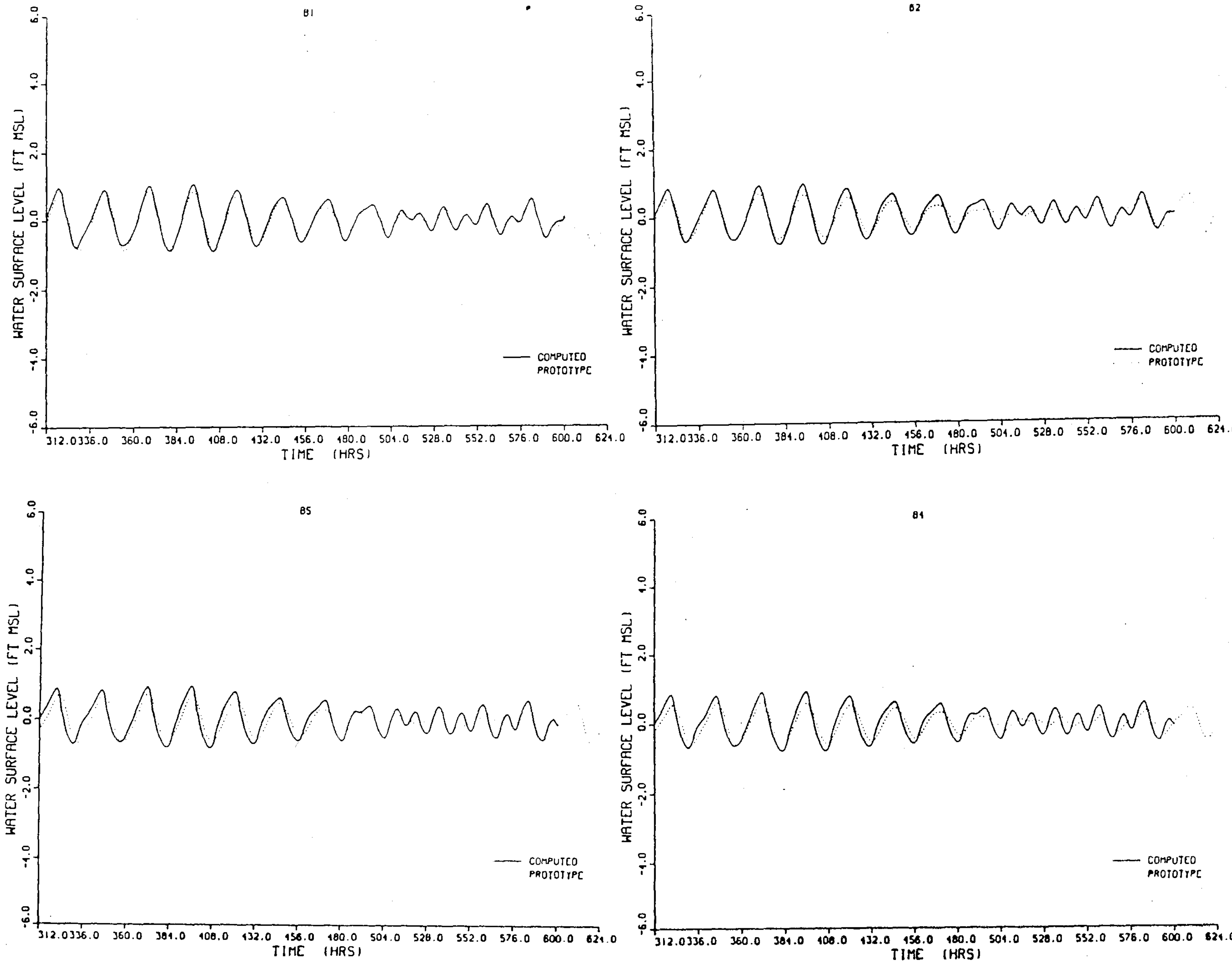
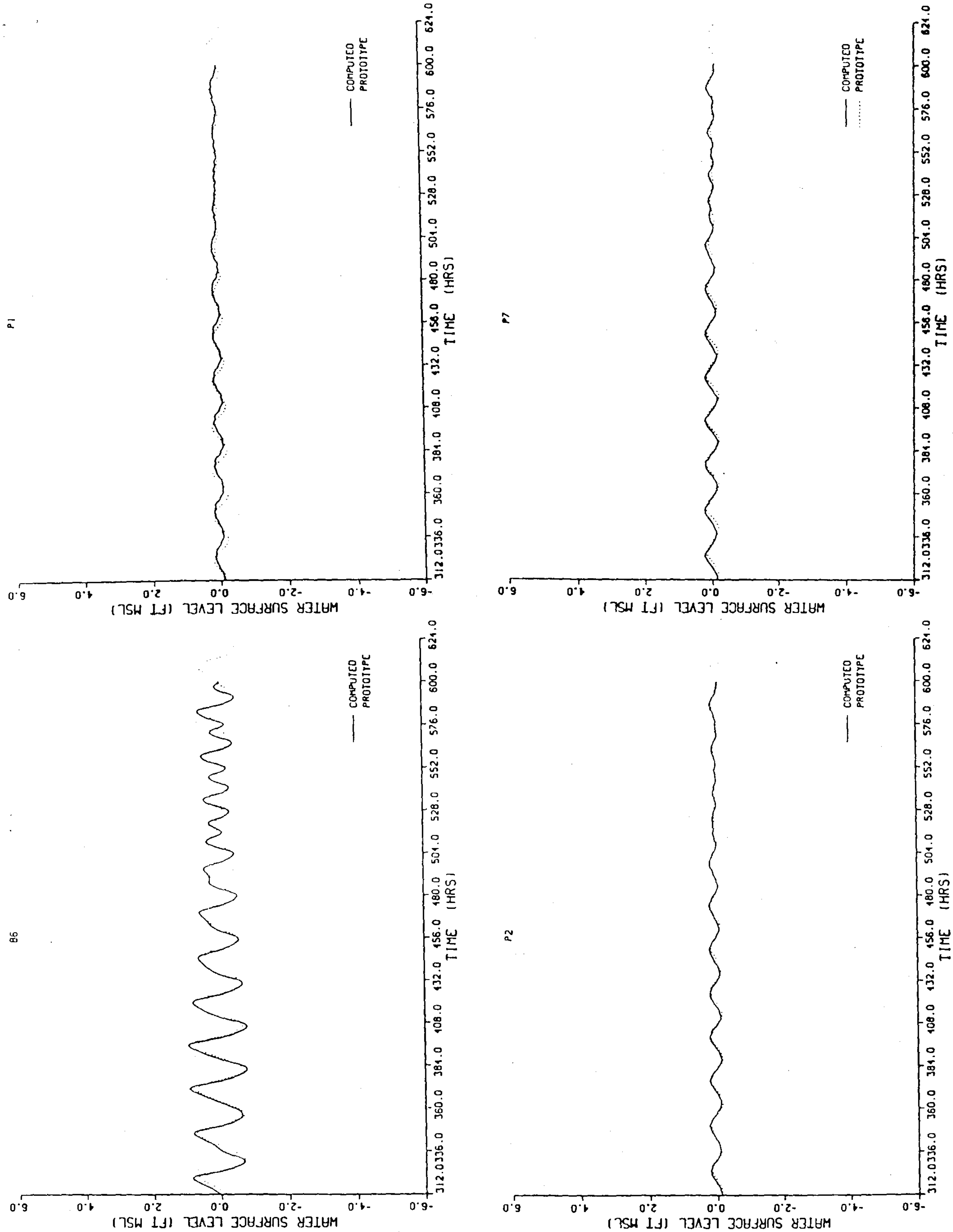


Figure 7 Location of Lake Pontchartrain/Lake Borgne tidal comparison stations



Figures 8-11 Tidal comparisons



Figures 12-15 Tidal comparisons - continued

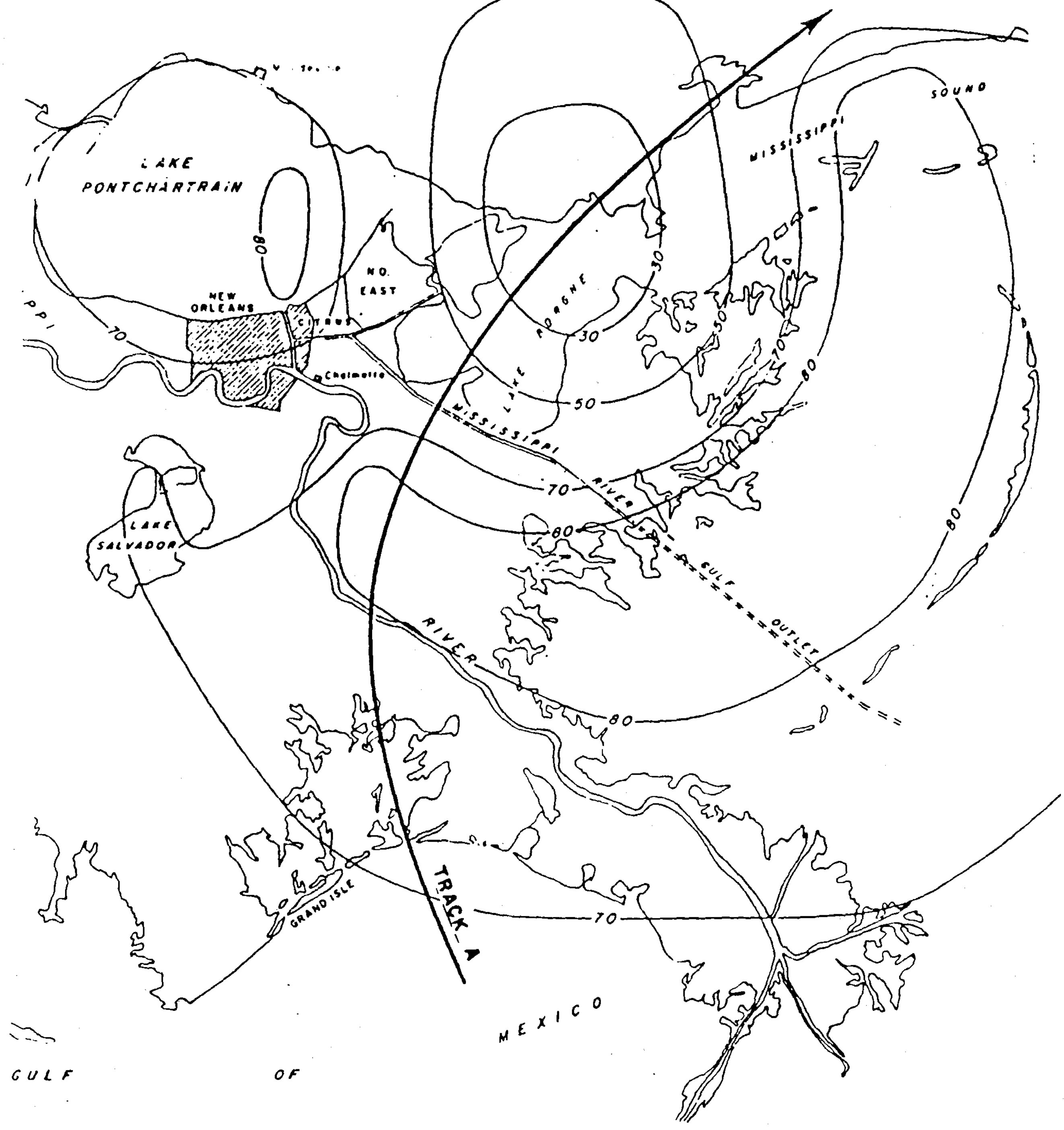


Figure 16 Storm track A

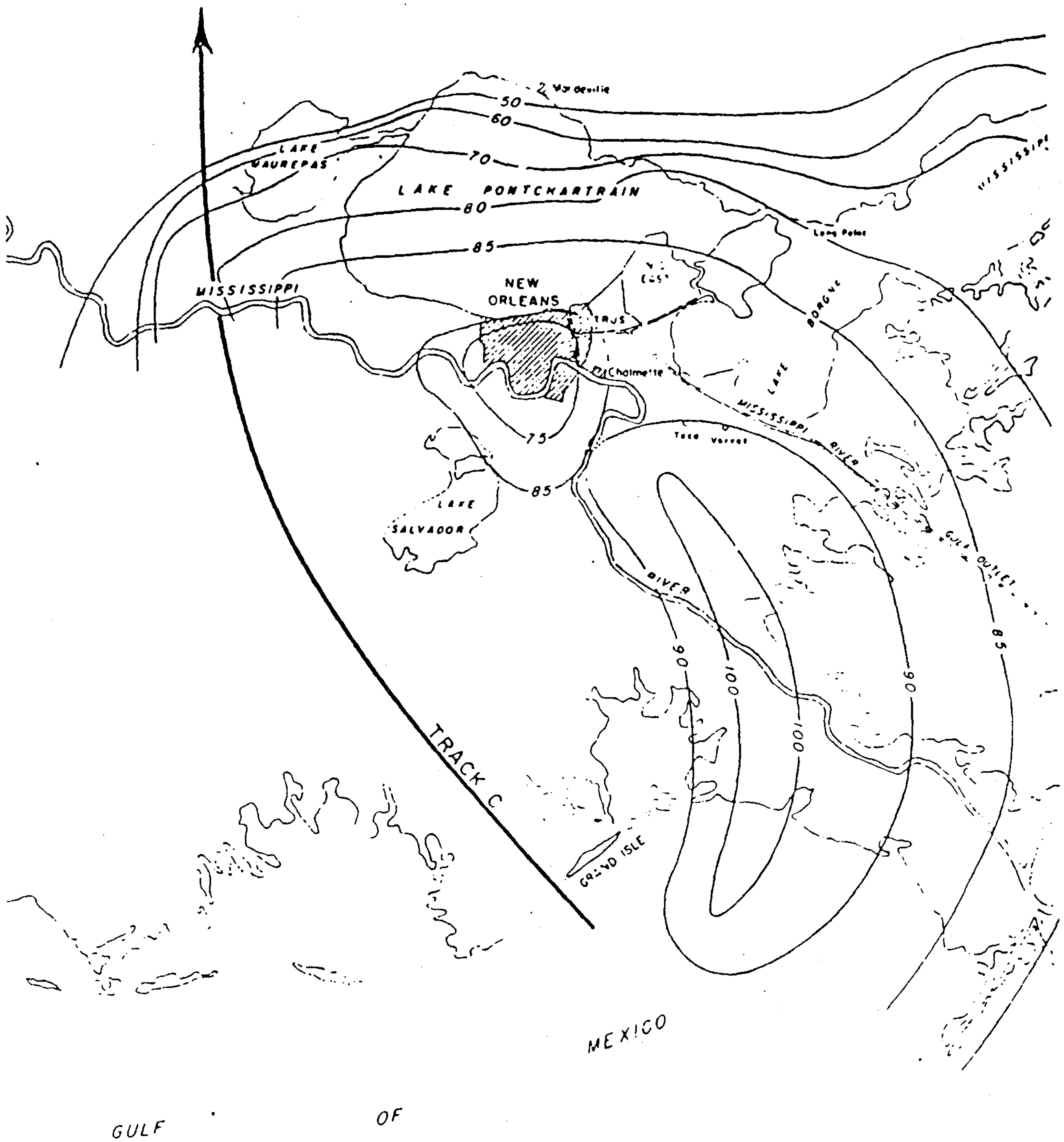


Figure 17 Storm track C

Figure 18 Total storm event path

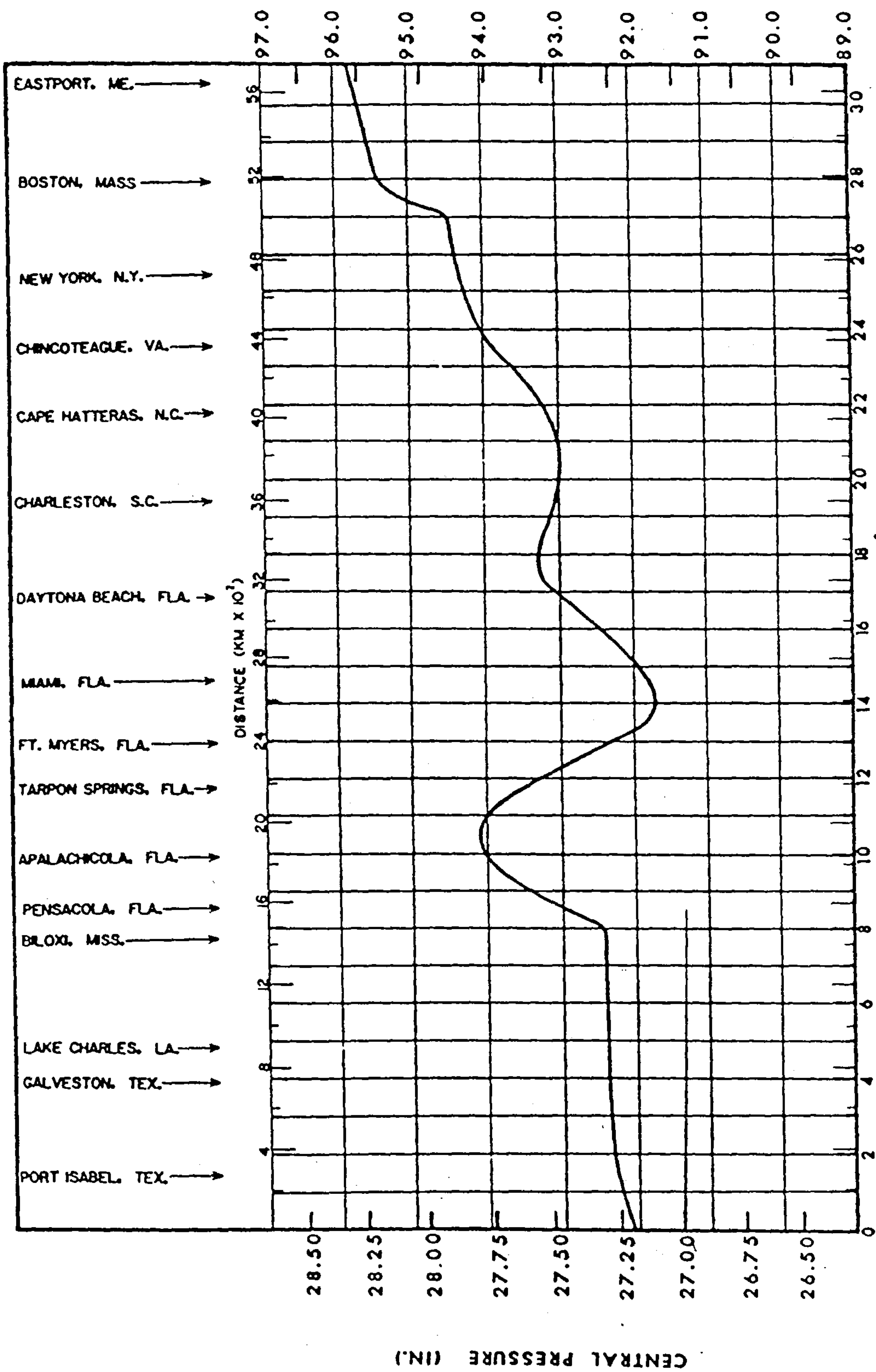


Figure 19 Central pressure along U.S. shoreline

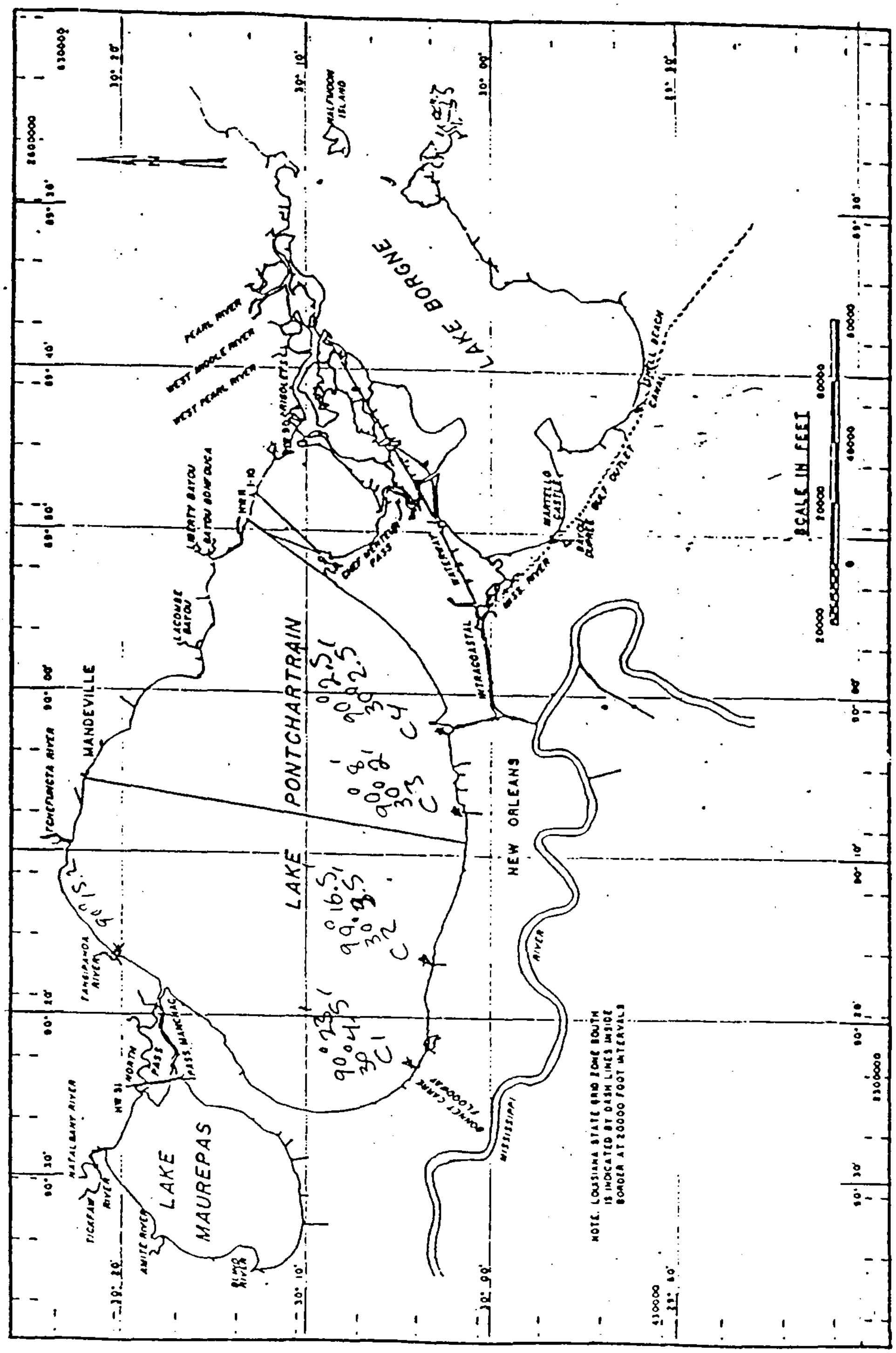


Figure 20 South shore tidal comparison gages

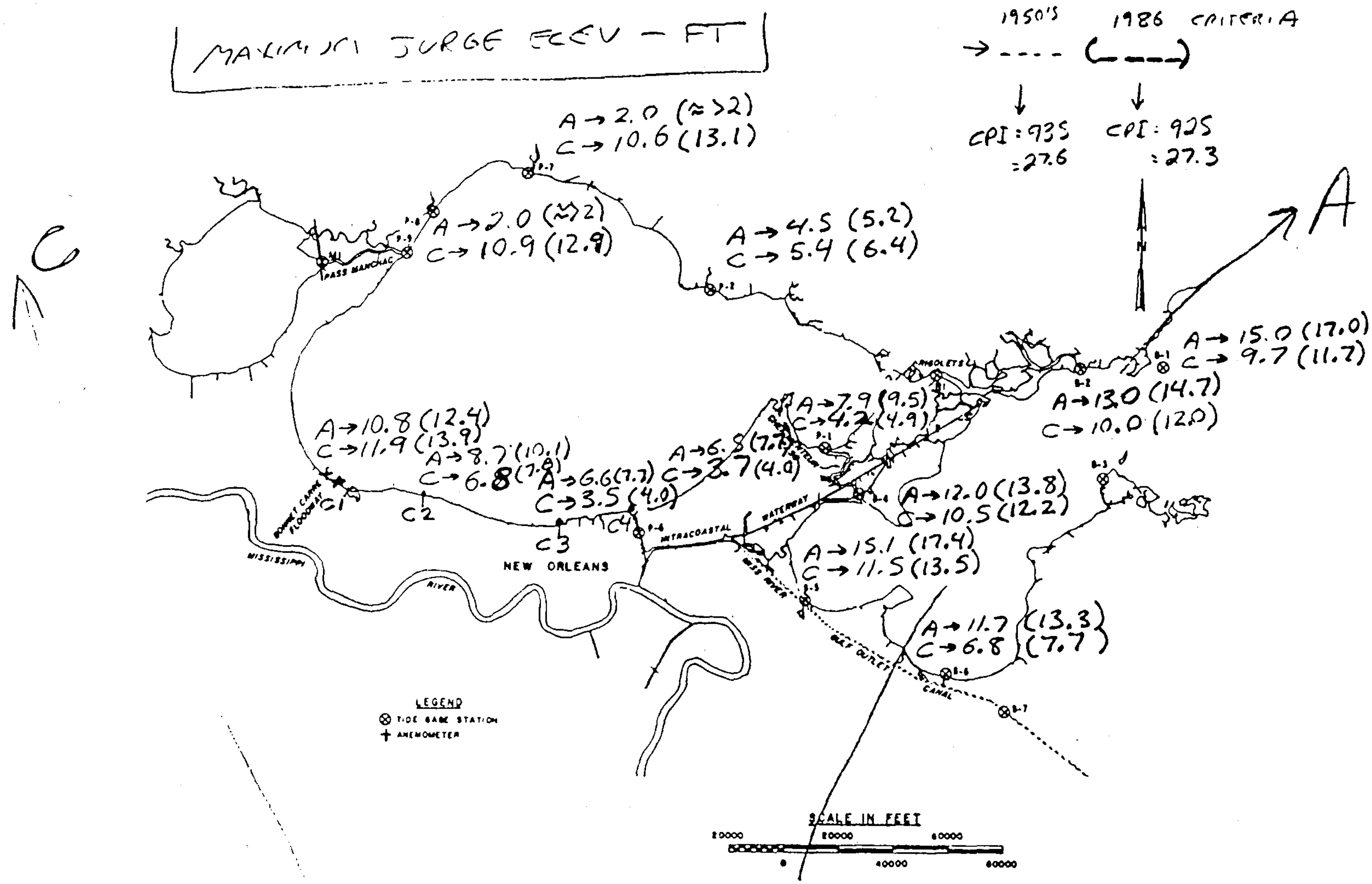


Figure 21 Peak storm surge elevations

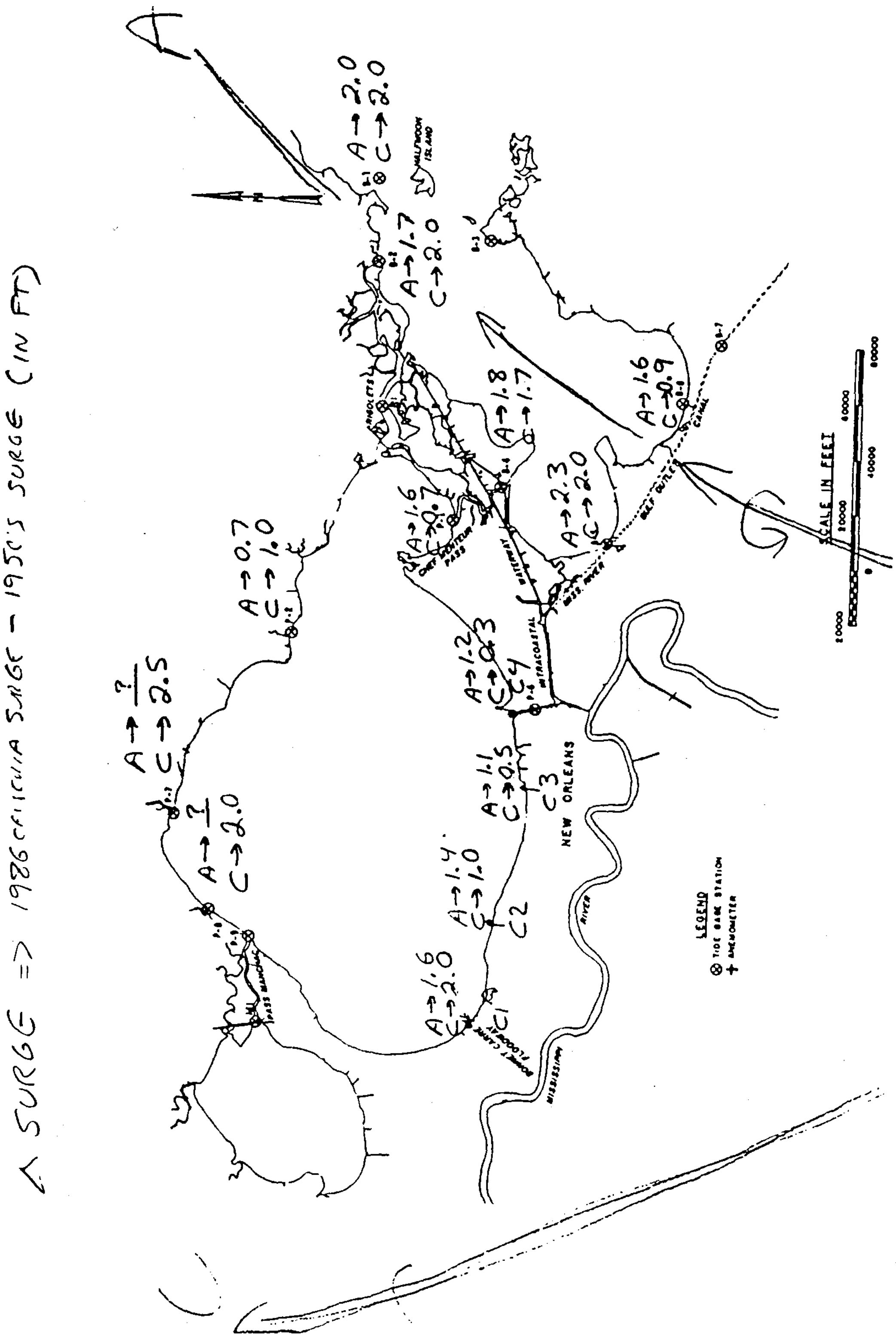


Figure 22 New SPH criteria increase in surge level

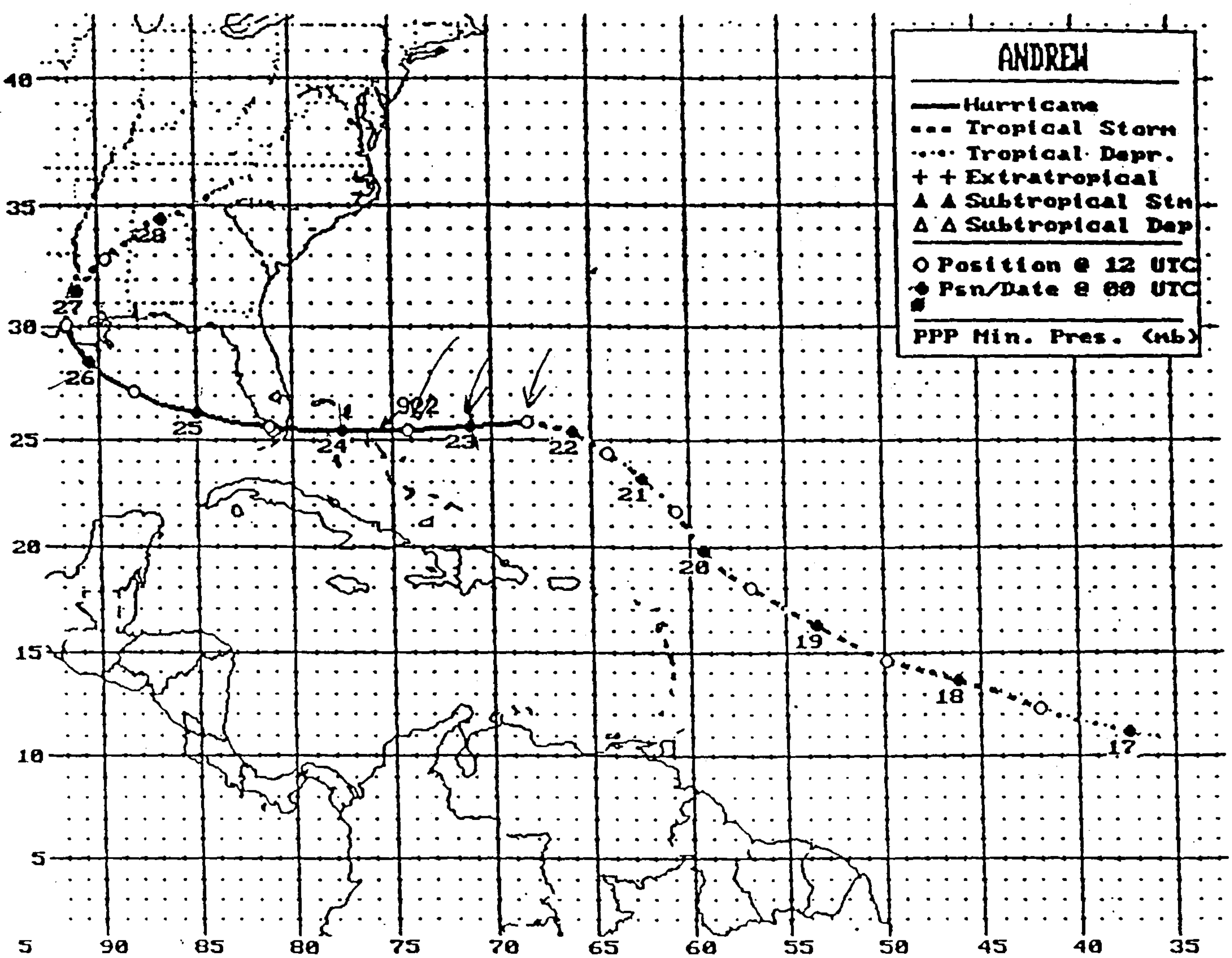


Figure 23 Hurricane Andrew Track

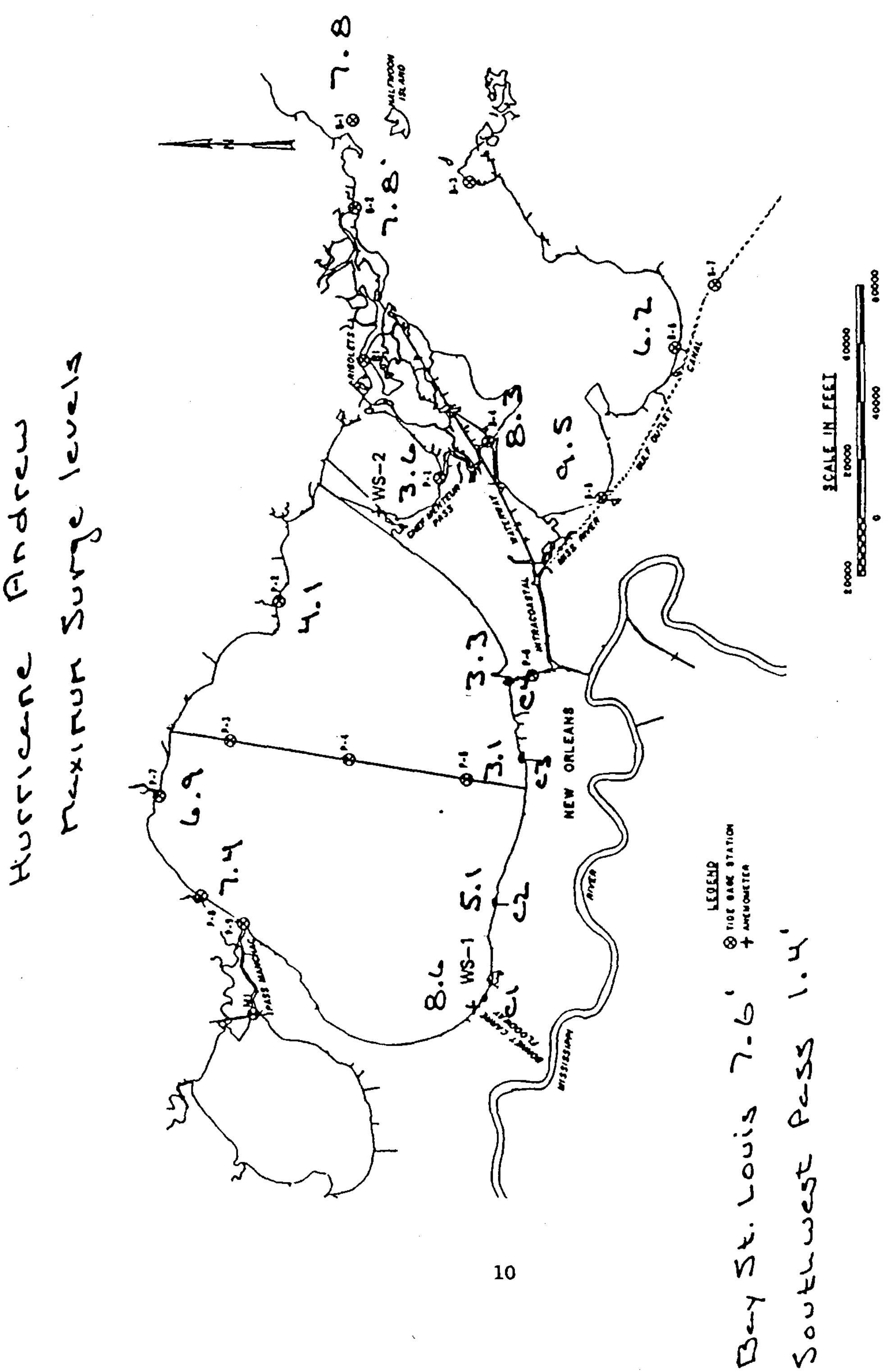


Figure 24 Maximum storm surge due to Hurricane Andrew

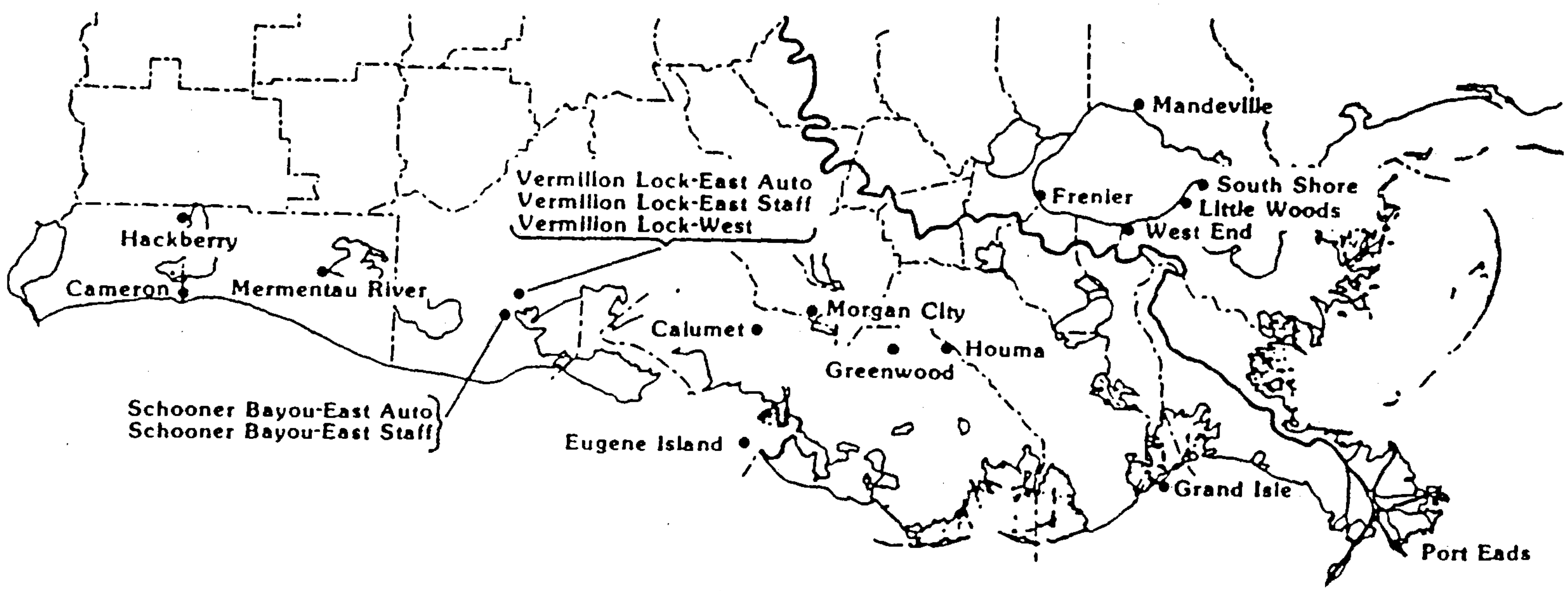


Figure 25 Relative sea level change monitoring stations