EFFECTS ON LAKE PONTCHARTRAIN, LA., OF HURRICANE SURGE CONTROL STRUCTURES AND MISSISSIPPI RIVER-GULF OUTLET CHANNEL

Hydraulic Model Investigation

TECHNICAL REPORT NO. 2-636

November 1963

U. S. Army Engineer Waterways Experiment Station
CORPS OF ENGINEERS
Vicksburg, Mississippi

U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss. EFFECTS ON LAKE PONTCHARTRAIN, LA., OF HURRICANE SURGE CONTROL STRUCTURES AND MISSISSIPPI RIVER-GULF OUTLET CHANNEL; Hydraulic Model Investigation, by I. C. Tallant and H. B. Simmons. November 1963, viii, 43 pp and appendix - illus - table. (Technical Report No. 2-636)

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ARMY-MRC VICKSBURG, MISS.

PREFACE

The model investigations reported herein were approved by the Office, Chief of Engineers, on 18 November 1958 and were authorized by the U. S. Army Engineer District, New Orleans, on 17 December 1958. The Gulf of Mexico Outlet Channel extension to the model was approved by 1st indorsement dated 1 June 1960 to a letter dated 25 April 1960, subject: "Addition of Gulf Outlet Channel to Lake Pontchartrain Model," from the U. S. Army Engineer Waterways Experiment Station to the New Orleans District, and the addition was authorized by the New Orleans District on 19 July 1960. Prototype data were furnished by the New Orleans District during the calendar year 1959 and part of 1960. The studies were conducted in the Hydraulics Division of the Waterways Experiment Station during the period January 1960 to June 1961 under the direction of Mr. E. P. Fortson, Jr., Chief of the Hydraulics Division, and Mr. G. B. Fenwick, Chief of the Rivers and Harbors Branch. The tests were conducted by Messrs. Allen J. Banchetti, James B. Askew, John W. Carsley, and Hubert R. Smith, under the supervision of Messrs. Henry B. Simmons and Irby C. Tallant. This report was prepared by Mr. Tallant with the assistance of Mr. Simmons.

Close liaison was maintained between the New Orleans District, the Waterways Experiment Station, and the U. S. Fish and Wildlife Service which was also concerned with the results of the study. During the course of the study frequent conferences were held and inspections of the model were made by all those concerned to discuss the results of the tests completed and to revise the testing program as needed. Monthly progress reports were also submitted by the Waterways Experiment Station to the New Orleans District, and as tests were completed, the results of tests, in preliminary form, were furnished those concerned.

Directors of the Waterways Experiment Station during the conduct of the study and preparation and publication of this report were Col. Edmund H. Lang, CE, and Col. Alex G. Sutton, Jr., CE. Technical Director was Mr. J. B. Tiffany.

CONTENTS

SUMMARY

The Lake Pontchartrain model was a fixed-bed model, constructed to scales of 1:2000 horizontally and 1:100 vertically, in which were reproduced the western portion of Mississippi Sound (beginning at Pass Marianne), Lake Borgne, Lake Pontchartrain, and Lake Maurepas, with the connecting waterways of Chef Menteur, Rigolets, and Pass Manchac. Also included was the Mississippi River-Gulf Outlet Channel extending from Lake Pontchartrain, through the Inner Harbor Navigation Canal and a portion of the Intracoastal Waterway, and thence southeast through the marshes into Breton Sound past Gardner Island and Grace Point. The model was equipped with necessary appurtenances for the accurate reproduction and measurement of tides, tidal currents, salinity intrusion, freshwater inflow, and other significant prototype phenomena. The purpose of the model study was to determine the effects of gated structures--component parts of a proposed hurricane surge barrier system for the protection of New Orleans--in Chef Menteur, Rigolets, and the Inner Harbor Navigation Canal and of the Mississippi River-Gulf Outlet Channel on the salinity and hydraulic regimens of Lake Pontchartrain, its connecting waterways, and connected lakes. It was feared that changes in these regimens might adversely affect the important fish and oyster life of these waters.

Model verification tests indicated that the model hydraulic and salinity regimens were in satisfactory agreement with those of the prototype for comparable conditions. It therefore can be assumed that the model provided quantitative answers concerning the effects of the proposed structures on the hydraulic and salinity regimens of the lake system.

The main conclusions drawn from an analysis of the results of tests follow:

a. Construction of gated structures in Chef Menteur and Rigolets, which would reduce the cross-sectional area to 25 percent of the original cross-sectional area, would cause no appreciable change in the salinity of Lake Pontchartrain. Further, construction of the proposed structures would raise the average water-surface elevation in Lake Pontchartrain 0.1 ft with normal freshwater inflow into the lake; with the Bonnet Carre Spillway discharging the design flow of 250,000 cfs into the lake, the average water-surface elevation would be raised 0.4 ft.

b. Tests of the Mississippi River-Gulf Outlet Channel indicated an average increase in salinity in Lake Pontchartrain resulting from the addition of the channel to the system of 5029 ppm, or from 1147 ppm without the channel to 6176 ppm with the channel, for conditions of a high freshwater inflow year and the proposed gated structures installed in Chef Menteur and Rigolets. For conditions of a low freshwater inflow year with structures installed in Chef Menteur and Rigolets, the average increase was 5921 ppm, or from 3231 ppm without the channel to 9152 ppm with the channel. The average increase for high and low inflow years resulting from addition of the channel was 5475 ppm with structures installed in Chef Menteur and Rigolets. Further tests indicated that a gated structure installed at the entrance of the Mississippi River-Gulf Outlet Channel (through the Inner Harbor Navigation Canal) into Lake Pontchartrain could be operated in such a manner that, by increasing or decreasing the discharge through the structure, any desired degree of salinity could be obtained in Lake Pontchartrain.

c. Tests of complete closure of all structures (in Chef Menteur and Rigolets Passes and in the Gulf Outlet Channel) for a 2-week period simulating that between 23 May and 5 June 1959 (the time of passage of a hurricane over the area) indicated a relatively minor reduction of about 500 ppm in the average salinity of Lake Pontchartrain. Upon reopening of the structures, return to normal salinity was fairly rapid (approximately 11 weeks). The maximum increase in water-surface elevations in Lake Pontchartrain (at West End) resulting from complete closure was 1.2 ft, and this maximum increase was attained just 1 day before the reopening of the structures.

d. Operation of the Bonnet Carre Spillway discharging as much as the design flow with both the Gulf Outlet Channel connected and hurricane surge control structures installed in Chef Menteur and Rigolets would raise the high-water elevation in Lake Pontchartrain to a maximum of 1.4 ft msl.

EFFECTS ON LAKE PONTCHARTRAIN, LA., OF HURRICANE SURGE CONTROL STRUCTURES AND MISSISSIPPI RIVER-GULF OUTLET CHANNEL

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PART I: INTRODUCTION

The Prototype

1. Lake Pontchartrain (see fig. 1) lies adjacent to and just north of the city of New Orleans, La., and is connected with Lake Maurepas on the west by Pass Manchac, with Lake Borgne on the east by Chef Menteur and Rigolets Passes, and with the Mississippi River-Gulf Outlet Channel (under construction) by the Inner Harbor Navigation Canal and Intracoastal Waterway. Lake Pontchartrain is about 25 miles wide at its widest point, about 40 miles long, and covers approximately 1195 square miles. Its depth averages 12 ft west and 16 ft east of a 25-mile-long causeway that connects New Orleans with the north shore near Mandeville, La.

2. The principal streams that flow into Lake Pontchartrain are (see fig. 1): the Blind, Amite, and Tickfaw Rivers, which flow into Lake Maurepas and thence into Lake Pontchartrain through Pass Manchac; the Tangipahoa and Tchefuncta Rivers and the Lascombe and Bonfouca Bayous from the north; and Bayou St. John in the heart of New Orleans from the south. Also connected with Lake Pontchartrain on the south are the Inner Harbor Navigation Canal, which can be connected with the Mississippi River by lock, and the Bonnet Carre Spillway with a design capacity of 250,000 cfs, which passes flow from the Mississippi River to Lake Pontchartrain when necessary to reduce Mississippi River floodflows that would endanger low-lying areas downstream from the spillway. The Pearl River, with its branches of West and Middle Pearl Rivers, flows from the north into Lake Borgne near the eastern end of Rigolets. Lake Borgne is connected with the Mississippi River-Gulf Outlet Channel by several bayous; the principal ones are Bayous Bienvenue, Dupre, Ysclosky, La Loutre, and St. Malo. The total drainage area having significant effect on the lake system covers approximately 13,565 square miles.

Hydraulic characteristics

3. Tides are diurnal in Lake Pontchartrain and adjoining lakes. The mean tide range at Long Point, near the eastern end of Rigolets, is 1.0 ft. In Lake Pontchartrain the range decreases to about 0.4 ft, and further decreases to about 0.3 ft in Pass Manchac and Lake Maurepas for conditions of mean freshwater discharge. The mean freshwater discharge into the lake system is about 18,096 cfs, of which 60 percent is from the Pearl River and its branches. The mean tidal prism at Rigolets is about 9 billion cu ft. The approximate mean maximum current velocity in Rigolets is 1.9 fps, in Chef Menteur 2.8 fps, and in Pass Manchac 2.0 fps, while current velocities in Lake Pontchartrain are of the order of 0.5 fps or less. The maximum velocities are about the same for both flood and ebb currents, but the duration of the ebb currents is slightly longer.

4. The mean tide range at Point Chicot in Chandeleur Sound, which is the point of prototype tidal observations nearest the entrance to the Mississippi River-Gulf Outlet Channel into the Gulf of Mexico, is 1.3 ft.* This range gradually decreases upchannel toward New Orleans until at Seabrook Bridge, over the Inner Harbor Navigation Canal near its junction with Lake Pontchartrain, the range is only 0.3 ft. The time of high water at Point Chicot precedes the time of high water at Long Point by 1.5 hr. The tidal prism at the Gulf of Mexico entrance to the channel is about 130 million cu ft. The mean maximum velocities in the channel between Lake Pontchartrain and the Gulf range from 0.8 to 1.7 fps, being greater near Lake Pontchartrain in the Inner Harbor Navigation Canal. The maximum velocities are generally greater for the flood currents than for the ebb currents. The duration of the flood currents is slightly longer near Lake Pontchartrain in the Inner Harbor Navigation Canal, and the duration of the ebb currents is slightly longer near the Gulf in the vicinity of Bayou Ysclosky.

Salinity characteristics

5. Salinity in Lake Pontchartrain and connected lakes does not occur

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* Data presented for the Mississippi River-Gulf Outlet Channel, except the tide range at Point Chicot, were derived from model observations as the prototype channel was under construction at the time of preparation of this report.

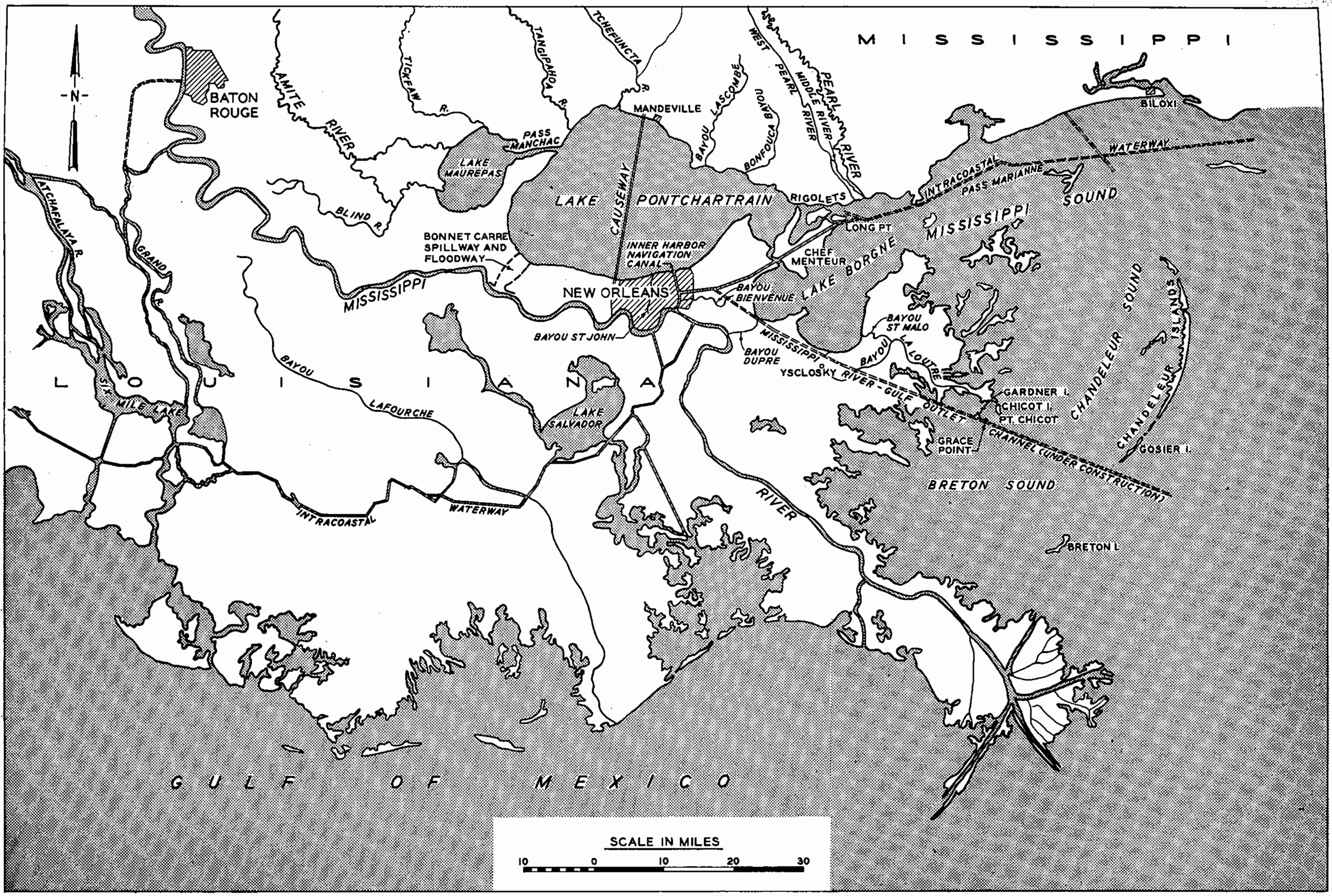


Fig. 1. Location map

in stratified form, as is the case in many estuaries. Rather the lake system is in the category of well-mixed estuaries in which salinities from surface to bottom are essentially uniform. Available prototype data indicate that salinities in Lake Pontchartrain vary from an average minimum of about 850 ppm to an average maximum of about 4250 ppm, in Lake Borgne from an average minimum of about 1125 ppm to an average maximum of about 8125 ppm, in Rigolets from an average minimum of about 425 ppm to an average maximum of about 7785 ppm, in Chef Menteur from an average minimum of about 1325 ppm to an average maximum of about 6585 ppm, and in Pass Manchac from an average minimum of about 75 ppm to an average maximum of about 1990 ppm. Similar variations in salinity also occur in Lake Maurepas. These variations can be attributed to the varying freshwater inflow from the streams tributary to the lake system and the varying salinity of the tidal flow from Mississippi Sound. The salinity of Mississippi Sound varies from an average of about 7290 ppm in the area west of Pass Marianne to an average of about 15,625 ppm in the area east of Pass Marianne. Again, the variation in salinities is attributed to the freshwater inflow into the Sound, the water nearer the major points of inflow being less saline than that farther away.

6. The Chandeleur-Breton Sound area of the Gulf of Mexico, into which the Mississippi River-Gulf Outlet Channel will enter, has an average salinity of about 31,300 ppm near Chandeleur, Gosier, and Breton Islands, decreasing gradually shoreward to an average salinity of about 21,700 ppm in the vicinity of Chicot Island. The overall average salinity of the Chandeleur-Breton Sound area, as determined from salinity observations at several stations, is about 28,000 ppm. From model observations it has been determined that on completion of the Mississippi River-Gulf Outlet Channel, with no obstruction between the channel and Lake Pontchartrain, the following salinity conditions will exist in the channel:

<u>a</u>. For a high freshwater inflow year, bottom salinities will decrease from the average of 28,000 ppm at the channel entrance into the Sound to a mean of about 26,000 ppm in the Inner Harbor Navigation Canal near its entrance into Lake Pontchartrain, while surface salinities, which are essentially the same as bottom salinities at the entrance into the Sound, will decrease to a mean of about 7500 ppm near the entrance into Lake Pontchartrain.

b. For a low freshwater inflow year, bottom salinities will decrease about the same amount as for the high inflow year, while surface salinities will decrease to a mean of about 10,000 ppm.

These relatively large decreases in surface salinities are attributed to a layer of less saline water from Lake Pontchartrain that overrides and mixes with the upper layers of the salt wedge moving upchannel; this layer of less saline water gradually dissipates as it moves downchannel toward the Gulf.

The Problem

7. That part of southeast Louisiana bordering the Gulf of Mexico is periodically subject to damaging hurricanes which produce surges that sweep through Mississippi Sound and into Lakes Borgne and Pontchartrain, raising water-surface elevations by several feet (as much as 10 or 12 ft has been experienced), thus threatening New Orleans with inundation and severe wave damage. To protect New Orleans from this danger, a system of hurricane barriers along the south shore and across the eastern end of Lake Pontchartrain has been proposed and is now under study. As integral parts of this system, gated structures would be installed in Chef Menteur and Rigolets. The gates of the structures would normally remain open, but could be closed at the approach of and during a hurricane. For economic reasons, the size of these proposed structures is such that the cross-sectional area of Rigolets and Chef Menteur would be reduced to 25 percent of their present cross-sectional area.

8. In addition to the proposed construction of a hurricane barrier system, the Mississippi River-Gulf Outlet Channel, a Gulf-level ship channel connecting the Inner Harbor Navigation Canal in New Orleans with the Gulf of Mexico, is being constructed. This channel will reduce the distance from New Orleans to the Gulf by several miles, thus reducing sailing time, and will avoid the navigation hazards existing at the mouth of the Mississippi River due to shoaling. Additionally, more modern and expanded docking facilities will be available along the Inner Harbor Navigation Canal than exist at present along the Mississippi River. This outlet channel will be approximately 75 miles long; its project dimensions are

500 ft wide and 36 ft deep except for the outer 5 miles which will gradually increase to 600 ft wide and 38 ft deep. This channel commences at the Inner Harbor Navigation Canal in New Orleans, follows the Gulf Intracoastal Waterway for approximately 5 miles, continues in a southeasterly direction along the south shore of Lake Borgne, and thence through the marshes to and across Chandeleur Sound in the vicinity of Breton Island to deep water (minus 38-ft contour) in the Gulf of Mexico.

9. Lake Pontchartrain, with its connecting lakes, rivers, and bayous, is an important fishing center for both sport and commercial fishermen; there are also extensive oyster beds in this area which are of economic importance. Therefore, the problem was to determine the effects of both the proposed gated structures in Chef Menteur and Rigolets (with the reduced cross-sectional area) and the Mississippi River-Gulf Outlet Channel on the salinity and hydraulic regimens of this entire lake system that might adversely affect the fish and oyster life of these waters.

Purpose of Model Study, and Scope of This Report

10. In order to determine the effects on the salinity and hydraulic regimens in Lake Pontchartrain and adjoining lakes of hurricane barriers in Chef Menteur and Rigolets and of the Mississippi River-Gulf Outlet Channel, a comprehensive model study was conducted. This report describes the model and its adjustment and verification, gives results of all significant tests, and presents conclusions reached after analysis of these results. However, the optimum salinity, a deviation from which would have adverse effects on the fish and oyster life, is not within the purview of this report; rather it is a matter for determination by the U. S. Fish and Wildlife Service.

PART II: THE MODEL

Description

11. Reproduced in the Lake Pontchartrain model (figs. 2 and 3) were the western part of Mississippi Sound, Lakes Borgne, Pontchartrain, and Maurepas with the connecting passes of Chef Menteur, Rigolets, and Pass Manchac, and the points of inflow of all major streams and bayous tributary to the system. Also reproduced was that part of the Mississippi River-Gulf Outlet Channel beginning at Lake Pontchartrain, extending through the Inner Harbor Navigation Canal at New Orleans, continuing through a portion of the Gulf Intracoastal Waterway, and thence southeast through the marshes along the south shore of Lake Borgne into Chandeleur and Breton Sounds, just southeast of Gardner Island and Grace Point. The area reproduced in the model is equivalent to about 1365 square miles prototype.

12. The model was constructed to linear scale ratios, model to prototype, of 1:2000 horizontally and 1:100 vertically. These scale ratios

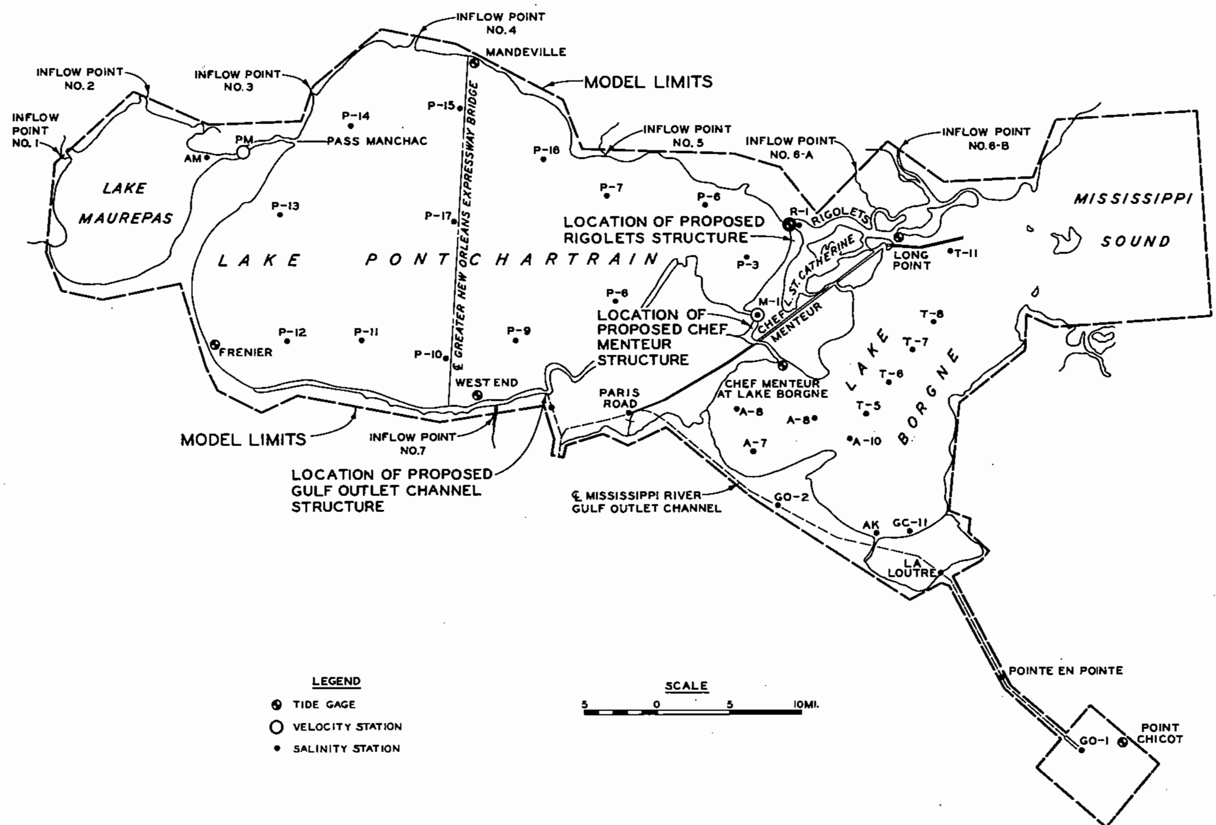
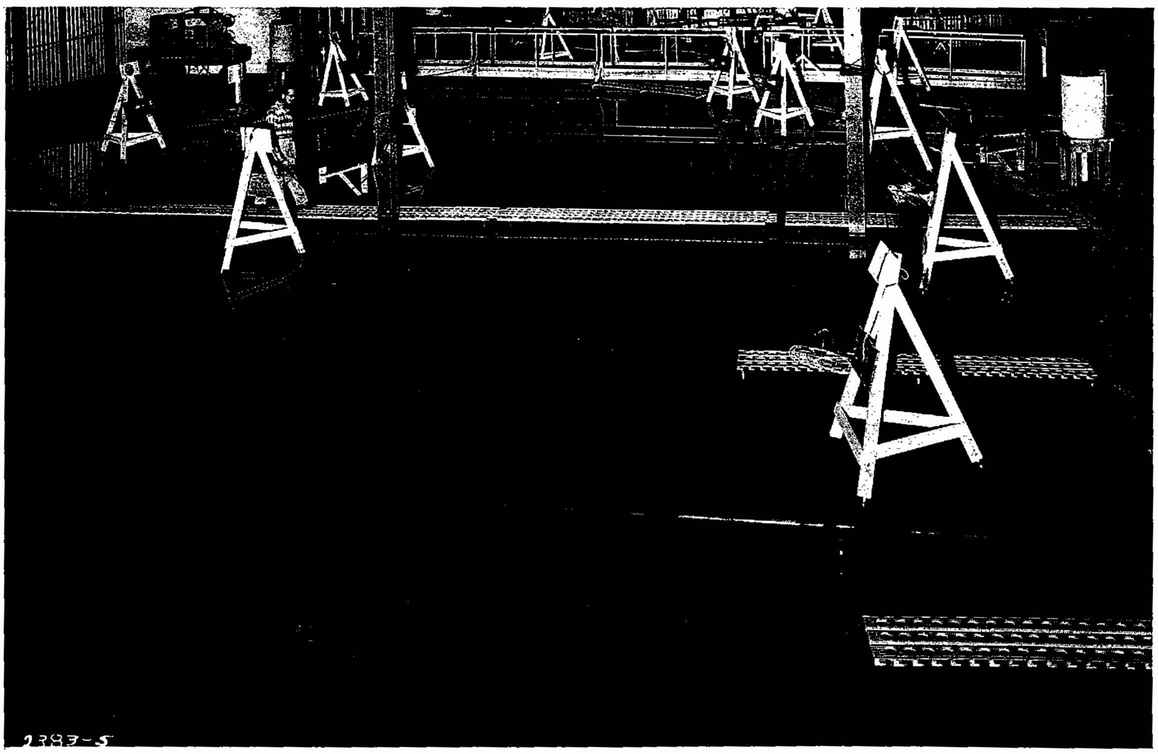


Fig. 2. Location map

a. View looking southwest toward Lake Borgne and Rigolets from northeast of Grand Isle in Mississippi Sound



b. View looking east toward the causeway from near Frenier

Fig. 3. Lake Pontchartrain and Mississippi River-Gulf Outlet Channel model

determined the following relations: slope, 20:1; velocity, 1:10; time, 1:200; discharge, 1:2,000,000; and volume, 1:400,000,000. The salinity scale ratio for the study was 1:1. One prototype tidal cycle (diurnal tide) of 24 hr and 50 min was reproduced in the model in 7.45 min. The model was approximately 160 ft long, 65 ft wide at its widest point, and covered an area of about 9500 sq ft. It was completely inclosed to protect it and its appurtenances from the weather, and to permit uninterrupted operation.

13. The entire bed of the model was molded of concrete to conform to the latest hydrographic surveys available at the time of construction, or in the case of the Mississippi River-Gulf Outlet Channel, to project dimensions. The overbank was molded of concrete to a flat elevation of sufficient height to preclude overflow from the normal tidal flow reproduced.

Appurtenances

14. The model was equipped with the necessary appurtenances to reproduce and measure all pertinent hydraulic and salinity phenomena. These appurtenances included two primary tide generators, a tide recorder and tide controls, freshwater inflow measuring devices (flowmeters), chemical titration equipment (for salinity measurement), current meters, tide gages, and salinity samplers. These appurtenances are described in detail in the following paragraphs.

Tide generators

15. The rise and fall of the tide in the model with the resultant flood and ebb tidal currents were reproduced by means of two primary tide generators, one of which was located at the Mississippi Sound end of the model (fig. 4) and the second located at the Chandeleur-Breton Sound end of the Mississippi River-Gulf Outlet Channel (fig. 5). The primary generators maintained a continuous balance between a pumped inflow of water to the model and a gravity outflow of water from the model as required to reproduce all the characteristics of the prototype tide at Long Point in Lake Pontchartrain and Point Chicot in Breton Sound. These tide generators were synchronized so that the tides at both stations were correctly time-phased.

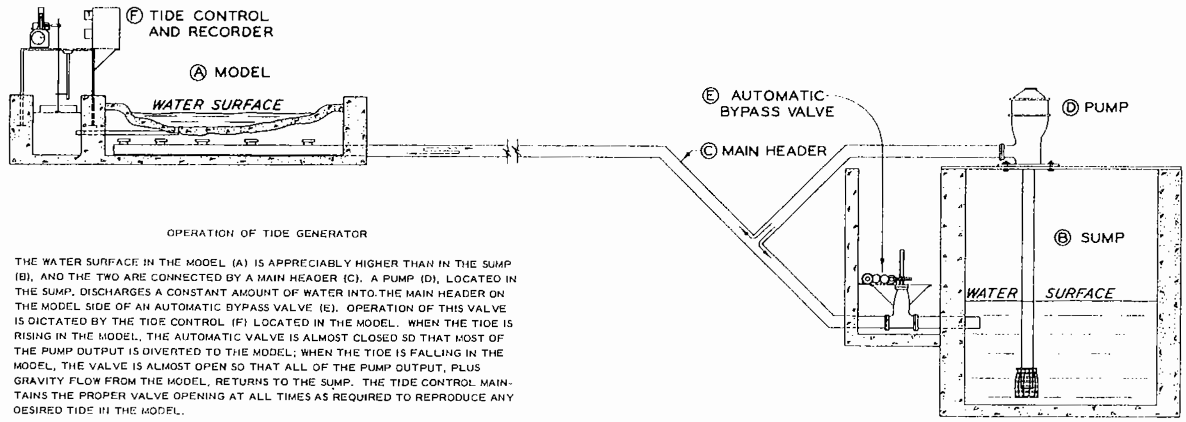


Fig. 4. Primary tide generator for Mississippi Sound

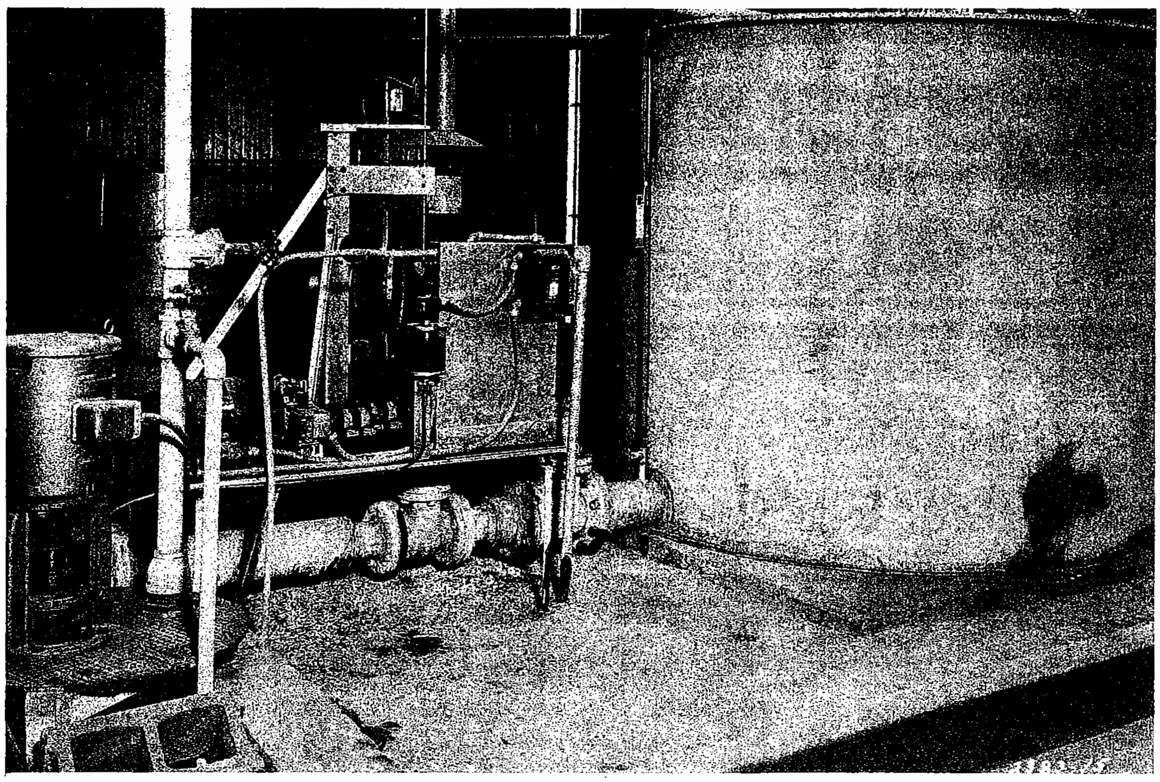


Fig. 5. Primary tide generator for Breton Sound

Tide recorder and controls

16. The master tide control station at Long Point was equipped with a continuous tide recorder (fig. 6) so that the accuracy of the model tide reproduction could be checked visually at any time. The tide control mechanism was a system of mercury switches which were controlled through adjustable cams to activate the tide generating apparatus in the amount

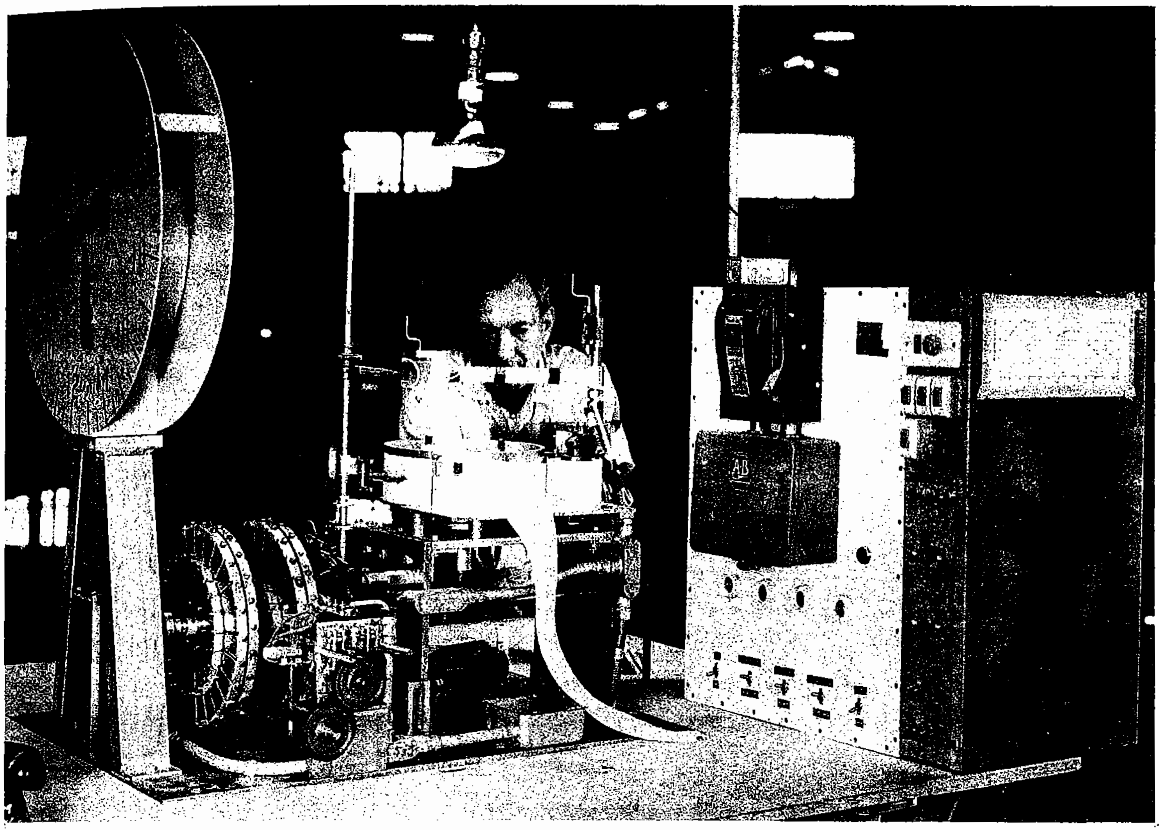


Fig. 6. Tide recorder and control for Mississippi Sound tide generator

necessary to reproduce the prototype tide accurately. The Breton Sound tide control did not include a recorder, but the tide generating mechanism was controlled in the same manner as the Mississippi Sound tide generator. The reproduction of the tide by the Breton Sound control was checked by periodic observations of tidal heights made with a point gage located at Point Chicot.

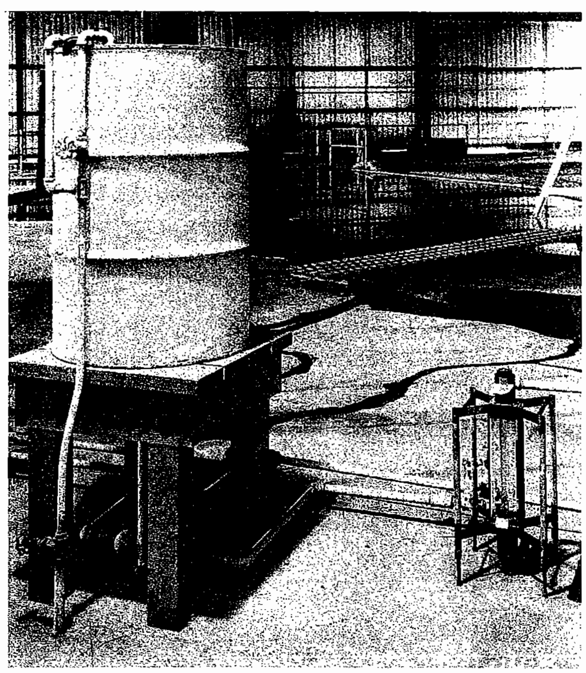


Fig. 7. Flowmeter and constant-head tank

Flowmeters

17. The model was equipped with flowmeters (fig. 7), calibrated to the model discharge scale, for the precise measurement of the freshwater

inflow from all the significant streams into the lake system. These flowmeters were fed from barrel-type, constant-head tanks in which the head was maintained by float-type automatic valves.

Chemical titration equipment

18. All salinity concentrations were determined by the chemical titration method using silver nitrate. The equipment consisted of a graduated burette for measuring the volume of silver nitrate, selected pipettes for measuring the volume of salinity samples used, sample jars in which to perform the titration, a supply of silver nitrate, and a quantity of potassium chromate for use as an end-point indicator in the titration process. The method consisted of adding a known concentration of silver nitrate solution to a known volume of the model salinity sample; the amount of silver nitrate required to precipitate the salt contained in the sample was then converted to salinity in parts per million of NaCl.

Current meters

19. Current velocity measurements were made in the model with miniature, Price-type current meters (fig. 8) which were calibrated frequently to ensure the accuracy of measurements. The meter cups were about 0.02 ft in diameter, and the cup wheels were about 0.08 ft in diameter. The meters

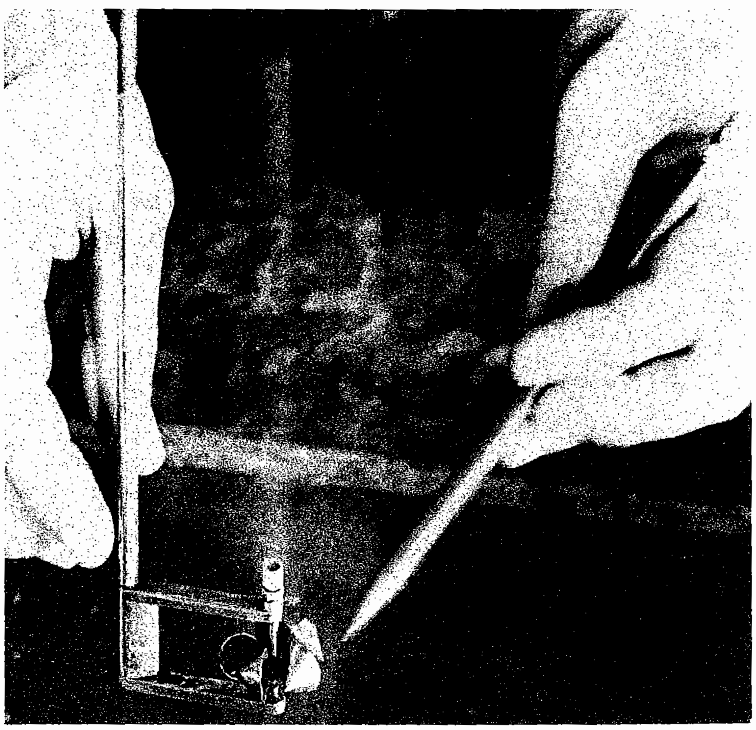


Fig. 8. Miniature Price-type current meters

were capable of measuring actual minimum velocities of about 0.05 fps (0.5 fps prototype).

Tide gages

20. Permanently mounted point gages (fig. 9) were installed on the model at the locations of important prototype tide gages. These gages were graduated to 0.001 ft (0.1 ft prototype) and were used to measure tidal elevations throughout the model. Portable point gages were used to measure tidal elevations at other points, as required.

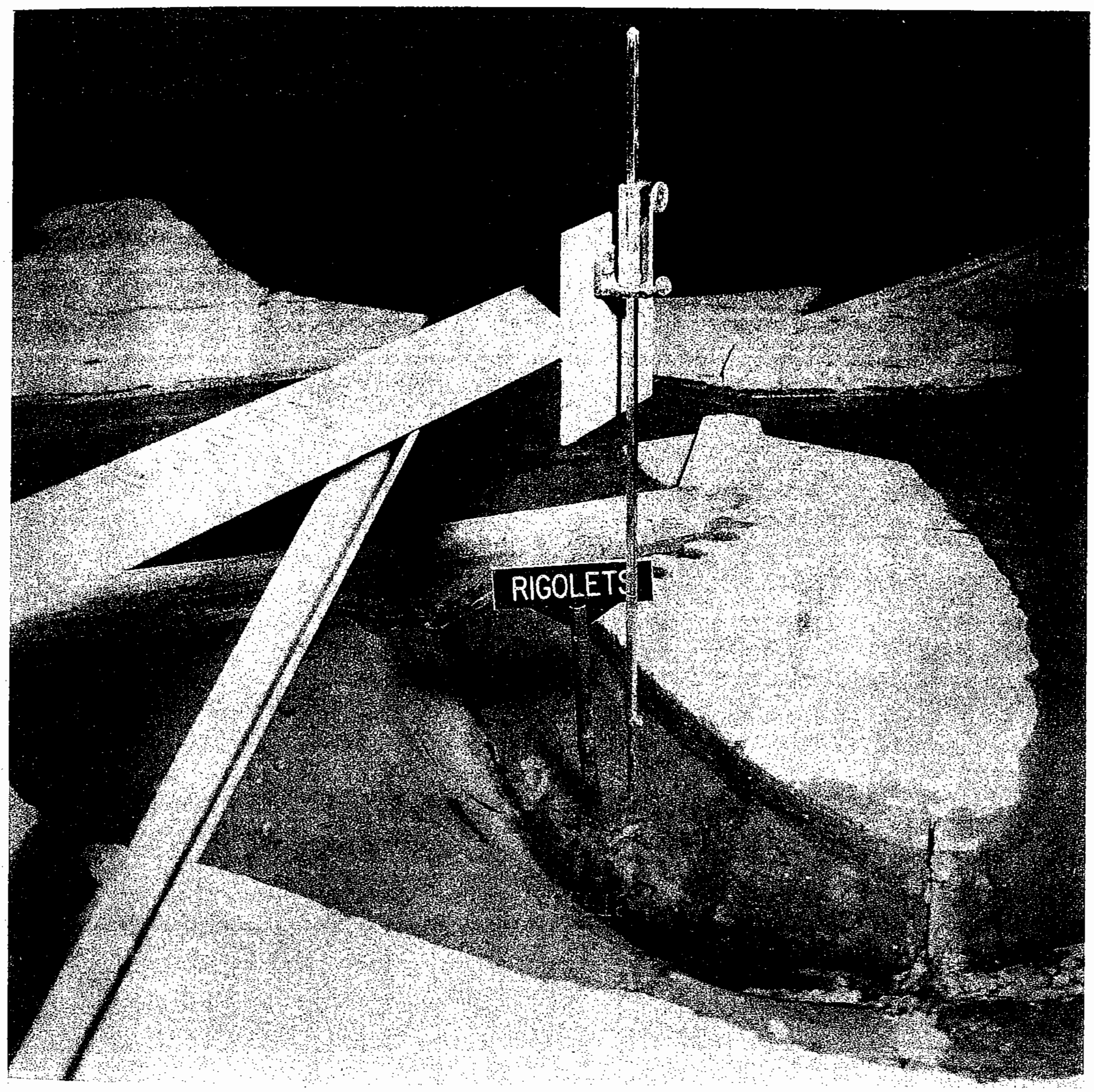


Fig. 9. Point gage

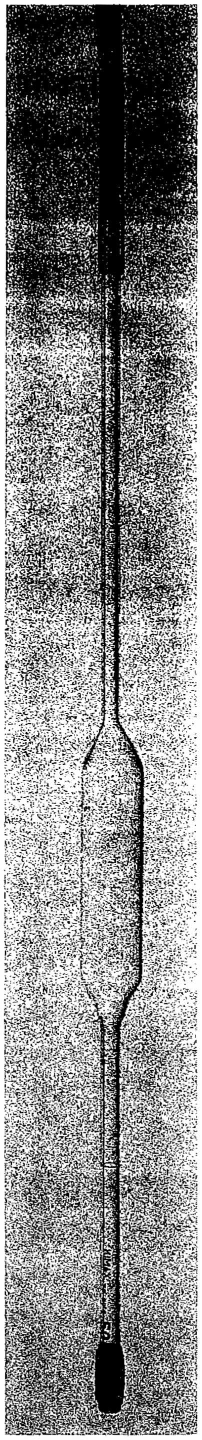


Fig. 10. Bottom sampler

Salinity samplers

21. Most of the salinity samples were taken at one depth (bottom); therefore, the principal sampling device used was a single pipette of the size necessary to obtain the size sample required, with a short length of plastic tubing attached for the convenience of the operator. The sample was obtained by suction applied to the tubing (fig. 10). For obtaining simultaneous, multidepth samples, a multidepth sampler was devised (fig. 11). It consisted of several (depending on the number of depths at which samples were required) small copper tubes taped together, each fitted with a two-hole stopper to which was attached a small sample bottle. Each tube was slotted at the depth at which the sample was to be taken when the sampler was in a vertical position at the sampling station, with the longest tube resting on the bottom. As suction was applied to a single plastic tube connected to all the tubes through the bottles by separate plastic tubes, a sample was drawn from each depth into the bottles attached to the respective tubes.

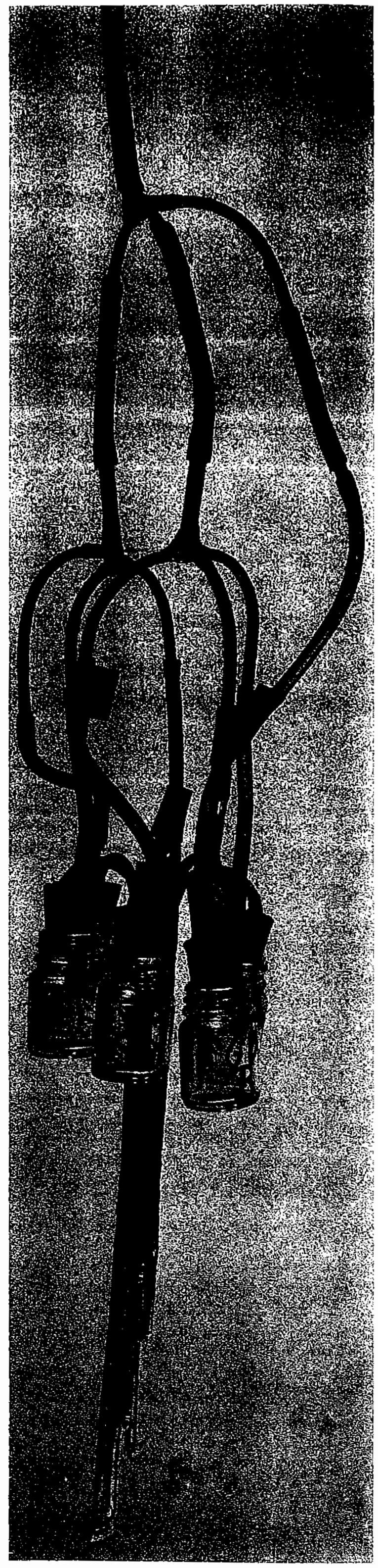


Fig. 11. Multidepth sampler

PART III: VERIFICATION OF THE MODEL

22. Verification of the Lake Pontchartrain and Mississippi River-Gulf Outlet Channel model consisted of two phases: (a) hydraulic verification, which ensured that tidal elevations and times, and current velocities were in proper agreement with the prototype, and (b) salinity verification which proved that salinity phenomena in the model corresponded to those of the prototype for similar conditions of tide, source (Mississippi or Chandeleur Sound) salinity, and freshwater inflow. Verification is a necessary phase in model studies of this type, because the value of the study is dependent upon the ability of the model to predict, with a reasonable degree of accuracy, phenomena which can be expected to occur in the prototype under conditions similar to those set up in the model.

Hydraulic Verification

23. As an essential part of the hydraulic verification, the model was adjusted to reproduce a prototype neap tide and a prototype spring tide at the Long Point (control) gage; the dates on which these tides occurred in the prototype were 27-28 May 1958 and 2-3 June 1958, respectively. This adjustment was followed by a series of measurements to determine the need for supplemental frictional resistance in Chef Menteur, Rigolets, and Pass Manchac, and the results indicated that tidal elevations and times throughout the model were in good agreement with the tidal elevations and times recorded during the aforementioned prototype tides without supplemental frictional resistance other than that supplied by the concrete bed of the model itself. Model tests and observations indicated that the effects of varying sump (source) salinities and varying freshwater inflows into the system were insignificant for the hydraulic portion of model verification.

24. Plates 1-4 illustrate the accuracy attained in adjusting the model to reproduce tidal elevations, ranges, and times of high and low tide at six of the tide gages (gage locations are shown in fig. 2, page 7) for which prototype tidal data were furnished for both neap and spring tides for the dates used in verification; model tidal elevations are superimposed on prototype tidal elevations. Plate 5 shows the accuracy with which the

mean tide was reproduced at Point Chicot in Chandeleur Sound. It will be noted that at several of the gages there are slight vertical deviations in tidal planes caused by wind effects not reproduced in the model; however, it is believed that the model tides accurately represent tides which would have occurred in the prototype in the absence of wind effects. The times of high and low tides and the tidal ranges were in very satisfactory agreement for all gages.

25. Prototype current velocity data for verification purposes were available for three stations, R-1, M-1, and PM (see fig. 2), at several depths for neap and spring tides; but because of the model scale and the size of the velocity meter, model velocities were observed at only three depths, surface, 0.6 depth, and bottom. Plates 6 through 11 show the results of these observations. The prototype spring tide data have been adjusted upward by a factor of 1.36, this adjustment representing the ratio between the average spring tide range for the year 1958, which was used for all model verification tests, compared with the range of the actual spring tide that occurred during the period of prototype velocity measurements. Portions of the prototype observations for the 0.6 and bottom depths at station M-1 for the neap tide were not plotted against the model observations because of what appeared to be discrepancies in prototype data for these depths. Although there were some deviations between model and prototype observations, it is believed that the agreement was sufficiently close to give satisfactory test results.

Salinity Verification

26. Because determination of the effect of the hurricane surge control structures, previously described, on the salinity of Lake Pontchartrain was the main purpose of the model study, salinity verification was of prime importance; therefore, the test data presented for salinity verification are more comprehensive than those for hydraulic verification. Reproduction of prototype salinity in the model required maintenance of the proper salinity in the water-supply sump (source salinity), introduction of the proper freshwater discharge into the system, and reproduction of all significant forces which affect vertical and lateral mixing of fresh and

salt water. The determination of these factors, and their proper phasing to reproduce the prototype salinity pattern required extensive analysis and preliminary testing prior to salinity verification.

27. Prototype salinity data were available from 48 different salinity stations for a year's observations (1958), generally taken weekly and at several depths at most stations. Observations at all stations and all depths were not used during salinity verification. Only data at a sufficient number of stations to adequately represent the area were used. After analysis of all the prototype data, it was determined that surface and bottom salinities were essentially the same in practically all cases; therefore, bottom salinities were used for verification.

28. Prototype salinity observations for the Mississippi Sound area were incomplete and covered widely scattered periods, making an accurate analysis of the salinity pattern of the area difficult. Consequently, a method for determining a satisfactory source salinity pattern was devised and will be explained subsequently. Prototype salinity observations for the Chandeleur-Breton Sound area were more complete; therefore, a determination of the source salinity pattern in that area was not difficult.

29. Because salt water and fresh water are well mixed in the Lake Pontchartrain system, a method of mixing in the model was required, since the mixing effects of wind and wave action were not reproduced. A method of mixing was devised consisting of 20 oscillating fans mounted approximately 3 ft above the water surface (see fig. 3, page 8), and so located that the entire Lake Pontchartrain-Lake Borgne area of the model was subjected to this mixing force when the fans were operating. The following tabulation shows the degree of mixing, surface to bottom, at certain key prototype salinity stations, and the accuracy with which this mixing was reproduced in the model.

Station	Mixing Index* Prototype	Mixing Index* Model	Station	Mixing Index* Prototype	Mixing Index* Model
GC-11	100	100	T-6	101	83
T-5	98	85	T-7	101	100

(Continued)

* The degree of mixing in both prototype and model was determined by a mixing index derived as follows:

$$\frac{\text{Surface salinity}}{\text{Bottom salinity}} = \text{percent} = \text{mixing index}$$

Station	Mixing Index Prototype	Mixing Index Model
T-8	98	100
A-6	99	96
A-8	99	88
A-10	100	91
M-1	100	91
R-1	97	93
P-6	100	97
P-7	95	97
P-8	100	100
P-9	100	100
P-10	101	90
P-11	99	97
P-12	100	89
P-13	99	100
P-14	94	69
P-15	91	91
P-16	100	100
P-17	99	98
Average	99	93

30. Prior to the verification tests, a technique of operation and a set of operating conditions were determined by trial and error, as there is no known method of computing the many variables that exist in a salinity study involving tidal hydraulics. It was determined from preliminary tests that salinities at most of the stations in Lakes Borgne and Pontchartrain followed the pattern of salinity at station T-8 (i.e. if prototype salinities were reproduced at station T-8, then prototype salinities were reproduced at most of the other stations). This station, located near the center of the entrance of Mississippi Sound into Lake Borgne, appeared to reflect most consistently the combined effects of variations in sump (source) salinities and variations in freshwater inflow into the system, since this station was influenced more by the total Pearl River inflow than any other station. Therefore, station T-8 was selected as a key salinity station. Further tests indicated that to reproduce the prototype salinity at station T-8 for the verification year 1958, the sump (source, Mississippi Sound) salinity had to be varied in relation to the freshwater inflow hydrograph for the year (see plate 12 for the 1958 weekly freshwater hydrograph).

31. The devised method of varying the sump (source) salinity consisted of adding fresh water, measured through a weir, to the sump when a decrease in salinity was required and of adding salt to the sump when an increase in salinity was required. A tentative, varying source-salinity curve was derived, based on two factors: (a) prototype salinity at station T-8 (there being a definite relation between source salinity and salinity at station T-8), and (b) total freshwater inflow into the lake system. Deviations from this tentative curve were made during operation of the

model in accordance with the requirement to increase or decrease the salinity at station T-8. Since there was sufficient data to make an accurate determination of the salinity pattern in the Chandeleur-Breton Sound area, the sump (source) salinity for the Mississippi River-Gulf Outlet Channel was maintained at 28,000 ppm. This was a compromise between prototype salinity inside and outside the Chandeleur Islands, weighted in proportion to the effective channel area exposed.

Verification procedure

32. Operating conditions determined by trial and error to be most suitable for the salinity verification tests were as follows: (a) model was adjusted to and operated for a mean tide; (b) initial salinity in Lake Pontchartrain, west of Rigolets and Chef Menteur, was 2000 ppm; (c) initial sump (source) salinity was 3850 ppm; and (d) a stabilization run of 40 cycles was made prior to beginning each verification test, with each of the freshwater inflow points discharging the average prototype inflow for the period 1 January to 4 March 1958 (approximating the two-month period just prior to the verification year) or a total average inflow of 35,492 cfs. During this stabilization run, the sump (source) salinity was maintained at 3850 ppm, which was also the initial salinity of Lake Borgne and the Mississippi Sound area east of Rigolets and Chef Menteur. The model was started at the time of low water with water-surface elevations throughout the model at the low-water elevation for mean tide of 0.5 msl.

Salinity verification test 5

33. With salinity verification test 5, a satisfactory verification was considered achieved. The accuracy of this verification can be seen in plates 13 through 17. In plate 13 the mean prototype salinity for station T-8 for the verification year is compared with the model salinity for the same period. In plate 14 the derived sump (source) salinity is compared with the actual sump salinity attained during the test. Plates 15 through 17 compare the model salinities reproduced during the test with the prototype salinities for the verification period for stations A-6, P-6, P-12, P-14, and P-17. These locations adequately represent the area for verification purposes. (Station locations are shown in fig. 2.)

Salinity verification test 7

34. In order to determine the ability of the model to reproduce

short-period fluctuations in prototype salinities that occurred when the tides were significantly influenced by winds and other meteorological factors, a period (8 July through 14 October 1958 or cycles 135 through 225) of the verification year that met these conditions was selected for testing. A test, verification test 7,* was run with the actual tides of this period reproduced in the model. All other conditions were identical with those of verification test 5 for the same period, except that the sump (source) salinity was increased during cycles 155 through 215. Plate 18 compares the derived sump (source) salinity with the actual salinity attained in the sump during the test. Plates 19 and 20 present the results of test 7 at three stations, T-8, P-6, and P-17, a sufficient number to verify the ability of the model to reproduce the short-period fluctuations in prototype salinities resulting from tidal fluctuations caused by meteorological factors.

Discussion of Results of Verification Tests

35. Agreement between model and prototype hydraulic phenomena, as illustrated by the results of the hydraulic verification, was considered satisfactory. Although there were some deviations between model and prototype tidal planes and current velocities caused by wind effects in the prototype, the overall reproduction of hydraulic phenomena was sufficiently accurate to provide quantitative answers concerning the effects of the proposed structures on the hydraulic and salinity regimens of the lake system.

36. The accuracy with which the model reproduced prototype salinities for long-term mean tide conditions and for shorter term fluctuating tide conditions clearly demonstrated the ability of the model to reproduce all significant salinity phenomena of the prototype.

* Verification test 6 was a check run of test 5.

PART IV: TESTS AND RESULTS

37. In this part, the base tests (tests of existing prototype conditions) are described first, then the tests of the Gulf Outlet Channel and of the proposed hurricane surge control structures under various tide and freshwater inflow conditions are described, and results are discussed.

38. During certain of the tests, salinity samples were taken at the following stations in the Gulf Outlet Channel at the request of the U. S. Fish and Wildlife Service: GO-1, Pointe-en-Pointe Bayou, Bayou La Loutre, GO-2, Paris Road, and Navigation Canal. Locations of these stations are shown in fig. 2. Samples were taken at surface and bottom at all stations except GO-2 and Navigation Canal, where they were taken at 6-ft increments of depth. Since the data obtained are not pertinent to the model study, they are not discussed herein; however, plots of the salinities are included as an appendix to this report (plates A1-A21) for record purposes.

Base Tests

Freshwater and salinity conditions

39. Base tests (tests of existing prototype conditions) were conducted to provide a basis with which the results of subsequent tests could be compared to show the effects of various conditions introduced into the model on the salinity regimen of the lake system. Base tests were run for each of three freshwater inflow years: high (1949), medium (1951), and low (1954). It was anticipated that the effects of the proposed changes in prototype conditions would also be determined for each of the inflow years; however, only the high and low inflow years were used in the tests of the Gulf Outlet Channel and gated structures.

40. Prior to the base tests it was necessary to determine the source (Mississippi Sound) salinity pattern for the entire year for each of the years studied. To do this, a source salinity curve was constructed as follows. The average sump (source) salinity attained during verification test 5 was determined for each four-week period during the entire verification year, and these salinities were plotted against the prototype freshwater inflow for the corresponding four-week periods.

Then a curve was drawn based on these plotted points (see plate 21). Using this curve as a basis, derived source salinity curves were constructed for each of the base test inflow years. Plates 22, 23, and 24 present these curves for the high, medium, and low inflow years, respectively, with the actual source salinity attained in the sump during each of the tests plotted thereon for comparison.

Test procedure

41. For all base tests the prototype conditions existing during the verification period, 1 March 1958 to 1 March 1959, were reproduced in the model. A mean tide was continuously reproduced throughout the entire period and was started at the time of low water with the water-surface elevation throughout the model at the low-water elevation. Prior to the actual tests, a 40-cycle stabilization run was made with the total average freshwater inflow being the 35,492 cfs which occurred during the prototype period 1 March-23 May 1958, and which was also used in the stabilization run during verification. This inflow was introduced at the inflow points (see fig. 2) in accordance with data furnished by the U. S. Geological Survey through the New Orleans District. Plate 12 presents the weekly Lake Pontchartrain, Pearl River, and total inflows for the verification period. The initial salinities in Lake Pontchartrain west of Rigolets, Lake Borgne, the Mississippi Sound portion of the model, and the sump (source) were determined from the derived source-salinity curve for the appropriate year. These procedures were the same as those determined for and used in the verification tests.

Sampling

42. Salinity samples were obtained from the sump (source) each fifth cycle and at the following 24 salinity stations (see fig. 2) throughout the lake system each seventh cycle (equivalent to each prototype week): T-6, T-8, T-11, AK, GC-11, A-6, A-7, A-8, R-1, M-1, P-3, P-6, P-8, P-9, P-10, P-11, P-12, P-13, P-14, P-15, P-16, P-17, and AM. Samples were taken at the time of tide at which the maximum salinity occurred, generally at high-water slack. An analysis of the samples indicated that salinities at stations P-12 and P-16 in Lake Pontchartrain and station T-6 in Lake Borgne were most representative of the average of all the stations in each of the lakes at any given time. This was also true for all subsequent tests.

High freshwater inflow year test

43. The test procedures described in paragraphs 41 and 42 were used for this test except that at the end of the 40-cycle stabilization period, flow according to the high inflow year hydrograph (plate 25) was started and inflow changes were made each seventh cycle, corresponding to weekly prototype changes. The average salinities for all stations in Lakes Borgne and Pontchartrain recorded throughout the test period (equivalent to one prototype year) are shown in plates 26 and 27, together with comparable data for the medium and low inflow year tests. In Lake Borgne the minimum average salinity was 850 ppm and occurred about cycle 125, while the maximum average was 6750 ppm and occurred at cycle 351 (the end of the test). In Lake Pontchartrain the minimum average salinity was 650 ppm and occurred about cycle 230, while the maximum average was 1850 ppm and occurred near the beginning of the test, about cycle 5. The average salinities for the test (year) were 2564* ppm for Lake Borgne and 1056 ppm for Lake Pontchartrain.

Medium freshwater inflow year test

44. The test procedures described in paragraphs 41 and 42 were used in this test except that after the 40-cycle stabilization period flow according to the medium inflow year hydrograph (plate 28) was started and changed in the same manner and frequency as that for the high inflow year test. The results of the test are shown in plates 26 and 27. In Lake Borgne the minimum average salinity was 1100 ppm and occurred at about cycle 115, while the maximum average was 9700 ppm and occurred at about cycle 317. In Lake Pontchartrain the minimum average salinity was 950 ppm and occurred at about cycle 135, while the maximum average was 2800 ppm and occurred at about cycle 344. The average salinities for the test (year) were 4858 ppm for Lake Borgne and 1640 ppm for Lake Pontchartrain.

Low freshwater inflow year test

45. Test procedures for this test were also the same as those described in paragraphs 41 and 42 except that after the 40-cycle

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* Where salinity concentrations are given to the nearest whole number in paragraph 43 and subsequently, it is not implied that salinities were measured to that degree of accuracy; actually, these concentrations resulted from averaging salinity concentrations at a number of stations.

stabilization period, flow according to the low inflow year hydrograph (plate 29) was started, and was changed in the same manner and frequency as for the high and medium inflow year tests. The results of this test are also plotted in plates 26 and 27. The minimum average salinity in Lake Borgne was 3275 ppm and occurred about cycle 140, while the maximum average was 10,125 ppm and occurred about cycle 337. The minimum average salinity in Lake Pontchartrain was 1675 ppm and occurred about cycle 140, while the maximum average was 3550 ppm and occurred at cycle 351 (the end of the test). The average salinities for the test (year) were 6463 ppm for Lake Borgne and 2278 ppm for Lake Pontchartrain.

Discussion of test results

46. A comparison and analysis of the data from the three base tests disclose the following facts:

- a. During the high inflow year test the total average weekly freshwater inflow was 30,047 cfs, of which 65 percent was from the Pearl River and its branches which enter the lake system at the eastern end of the Rigolets. The resulting average salinity was 2564 ppm for Lake Borgne and 1056 ppm for Lake Pontchartrain.
- b. During the medium inflow year test the total average weekly freshwater inflow was 18,236 cfs of which 63 percent was from the Pearl River system. The average resulting salinity was 4858 ppm for Lake Borgne and 1640 ppm for Lake Pontchartrain.
- c. During the low inflow year test the total average weekly freshwater inflow was 9346 cfs of which 60 percent was from the Pearl River system. The average resulting salinity was 6463 ppm for Lake Borgne and 2278 ppm for Lake Pontchartrain.
- d. A further analysis of the facts presented in a, b, and c above indicates that a reduction in total freshwater inflow into the system of approximately 40 percent resulted in an increase in the average salinity of Lake Borgne by a factor of 1.9 and of Lake Pontchartrain by a factor of 1.6; a reduction of approximately 70 percent in total freshwater inflow increased the average salinity of Lake Borgne by a factor of 2.5 and of Lake Pontchartrain by a factor of 2.2.

Effects of Gulf Outlet Channel

47. In the tests conducted to determine the overall effects of connecting the Gulf Outlet Channel to Lake Pontchartrain (see fig. 2) on the salinity regimen of the lake system, the model conditions and test

procedures were generally the same as those used for the base tests; differences will be described in detail in the appropriate test description.

New Orleans District test 2

48. This test was conducted under the low inflow year base test conditions for Lake Pontchartrain with the tide in the Gulf Outlet Channel being that resulting from a mean tide at Point Chicot in Breton Sound. Initial salinities were 2000 ppm in the lake system west of Rigolets and 5700 ppm in the system east of Rigolets. The initial salinity in the Gulf Outlet Channel and its source (sump) was 28,000 ppm. This salinity was maintained at the source throughout the test. As in the low inflow year base test, a 40-cycle stabilization run was conducted, with an average freshwater inflow into the system of 35,492 cfs, prior to the actual test. During this stabilization period the Gulf Outlet Channel was not connected with Lake Pontchartrain, but was connected at the beginning of the test.

49. The results of this test are presented in plate 30. As in the base test results, the average salinities for all the stations in Lakes Borgne and Pontchartrain are those plotted. A study of the results shows that there was a gradual increase in salinity in both Lake Borgne and Lake Pontchartrain. In Lake Borgne the minimum average salinity was 3050 ppm and occurred about cycle 50, while the maximum average was 11,075 ppm and occurred near the end of the test, about cycle 344. In Lake Pontchartrain the minimum average salinity was 2250 ppm and occurred near the beginning of the test, about cycle 5, and the maximum average salinity was 7850 ppm and occurred about cycle 344. The average salinities for the test (year) were 6597 ppm in Lake Borgne and 5108 ppm in Lake Pontchartrain. The salinities in Lakes Pontchartrain and Borgne for this test would probably have been further increased except for the fact that the mean tide level at Point Chicot was about 0.15 ft too low for most of the test. This discrepancy was caused by the exchange of salt and fresh water between the Gulf Outlet Channel and the remaining portion of the model; the rate at which salt water flowed from the Gulf Outlet to the remaining portion of the model exceeded the rate at which fresh or brackish water replenished this flow. In all subsequent tests this condition was corrected by adding salt water as required to maintain the correct mean tide level at Point Chicot at all times.

Low freshwater inflow year test

50. Test conditions for this test were the same as those used in New Orleans District test 2 with the following exceptions:

a. The mean tide plane at Point Chicot was held to the correct elevation.

b. The initial average salinity in Lake Pontchartrain was 6825 ppm. This salinity occurred during cycle 300 of New Orleans District test 2, and appeared to be the stable average salinity in Lake Pontchartrain with the Gulf Outlet Channel connected for a low inflow year.

c. On completion of this low inflow year test and after a stabilization period, flow according to the high inflow year hydrograph was introduced. (This test will be described later.)

51. The results of this test are presented in plate 30. A study of these data shows that the salinities in both Lake Borgne and Lake Pontchartrain gradually increased from the beginning of the test to the end. The minimum average salinity for Lake Borgne was 4150 ppm occurring about cycle 5, while the maximum average salinity was 10,925 ppm, occurring at cycle 351. In Lake Pontchartrain the minimum average was 7350 ppm, also occurring at cycle 5, while the maximum average was 9800 ppm occurring at cycle 351. The average salinities for the test (year) were 7589 ppm for Lake Borgne and 8412 ppm for Lake Pontchartrain.

High freshwater inflow year tests

52. Because of the large differences between the low and the high inflow year hydrographs, and the resulting differences in the source (Mississippi Sound) salinities, it was considered inadvisable to begin the high inflow year test immediately following the low inflow year test. Consequently, an arbitrary adjustment period of 50 cycles was provided between the two tests. During this period the source salinity was gradually reduced to 3100 ppm--the correct initial salinity of the high inflow year test. However salinities during the early part of the test were affected by the high concentrations of salt still prevalent throughout the model at the end of the low inflow year test, which gave an erroneous salinity picture for that part of the test; therefore, the relation between the salinities for the last 200 cycles of the high inflow year base test and the last 200 cycles of this test was determined and applied as a correction to the

salinities of the first 150 cycles, making the early salinities for this test more nearly correct. This correction was made to the Lake Pontchartrain salinities only. No dependable method of adjustment to the Lake Borgne salinities could be developed because some of the conditions clearly showed that salinities in Lake Borgne would be changed to a greater extent during the low inflow portions of the test year than during the high inflow portions; therefore, no adjustment was made.

53. The results of this test, with the adjustment applied to the Lake Pontchartrain salinities, are presented in plate 31. The minimum average salinity for Lake Borgne was 3100 ppm, occurring about cycle 222, while the maximum average was 6500 ppm, occurring about cycle 344. The minimum average salinity for Lake Pontchartrain was 4600 ppm and occurred about cycle 128, while the maximum average was 6200 ppm and occurred near the beginning of the test, at cycle 5; however, by the end of the test, at cycle 351, the salinity had almost reached this same concentration, and was about 6050 ppm. The average for the test was 4105 ppm in Lake Borgne and 5338 ppm in Lake Pontchartrain.

Discussion of test results

54. The results of the New Orleans District test 2 were disregarded because it is believed that they do not reflect a true picture of the effects of the Gulf Outlet Channel on the salinity regimen of the lake system. A study of the results of the other tests made to determine the effects of the Gulf Outlet Channel is presented in the following analysis. The factors enumerated in this analysis were developed by comparing the tests of this series with the appropriate base test and assigning an index of 1.0 to the base test salinities. For the low inflow year test the minimum average salinity in Lake Borgne was increased by a factor of 1.3, the maximum average salinity was increased by a factor of 1.1, and the test (year) average salinity was increased by a factor of 1.2. For the same test the minimum average salinity in Lake Pontchartrain was increased by a factor of 4.4, the maximum average salinity was increased by a factor of 2.8, and the test average salinity was increased by a factor of 3.7. For the high inflow year test the minimum average salinity in Lake Borgne was increased by a factor of 3.6, the maximum average salinity was decreased slightly with a factor of 0.96, while the test average salinity was

increased by a factor of 1.6. For this test the minimum average salinity in Lake Pontchartrain was increased by a factor of 7.1, the maximum average salinity was increased by a factor of 3.4, while the test average salinity was increased by a factor of 5.1. An overall appraisal indicates that the long-range effects of the addition of the Gulf Outlet Channel, using the averages of the high and low inflow years, will be to increase the yearly average salinity in Lake Borgne by a factor of 1.4 and in Lake Pontchartrain by a factor of 4.4. An analysis, assuming the last 50 cycles of each test to be the period of stabilized salinity concentrations, which appears to be the case, and using the average salinities for that period for determining the long-range effects of the Gulf Outlet Channel, indicates an increase in the average salinity for that 50-cycle period by a factor of 1.1 for Lake Borgne and by a factor of 3.4 for Lake Pontchartrain.

Effects of Hurricane Surge Control Structures

Calibration and installation of structures

55. Prior to installation of the Rigolets and Chef Menteur hurricane surge control structures in the distorted-scale model of Lake Pontchartrain, for the purpose of determining the effects of those structures on the salinity regimen of the lake system, it was necessary to determine the flow characteristics through the structures at an undistorted scale. This was necessary because to correctly reproduce the effects of the structures on salinity, the flow characteristics through the structures in the distorted-scale model must be the same as those through an undistorted structure. These flow characteristics were determined by installing 1:100-undistorted scale models of the structures in a flume of suitable size where the flow (discharge) and the elevations of headwaters and tailwaters could be accurately measured. Fig. 12 shows a typical installation of a structure. Plates 32 and 33 show details of the proposed prototype structures. The range of discharges expected in the prototype was introduced through the structures, and the resulting headwaters and tailwaters with the resultant slopes through the structures were obtained.

56. Reproduction of the structures in the distorted-scale comprehensive model consisted of placing the structures with the sill elevations

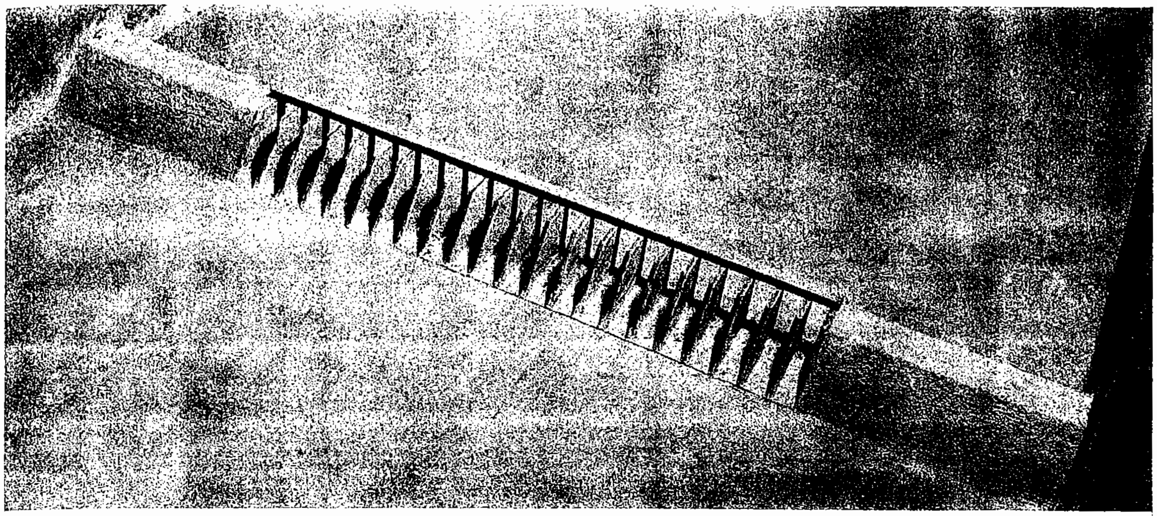


Fig. 12. 1:100-undistorted scale model of hurricane surge control structure installed in flume

and horizontal transitions as proposed for the prototype, but with the bottom transitions and the width of openings varied until the flow characteristics, as determined in the undistorted flume tests, were satisfactorily reproduced for the expected range of prototype discharge (see fig. 13).

General test conditions

57. These tests were conducted under the same model conditions as those for the low and high inflow year tests of the effects of the Gulf Outlet Channel (described in paragraphs 50 and 52, respectively), except that the hurricane surge control structures were installed in Chef Menteur and Rigolets.

Low inflow year tests

58. The results of this test are presented in plate 30. These results show that for Lake Borgne the minimum average salinity was 5000 ppm, occurring at cycle 50 and again at cycle 141, and the maximum average was 10,950 ppm, occurring about cycle 331; for Lake Pontchartrain, the minimum average salinity was 6950 ppm, occurring at cycle 39, and the maximum average salinity was 9425 ppm, occurring at the end of the test or cycle 351. The test average salinity was 7565 ppm for Lake Borgne and 7831 ppm for Lake Pontchartrain.

High inflow year tests

59. The results of this test are presented in plate 31. For Lake Borgne a minimum average salinity of 3325 ppm occurred at cycle 222, and a

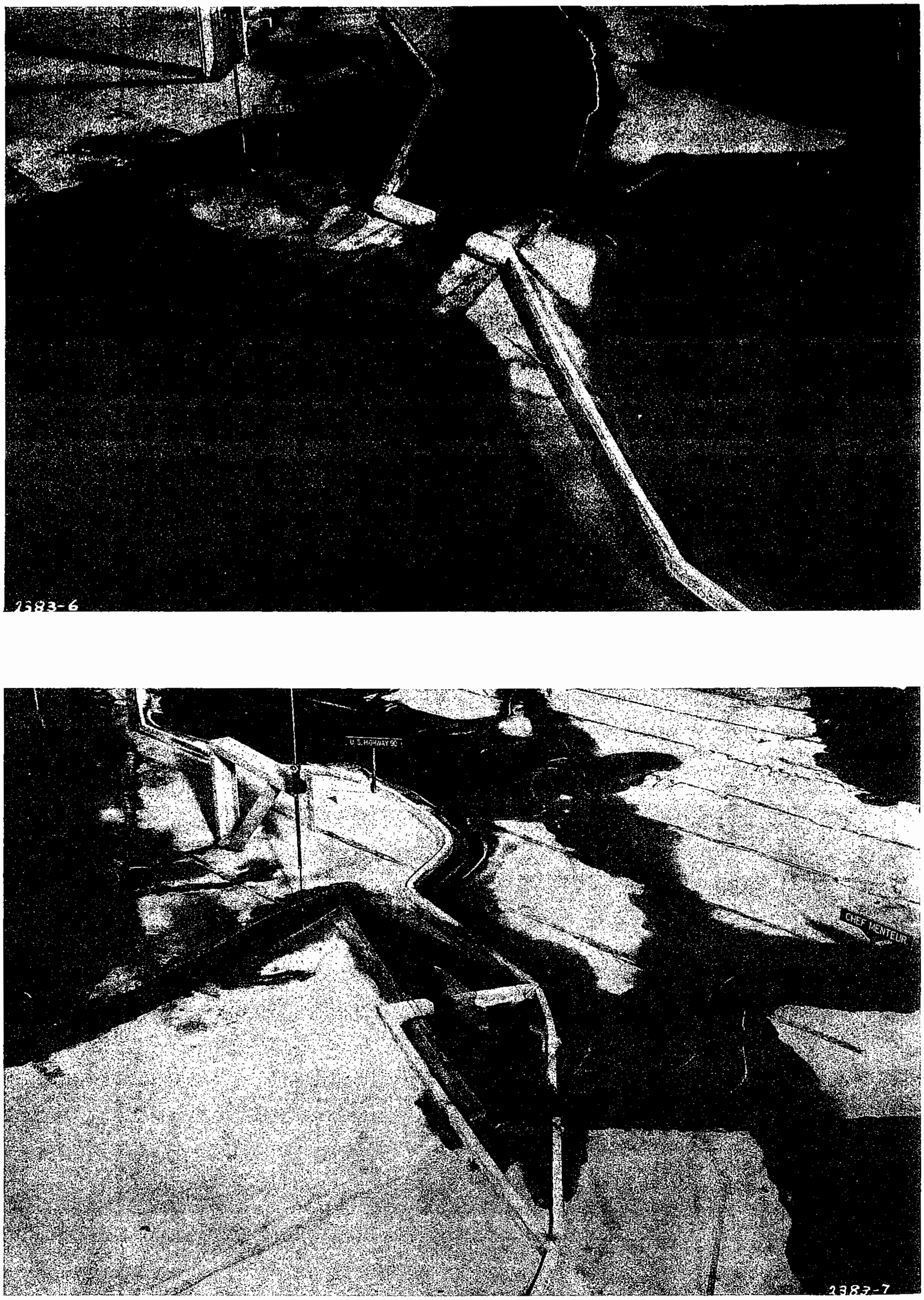


Fig. 13. Hurricane surge control structures installed in the distorted-scale comprehensive model

maximum average salinity of 7250 ppm occurred at cycle 337; for Lake Pontchartrain a minimum average salinity of 4500 ppm occurred at cycle 141, and a maximum average salinity of 6450 ppm occurred at cycle 344 and continued to the end of the test. The test average salinity for Lake Borgne was 4527 ppm and for Lake Pontchartrain 5389 ppm.

Discussion of results

60. A comparison of the results of the tests just described (with the hurricane control structures in the passes and the Gulf Outlet Channel operating) with the results of the preceding test series in which the Gulf Outlet Channel only was operated follows. For this comparison, an index of 1.00 was assigned to the salinities of the Gulf Outlet Channel tests without the structures. For the low inflow year test with the hurricane control structures, the minimum average salinity in Lake Borgne was increased, with a factor of 1.20; the maximum average showed no change, with a factor of 1.00; while the test average was decreased slightly, with a factor of 0.996. In Lake Pontchartrain the minimum average was decreased slightly, with a factor of 0.95; the maximum average was decreased slightly, with a factor of 0.96; while the test average also showed a small decrease, with a factor of 0.93. For the high inflow year test, the minimum average salinity in Lake Borgne was increased, with a factor of 1.07; the maximum average showed a greater increase, with a factor of 1.12; while the test average salinity was increased, with a factor of 1.10. In Lake Pontchartrain the minimum average was decreased slightly, with a factor of 0.98; the maximum average was increased slightly, with a factor of 1.04; while the test average showed a very slight increase, with a factor of 1.01. Evaluating the overall effects of the structures by averaging factors for the high and low inflow year tests, in Lake Borgne the minimum average salinity showed an increase, with a factor of 1.14; the maximum average salinity showed an increase, with a factor of 1.06; while the test (yearly) average showed an increase, with a factor of 1.05. For Lake Pontchartrain the minimum average showed a decrease, with a factor of 0.96; the maximum average showed no change, with a factor of 1.00; while the test average showed a slight decrease, with a factor of 0.97. A study of all the factors derived from an analysis of these tests indicated that the effects of the hurricane surge

control structures in the passes on salinities in both Lake Borgne and Lake Pontchartrain were negligible.

Effects of Gulf Outlet Channel Control Structure

Purpose of control structure

61. Since tests of the Gulf Outlet Channel had showed that long-range effects of this channel would be to increase the yearly average salinity in Lake Pontchartrain by a factor of 4.4 (see paragraph 54), a gated structure was proposed for controlling flow from the Gulf Outlet Channel into the lake. This structure, to be located at the junction of the channel and lake, would regulate flow by the opening and closing of the required number of gates. See plate 34 for details of the proposed structure.

Calibration and installation of structure

62. As in the tests of the proposed hurricane surge control structures, prior to installation of the gated structure in the distorted-scale model, it was necessary to determine flow characteristics through the structure at an undistorted scale. These flow characteristics were determined by installing a 1:100 undistorted-scale model of the proposed structure in a flume of suitable size (see fig. 12, page 29). Flow characteristics were determined for certain desired reductions in discharge by observing the headwaters and tailwaters and the resulting slopes through the structure for the different degrees of reduction. The degrees of reduction to be tested were: no reduction, one-third reduction, two-thirds reduction, and 100 percent reduction (complete closure). Plates 35 and 36 present the results of the flume tests of the undistorted structure, showing the relation between head differentials, discharge, and number of gates open or total width of opening.

63. In installing the structure in the distorted model, the same procedure used for the hurricane surge control structures was used, i.e. the total width of the opening in the structure was varied, while the sill elevation and transitions were maintained as proposed for the prototype structure, until the flow characteristics for the desired degrees of reduction were satisfactorily reproduced in the model. The width of openings determined in this manner were used during the appropriate discharge

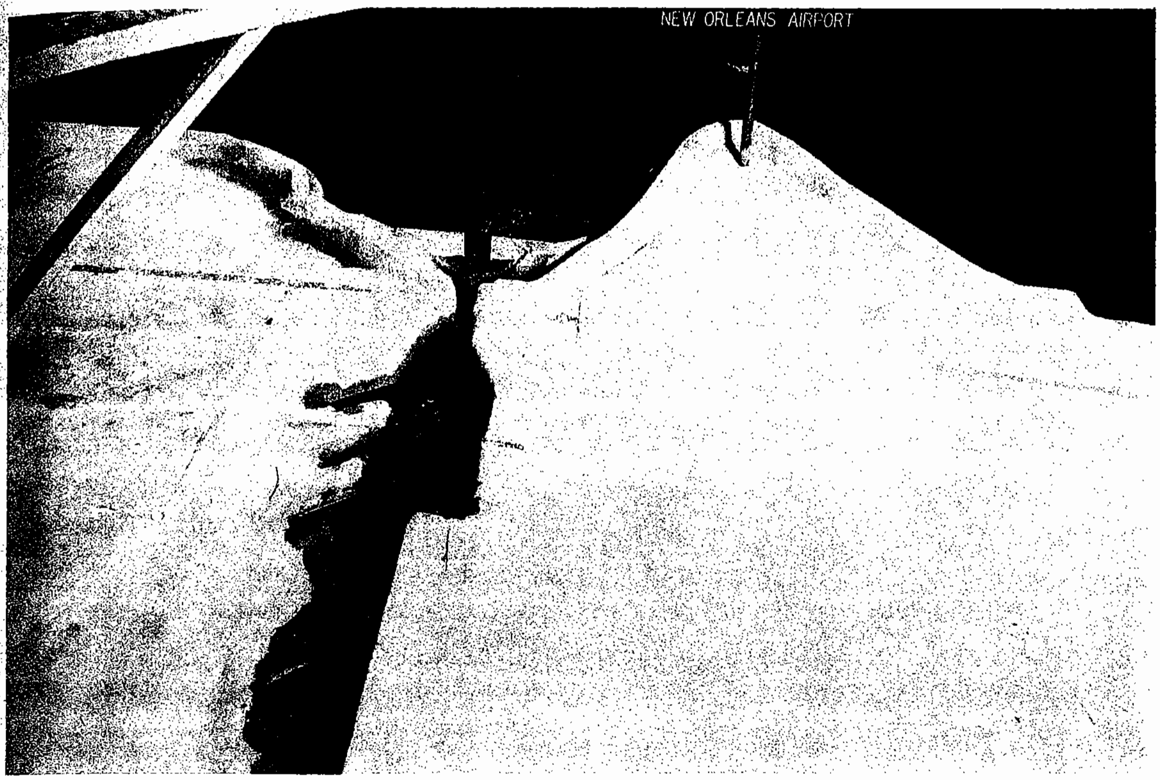


Fig. 14. Gulf Outlet Channel control structure installed in the model

reduction tests described in subsequent paragraphs. Fig. 14 shows the structure as installed in the model.

General test conditions

64. Except for deviations described in paragraphs pertaining to individual tests and the fact that the hurricane surge control structures were installed in the passes, these tests were conducted under the high inflow year base test conditions. A mean tide was reproduced, the high inflow year hydrograph was run, and initial salinities were 2000 ppm for Lake Pontchartrain and all the area west of Chef Menteur and Rigolets, and 3100 ppm for the source (Mississippi Sound) and all the area east of Chef Menteur and Rigolets. A 40-cycle stabilization run was made during which a constant freshwater inflow of 35,492 cfs was introduced; the Gulf Outlet Channel was not connected during this stabilization period. The source salinity of the Gulf Outlet Channel was maintained at 28,000 ppm.

Test of no reduction in discharge

65. Because the conditions existing during the test of hurricane

surge control structures, high inflow year, were the same as the requirements for this test, the data for that test were used. For convenience the results are again presented in plate 37 and certain data obtained during that test are repeated here. For Lake Borgne the minimum average salinity was 3325 ppm, occurring at cycle 222, and the maximum average salinity was 7250 ppm, occurring at cycle 337; for Lake Pontchartrain the minimum average salinity was 4500 ppm, occurring at cycle 141, and the maximum average salinity was 6450 ppm, occurring at cycle 344. The test average salinity was 4527 ppm for Lake Borgne and 5389 ppm for Lake Pontchartrain. It is pointed out that the salinities at the beginning of this test were high because of the high salinity concentrations prevailing at the end of the low inflow year test which preceded this test, even though a 50-cycle adjustment run was made between the tests during which the source salinity was gradually reduced to the correct initial salinity. (See paragraph 52 for a more detailed discussion of this high salinity condition and the corrections applied to compensate for it.)

Test of one-third
<u>reduction in discharge</u>

66. Test conditions for this test were as described in paragraph 64, with the discharge between the Gulf Outlet Channel and Lake Pontchartrain reduced one-third as determined and reproduced by the method described in paragraphs 62 and 63. The results of this test are also presented in plate 37. For Lake Borgne the minimum average salinity was 1950 ppm, occurring at cycle 46 and again at cycle 128, and the maximum average salinity was 6625 ppm, occurring at cycle 344; for Lake Pontchartrain the minimum average salinity was 1900 ppm, occurring at cycle 5, and the maximum average salinity was 4575 ppm, occurring at cycle 351, the end of the test. The test average salinities were 3203 ppm for Lake Borgne and 3008 ppm for Lake Pontchartrain.

Test of two-thirds
<u>reduction in discharge</u>

67. Test conditions for this test were as described in paragraph 64 with the discharge between the Gulf Outlet Channel and Lake Pontchartrain reduced two-thirds, determined and reproduced as described in paragraphs 62 and 63. The results are presented in plate 37. These results show that

for Lake Borgne the minimum average salinity was 2600 ppm, occurring at cycle 114 and again at cycle 141, and the maximum average salinity was 6250 ppm, occurring at cycle 344; for Lake Pontchartrain the minimum average salinity was 1950 ppm, occurring at cycle 101, and the maximum average salinity was 3800 ppm, occurring at cycle 351, the end of the test. The test average salinities were 3707 ppm for Lake Borgne and 2622 ppm for Lake Pontchartrain.

Test of 100 percent reduction
in discharge (complete closure)

68. This test was conducted under the high inflow year base test conditions with the Gulf Outlet Channel closed and the connecting bayous between Lake Borgne and the Gulf Outlet Channel also closed. All conditions were therefore identical with the high inflow year base test except that the hurricane surge control structures were installed in the passes. The results of the test are presented in plate 37. The results indicate that for Lake Borgne the minimum average salinity was 750 ppm, occurring first at cycle 115 and continuing to cycle 128, and the maximum average was 6300 ppm, occurring at cycle 344; for Lake Pontchartrain the minimum average salinity was 700 ppm, occurring at cycle 277, and the maximum average salinity was 1900 ppm, occurring at cycle 5. The test average salinities were 2430 ppm for Lake Borgne and 1079 ppm for Lake Pontchartrain.

Discussion of test results

69. A comparison of the results of the series of tests just described is presented in the following analysis in which an index of 1.0 is assigned to the salinities obtained in the no-reduction-in-discharge test as a base. The comparative reduction in salinities of the other tests of the series can be readily seen in the following tabulation.

Test	Average Salinity Factor Minimum	Maximum	Test
Lake Borgne			
No reduction in discharge	1.0	1.0	1.0
One-third reduction in discharge	0.59	0.91	0.71
Two-thirds reduction in discharge	0.78	0.86	0.82
100 percent reduction in discharge	0.22	0.87	0.54
High inflow year base test	0.26	0.93	0.57

(Continued)

Test	Average Salinity Factor Minimum	Maximum	Test
Lake Pontchartrain			
No reduction in discharge	1.0	1.0	1.0
One-third reduction in discharge	0.42	0.71	0.56
Two-thirds reduction in discharge	0.43	0.59	0.49
100 percent reduction in discharge	0.16	0.29	0.20
High inflow year base test	0.14	0.29	0.20

70. A comparison of the factors derived for the high inflow year base test and the test of 100 percent reduction in which hurricane surge control structures were installed in the passes further verifies the negligible effects of structures in the passes, as pointed out in paragraph 60.

Effects of Complete Closure of All Structures During Hurricane Conditions

Test conditions and test

71. The test conditions at the beginning of and during this test were as follows. Initial source (Mississippi Sound) salinity was 3100 ppm, the initial Lake Pontchartrain salinity west of Chef Menteur and Rigolets was 5825 ppm (the average of the last 50 cycles of the high inflow year test described in paragraph 59), and the initial Gulf Outlet Channel source (Breton Sound) salinity was 28,000 ppm and was maintained throughout the test. A 40-cycle stabilization run with the Gulf Outlet Channel connected was made with a constant freshwater inflow of 35,492 cfs; mean tides at both Long Point and Point Chicot were reproduced throughout the test. The high inflow year (1949) hydrograph was run until cycle 137, then the high inflow which accompanied the 1959 hurricane was introduced. Flow according to this hydrograph was continued through cycle 150, when the 1949 hydrograph was resumed and continued for the remainder of the test. See plate 38 for this hydrograph. During this 14-cycle (2 week) period (21 May through 3 June 1959--model time) all the structures and the connecting bayous between Lake Borgne and the Gulf Outlet Channel were completely closed. Salinity samples were taken in the Lake Borgne-Lake Pontchartrain system.

Results

72. The results of this test are presented in plate 39, on which are also plotted the results of the high inflow year base test and the test of

no reduction in discharge of the last series of tests, for comparison. A study of these results shows that for Lake Borgne the minimum average salinity was 3425 ppm and occurred from cycle 229 through cycle 236, while the maximum average salinity was 6975 ppm and occurred at cycle 337; for Lake Pontchartrain the minimum average salinity was 3800 ppm and occurred at cycle 154, while the maximum average was 6350 ppm and occurred at cycle 12. The test average salinities were 4217 ppm for Lake Borgne and 4822 ppm for Lake Pontchartrain.

73. Analysis of the results of this test by comparison with the results of the no-reduction-in-discharge test is difficult because the mean salinity in Lake Pontchartrain at the time of closing the structures was not the same for both tests (plate 39). However, taking into consideration that the mean salinity in Lake Pontchartrain for the closure test was about 300 ppm lower than the other test, it appears that the principal effect of the closure was to reduce the mean salinity of Lake Pontchartrain by a maximum of about 400 ppm. The recovery was fairly rapid after reopening the gates, and the effects of the closure appeared to have been negligible after about 80 tidal cycles. A second analysis of effects may be made from the results of the closure test alone. This shows that for Lake Pontchartrain a minimum salinity occurred at cycle 154 or 17 cycles after closure (4 cycles after reopening), and complete return to the salinity which existed at the time of closure was reached at cycle 225, 75 cycles (11 prototype weeks) after reopening of all the structures. This maximum reduction in salinity amounted to 12 percent and occurred at cycle 154. For Lake Borgne the minimum salinity resulting from complete closure of all structures occurred at cycle 141, or 4 cycles after closure, and full return to the salinity existing at the time of closure appeared to be made at cycle 157, or 7 cycles (1 prototype week) after reopening. Although the salinity was less later in the test, this appeared to be a trend in the Lake Borgne salinity pattern rather than the result of closure. The reduction in salinity in Lake Borgne resulting from the closure amounted to 5 percent.

74. An overall appraisal of the results of this test indicates that the reduction in salinity in both Lake Borgne and Lake Pontchartrain was of a low order and lasted a short period of time, full recovery being made within 10 to 12 weeks. A study made during this test of the maximum tidal

heights at West End (which has been determined to be representative of the average tidal heights in Lake Pontchartrain) showed that complete closure raised the high-water elevation a maximum of 1.2 ft above that which existed prior to closure, the rise being gradual and occurring during cycle 150, which was the last cycle of closure, and that after reopening, the high-water elevation decreased gradually until cycle 159, at which time it was that which existed prior to closure.

Bonnet Carre Spillway Tests

75. Tests were made with the Bonnet Carre Spillway in operation, with the experienced (1950) discharge of 223,000 cfs and the design discharge of 250,000 cfs reproduced for several different model conditions. The purpose of these tests was to determine the average high-water elevations which would occur in Lake Pontchartrain under various prototype conditions and spillway flows. The conditions tested and the resulting observations are presented in tabular form below.

	Average High-Water Elevations in Lake Pontchartrain, ft msl		
Condition Tested	During Normal Inflow	During Experienced (223,000 cfs) Discharge Through Bonnet Carre	During Design (250,000 cfs) Discharge Through Bonnet Carre
Existing conditions	0.30	0.95	
Gulf Outlet Channel			1.00
Hurricane surge structures		1.20	
Gulf Outlet Channel and hurricane surge structures	0.40		1.40

76. The conclusions drawn from these observations are:

<u>a</u>. For conditions of normal inflow into the lake system, the present average elevation of high water in Lake Pontchartrain would be increased by about 0.1 ft by the combined effects of the Gulf Outlet Channel and the hurricane surge control structures.

<u>b</u>. For conditions of the 1950 experienced operation of Bonnet Carre (a discharge of 223,000 cfs through the structure), the average high-water elevation in Lake Pontchartrain would be increased about 0.25 ft by installation of the hurricane

surge control structures. (It is important to note that the Gulf Outlet Channel was not open in this test.)

_c_. For conditions of a design discharge (250,000 cfs) through Bonnet Carre, installation of the hurricane surge control structures would increase the average high-water elevation in Lake Pontchartrain by about 0.4 ft as compared to that with the Gulf Outlet Channel open but without the hurricane surge control structures.

PART V: DISCUSSION

Verification Tests

77. Tests indicated that the model reproduced prototype tidal heights, velocities, and salinity patterns to the degree of accuracy required for satisfactory prediction of prototype phenomena that would occur under the planned or anticipated prototype conditions tested in the model.

Base Tests

78. These tests indicated that the salinity patterns of the western portion of Mississippi Sound, Lake Borgne, and Lake Pontchartrain were inversely related to the freshwater inflow into the system. The salinity of Mississippi Sound varied from a low of 2000 ppm during a high freshwater inflow year (weekly average of 30,047 cfs) to a high of 14,625 ppm during a low freshwater inflow year (weekly average of 9346 cfs). The salinity of Lake Borgne varied from a low of 850 ppm during a high freshwater inflow year to a high of 10,125 ppm during a low freshwater inflow year. The salinity of Lake Pontchartrain varied from a low of 650 ppm during a high freshwater inflow year to a high of 3550 ppm during a low freshwater inflow year.

Gulf Outlet Channel Tests

79. These tests indicated that the connection of the Gulf Outlet Channel to Lake Pontchartrain would increase the salinity of the lake system to a considerable degree. For a high freshwater inflow year the average annual increase in salinity in Lake Pontchartrain was from 1056 ppm to 5338 ppm, and in Lake Borgne from 2564 ppm to 4105 ppm. For the low freshwater inflow year the average annual increase in salinity in Lake Pontchartrain was from 2278 ppm to 8412 ppm, and in Lake Borgne from 6463 ppm to 7589 ppm. Factors of increase in salinity vary from 3.7 for the low inflow year to 5.1 for the high inflow year in Lake Pontchartrain, and from 1.2 for the low inflow year to 1.6 for the high inflow year in Lake Borgne.

Hurricane Surge Control Structures Tests

80. This series of tests indicated that installation of the hurricane surge control structures in Chef Menteur and Rigolets would decrease the average annual salinity in Lake Pontchartrain from 8412 ppm to 7831 ppm, and in Lake Borgne from 7589 ppm to 7565 ppm for the low freshwater inflow year; for the high freshwater inflow year the average annual increase in salinity would be from 5338 ppm to 5389 ppm for Lake Pontchartrain and from 4105 ppm to 4527 ppm for Lake Borgne.

81. When the results of the high freshwater inflow year test with the hurricane surge control structures installed in the passes and the Gulf Outlet Channel not connected are compared with the high freshwater inflow year base test, the following average annual salinity changes were noted: The salinities in Lake Pontchartrain were increased from 1056 ppm to 1079 ppm and the salinities in Lake Borgne were decreased from 2564 ppm to 2430 ppm. The separate comparisons described in this and preceding paragraphs indicate that the effects of the hurricane surge control structures in the passes were minor.

Gulf Outlet Channel Control Structure Tests

82. These tests indicated that for a high freshwater inflow year (the only year for which these tests were conducted) a one-third reduction in discharge through the structure resulted in a reduction in the yearly average salinity in Lake Pontchartrain of from 5389 ppm to 3008 ppm and in Lake Borgne of from 4527 ppm to 3203 ppm. A two-thirds reduction in discharge through the structure resulted in a reduction of the yearly average salinity for Lake Pontchartrain of from 5389 ppm to 2622 ppm and for Lake Borgne of from 4527 ppm to 3707 ppm. Complete closure of the structure, or 100 percent reduction in discharge through it, resulted in essentially the same yearly average salinities as those which resulted from the high freshwater inflow year base test, except for the minor differences which resulted from the installation of the hurricane surge control structures in the passes, as discussed in paragraph 81.

Tests of Complete Closure of All Structures During Hurricane Conditions

83. Complete closure of all structures during a 2-week hurricane period, with the accompanying increase in freshwater inflow into the system, resulted in a maximum reduction in salinity of 12 percent in Lake Pontchartrain and of 4 percent in Lake Borgne; the reductions were only temporary and the salinity of the lakes had returned to normal within 11 weeks in Lake Pontchartrain and within one week in Lake Borgne. During this complete closure the average high-water elevation in Lake Pontchartrain was increased a maximum of 1.2 ft which lasted for only two cycles or two prototype days.

Bonnet Carre Tests

84. Although all possible combinations of conditions were not tested, a sufficient number, including the most critical conditions, were tested to determine the effects on tidal heights in Lake Pontchartrain which could be expected from the operation of the Bonnet Carre Spillway. For normal inflow (Bonnet Carre closed) the combined effects of the Gulf Outlet Channel and the hurricane surge control structures could be expected to raise the high-water elevation in Lake Pontchartrain 0.1 ft. With the 1950 experienced flow (223,000 cfs) through Bonnet Carre, the hurricane surge control structures alone could be expected to raise the high-water elevation in Lake Pontchartrain 0.25 ft. With the design flow (250,000 cfs) through Bonnet Carre, the effects of the hurricane surge control structures could be expected to raise the high-water elevation in Lake Pontchartrain 0.4 ft above the high-water elevation attained with only the Gulf Outlet Channel connected.

Summary of Salinity Tests

85. Table 1 is a comparison of certain critical salinities of all the salinity tests conducted. An index of 1.0 was assigned to the basic tests with which comparisons were made for the purpose of arriving at factors of increase or decrease in salinity for the tests tabulated.

PART VI: CONCLUSIONS

86. After a thorough study of all the tests conducted and an analysis of all the data obtained during the tests, the following major conclusions are drawn:

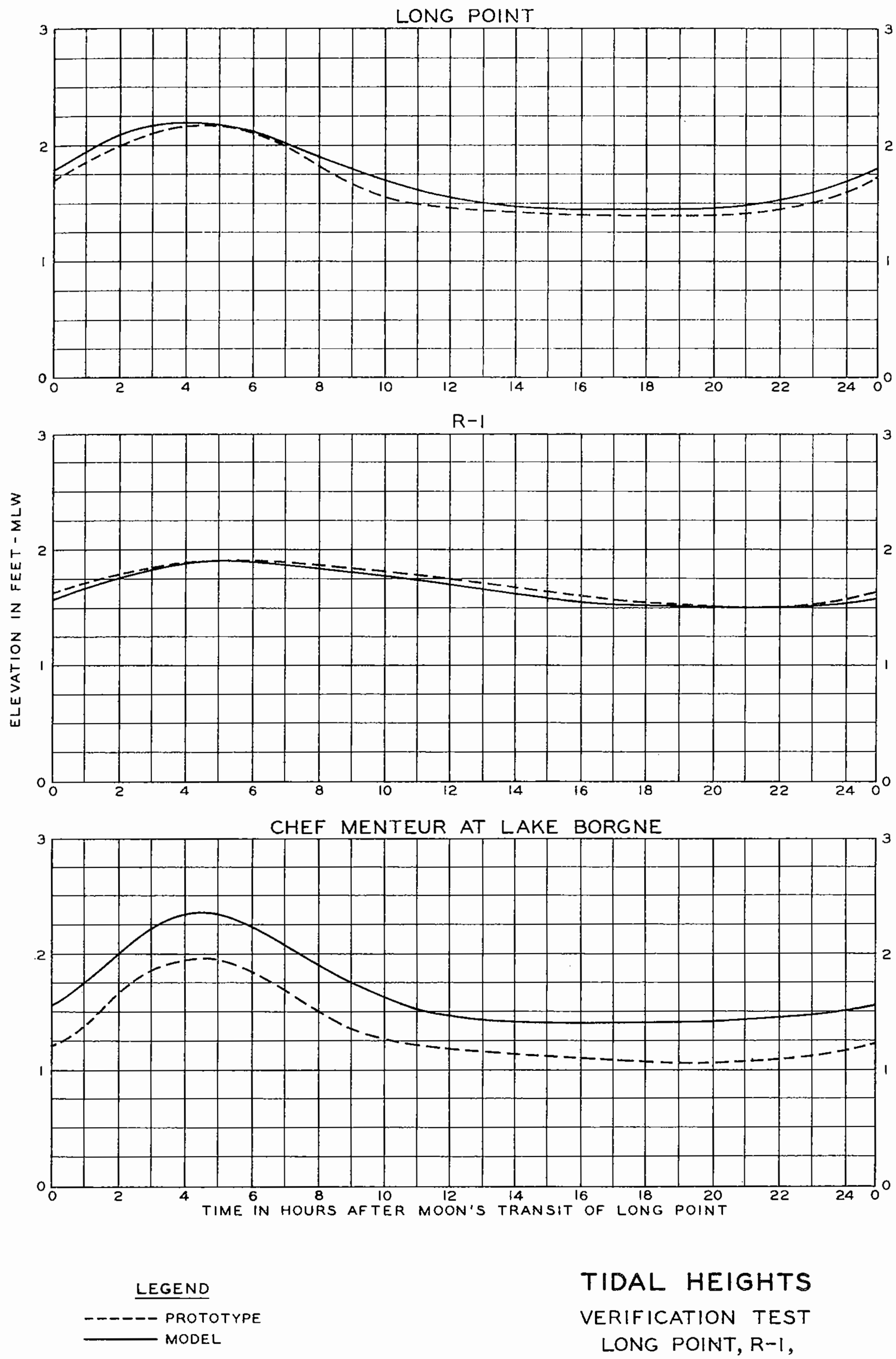
- a. There is a distinct relation between the freshwater inflow from the streams tributary to the area studied and the salinity of the lake system, including the western portion of Mississippi Sound; this relation is such that the freshwater inflow experienced or predicted must be given equal consideration with any other factor or combination of factors that might change the salinity regimen of the lake system.
- b. The effects of the installation of hurricane surge control structures in Chef Menteur and Rigolets as presently designed (75 percent reduction in cross-sectional area) on both salinities and tidal heights would be negligible.
- c. Connection of the Gulf Outlet Channel to Lake Pontchartrain, through the Inner Harbor Navigation Canal, would increase the salinity of Lake Pontchartrain to such a degree that a salinity control structure near the junction of the channel with Lake Pontchartrain would be required to control the salinity level; further, the operation of such a structure, which should be gated, in conjunction with accurate freshwater inflow predictions, could be used to maintain the level of salinity in Lake Pontchartrain at any desired concentration between that which now occurs and that which would occur without a control structure.
- d. Complete closure of all structures during periods of hurricane conditions (relatively short periods) would not produce any serious adverse salinity conditions, and any lowering of salinity levels in Lake Pontchartrain would be of short duration. The maximum high-water elevation to be expected during this closure would be 1.4 ft msl.
- e. Operation of the Bonnet Carre Spillway, discharging as much as the design flow (250,000 cfs), with both the Gulf Outlet Channel connected and hurricane surge structures installed in Chef Menteur and Rigolets would raise the high-water elevation in Lake Pontchartrain to a maximum of 1.4 ft msl.

Table 1

Summary of Salinity Tests

Test	Lake Pontchartrain Minimum ppm	Lake Pontchartrain Minimum Factor	Lake Pontchartrain Maximum ppm	Lake Pontchartrain Maximum Factor	Lake Pontchartrain Test Average ppm	Lake Pontchartrain Test Average Factor	Lake Borgne Minimum ppm	Lake Borgne Minimum Factor	Lake Borgne Maximum ppm	Lake Borgne Maximum Factor	Lake Borgne Test Average ppm	Lake Borgne Test Average Factor
Effects of Freshwater Inflow												
High inflow year base test	650	1.0	1850	1.0	1056	1.0	850	1.0	6,750	1.0	2564	1.0
Medium inflow year base test	950	1.46	2800	1.51	1640	1.55	1100	1.29	9,700	1.44	4858	1.89
Low inflow year base test	1675	2.58	3550	1.92	2278	2.16	3275	3.85	10,125	1.50	6463	2.52
Effects of Gulf Outlet Channel and Structures in the Passes, Low Inflow Year												
Low inflow year base test	1675	1.0	3550	1.0	2278	1.0	3275	1.0	10,125	1.0	6463	1.0
New Orleans District test 2 without structures in the passes	2250	1.34	7850	2.21	5108	2.24	3050	0.93	11,075	1.09	6597	1.02
Gulf Outlet Channel without structures in the passes	7350	4.39	9800	2.76	8412	3.69	4150	1.27	10,925	1.08	7589	1.17
Gulf Outlet channel with structures in the passes	6950	4.15	9425	2.65	7831	3.44	5000	1.53	10,950	1.08	7565	1.17
Effects of Gulf Outlet Channel and Structures in the Passes, High Inflow Year												
High inflow year base test	650	1.0	1850	1.0	1056	1.0	850	1.0	6,750	1.0	2564	1.0
Gulf Outlet Channel without structures in the passes	4600	7.08	6200	3.35	5338	5.05	3100	3.65	6,500	0.96	4105	1.60
Gulf Outlet Channel with structures in the passes	4500	6.92	6450	3.49	5389	5.10	3325	3.91	7,250	1.07	4527	1.76
Effects of Reduction in Discharge Through the Gulf Outlet Channel Control Structure												
No reduction in discharge through Gulf Outlet Channel structure*	4500	1.0	6450	1.0	5389	1.0	3325	1.0	7,250	1.0	4527	1.0
One-third reduction in discharge*	1900	0.42	4575	0.71	3008	0.56	1950	0.59	6,625	0.91	3203	0.71
Two-thirds reduction in discharge*	1950	0.43	3800	0.59	2622	0.49	2600	0.78	6,250	0.86	3707	0.82
100 percent reduction in discharge*	700	0.16	1900	0.29	1079	0.20	750	0.22	6,300	0.87	2430	0.54
High inflow year base test	650	0.14	1850	0.29	1056	0.20	850	0.26	6,750	0.93	2564	0.69
Effects of Complete Closure of All Structures During Hurricane Conditions												
High inflow year base test	650	1.0	1850	1.0	1056	1.0	850	1.0	6,750	1.0	2564	1.0
No reduction in discharge, high inflow year*	4500	6.92	6450	3.49	5389	5.10	3325	3.91	7,250	1.07	4527	1.76
Complete closure during hurricane conditions, high inflow year*	3800	5.85	6350	3.44	4822	4.57	3425	4.03	6,975	1.03	4217	1.64

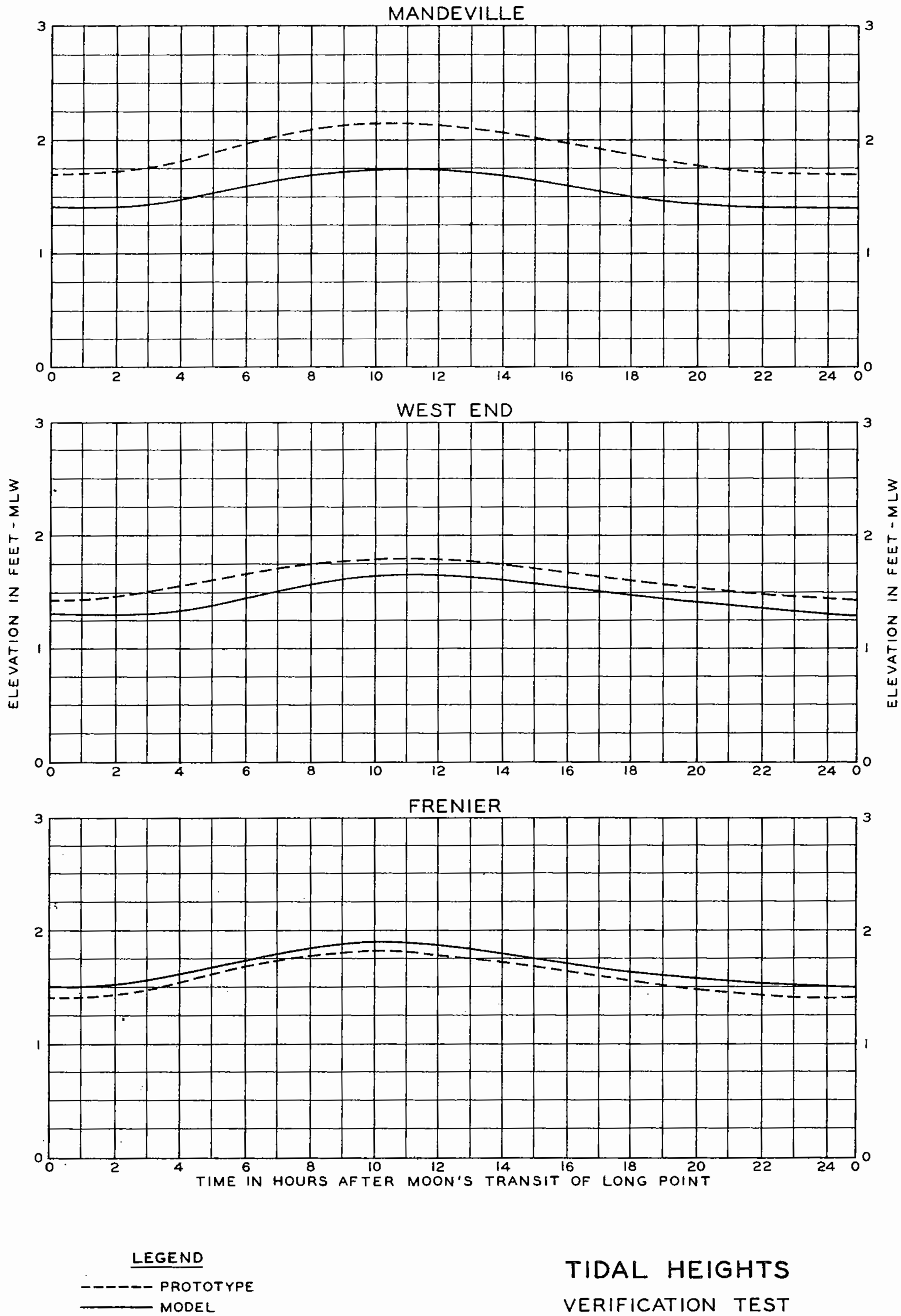
* With structures in the passes.



TIDAL HEIGHTS

VERIFICATION TEST
LONG POINT, R-1,
AND CHEF MENTEUR AT LAKE BORGNE

NEAP TIDE ; FRESHWATER DISCHARGE 39,982 CFS



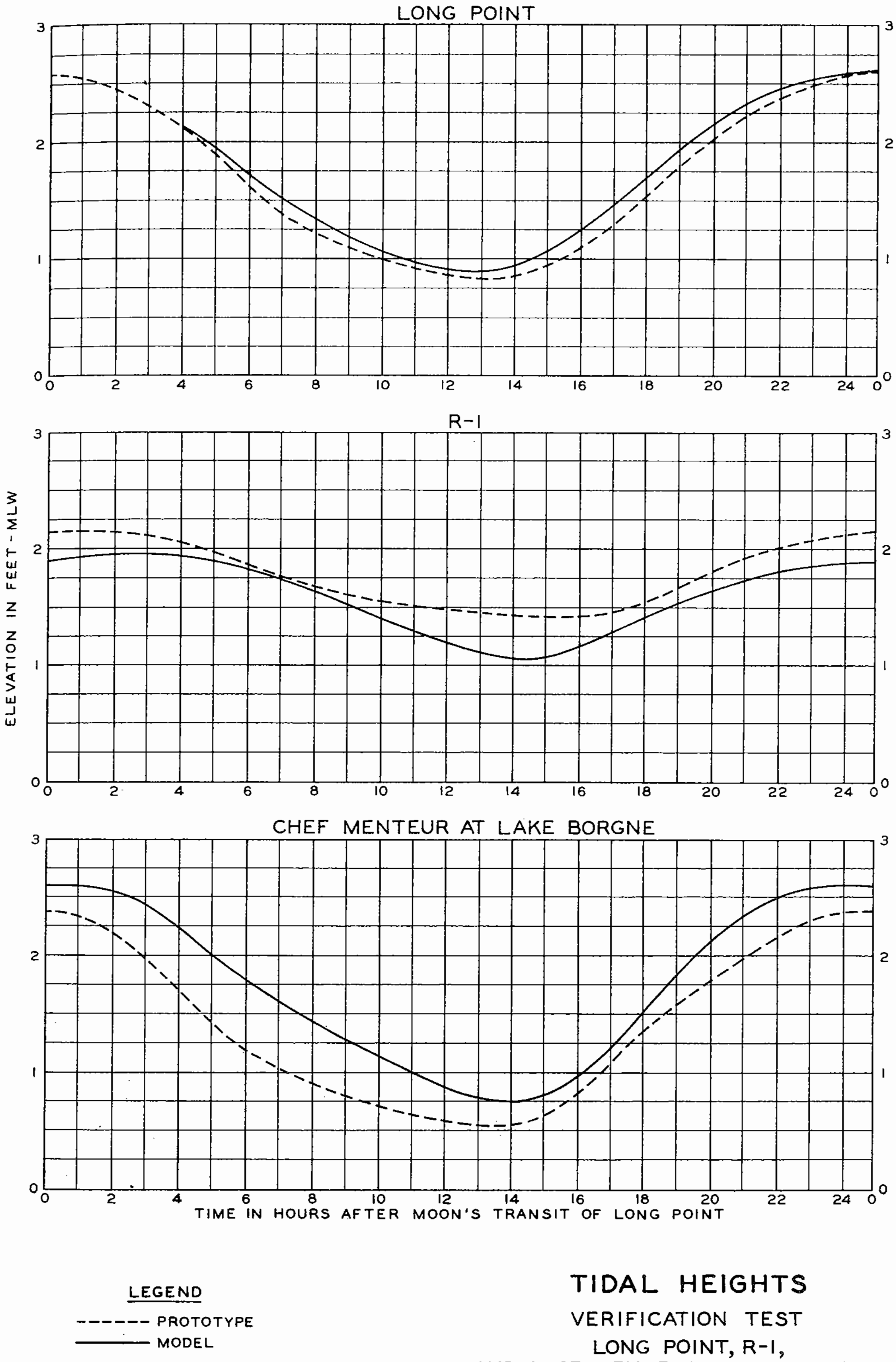
TIDAL HEIGHTS

VERIFICATION TEST

MANDEVILLE, WEST END, AND FRENIER

NEAP TIDE; FRESHWATER DISCHARGE 39,982 CFS

PLATE 2

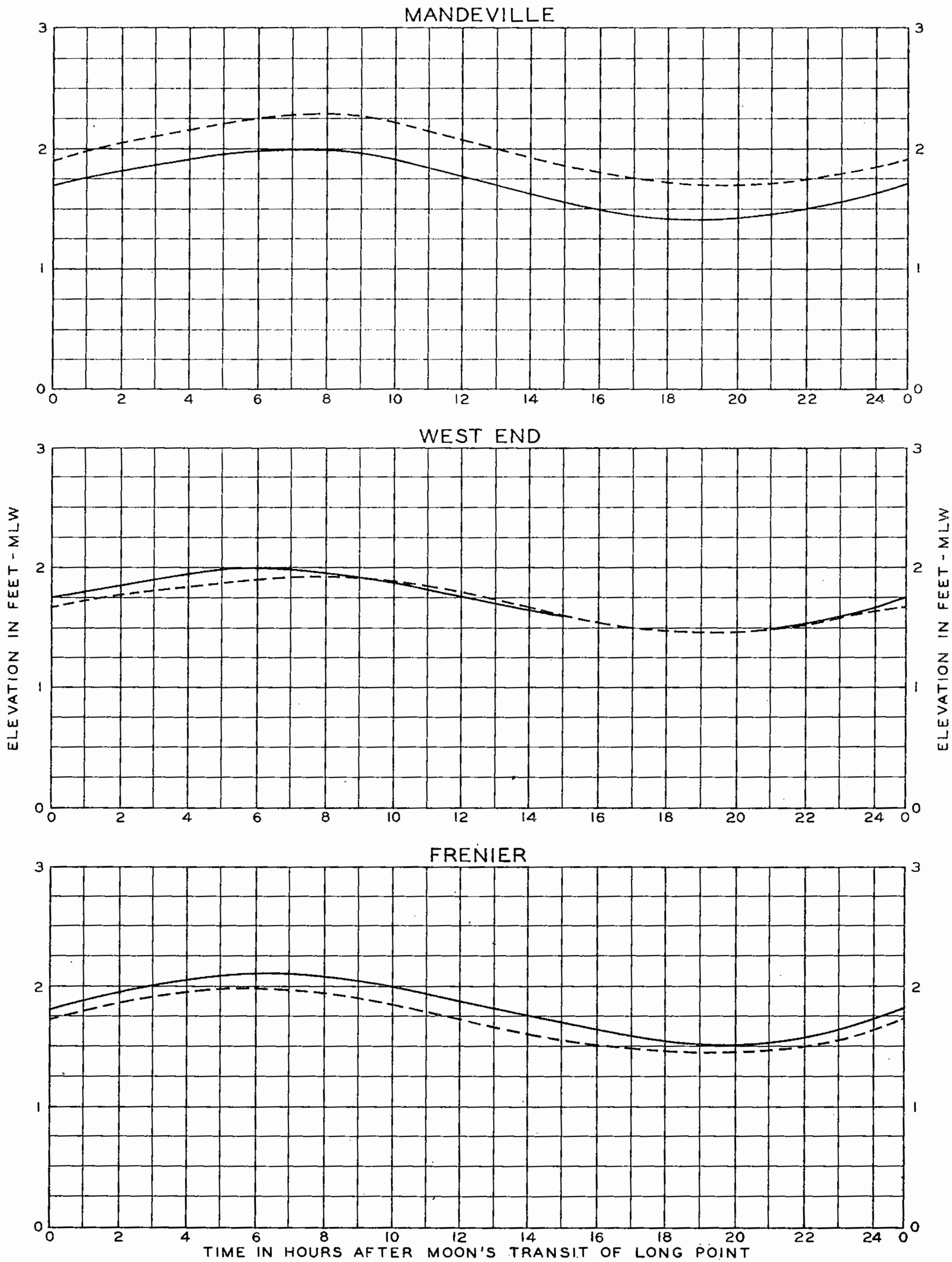


TIDAL HEIGHTS

VERIFICATION TEST

LONG POINT, R-1,
AND CHEF MENTEUR AT LAKE BORGNE

SPRING TIDE; FRESHWATER DISCHARGE 15,000 CFS



LEGEND

------ PROTOTYPE

——— MODEL

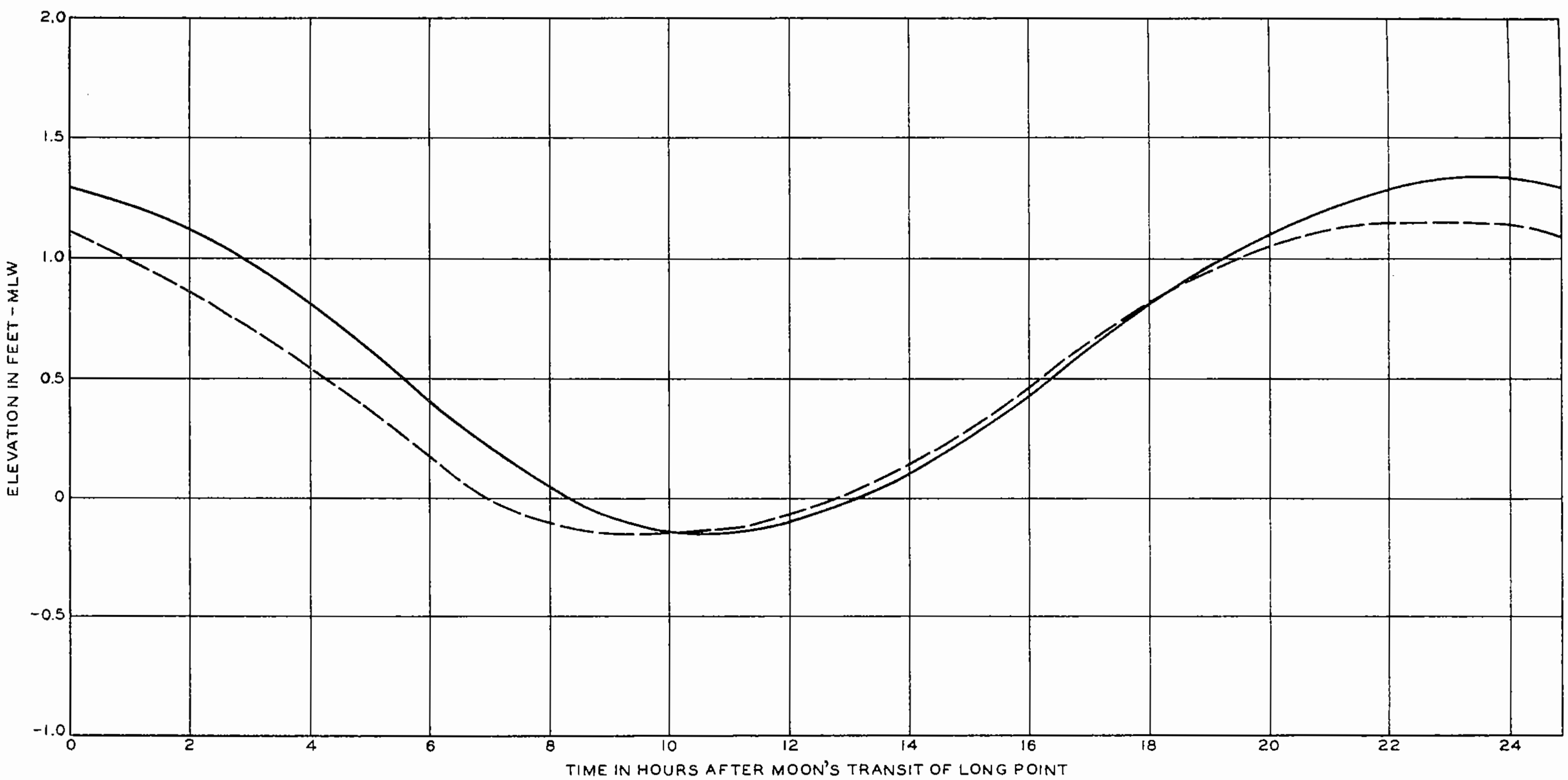
TIDAL HEIGHTS

VERIFICATION TEST

MANDEVILLE, WEST END, AND FRENIER

SPRING TIDE; FRESHWATER DISCHARGE 15,000 CFS

PLATE 4



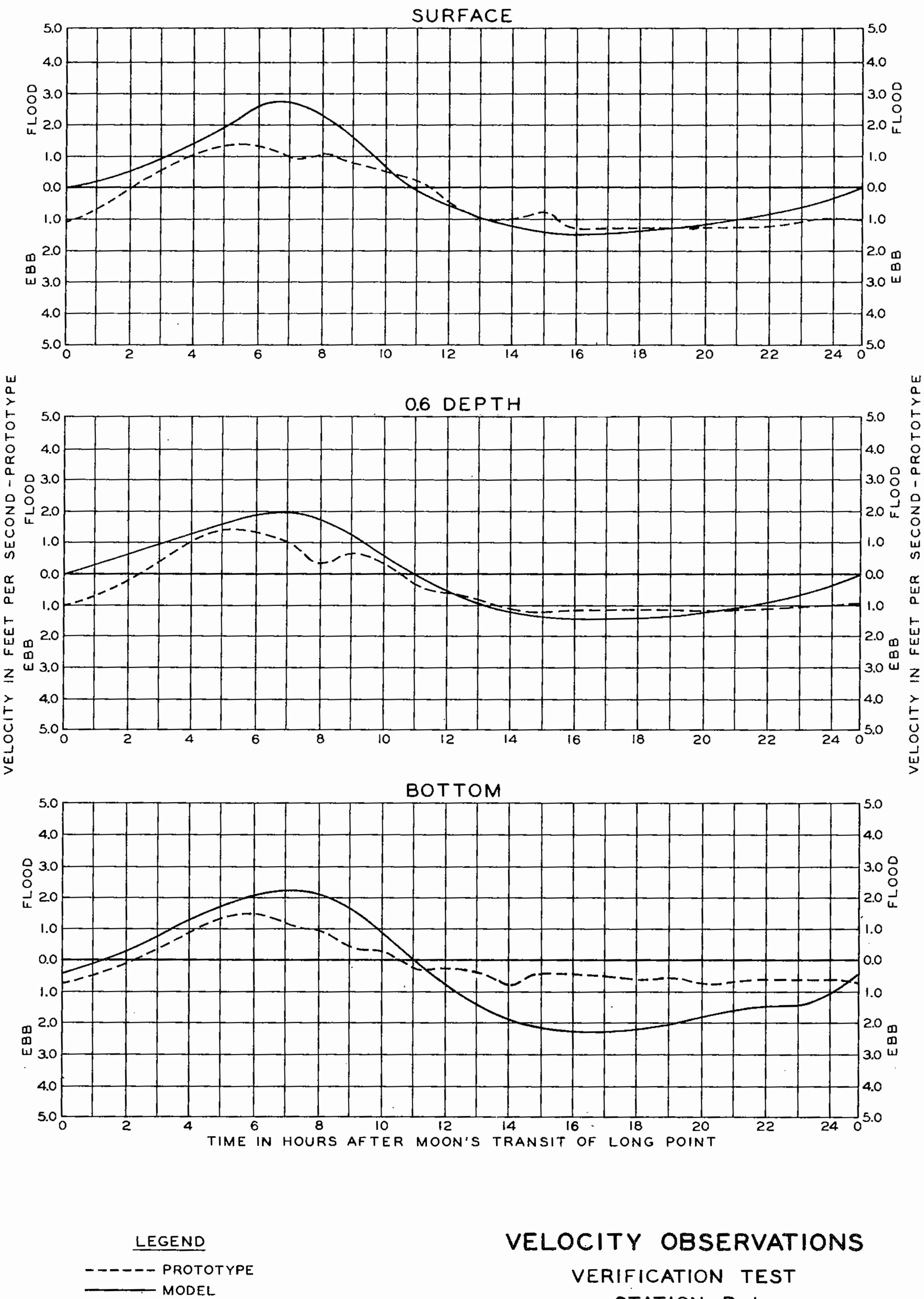
LEGEND

PROTOTYPE (dashed line)
MODEL (solid line)

MODEL TEST DATA

TIDE MEAN
FRESHWATER DISCHARGE 18,096 CFS

TIDAL HEIGHTS
VERIFICATION TEST
POINT CHICOT

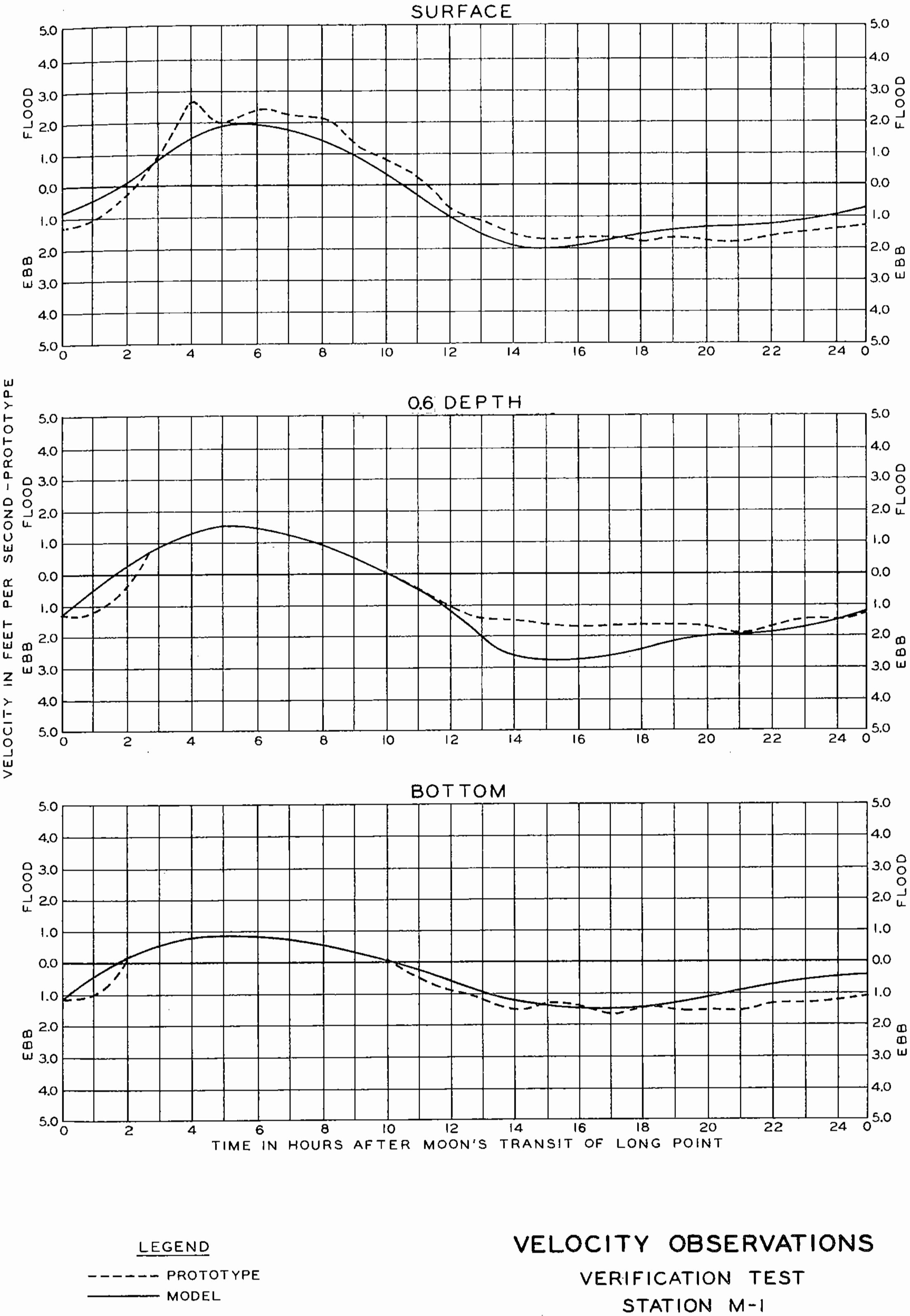


VELOCITY OBSERVATIONS

VERIFICATION TEST

STATION R-1

NEAP TIDE ; FRESHWATER DISCHARGE 39,982 CFS

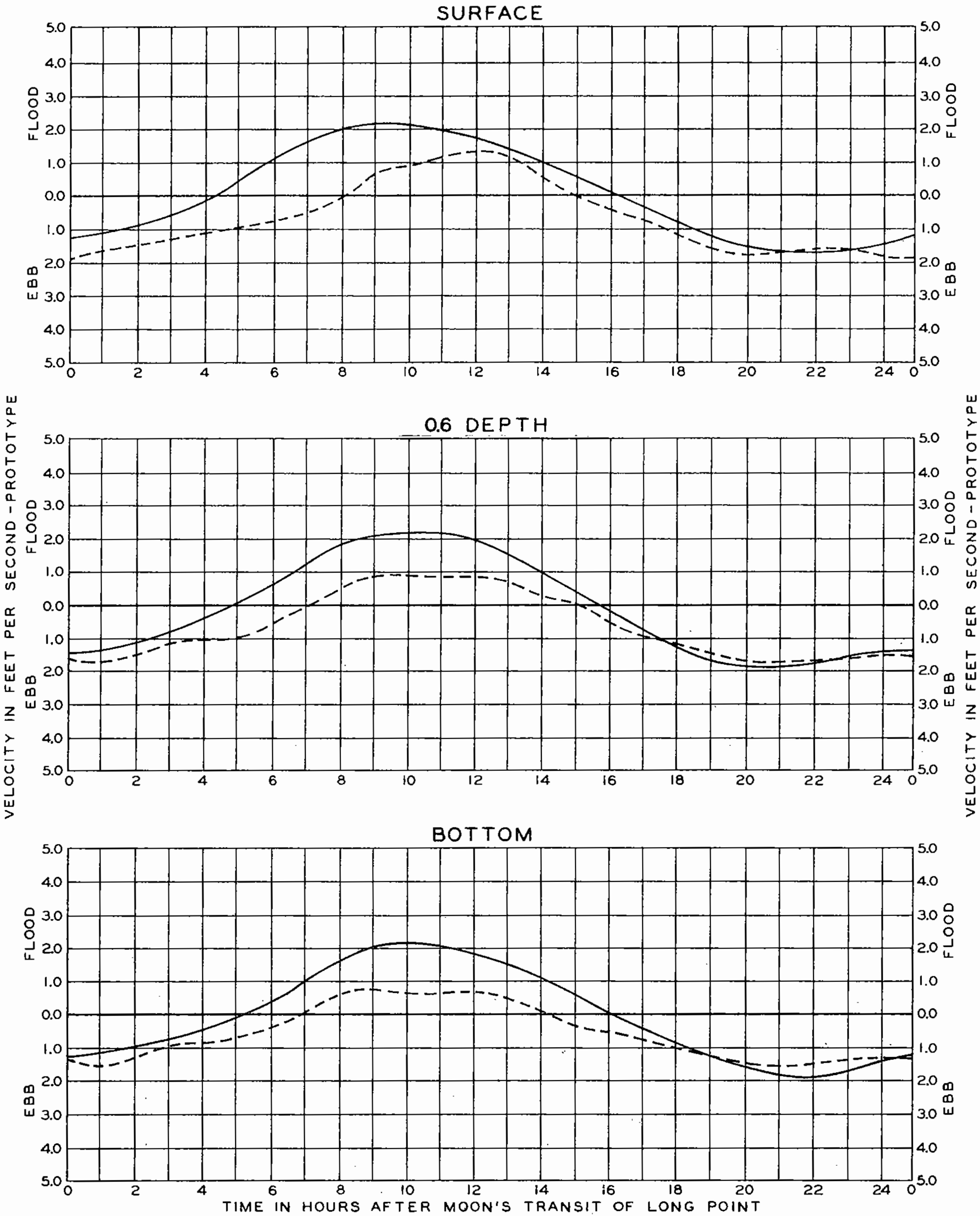


VELOCITY OBSERVATIONS

VERIFICATION TEST

STATION M-1

NEAP TIDE ; FRESHWATER DISCHARGE 39,982 CFS



LEGEND

------ PROTOTYPE

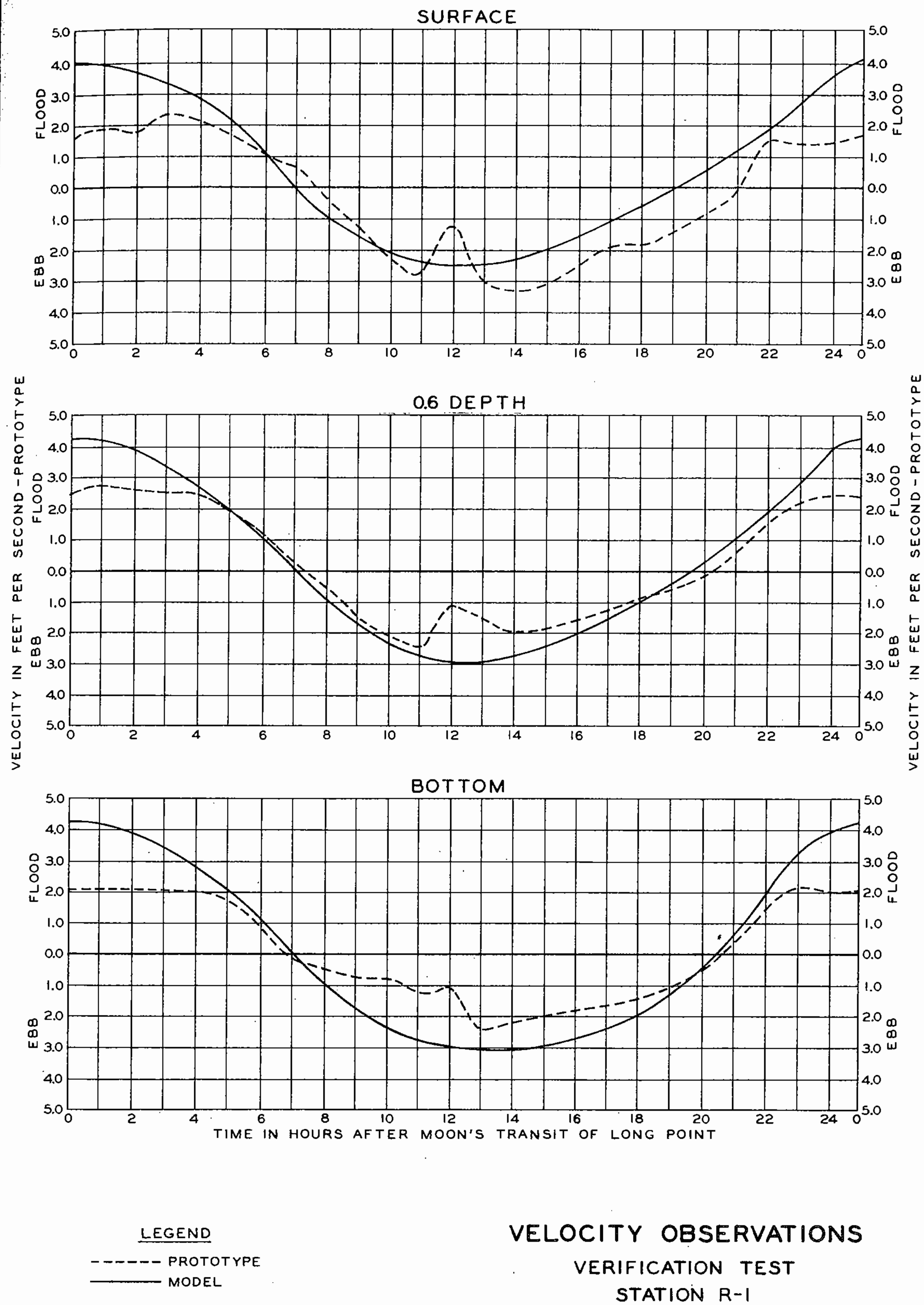
——— MODEL

VELOCITY OBSERVATIONS

VERIFICATION TEST

STATION PM

NEAP TIDE; FRESHWATER DISCHARGE 39,982 CFS

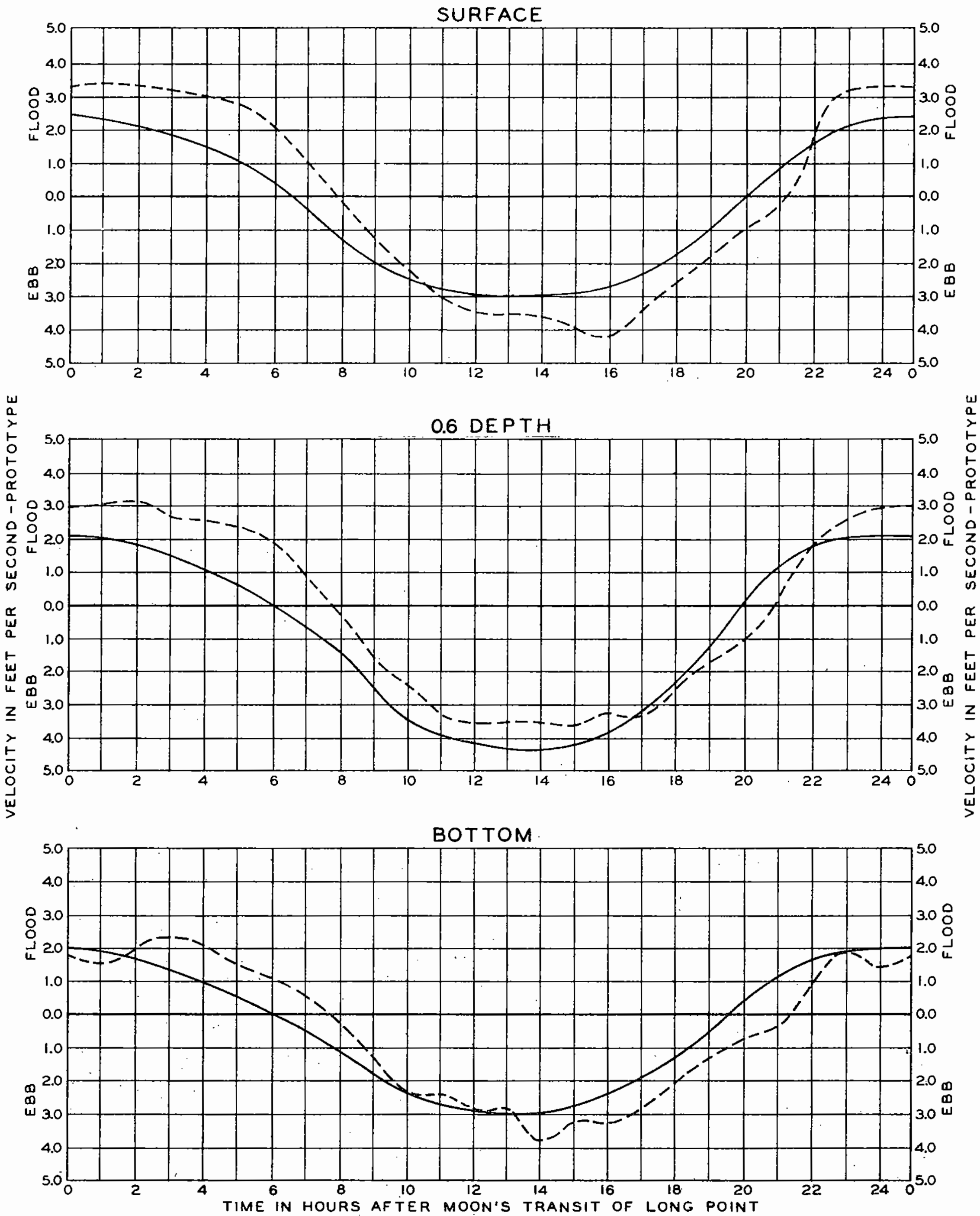


VELOCITY OBSERVATIONS

VERIFICATION TEST

STATION R-1

SPRING TIDE ; FRESHWATER DISCHARGE 15,000 CFS



LEGEND

------ PROTOTYPE

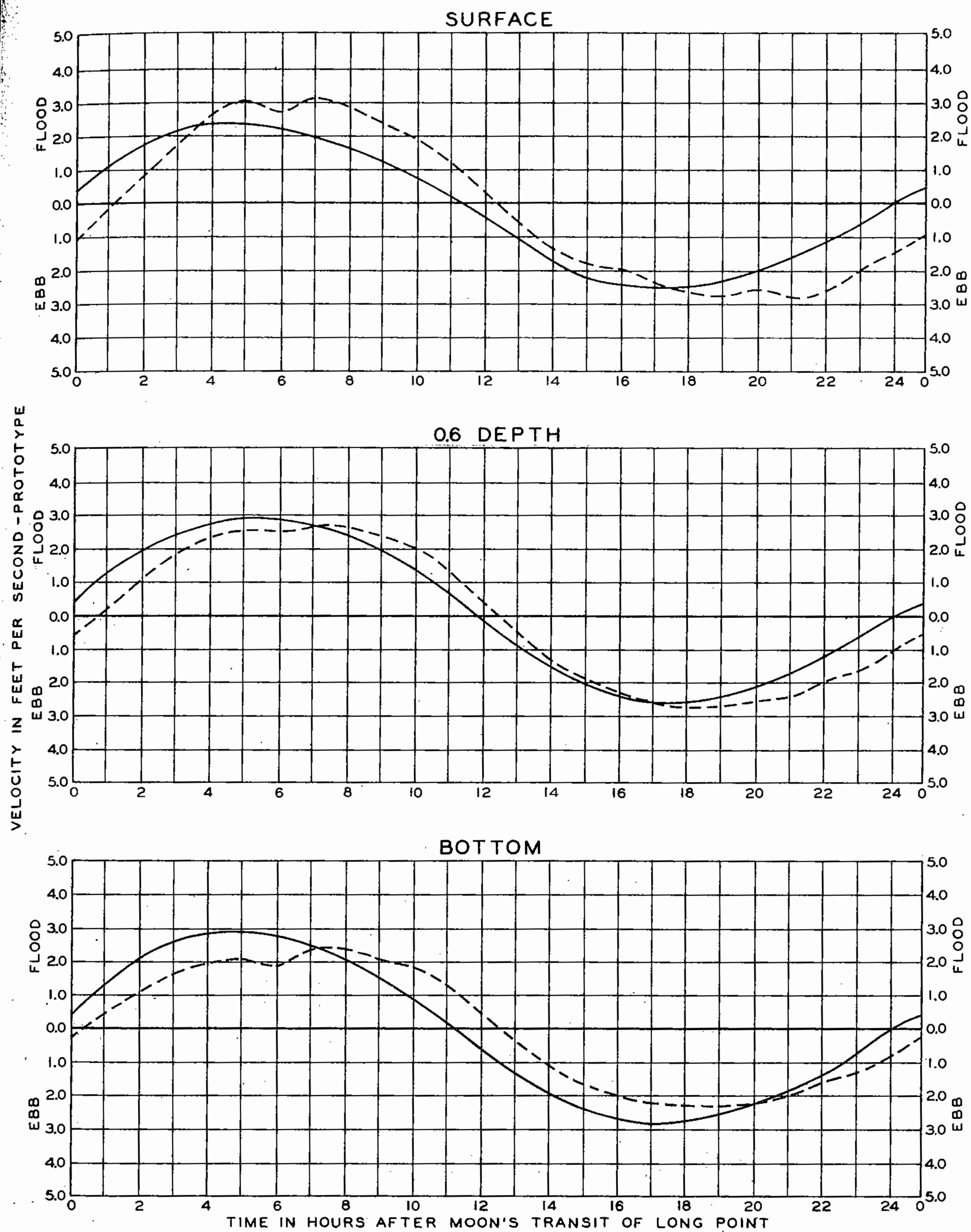
——— MODEL

VELOCITY OBSERVATIONS

VERIFICATION TEST

STATION M-1

SPRING TIDE ; FRESHWATER DISCHARGE 15,000 CFS



LEGEND

------ PROTOTYPE

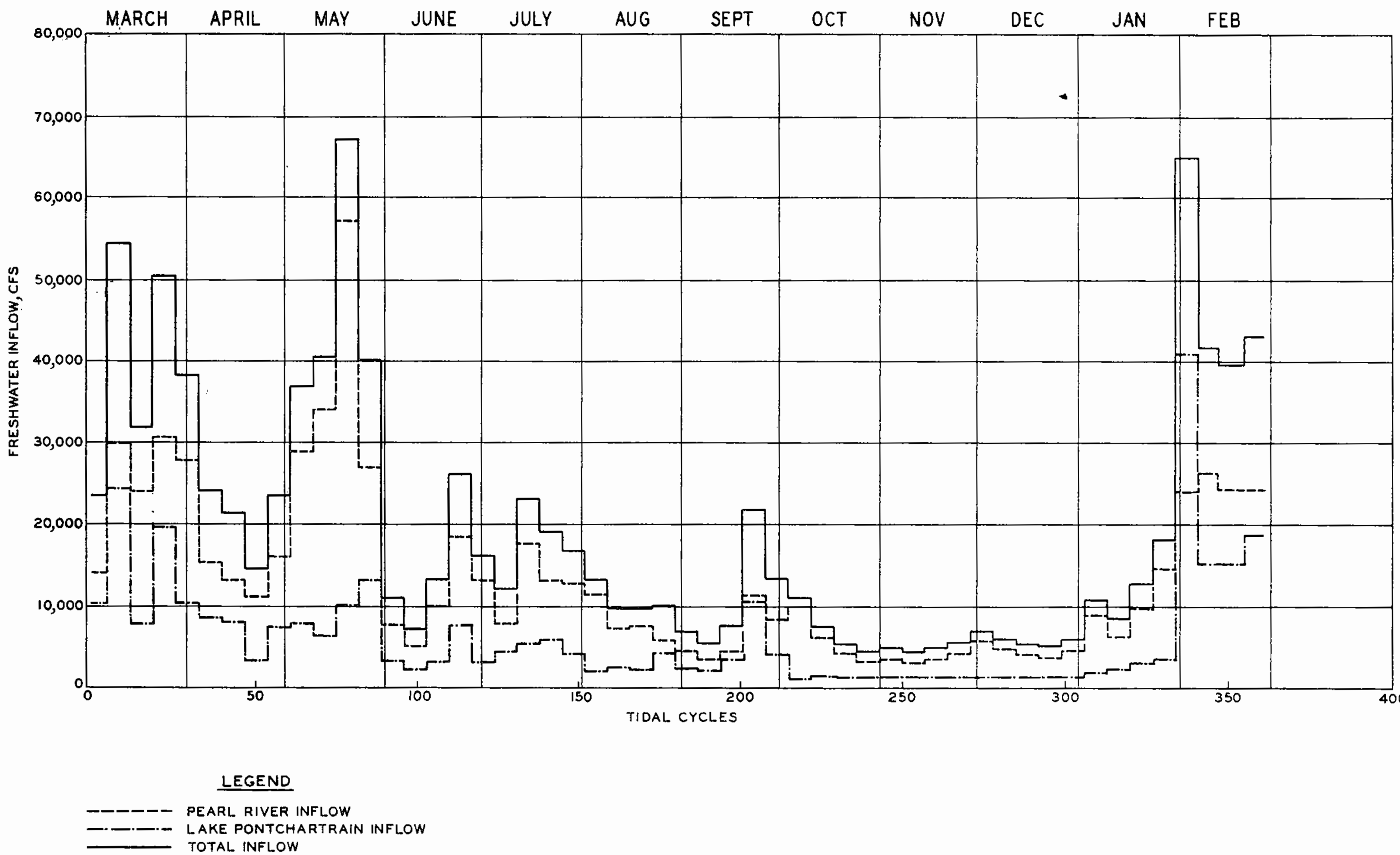
——— MODEL

VELOCITY OBSERVATIONS

VERIFICATION TEST

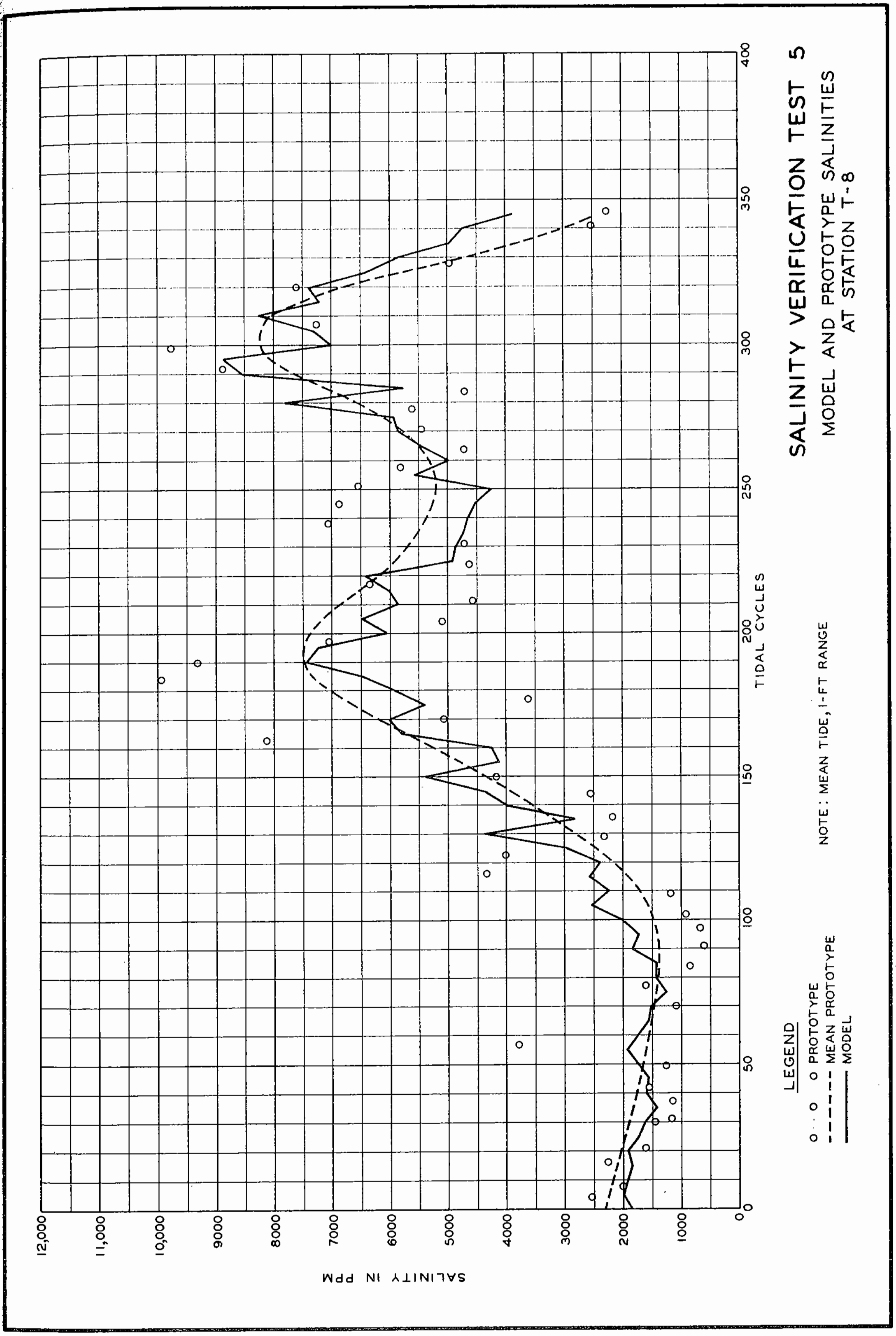
STATION PM

SPRING TIDE; FRESHWATER DISCHARGE 15,000 CFS



FRESHWATER INFLOW HYDROGRAPH
VERIFICATION YEAR 1958

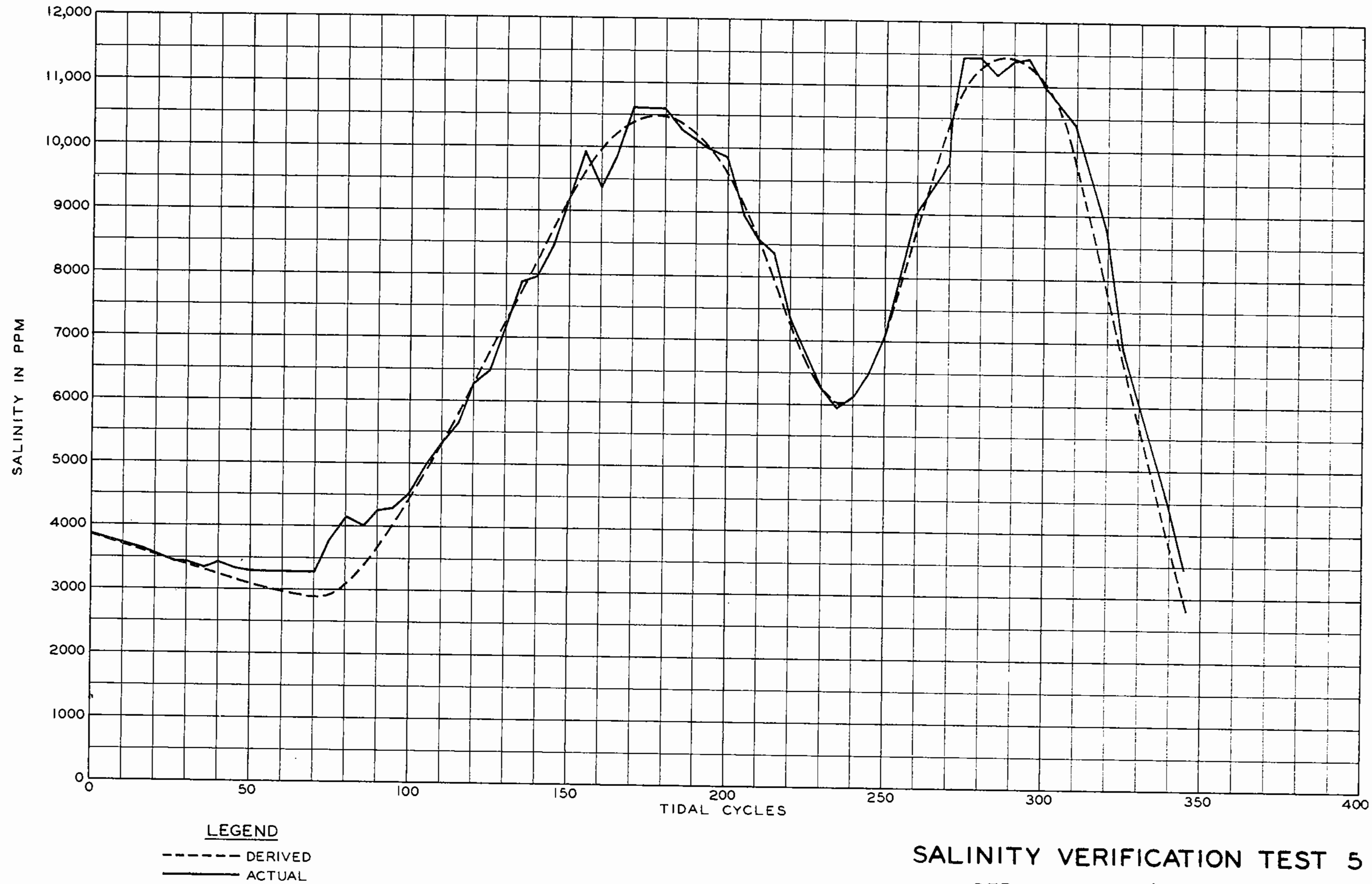
PLATE 12



SALINITY VERIFICATION TEST 5
MODEL AND PROTOTYPE SALINITIES
AT STATION T-8

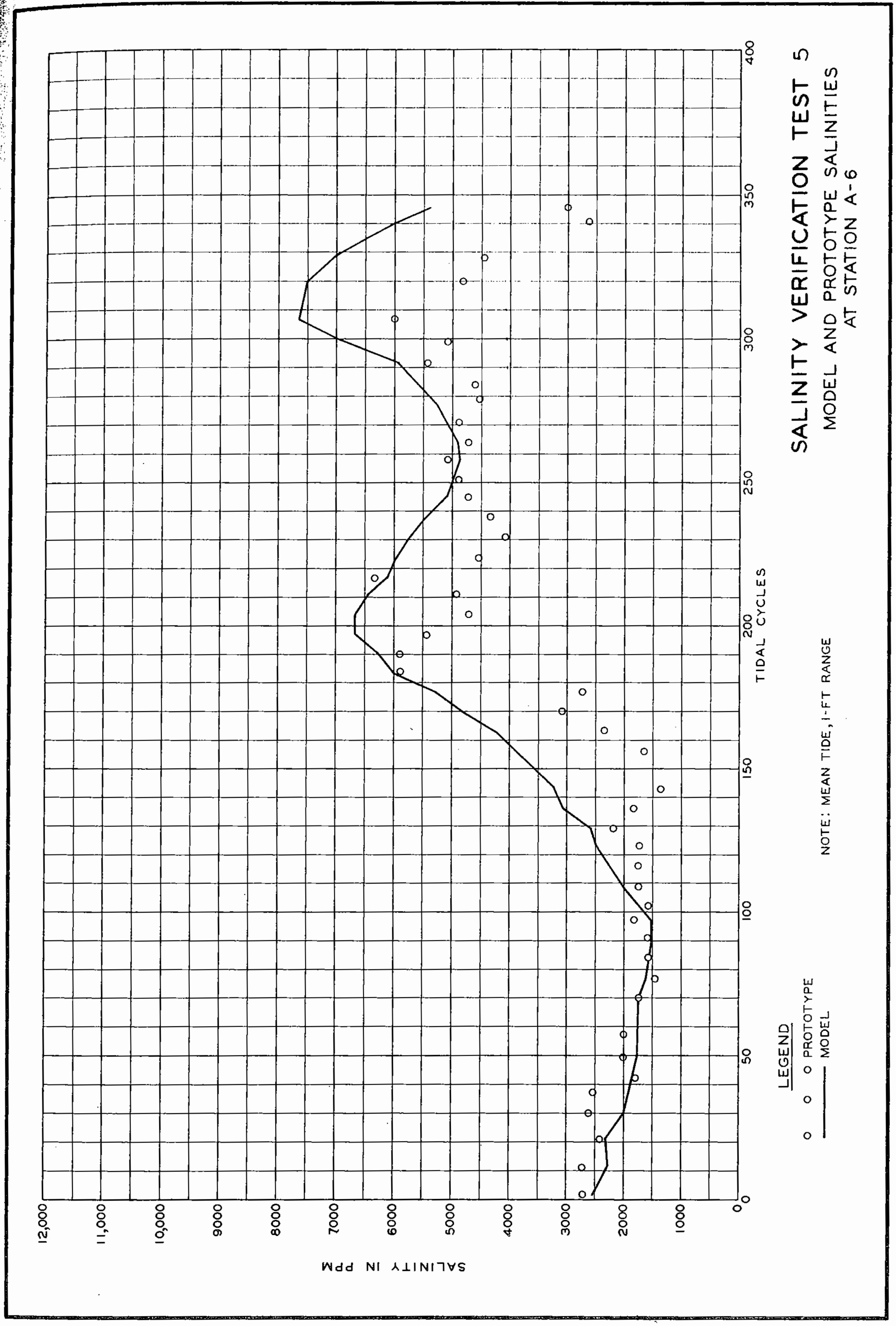
PLATE 13

PLATE 14

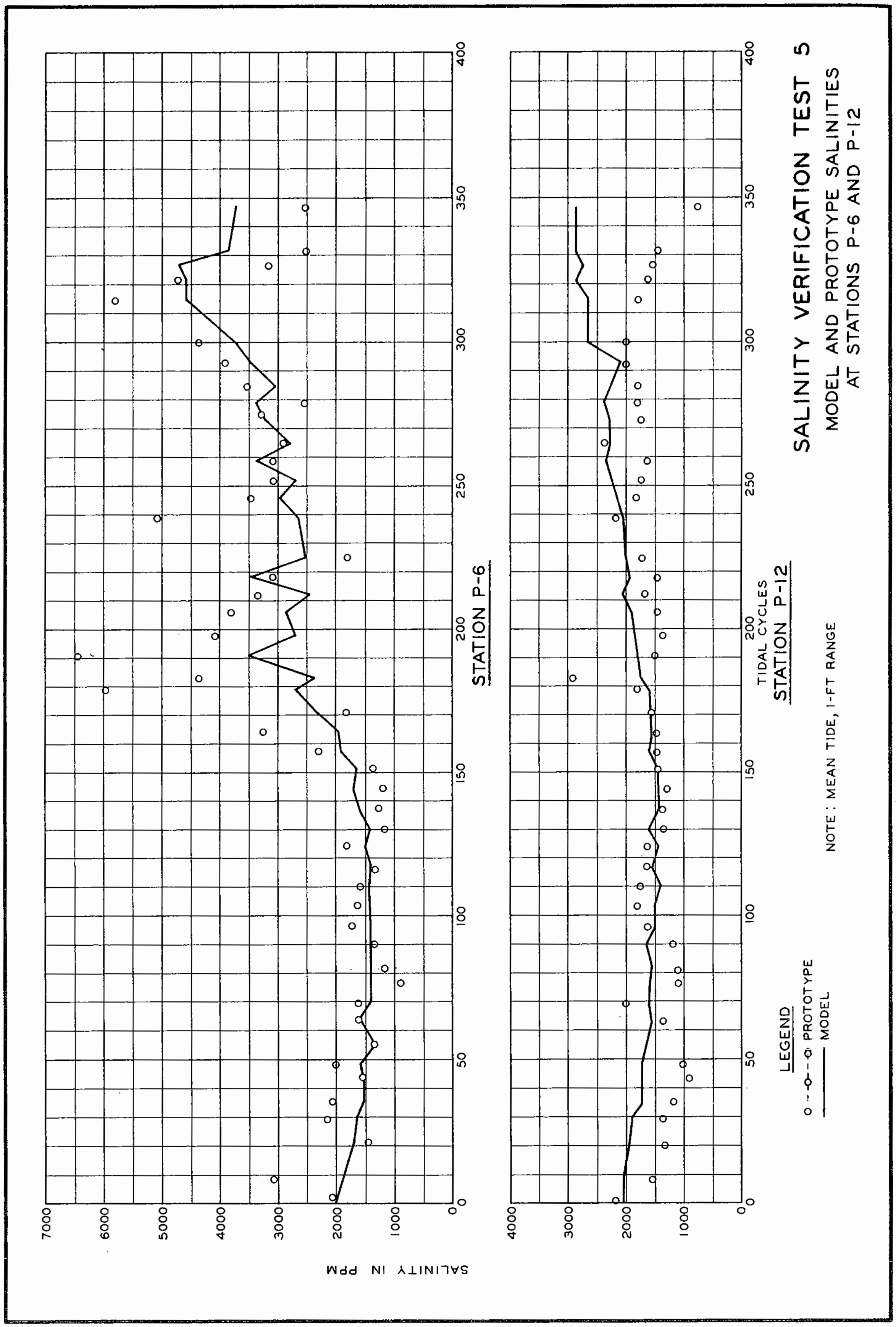


SALINITY VERIFICATION TEST 5

DERIVED SUMP (SOURCE) AND ACTUAL SALINITIES

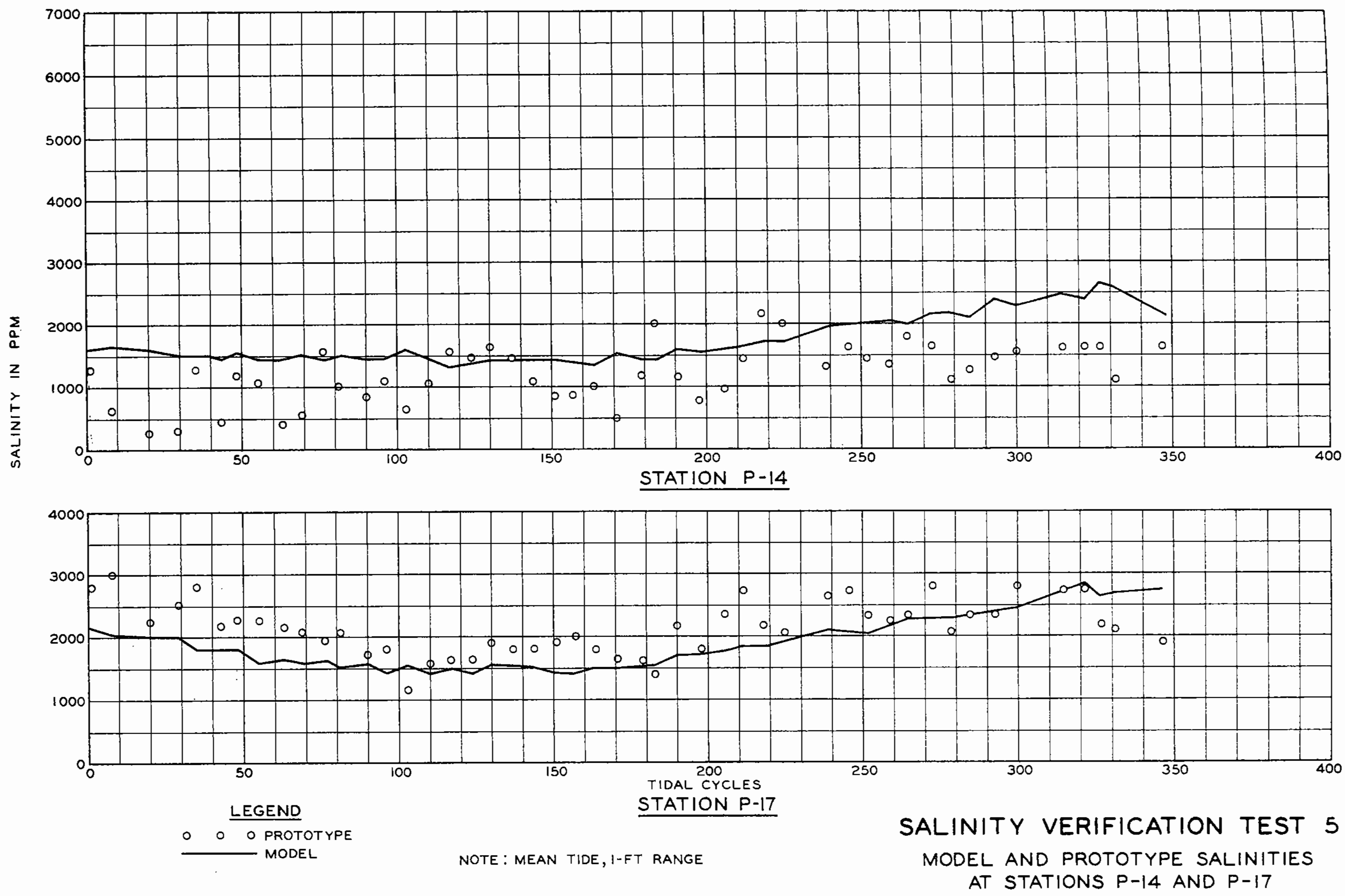


SALINITY VERIFICATION TEST 5
MODEL AND PROTOTYPE SALINITIES
AT STATION A-6



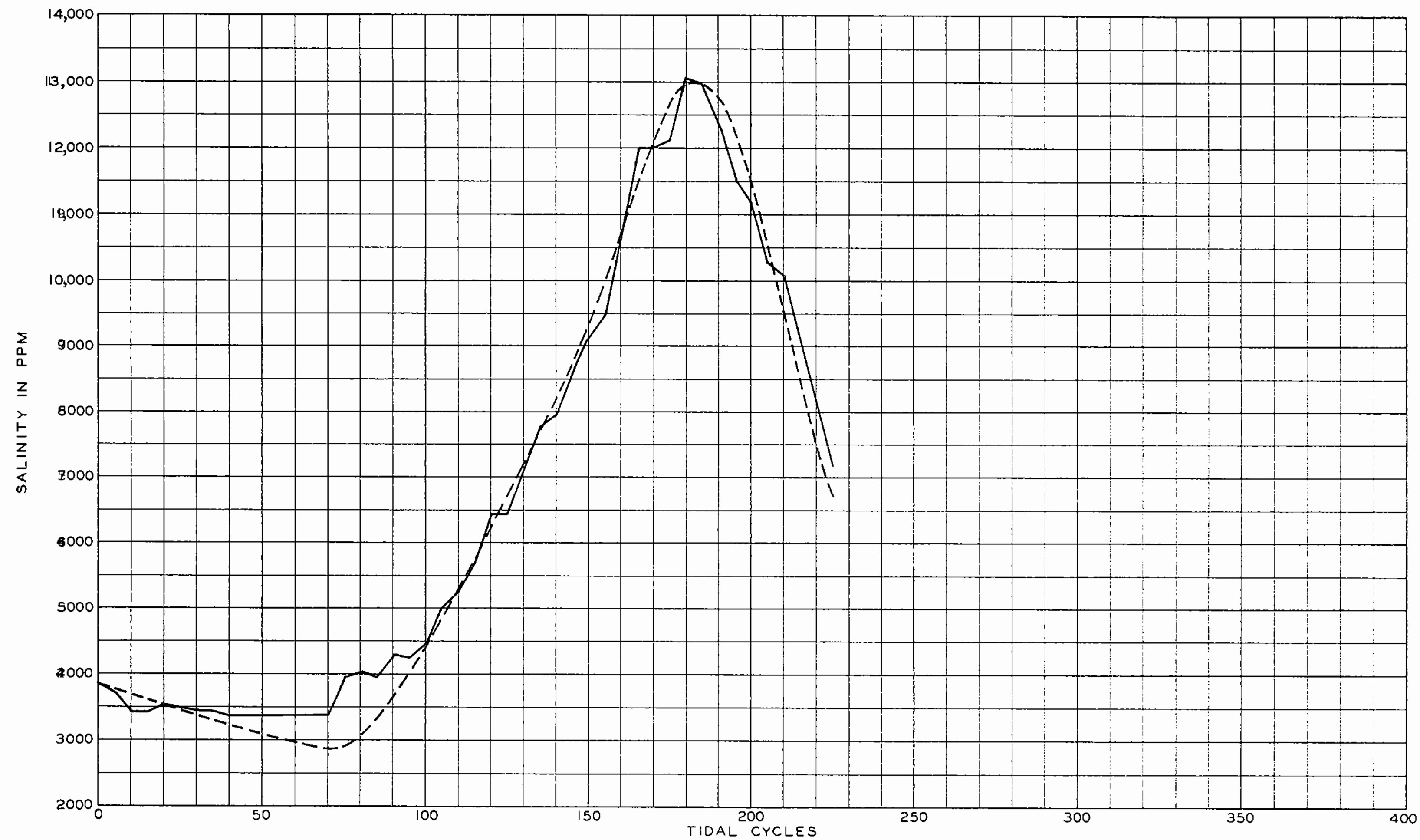
SALINITY VERIFICATION TEST 5
MODEL AND PROTOTYPE SALINITIES
AT STATIONS P-6 AND P-12

PLATE 16



SALINITY VERIFICATION TEST 5

MODEL AND PROTOTYPE SALINITIES AT STATIONS P-14 AND P-17

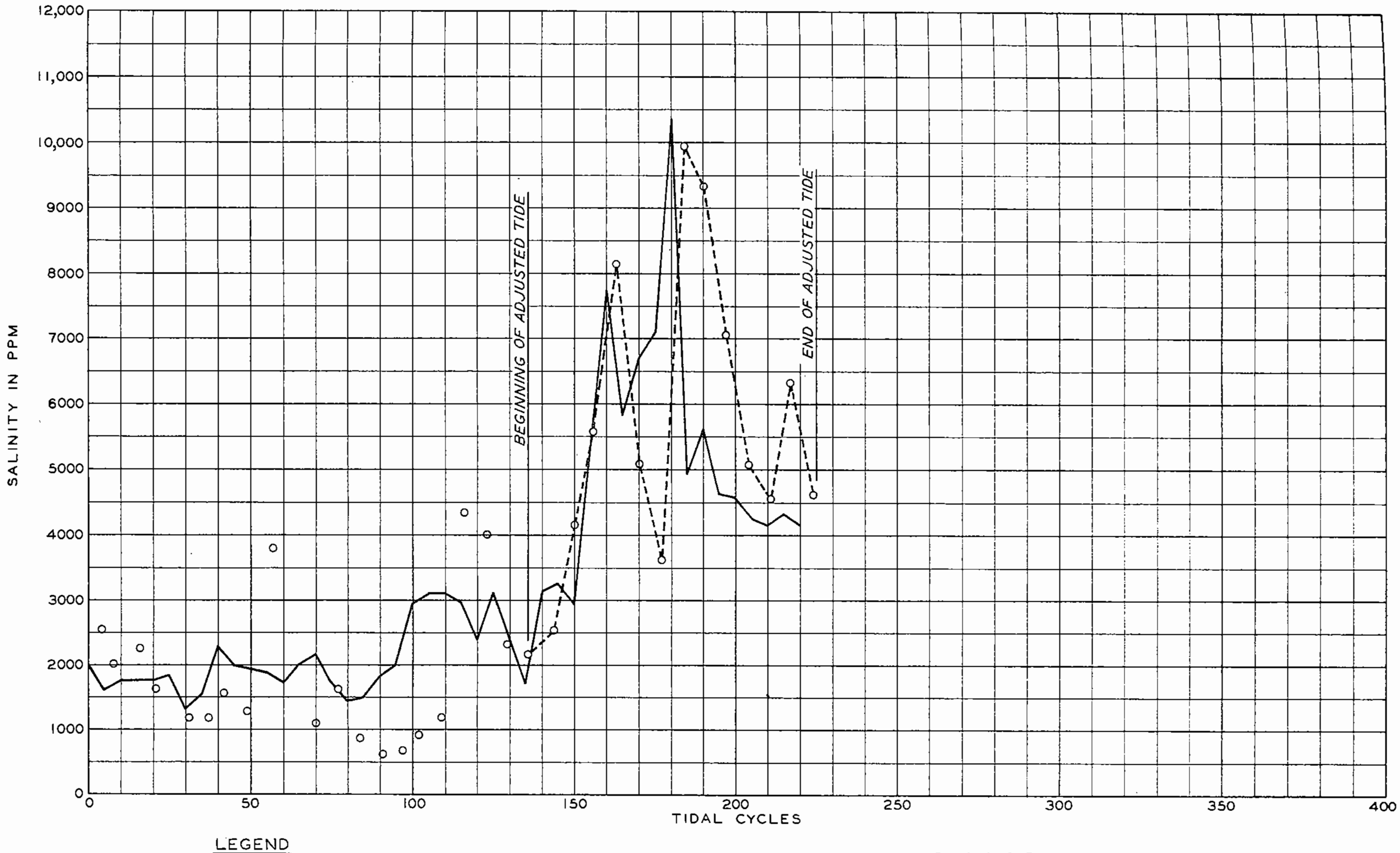


LEGEND
- - - - - DERIVED
——— ACTUAL

NOTE: MEAN TIDE ADJUSTED TO PROTOTYPE MEAN TIDE.
THIS TEST IS SUPPLEMENTAL TO TEST 5.

SALINITY VERIFICATION TEST 7

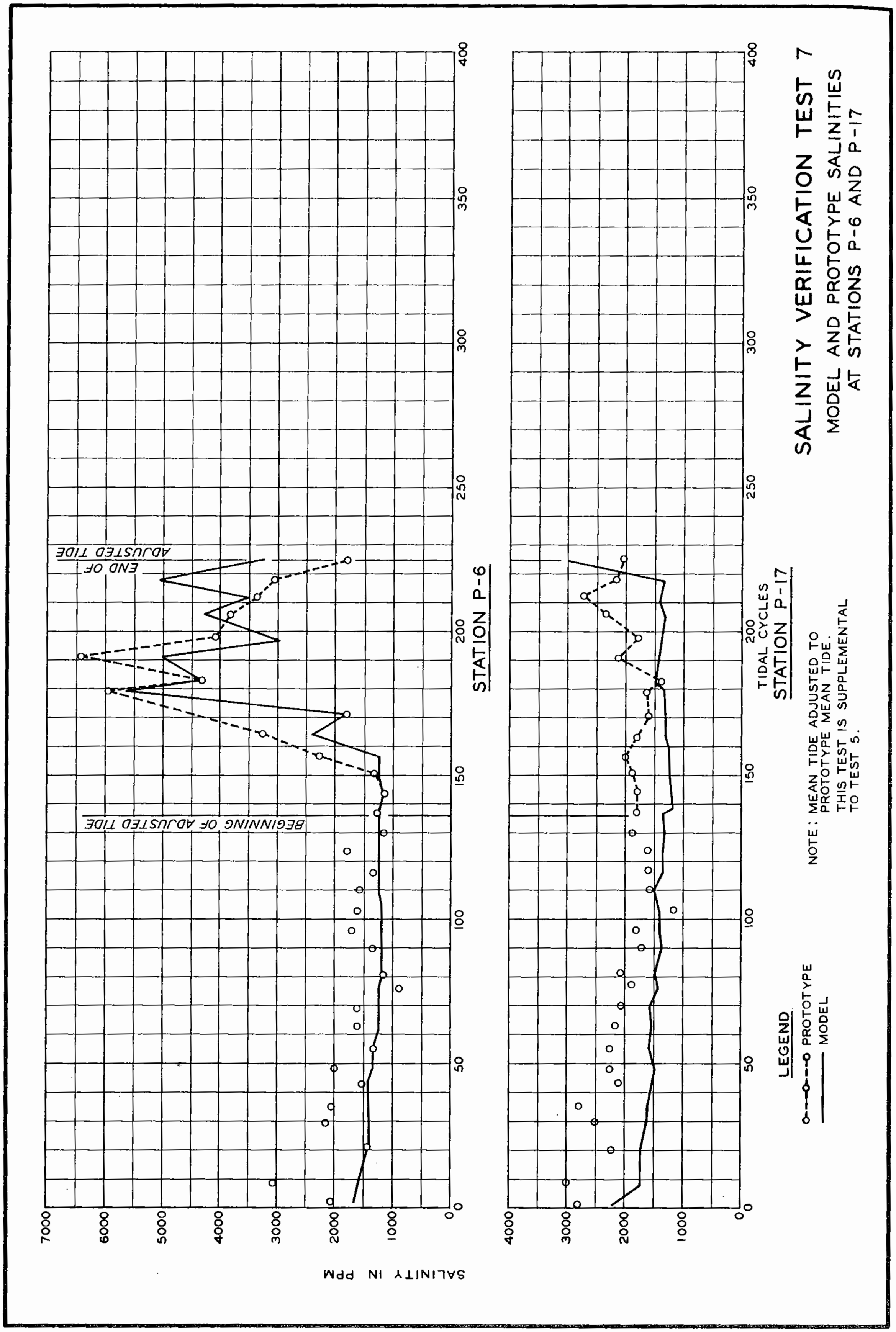
DERIVED SUMP (SOURCE) AND ACTUAL SALINITIES



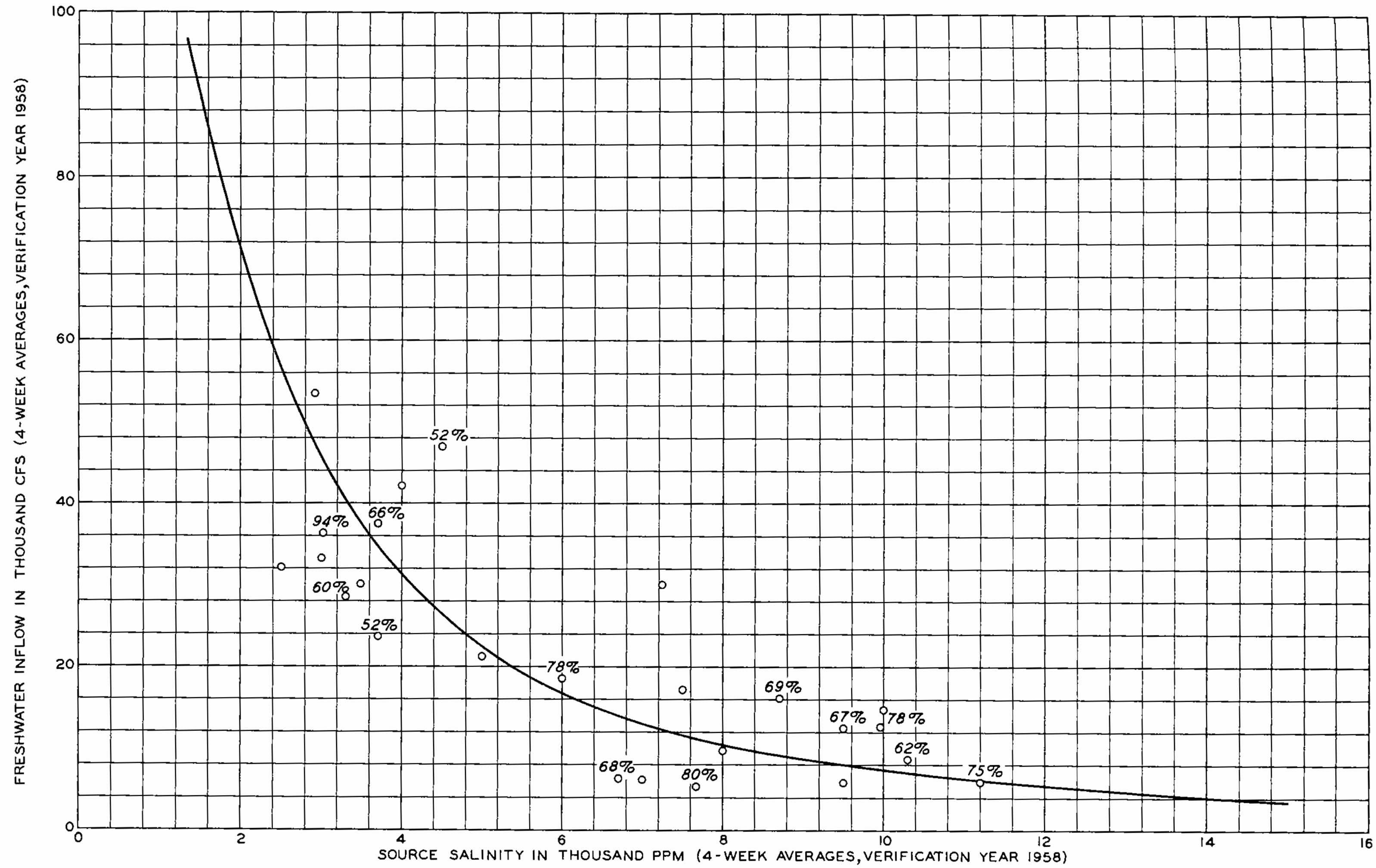
NOTE: MEAN TIDE ADJUSTED TO PROTOTYPE MEAN TIDE.
THIS TEST IS SUPPLEMENTAL TO TEST 5.

SALINITY VERIFICATION TEST 7

MODEL AND PROTOTYPE SALINITIES
AT STATION T-8



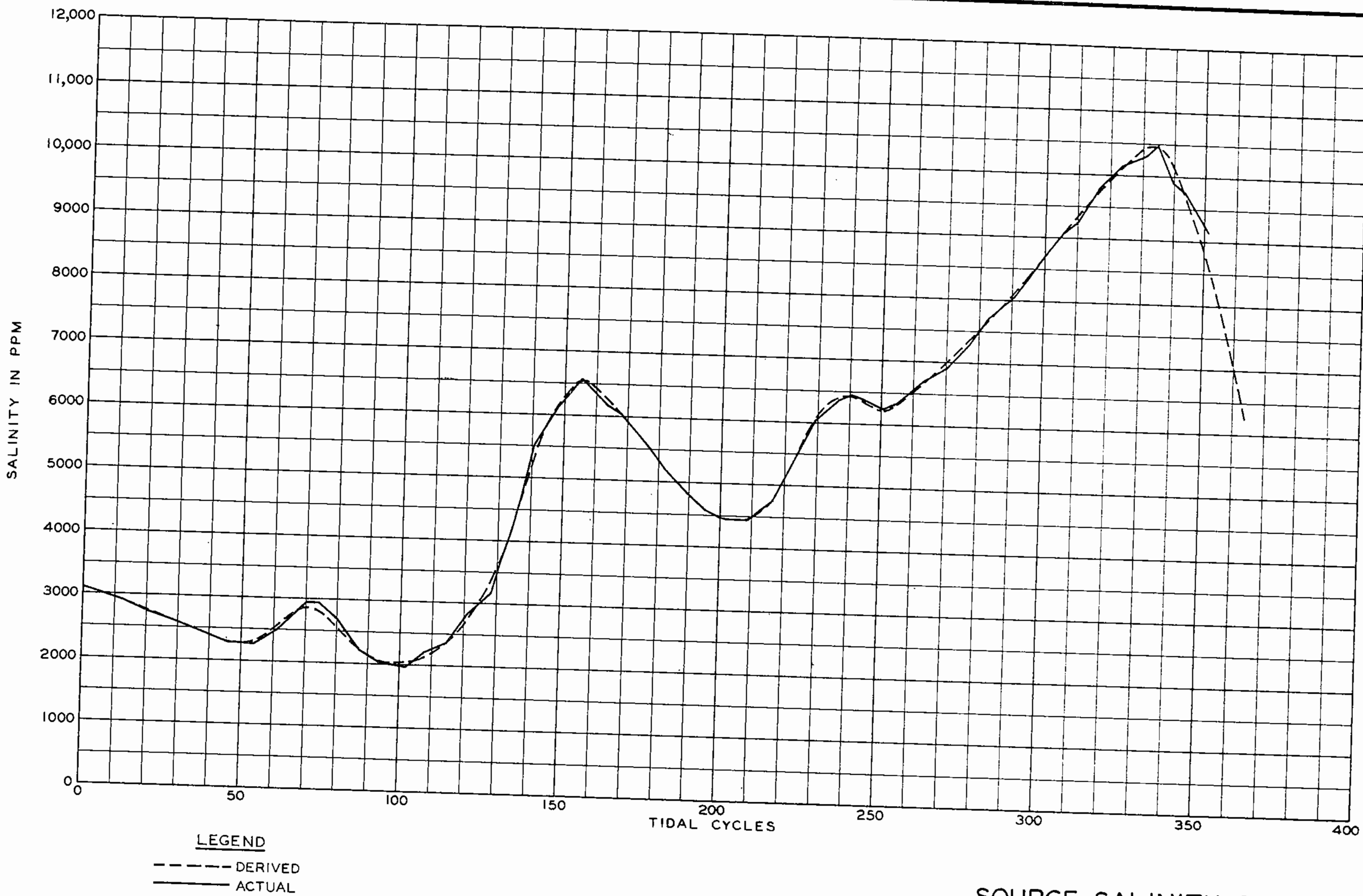
SALINITY VERIFICATION TEST 7
MODEL AND PROTOTYPE SALINITIES
AT STATIONS P-6 AND P-17



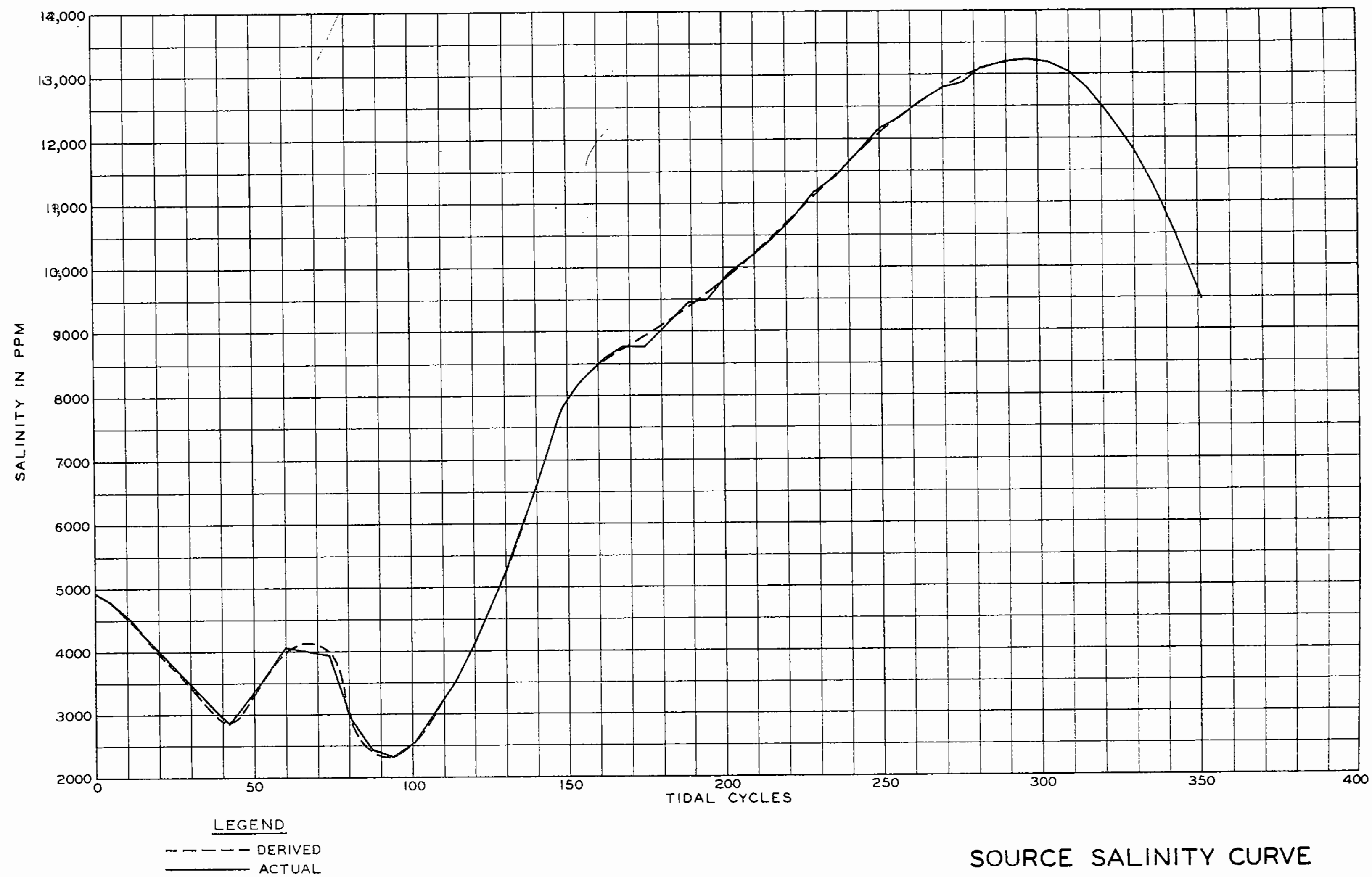
NOTE: FIGURES ABOVE BASIC POINTS INDICATE PERCENTAGE OF TOTAL PEARL RIVER FLOW COMPARED WITH TOTAL FLOW. AVERAGE = 69%

SOURCE SALINITY DERIVATION CURVE

PLATE 22



SOURCE SALINITY CURVE
HIGH FRESHWATER INFLOW YEAR, 1949



SOURCE SALINITY CURVE
MEDIUM FRESHWATER INFLOW YEAR, 1951

PLATE 23

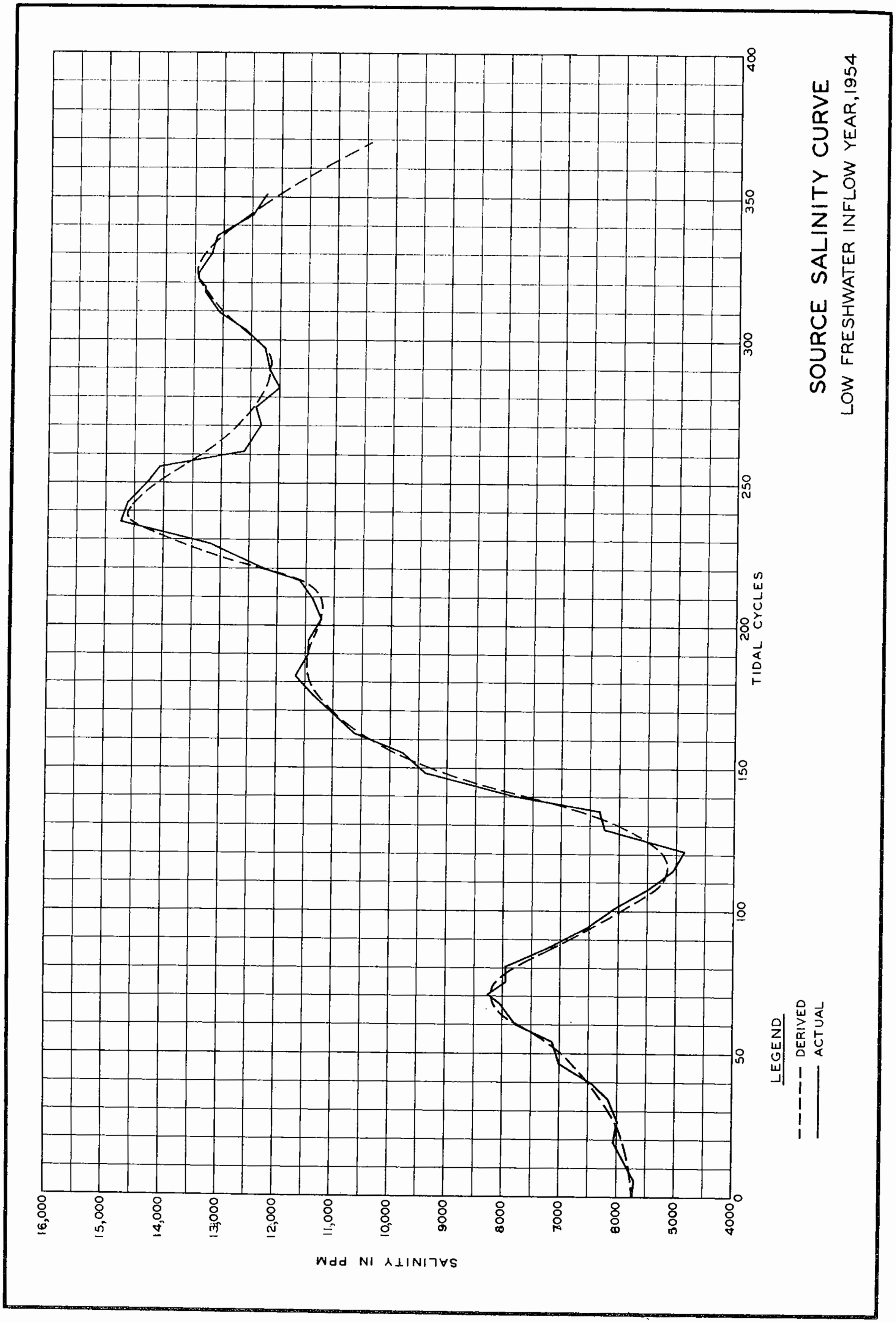
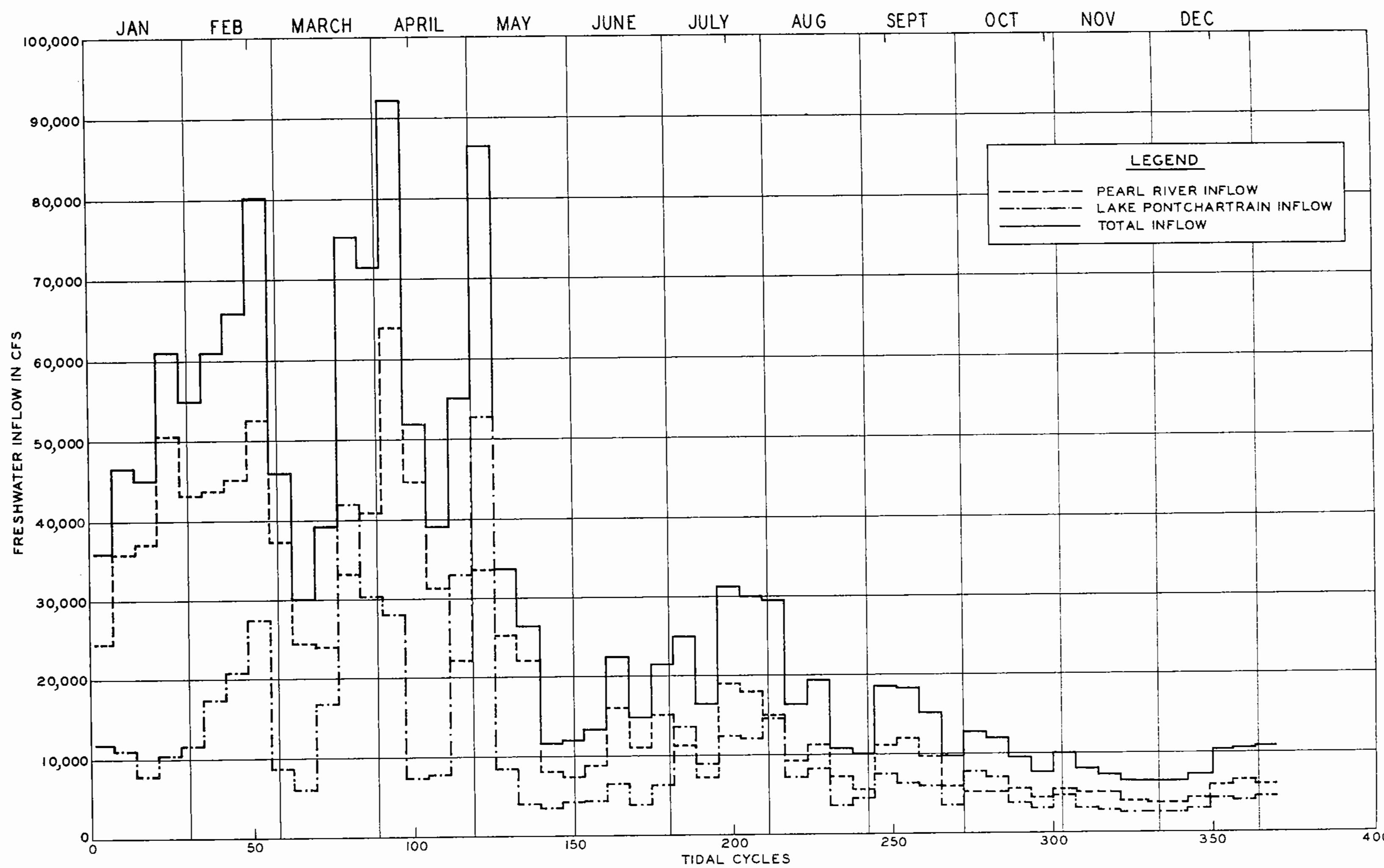
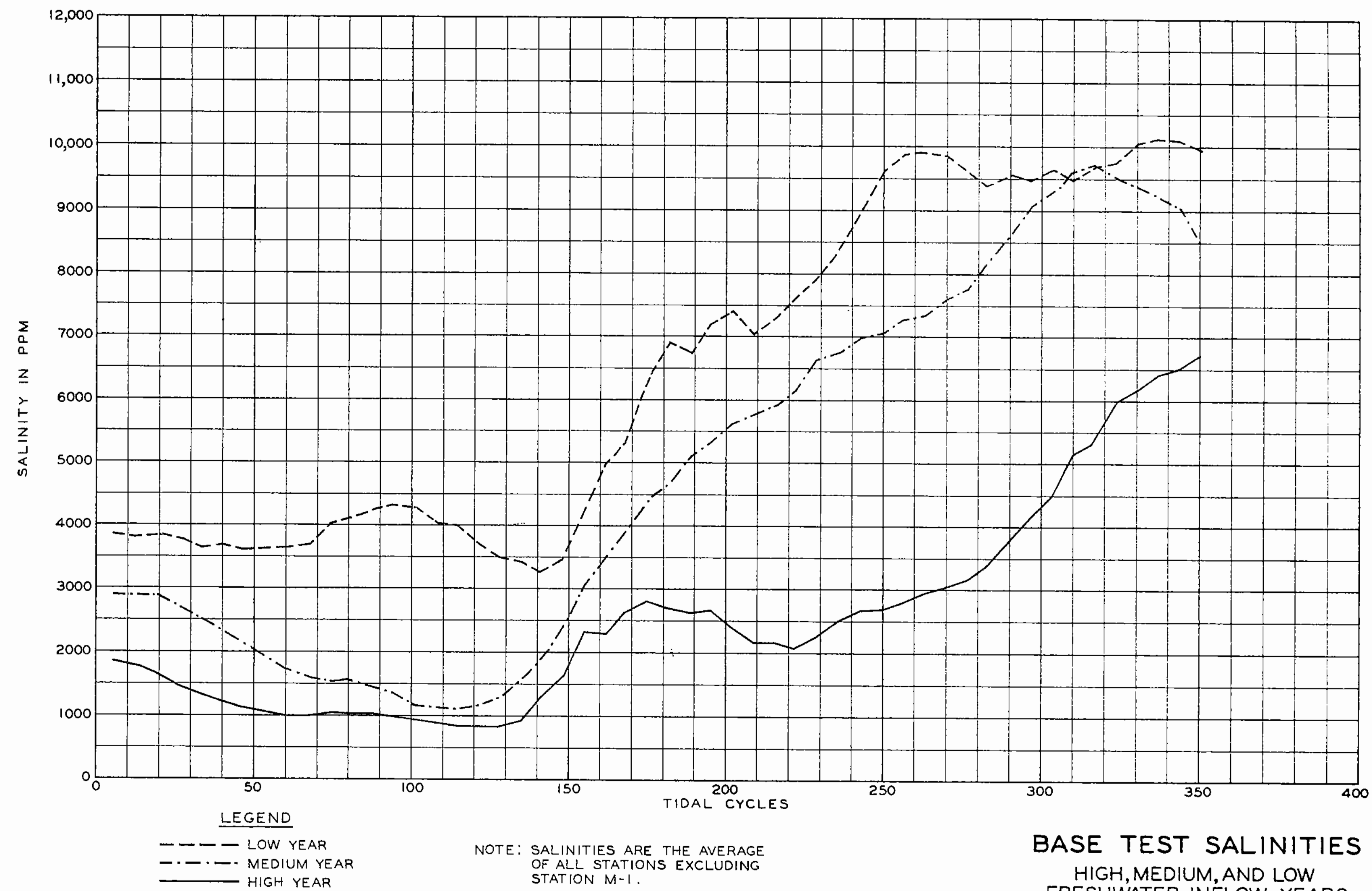

SOURCE SALINITY CURVE
LOW FRESHWATER INFLOW YEAR, 1954
TIDAL CYCLES
SALINITY IN PPM
LEGEND
DERIVED
ACTUAL
0
50
100
150
200
250
300
350
400
4000
5000
6000
7000
8000
9000
10,000
11,000
12,000
13,000
14,000
15,000
16,000

PLATE 24



FRESHWATER INFLOW HYDROGRAPH

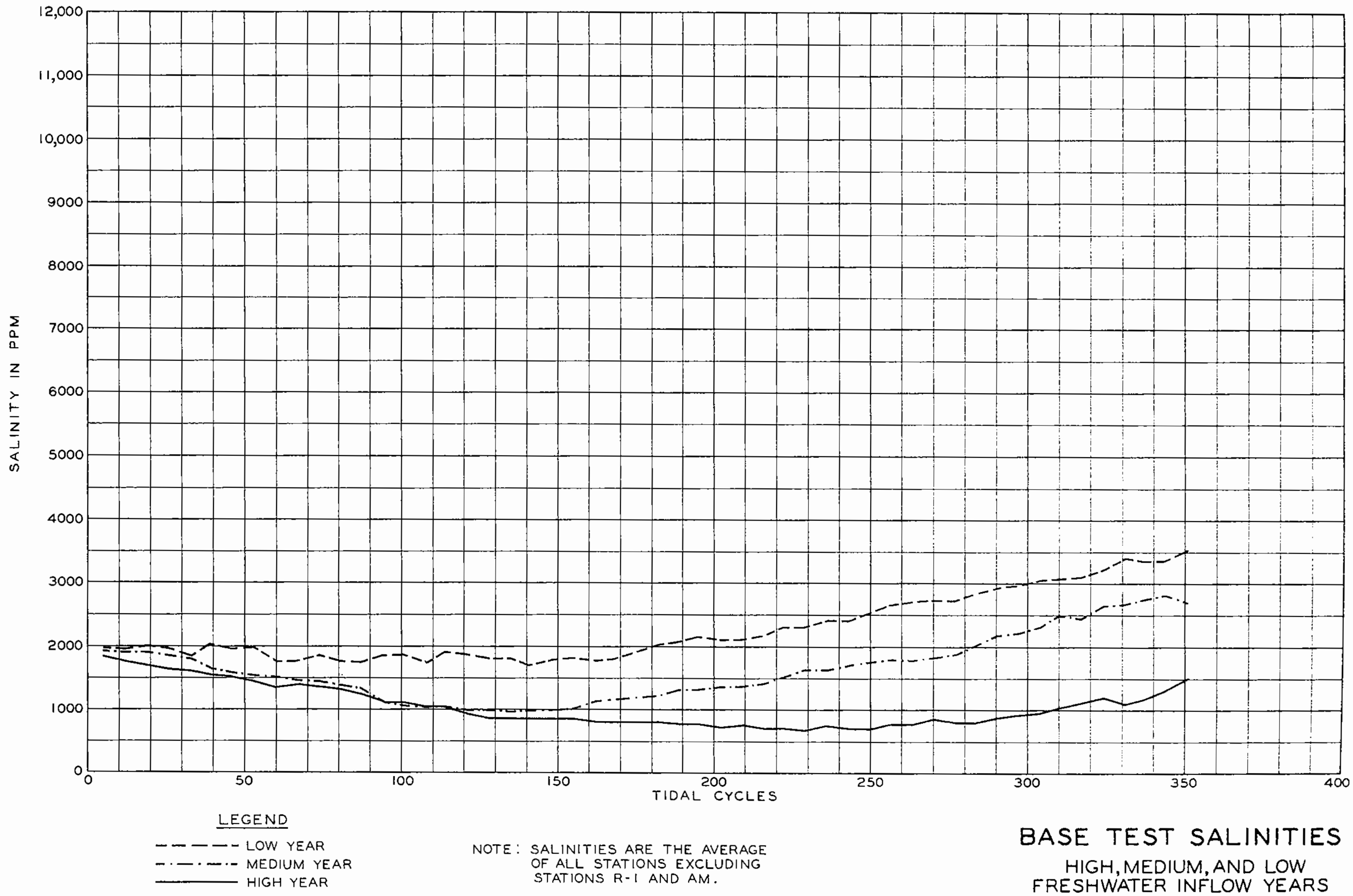
HIGH FRESHWATER INFLOW YEAR, 1949



BASE TEST SALINITIES

HIGH, MEDIUM, AND LOW
FRESHWATER INFLOW YEARS
LAKE BORGNE

PLATE 26



NOTE: SALINITIES ARE THE AVERAGE OF ALL STATIONS EXCLUDING STATIONS R-1 AND AM.

BASE TEST SALINITIES
HIGH, MEDIUM, AND LOW FRESHWATER INFLOW YEARS
LAKE PONTCHARTRAIN

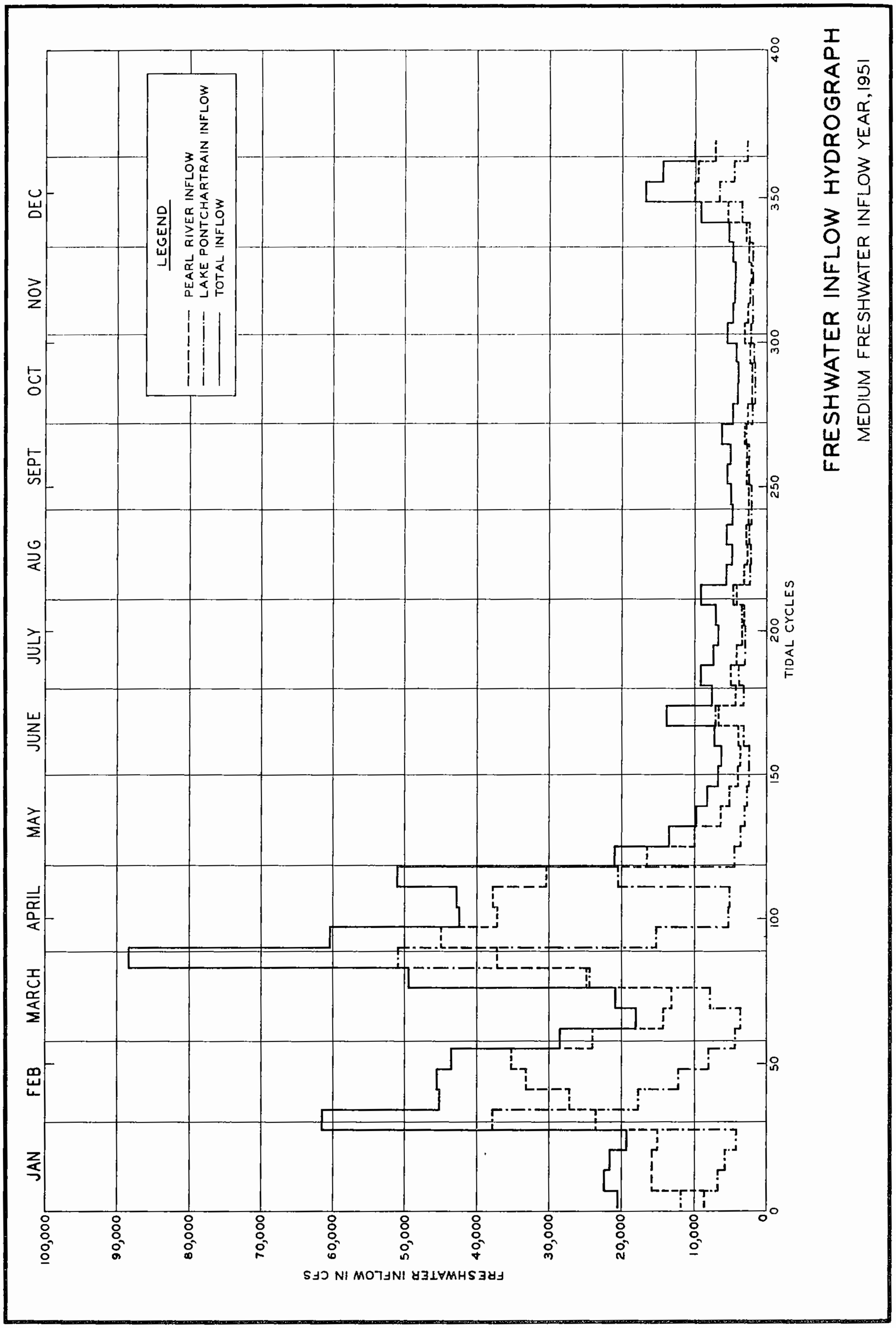
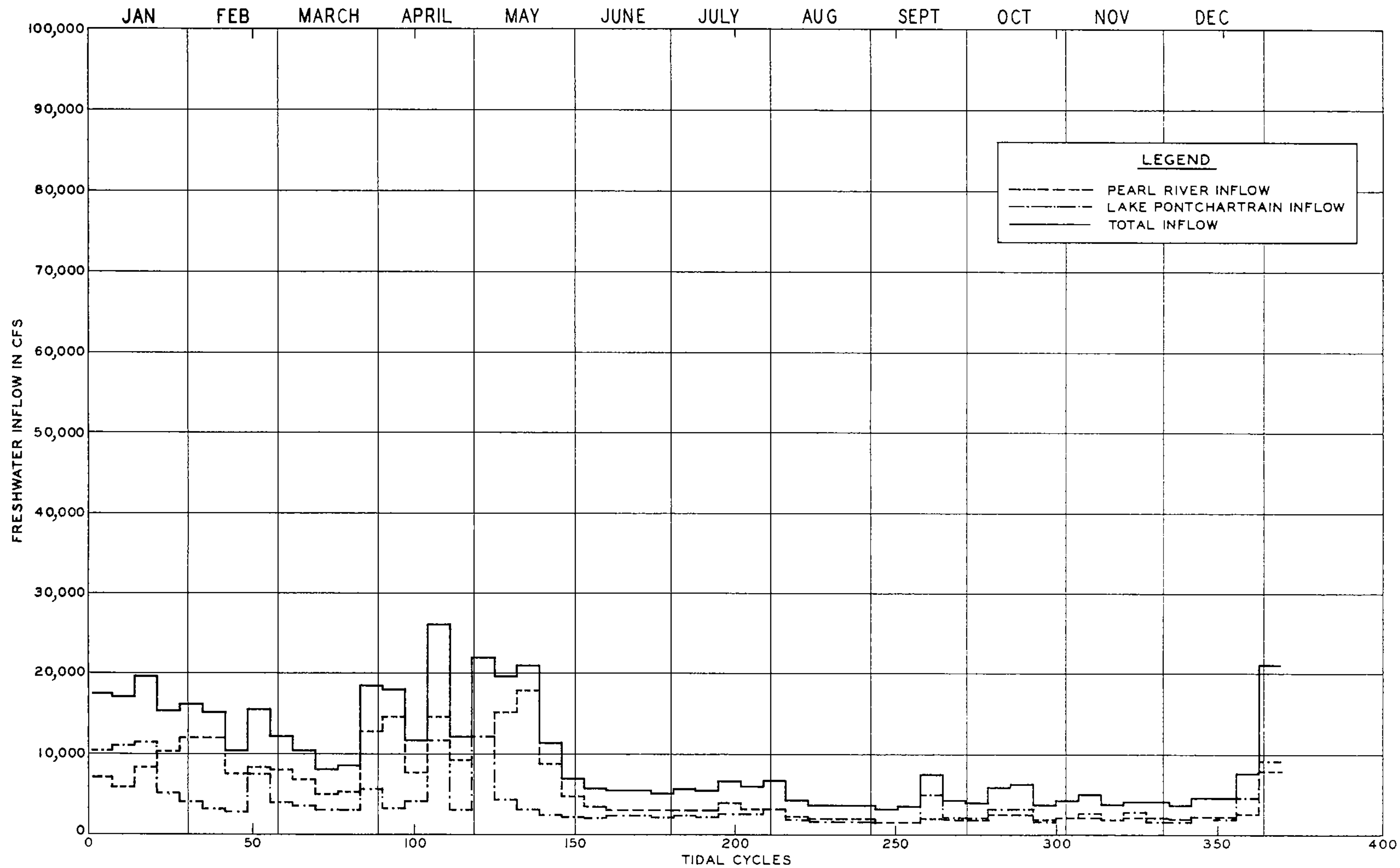
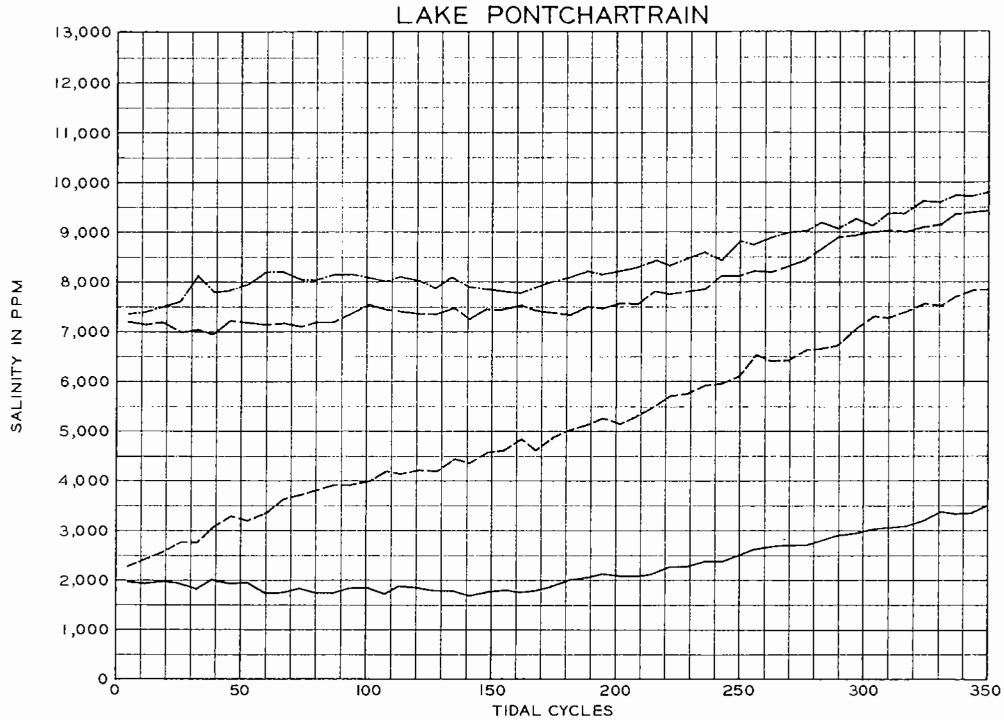

FRESHWATER INFLOW HYDROGRAPH
MEDIUM FRESHWATER INFLOW YEAR, 1951
LEGEND
PEARL RIVER INFLOW
LAKE PONTCHARTRAIN INFLOW
TOTAL INFLOW
FRESHWATER INFLOW IN CFS
TIDAL CYCLES
JAN
FEB
MARCH
APRIL
MAY
JUNE
JULY
AUG
SEPT
OCT
NOV
DEC
0
10,000
20,000
30,000
40,000
50,000
60,000
70,000
80,000
90,000
100,000
50
100
150
200
250
300
350
400

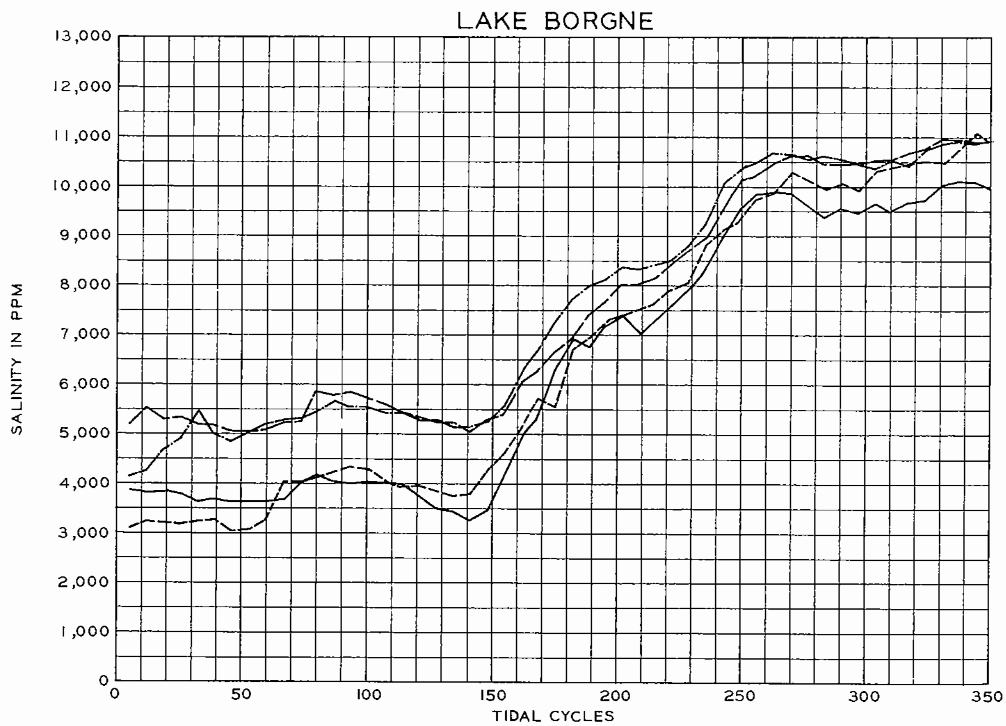
PLATE 28



FRESHWATER INFLOW HYDROGRAPH

LOW FRESHWATER INFLOW YEAR, 1954



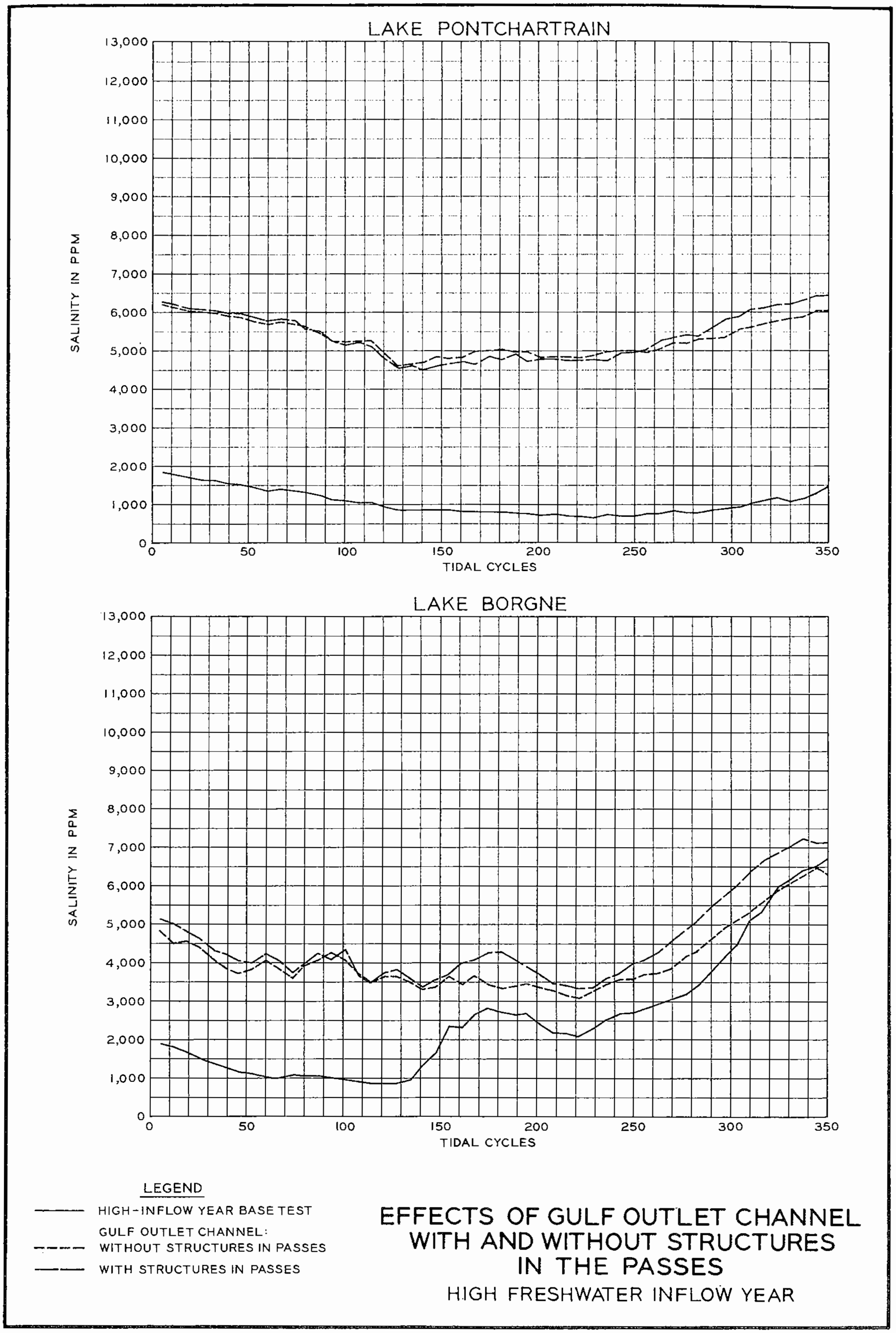


LEGEND

- ——— LOW INFLOW YEAR BASE TEST
- — — — NEW ORLEANS DISTRICT TEST 2
- GULF OUTLET CHANNEL:
- —·— WITHOUT STRUCTURES IN PASSES
- —— —— WITH STRUCTURES IN PASSES

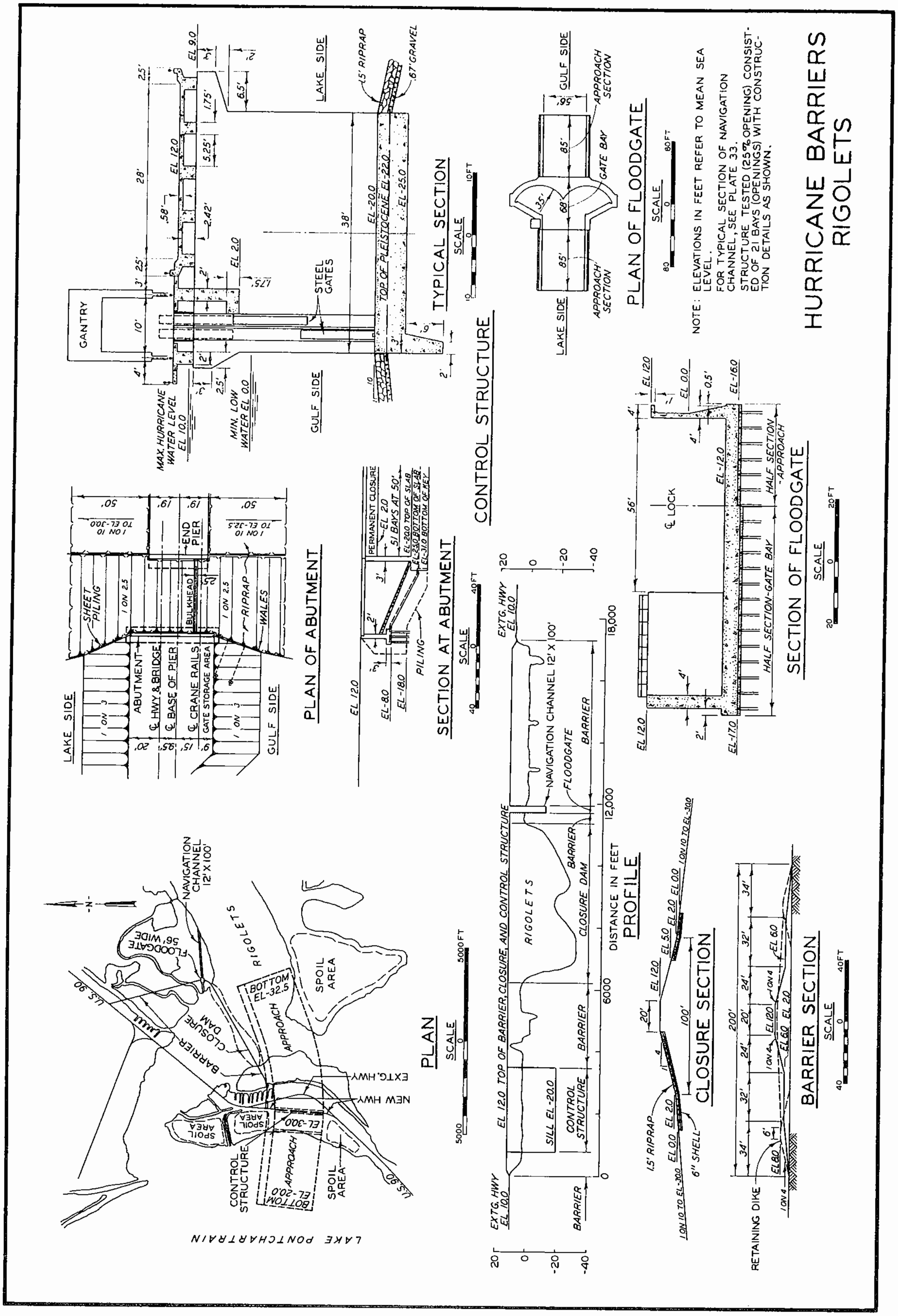
EFFECTS OF GULF OUTLET CHANNEL WITH AND WITHOUT STRUCTURES IN THE PASSES

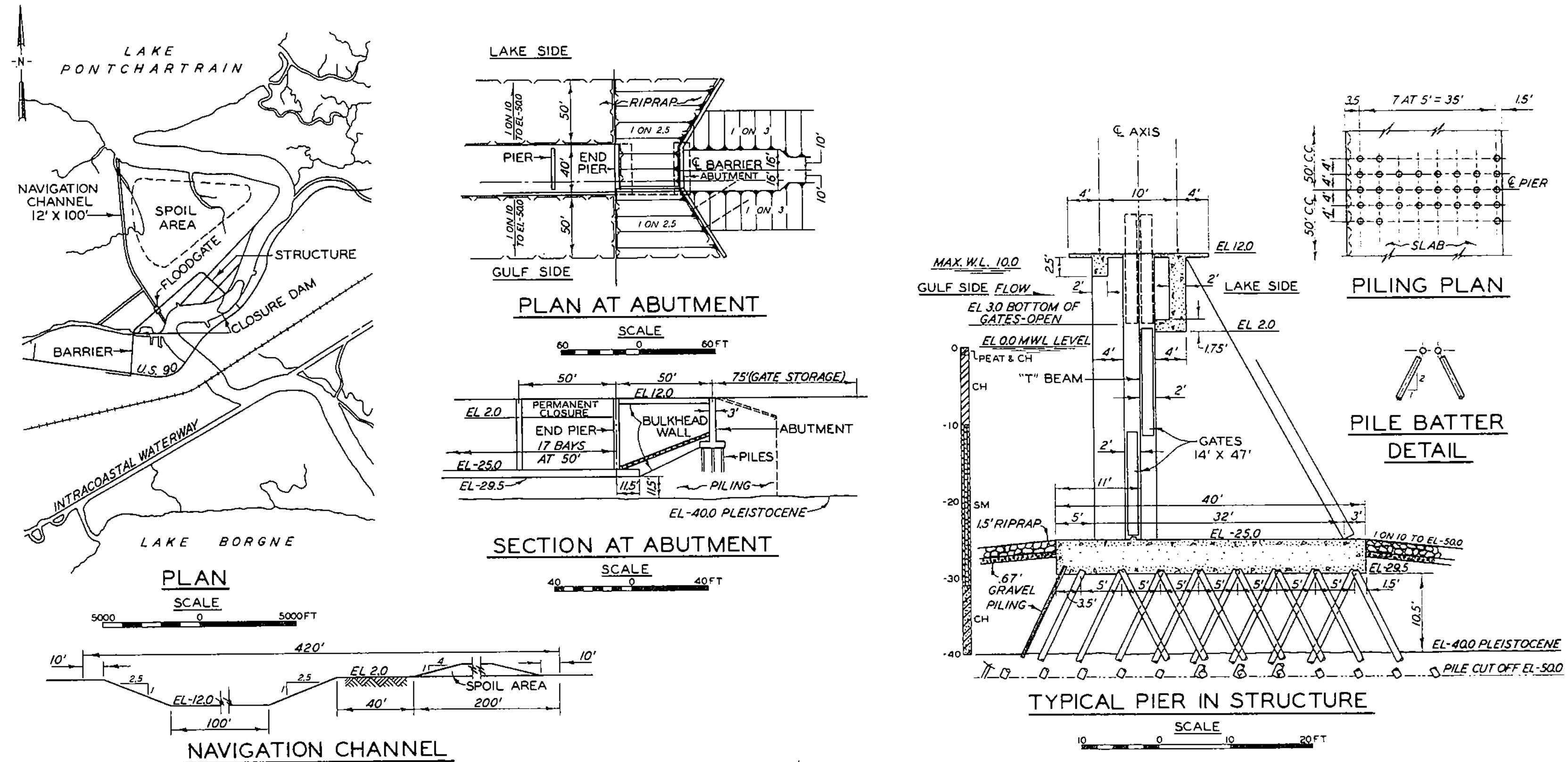
LOW FRESHWATER INFLOW YEAR

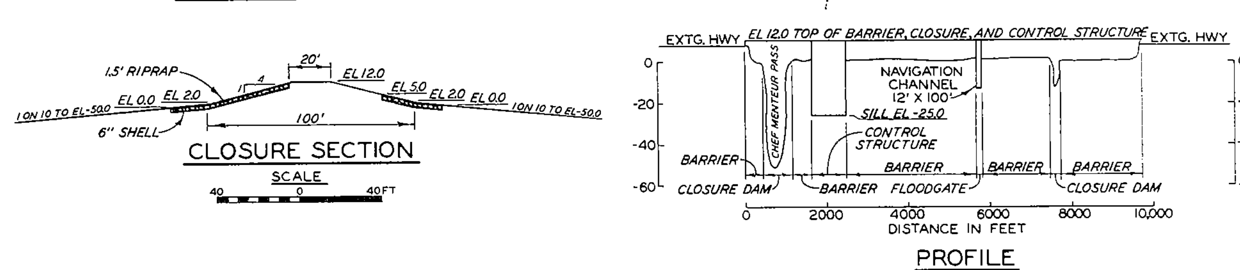


EFFECTS OF GULF OUTLET CHANNEL WITH AND WITHOUT STRUCTURES IN THE PASSES

HIGH FRESHWATER INFLOW YEAR


HURRICANE BARRIERS
RIGOLETS
NOTE: ELEVATIONS IN FEET REFER TO MEAN SEA LEVEL.
FOR TYPICAL SECTION OF NAVIGATION CHANNEL, SEE PLATE 33.
STRUCTURE TESTED (25% OPENING) CONSISTED OF 21 BAYS (OPENINGS) WITH CONSTRUCTION DETAILS AS SHOWN.
PLAN
LAKE PONTCHARTRAIN
RIGOLETS
NAVIGATION CHANNEL 12' X 100'
FLOODGATE 56' WIDE
CLOSURE DAM
BARRIER
APPROACH
SPOIL AREA
CONTROL STRUCTURE
EXTG. HWY
NEW HWY
U.S. 90
PROFILE
DISTANCE IN FEET
EL 12.0 TOP OF BARRIER, CLOSURE, AND CONTROL STRUCTURE
SILL EL -20.0
CLOSURE SECTION
BARRIER SECTION
RETAINING DIKE
PLAN OF ABUTMENT
LAKE SIDE
GULF SIDE
SHEET PILING
RIPRAP
WALES
END PIER
BULKHEAD
SECTION AT ABUTMENT
PILING
CONTROL STRUCTURE
TYPICAL SECTION
GANTRY
STEEL GATES
MAX. HURRICANE WATER LEVEL EL 10.0
MIN. LOW WATER EL 0.0
TOP OF PLEISTOCENE EL -22.0
1.5' RIPRAP
.67' GRAVEL
PLAN OF FLOODGATE
GATE BAY
APPROACH SECTION
SECTION OF FLOODGATE
℄ LOCK
HALF SECTION-GATE BAY
HALF SECTION-APPROACH
SCALE





NOTE: ELEVATIONS IN FEET REFER TO MEAN SEA LEVEL.
FOR TYPICAL SECTIONS OF BARRIER AND FLOODGATE, SEE PLATE 32.
STRUCTURE TESTED (25% OPENING) CONSISTED OF 8 BAYS (OPENINGS) WITH CONSTRUCTION DETAILS AS SHOWN.

HURRICANE BARRIERS CHEF MENTEUR

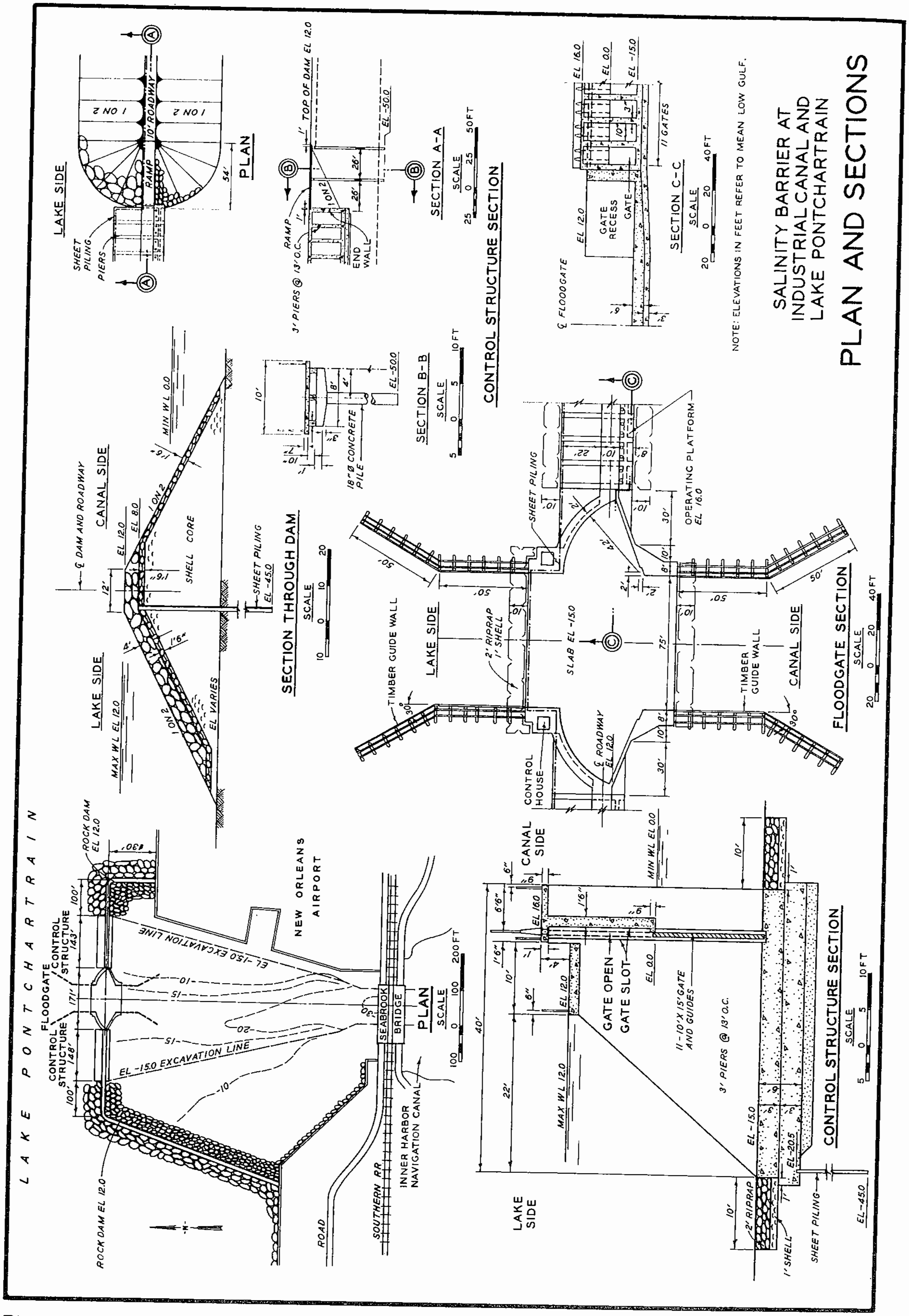
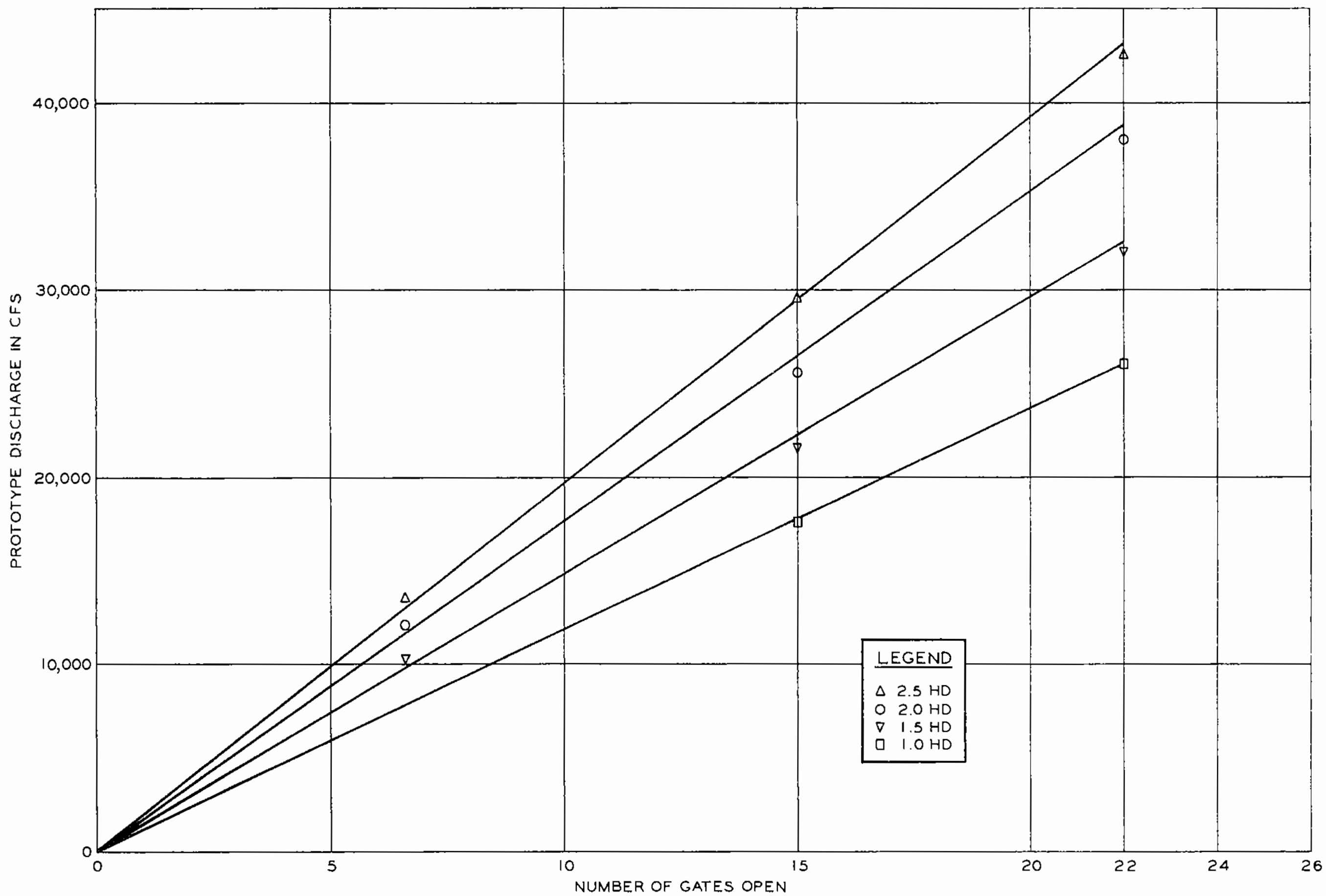
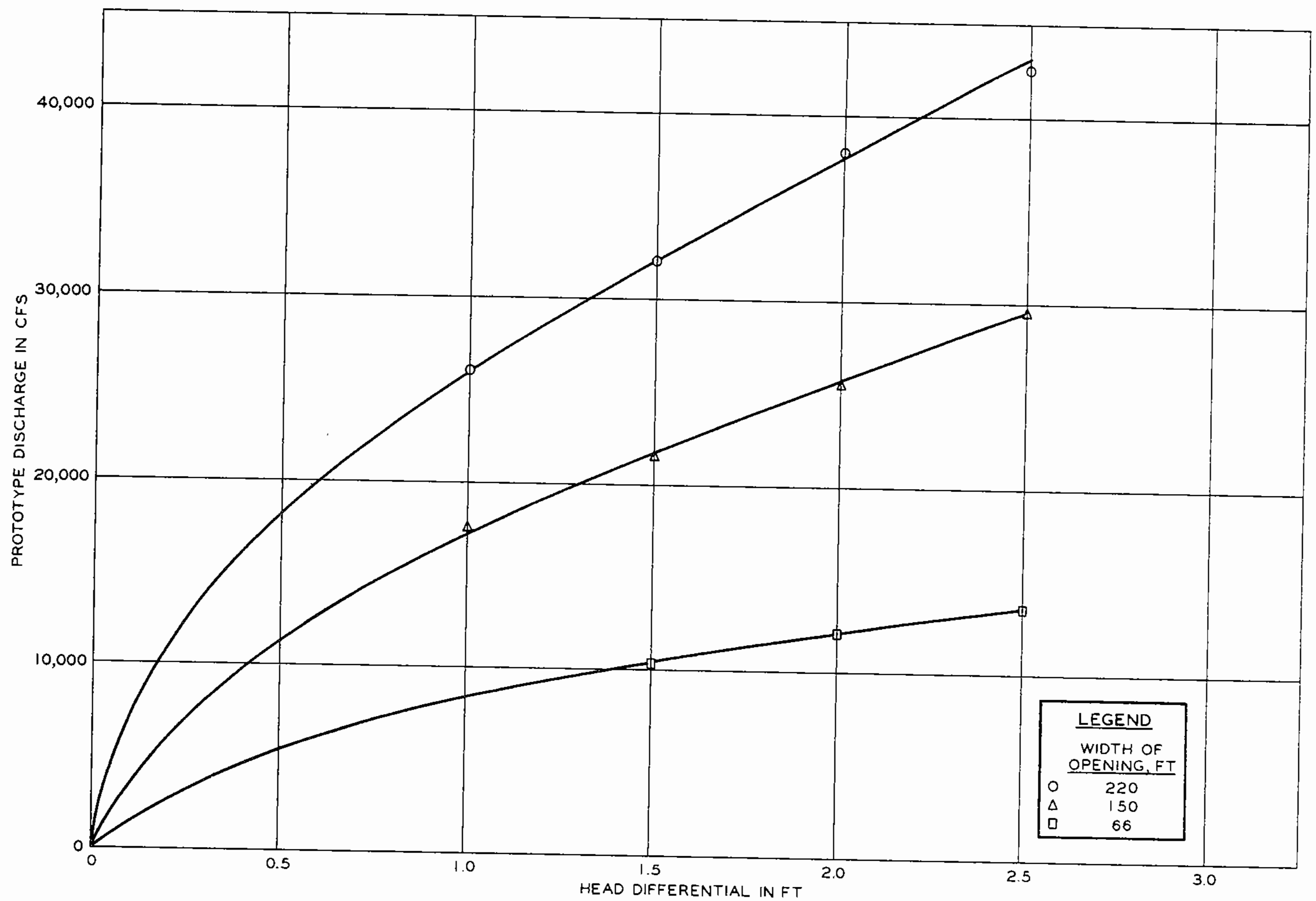

SALINITY BARRIER AT INDUSTRIAL CANAL AND LAKE PONTCHARTRAIN
PLAN AND SECTIONS
NOTE: ELEVATIONS IN FEET REFER TO MEAN LOW GULF.
LAKE PONTCHARTRAIN
PLAN
NEW ORLEANS AIRPORT
ROCK DAM EL 12.0
CONTROL STRUCTURE 148'
FLOODGATE 171'
CONTROL STRUCTURE 143'
EL -15.0 EXCAVATION LINE
SEABROOK BRIDGE
ROAD
SOUTHERN RR
INNER HARBOR NAVIGATION CANAL
SECTION THROUGH DAM
LAKE SIDE
CANAL SIDE
℄ DAM AND ROADWAY
MAX WL EL 12.0
MIN WL 0.0
SHELL CORE
SHEET PILING EL -45.0
EL VARIES
1 ON 2
CONTROL STRUCTURE SECTION
GATE OPEN
GATE SLOT
11-10'X 15' GATE AND GUIDES
3' PIERS @ 13' O.C.
2' RIPRAP
1' SHELL
SHEET PILING
EL -45.0
FLOODGATE SECTION
TIMBER GUIDE WALL
CONTROL HOUSE
℄ ROADWAY EL 12.0
SLAB EL -15.0
2' RIPRAP 1' SHELL
OPERATING PLATFORM EL 16.0
SHEET PILING
SECTION A-A
SECTION B-B
18" Ø CONCRETE PILE
RAMP
END WALL
TOP OF DAM EL 12.0
EL -50.0
SECTION C-C
GATE RECESS
11 GATES
℄ FLOODGATE

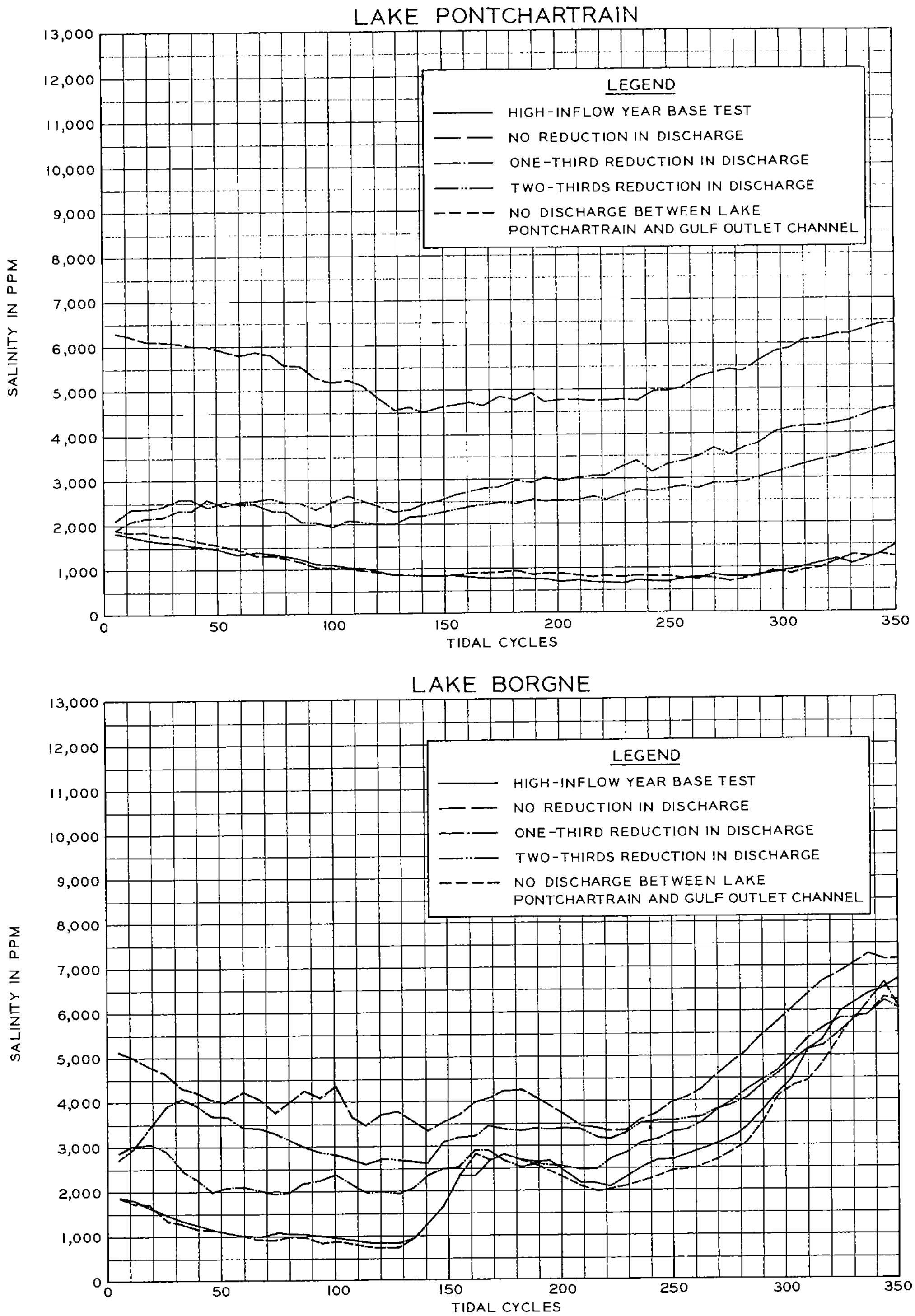
PLATE 34



RELATION BETWEEN DISCHARGE
AND NUMBER OF GATES OPEN IN
GULF OUTLET CHANNEL
CONTROL STRUCTURE

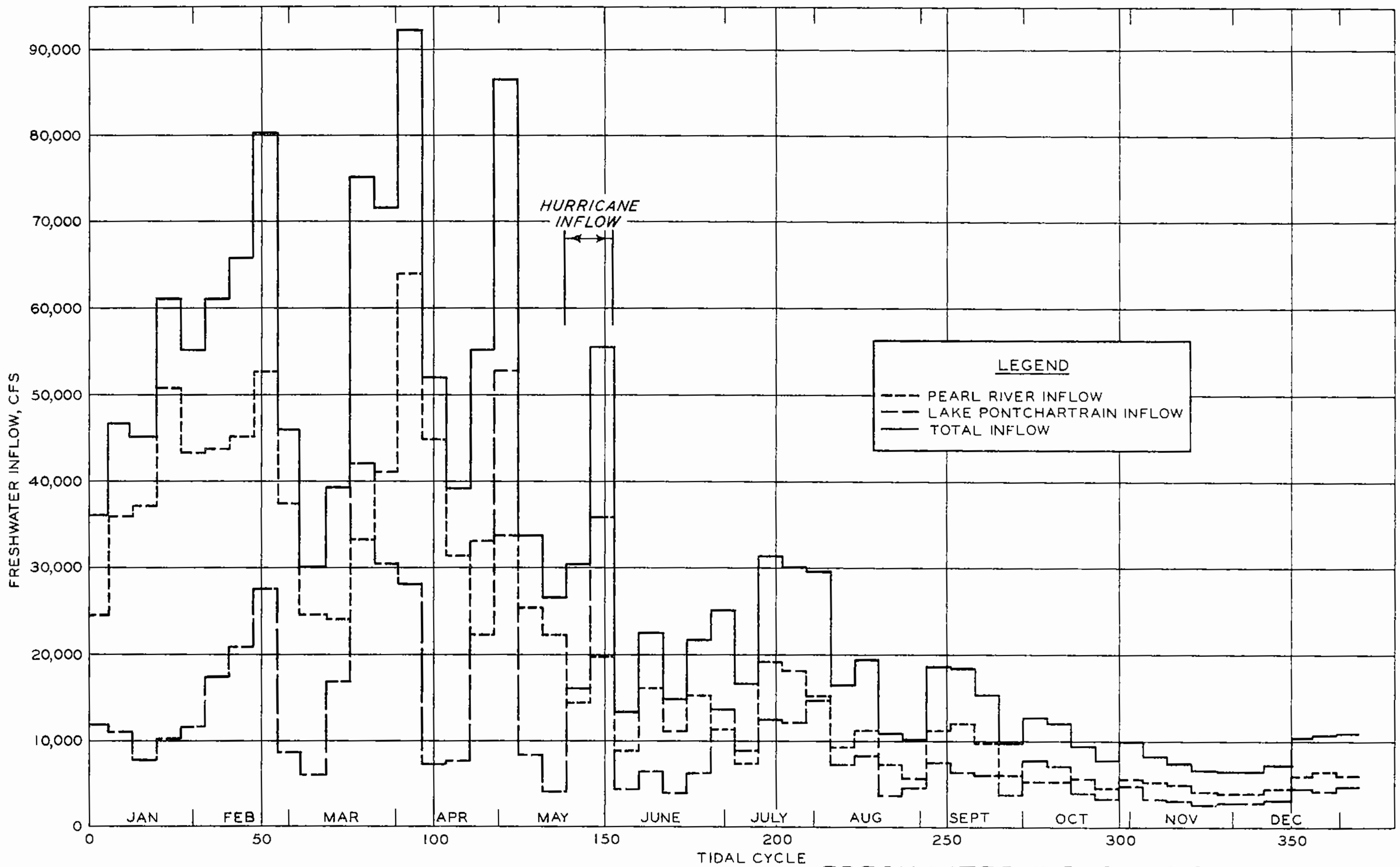


RELATION BETWEEN DISCHARGE AND HEAD DIFFERENTIAL IN GULF OUTLET CHANNEL CONTROL STRUCTURE



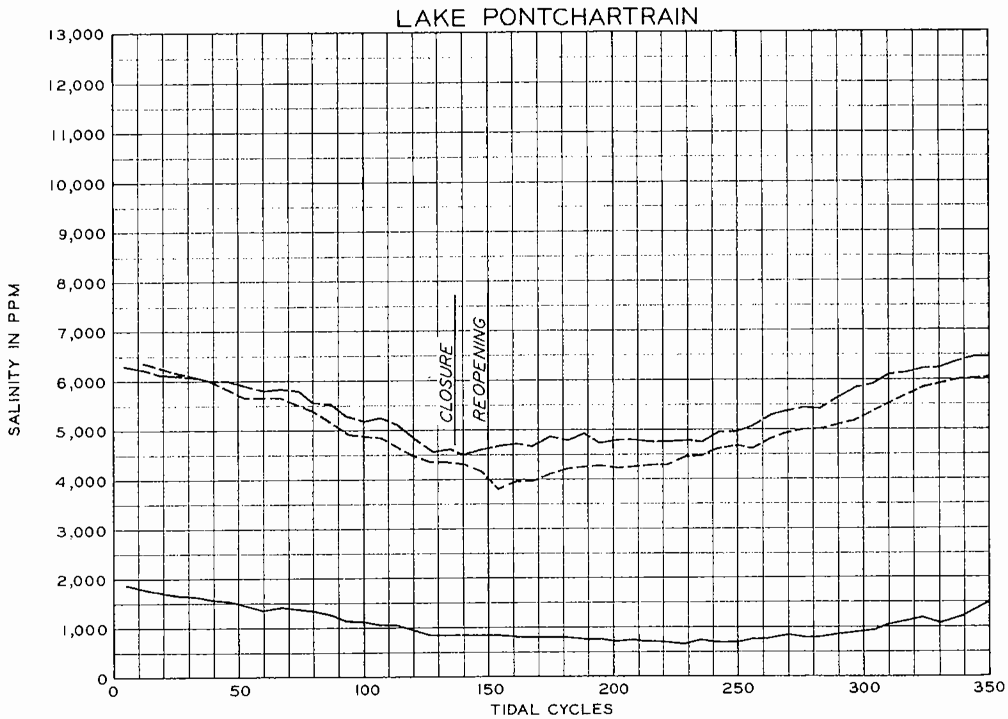
EFFECTS OF REDUCED DISCHARGE BETWEEN LAKE PONTCHARTRAIN AND GULF OUTLET CHANNEL WITH STRUCTURES IN THE PASSES

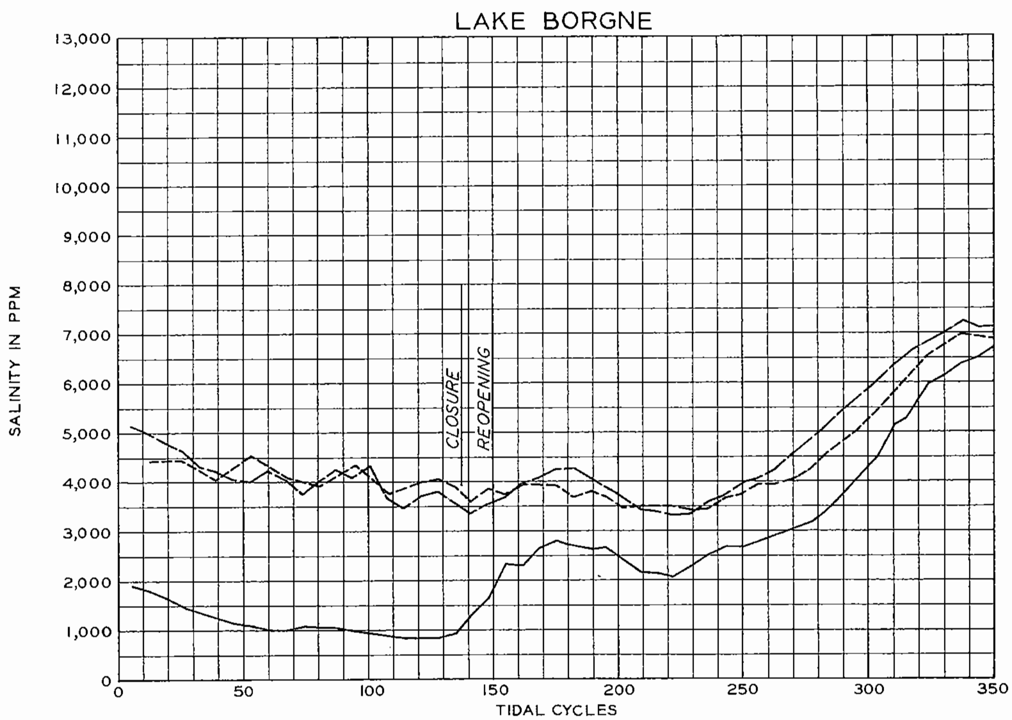
HIGH FRESHWATER INFLOW YEAR



FRESHWATER INFLOW HYDROGRAPH USED FOR TEST OF COMPLETE CLOSURE OF STRUCTURES DURING HURRICANE CONDITIONS

HIGH INFLOW YEAR WITH SUBSTITUTION OF HURRICANE INFLOW





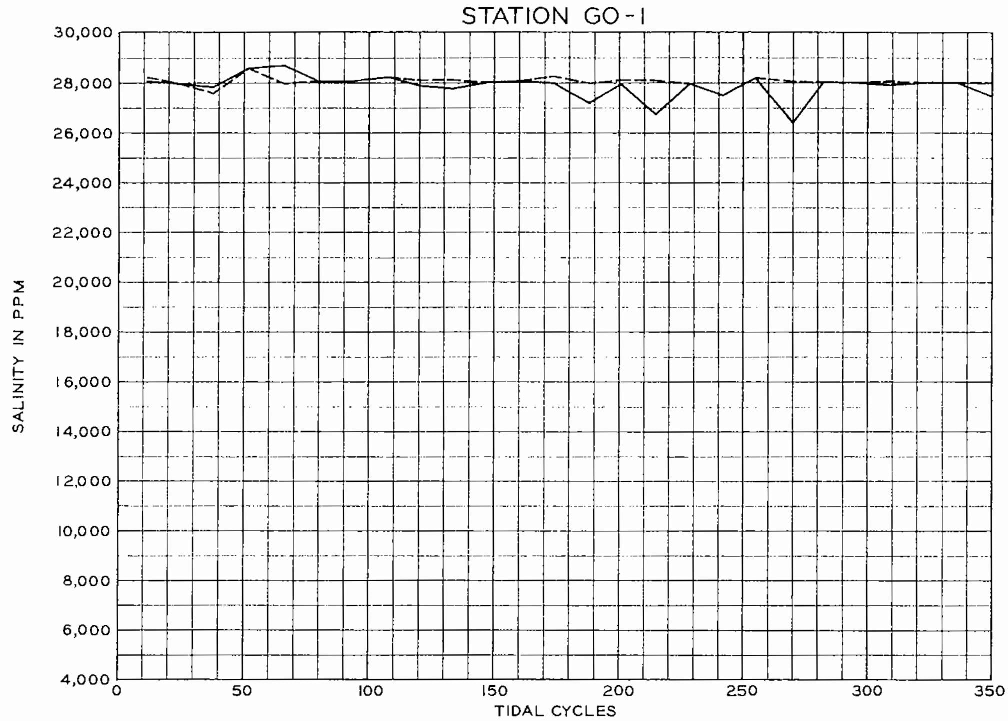
LEGEND

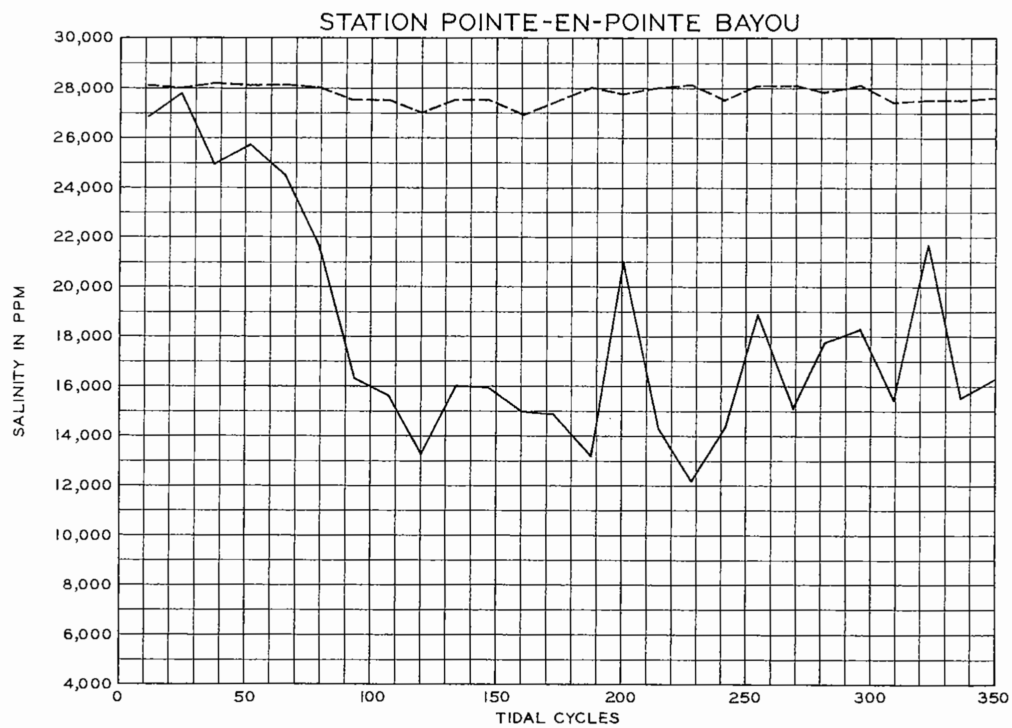
- ——— HIGH-INFLOW YEAR BASE TEST
- — — — WITHOUT CLOSURE
- - - - - WITH COMPLETE CLOSURE FOR A TWO-WEEK PERIOD

EFFECTS OF COMPLETE CLOSURE OF ALL STRUCTURES DURING HURRICANE CONDITIONS

HIGH FRESHWATER INFLOW YEAR

APPENDIX A: SALINITY OBSERVATIONS IN GULF OUTLET CHANNEL



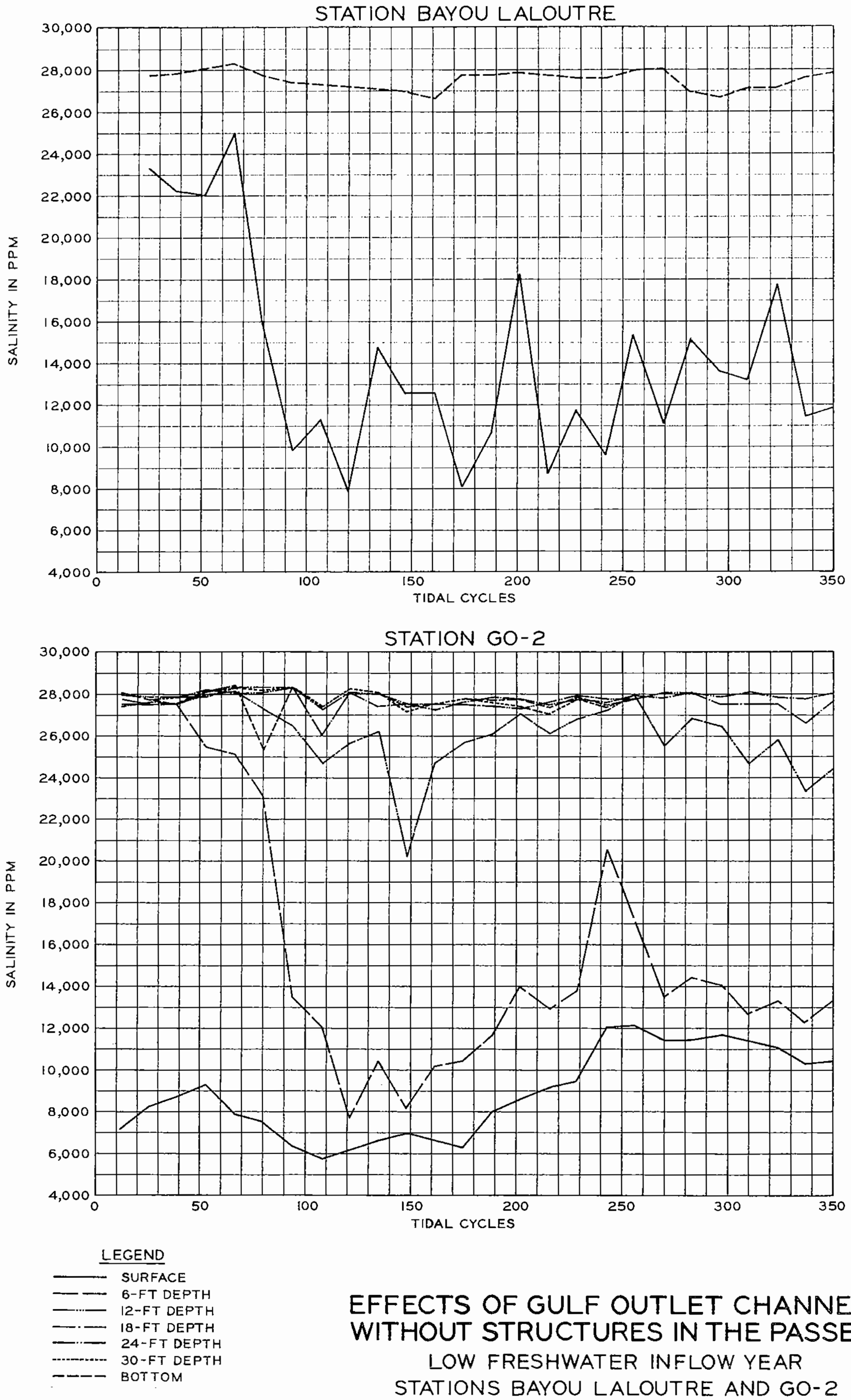


LEGEND
SURFACE
BOTTOM

EFFECTS OF GULF OUTLET CHANNEL WITHOUT STRUCTURES IN THE PASSES

LOW FRESHWATER INFLOW YEAR

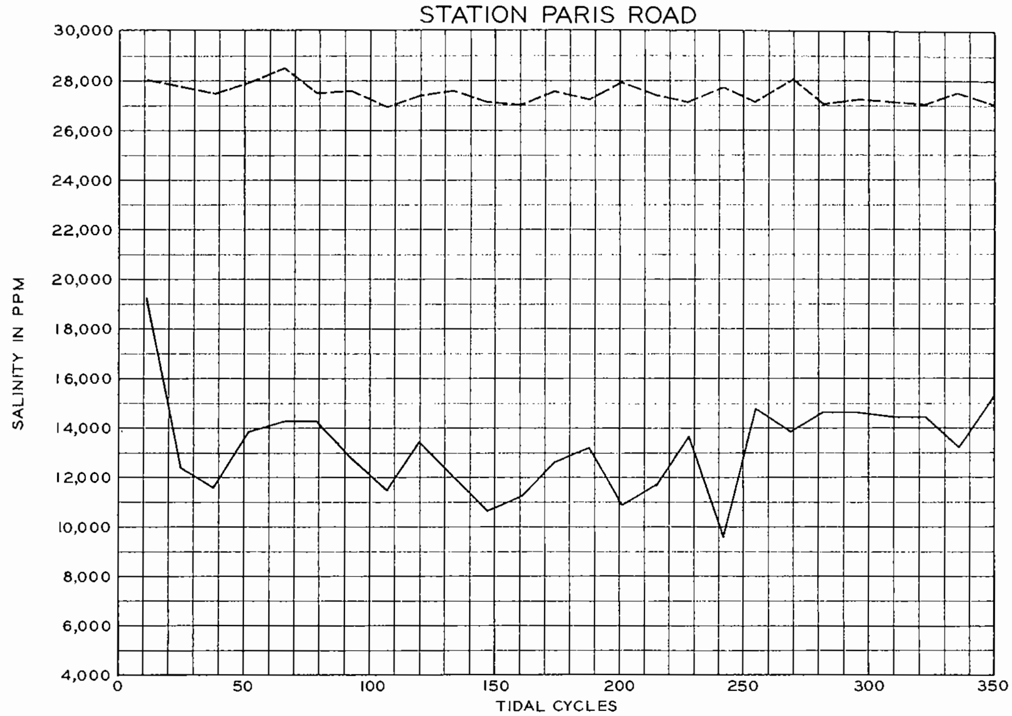
STATIONS GO-1 AND POINTE-EN-POINTE BAYOU

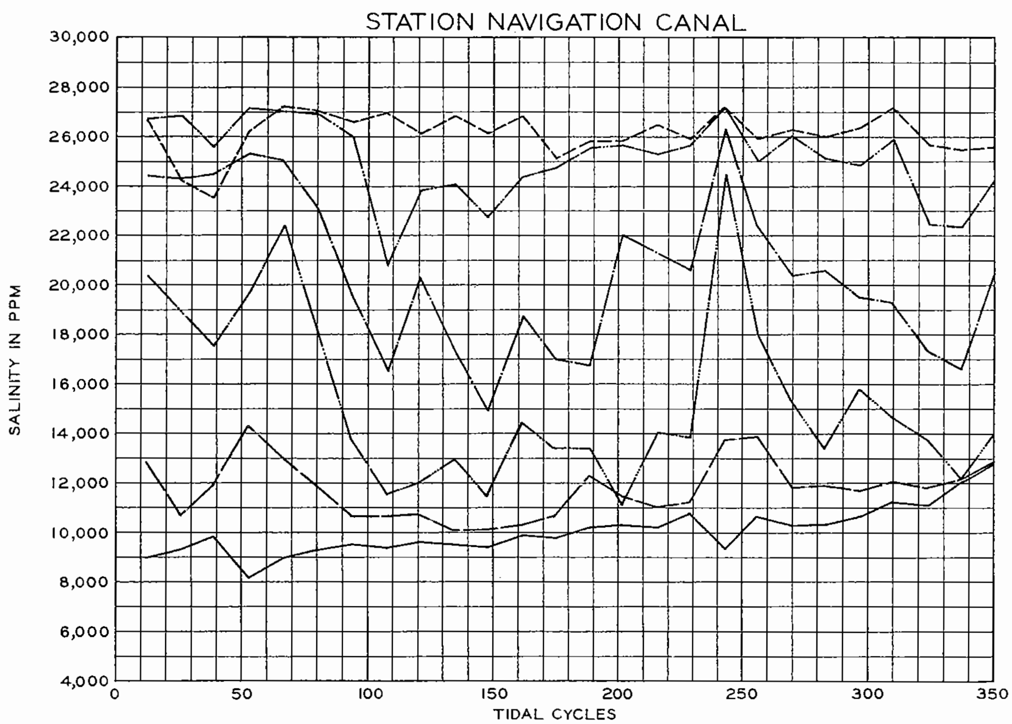


EFFECTS OF GULF OUTLET CHANNEL WITHOUT STRUCTURES IN THE PASSES

LOW FRESHWATER INFLOW YEAR

STATIONS BAYOU LALOUTRE AND GO-2





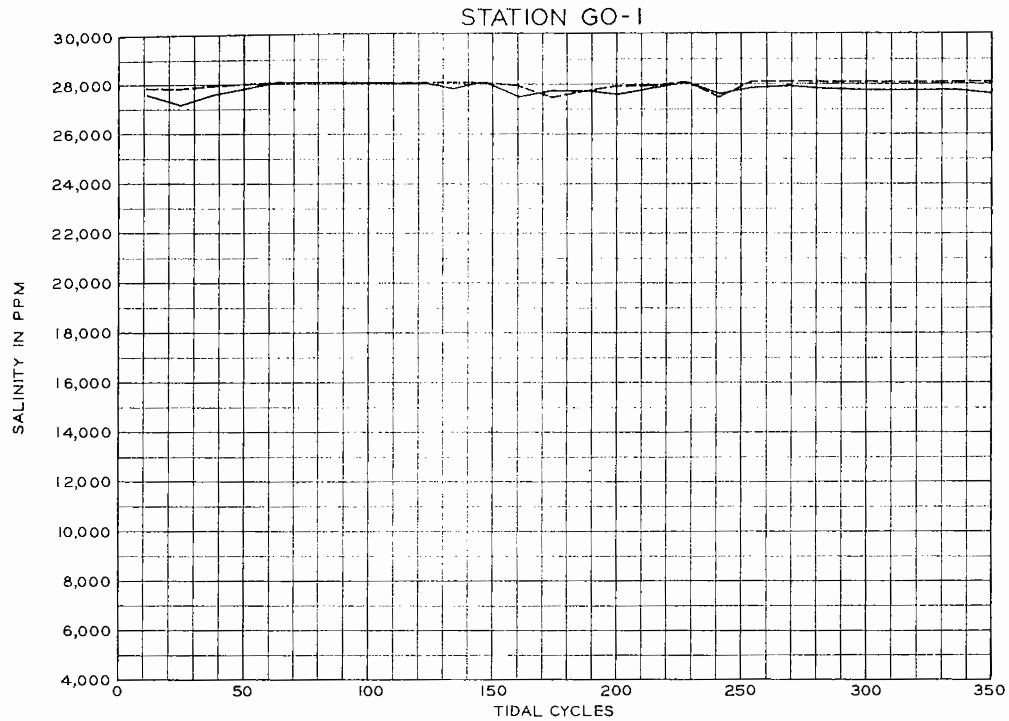
LEGEND

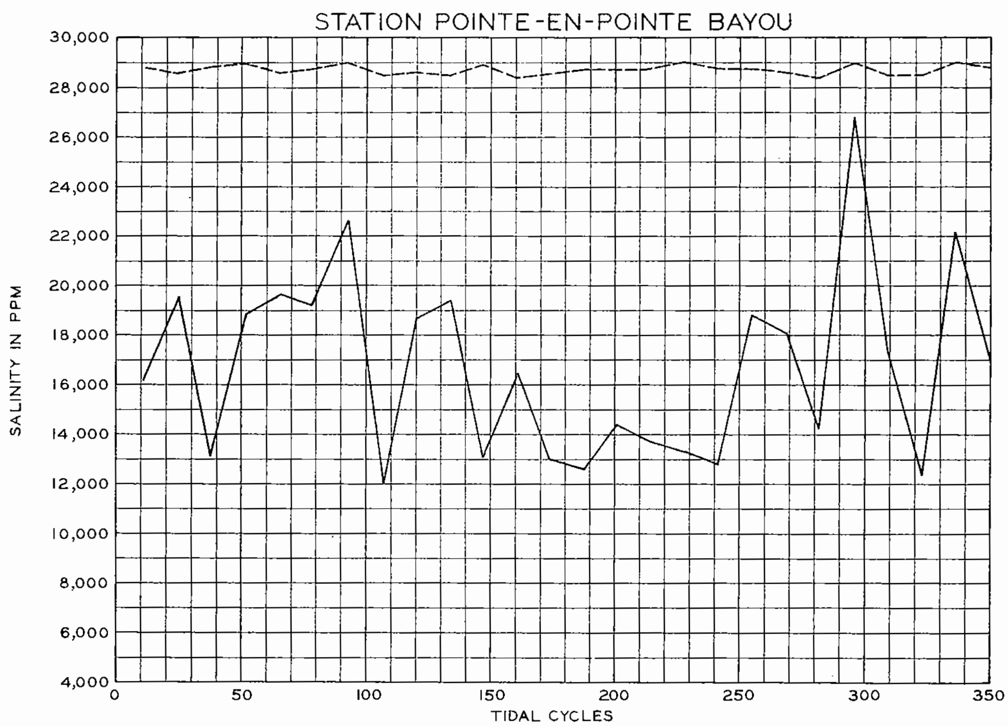
- SURFACE
- 6-FT DEPTH
- 12-FT DEPTH
- 18-FT DEPTH
- 24-FT DEPTH
- BOTTOM

EFFECTS OF GULF OUTLET CHANNEL WITHOUT STRUCTURES IN THE PASSES

LOW FRESHWATER INFLOW YEAR

STATIONS PARIS ROAD AND NAVIGATION CANAL



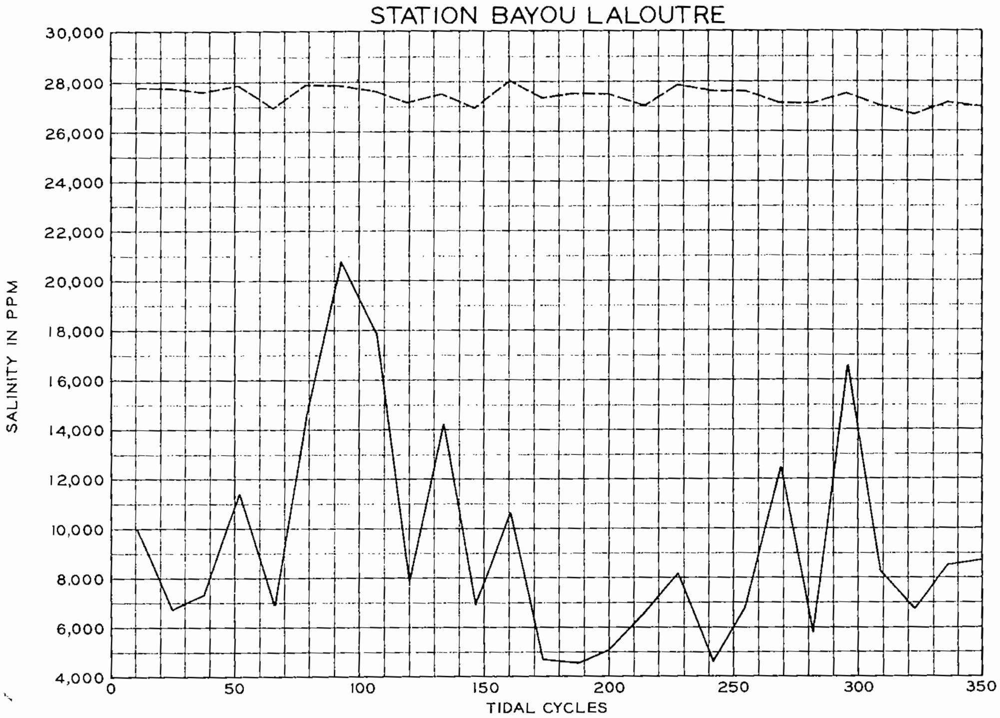


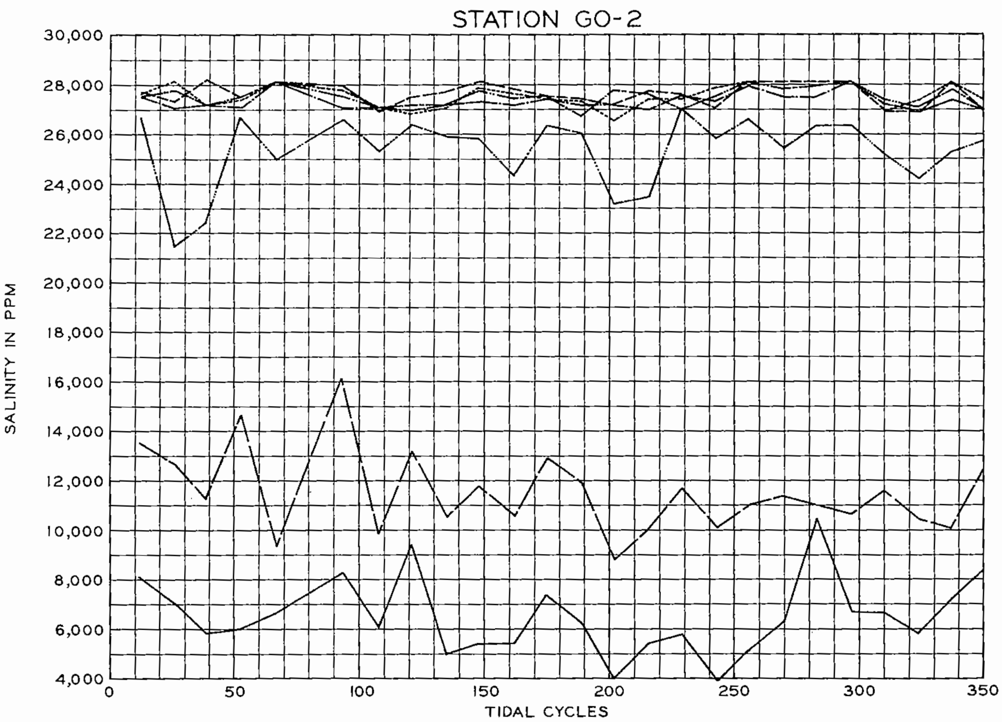
LEGEND
——— SURFACE
– – – – BOTTOM

EFFECTS OF GULF OUTLET CHANNEL WITHOUT STRUCTURES IN THE PASSES

HIGH FRESHWATER INFLOW YEAR

STATIONS GO-1 AND POINTE-EN-POINTE BAYOU





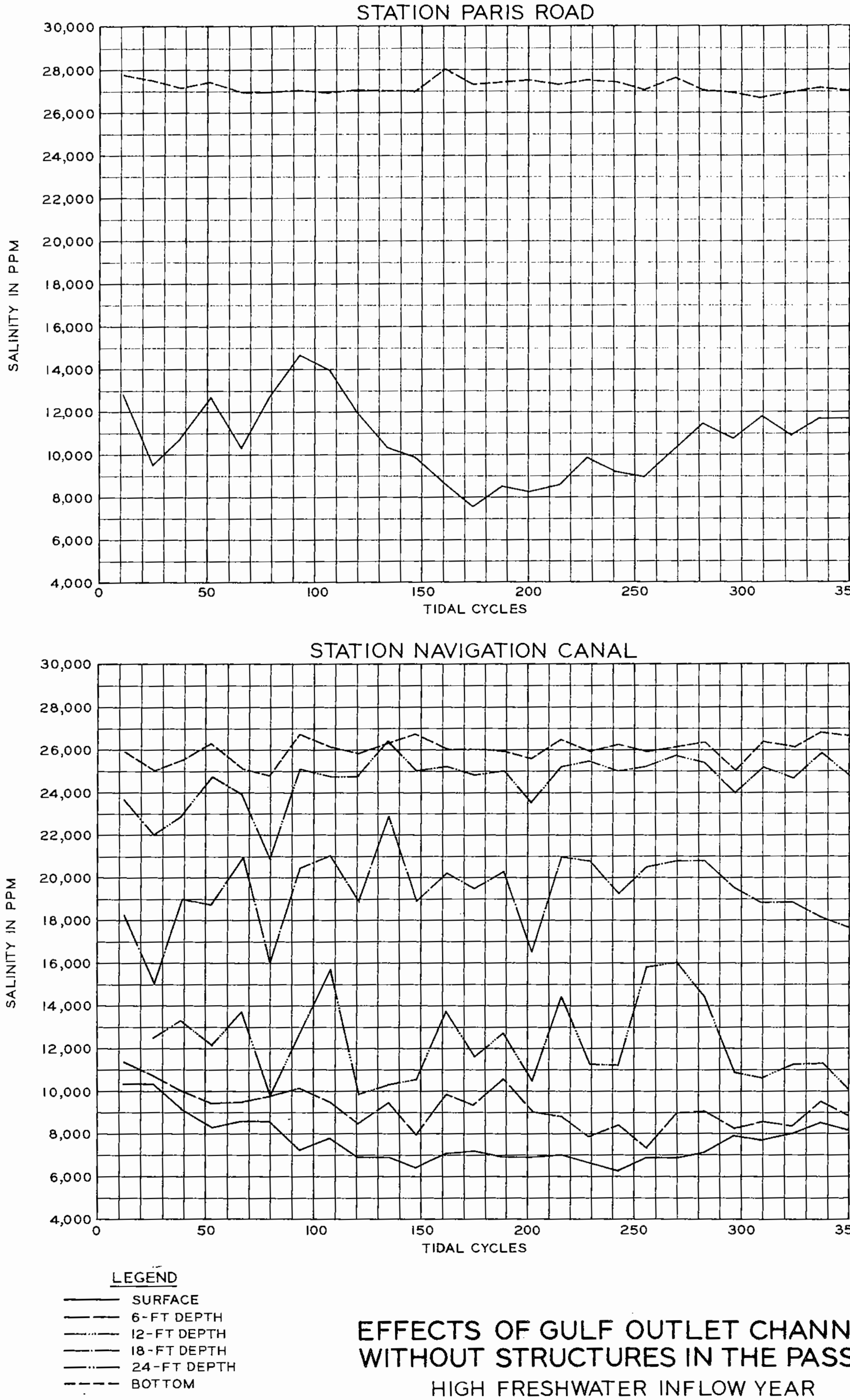
LEGEND

- SURFACE
- 6-FT DEPTH
- 12-FT DEPTH
- 18-FT DEPTH
- 24-FT DEPTH
- 30-FT DEPTH
- BOTTOM

EFFECTS OF GULF OUTLET CHANNEL WITHOUT STRUCTURES IN THE PASSES

HIGH FRESHWATER INFLOW YEAR

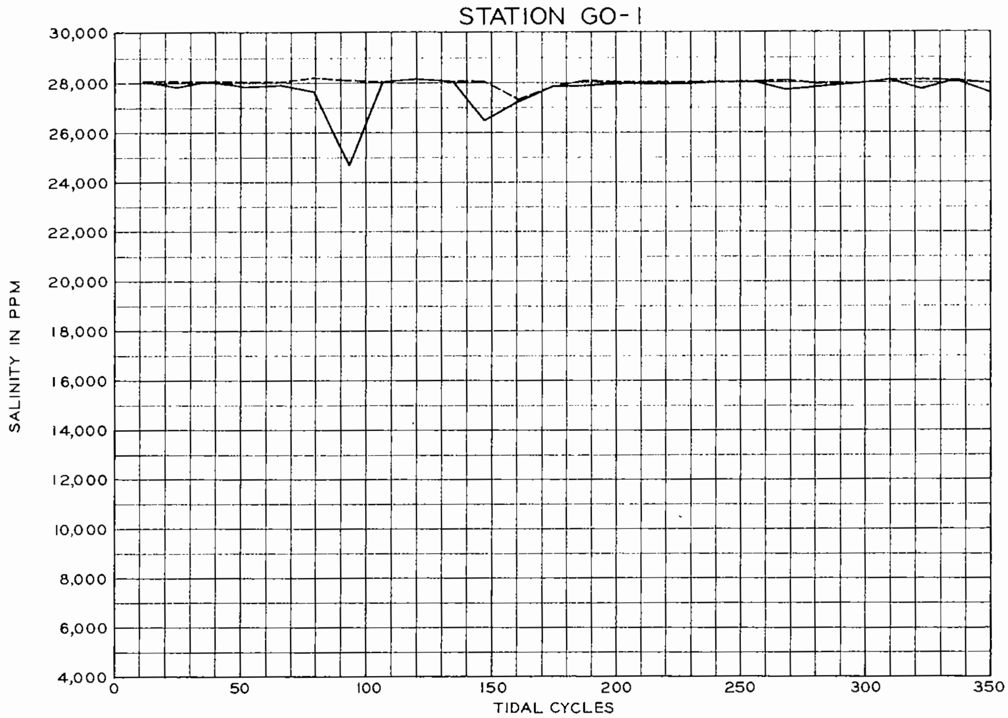
STATIONS BAYOU LALOUTRE AND GO-2

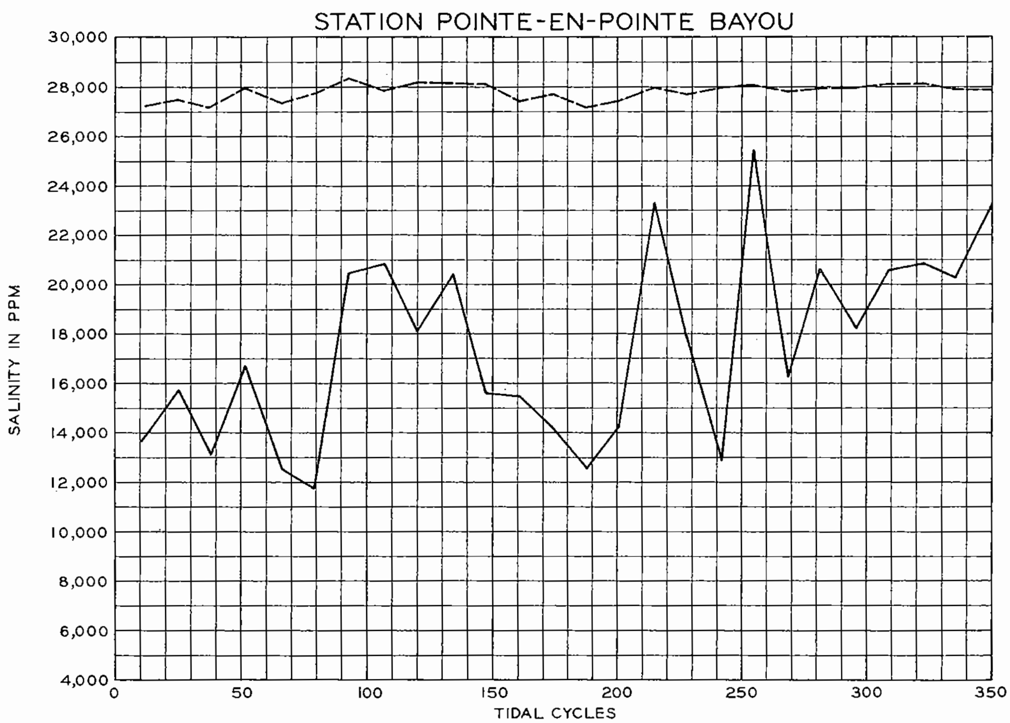


EFFECTS OF GULF OUTLET CHANNEL WITHOUT STRUCTURES IN THE PASSES

HIGH FRESHWATER INFLOW YEAR

STATIONS PARIS ROAD AND NAVIGATION CANAL



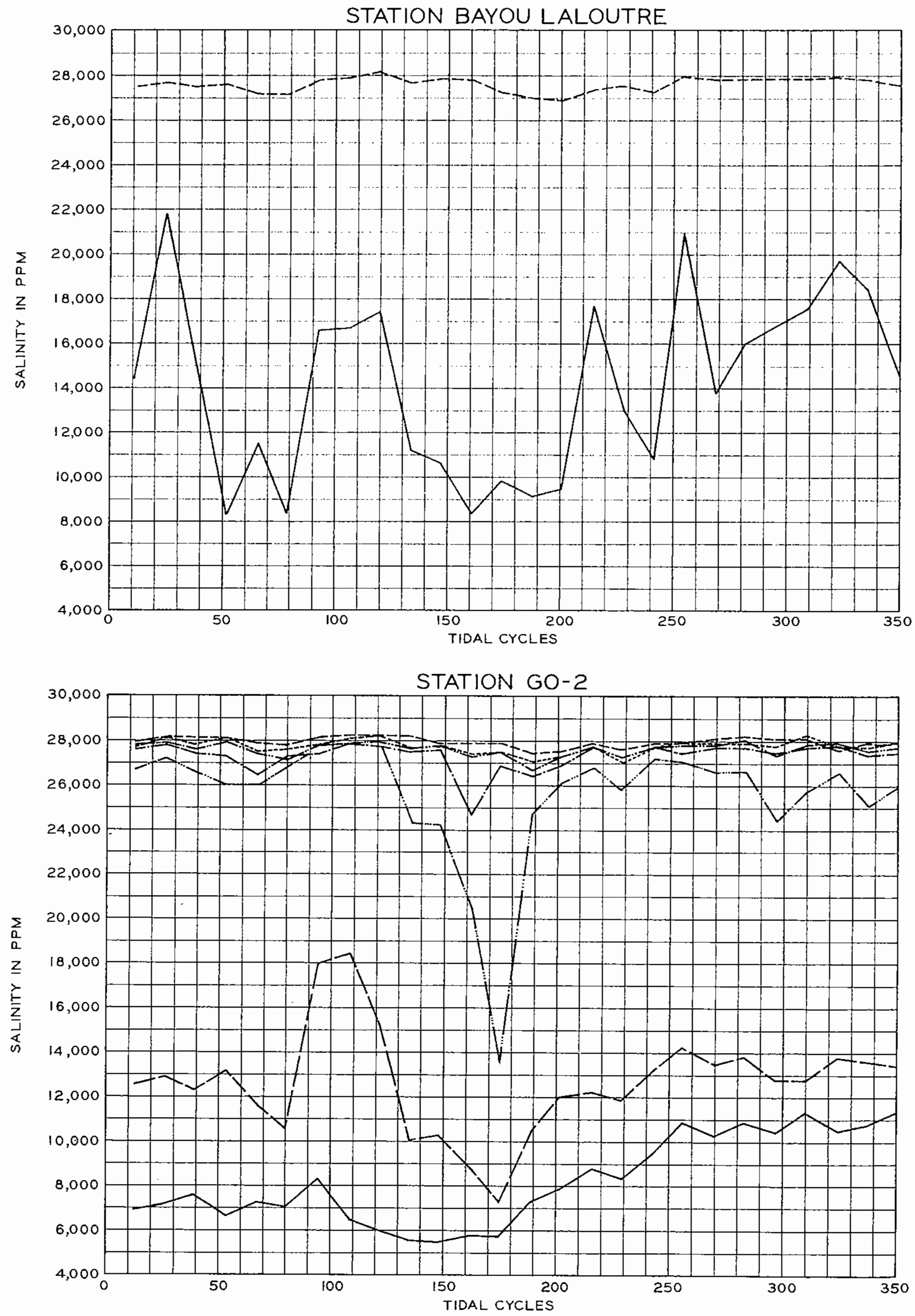


LEGEND
——— SURFACE
– – – – BOTTOM

EFFECTS OF GULF OUTLET CHANNEL AND HURRICANE SURGE CONTROL STRUCTURES

LOW FRESHWATER INFLOW YEAR

STATIONS GO-1 AND POINTE-EN-POINTE BAYOU



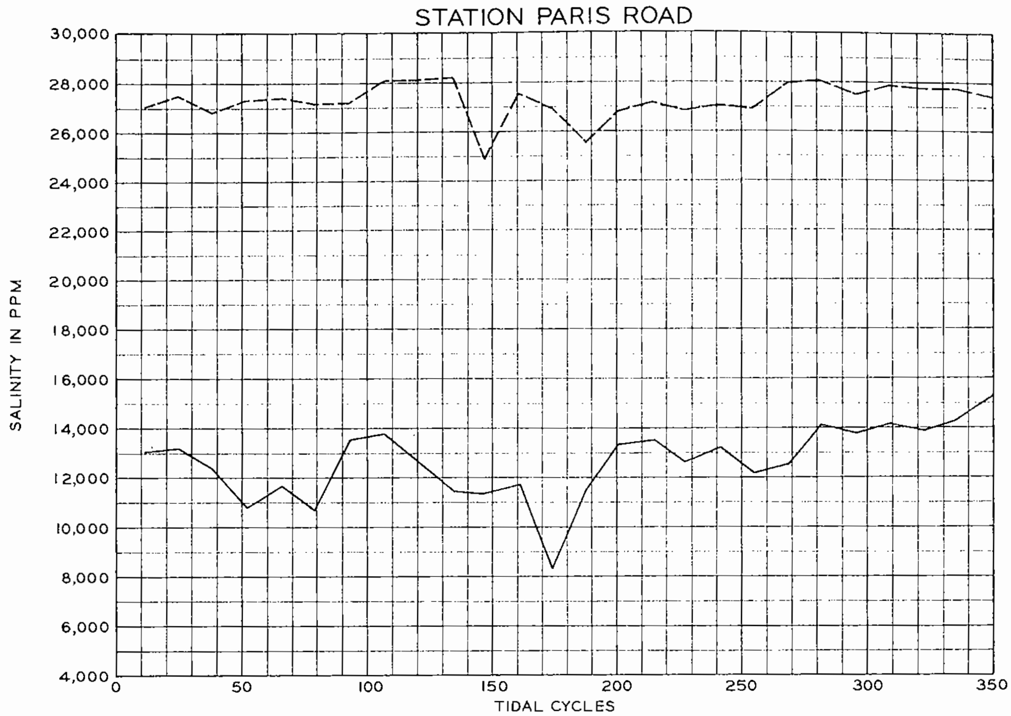
LEGEND

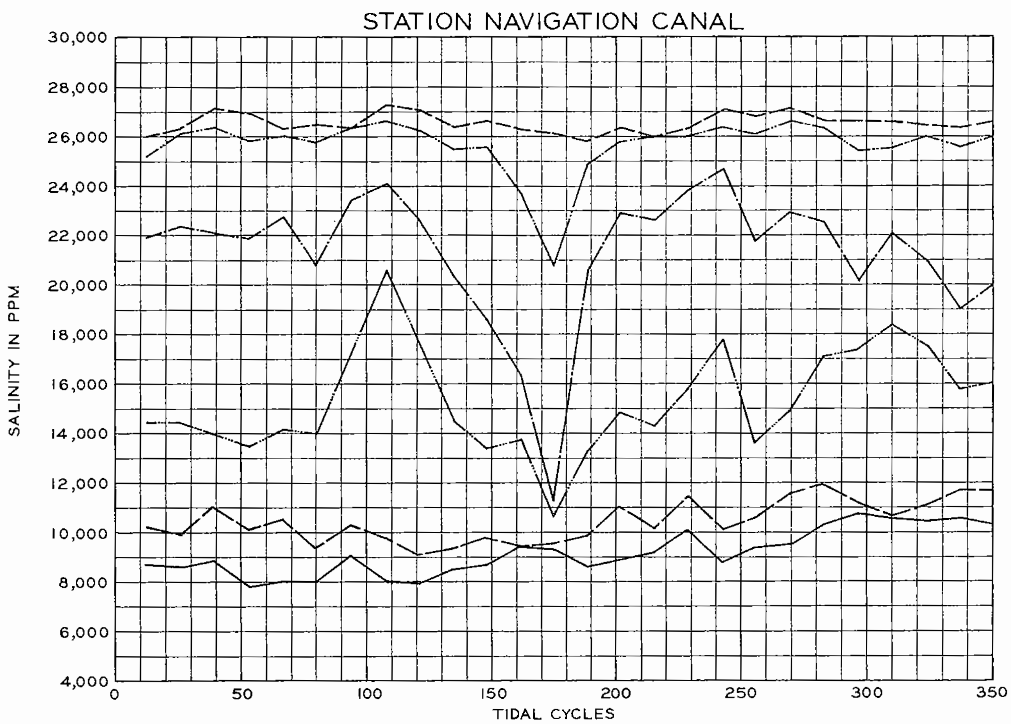
- SURFACE
- 6-FT DEPTH
- 12-FT DEPTH
- 18-FT DEPTH
- 24-FT DEPTH
- 30-FT DEPTH.
- BOTTOM

EFFECTS OF GULF OUTLET CHANNEL AND HURRICANE SURGE CONTROL STRUCTURES

LOW FRESHWATER INFLOW YEAR

STATIONS BAYOU LALOUTRE AND GO-2





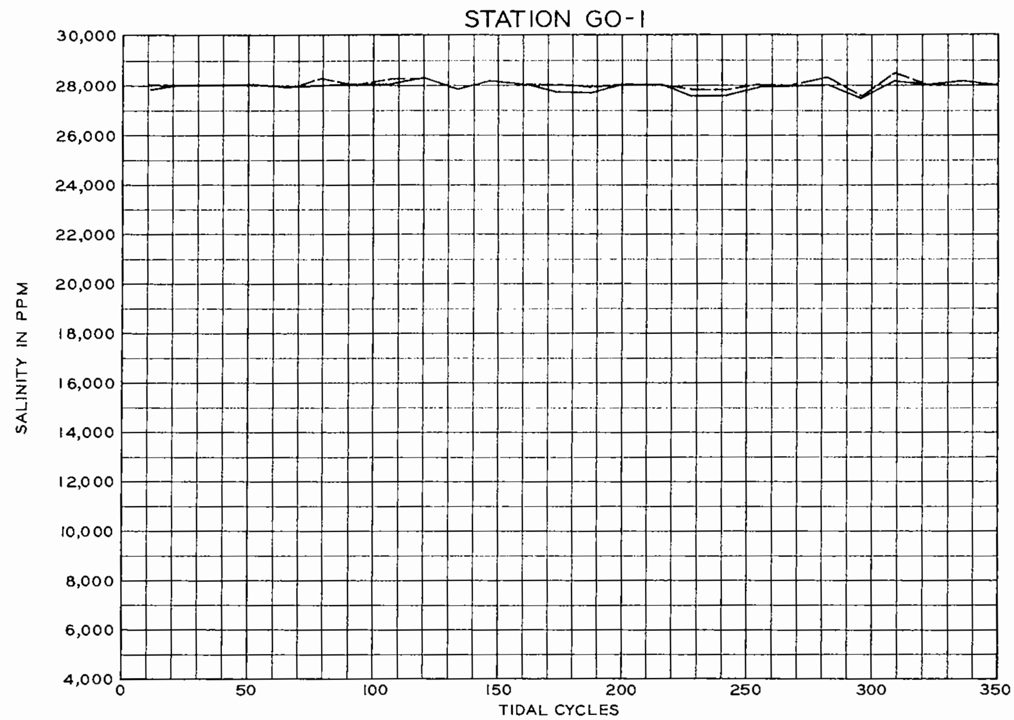
LEGEND

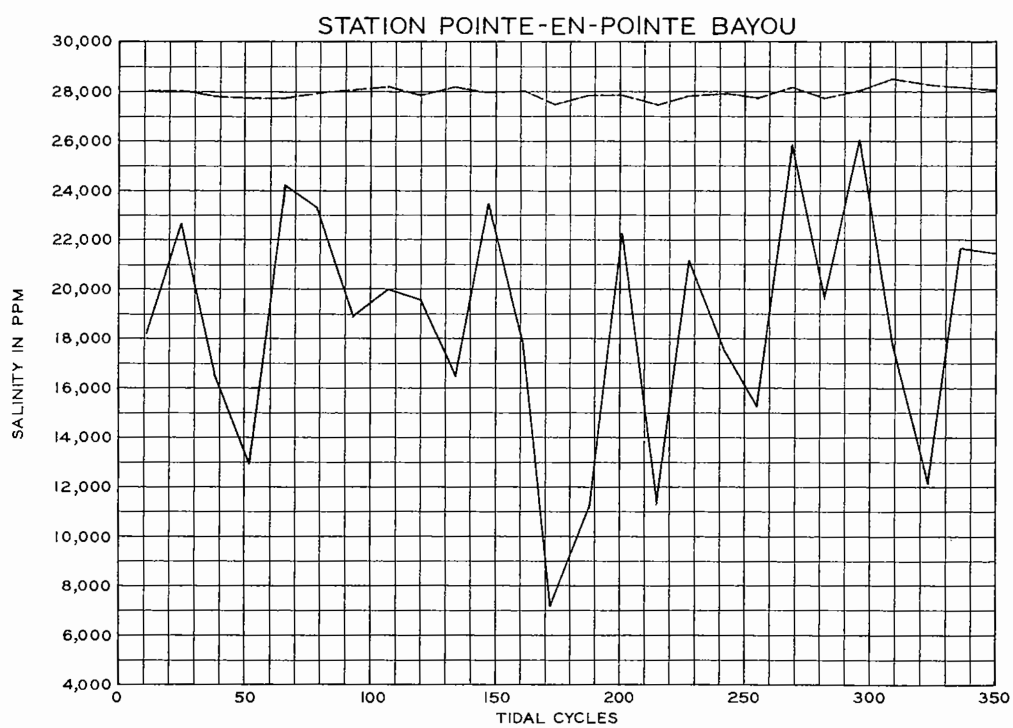
- SURFACE
- 6-FT DEPTH
- 12-FT DEPTH
- 18-FT DEPTH
- 24-FT DEPTH
- BOTTOM

EFFECTS OF GULF OUTLET CHANNEL AND HURRICANE SURGE CONTROL STRUCTURES

LOW FRESHWATER INFLOW YEAR

STATIONS PARIS ROAD AND NAVIGATION CANAL



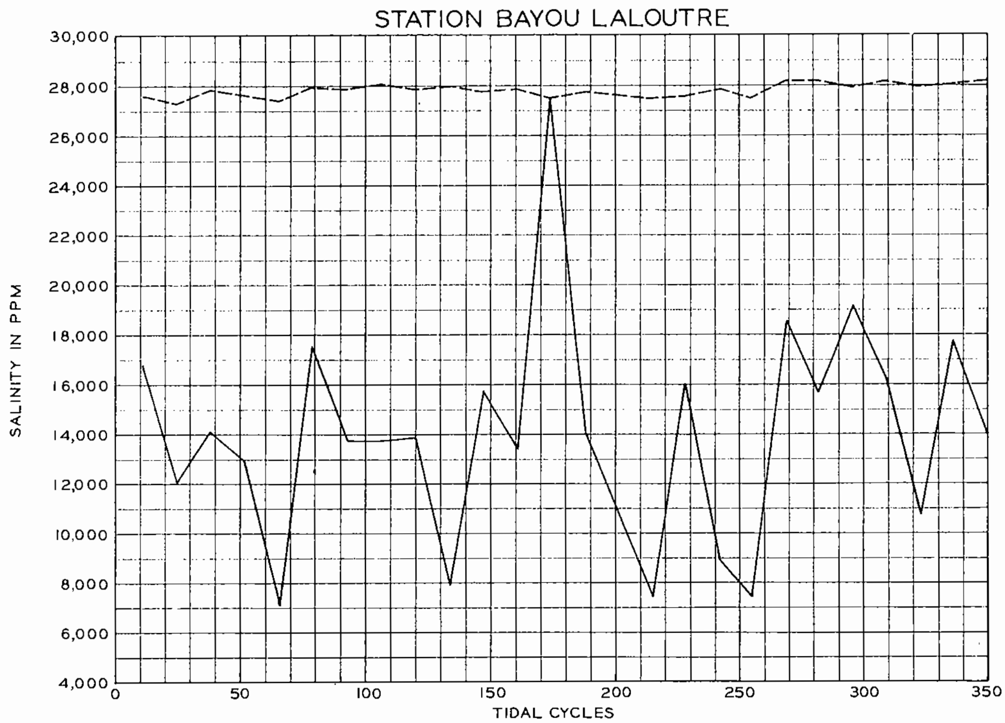


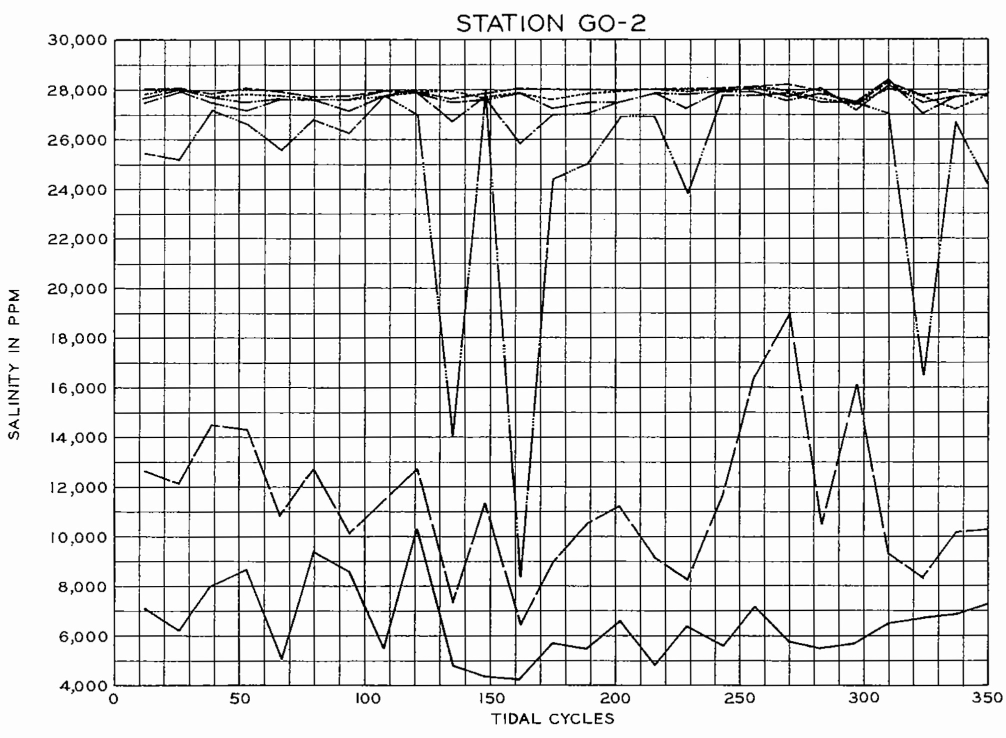
LEGEND
SURFACE
BOTTOM

EFFECTS OF GULF OUTLET CHANNEL AND HURRICANE SURGE CONTROL STRUCTURES

HIGH FRESHWATER INFLOW YEAR
STATIONS GO-1 AND POINTE-EN-POINTE BAYOU

PLATE A10





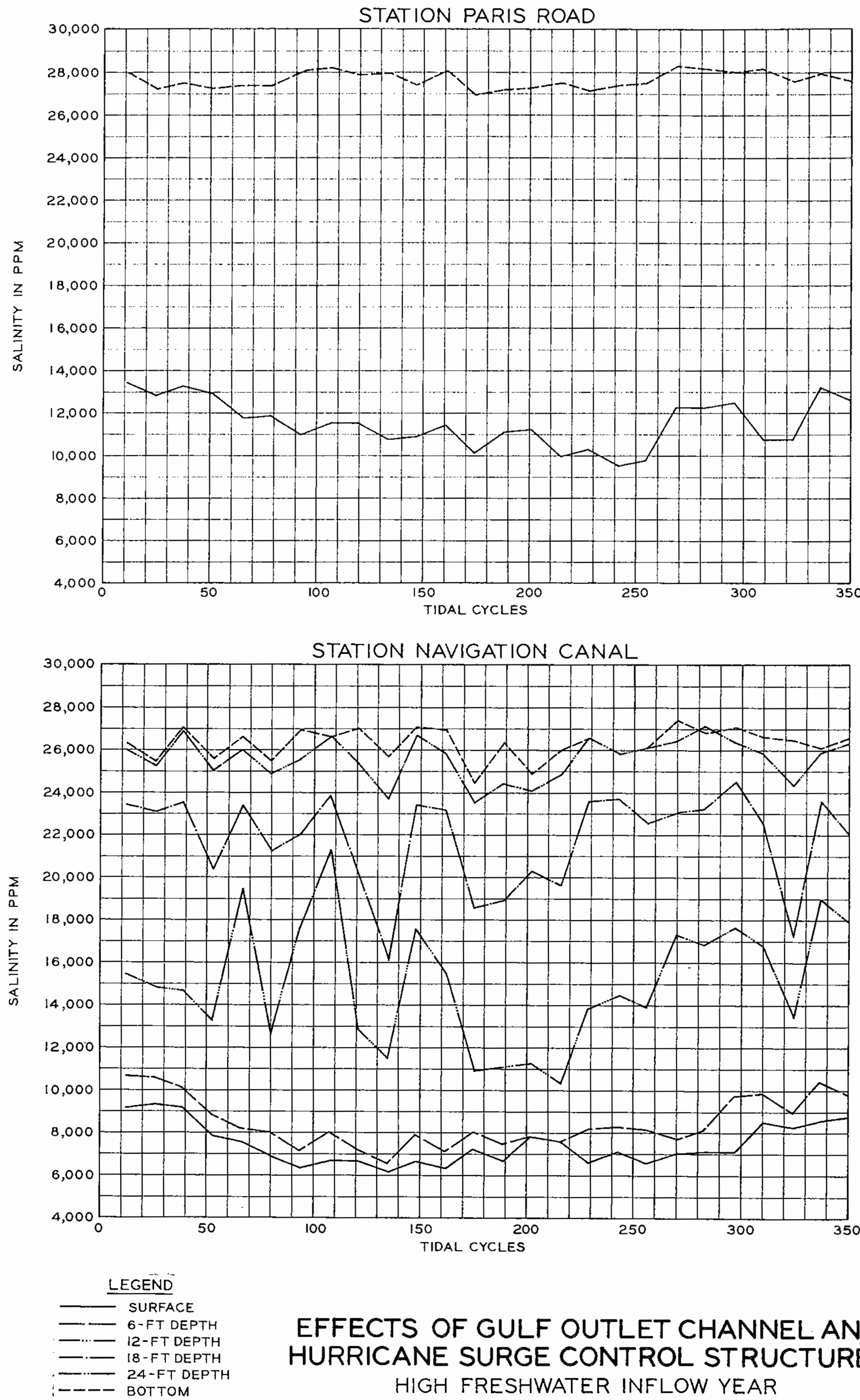
LEGEND

- SURFACE
- 6-FT DEPTH
- 12-FT DEPTH
- 18-FT DEPTH
- 24-FT DEPTH
- 30-FT DEPTH
- BOTTOM

EFFECTS OF GULF OUTLET CHANNEL AND HURRICANE SURGE CONTROL STRUCTURES

HIGH FRESHWATER INFLOW YEAR

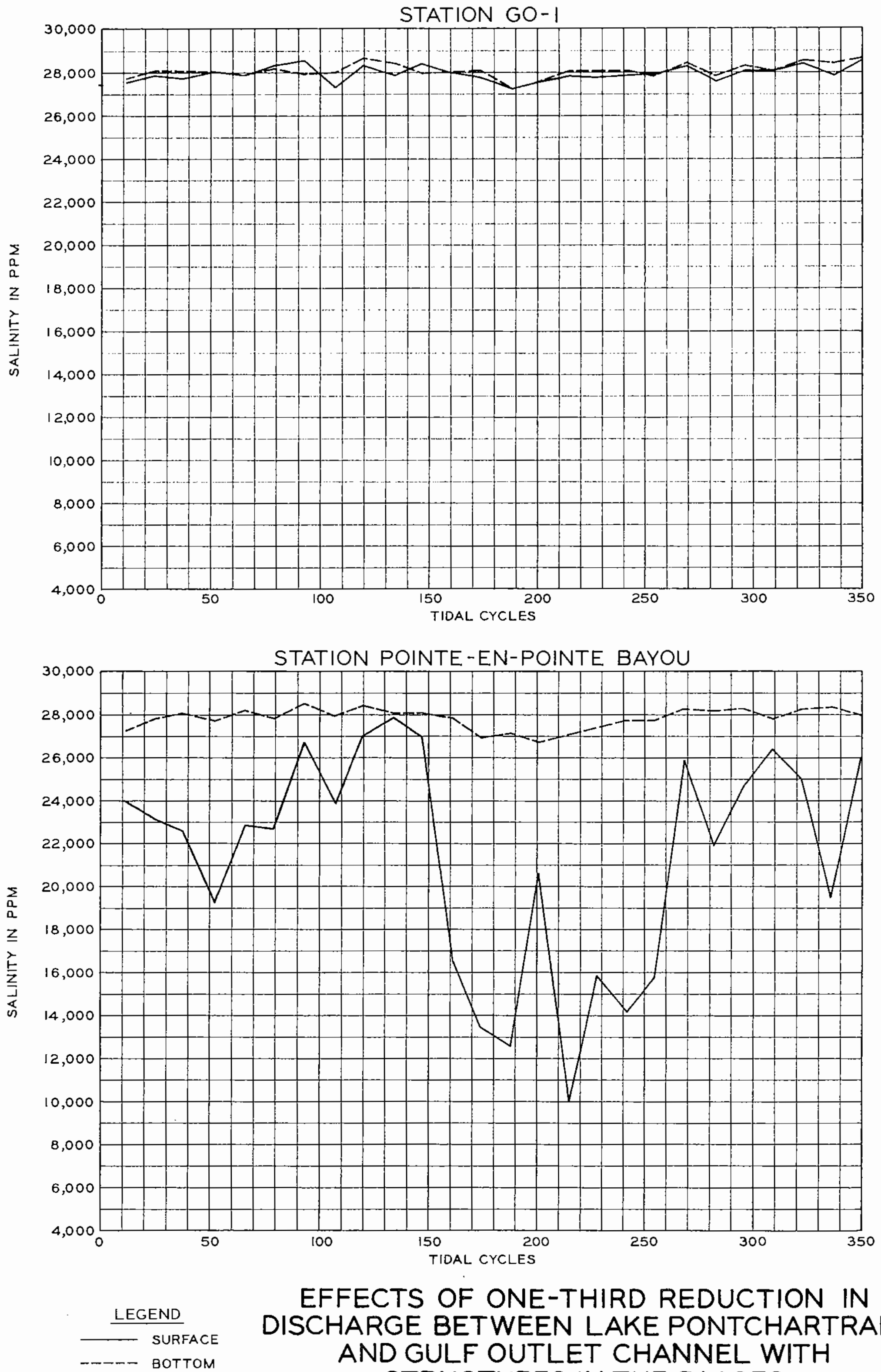
STATIONS BAYOU LALOUTRE AND GO-2



EFFECTS OF GULF OUTLET CHANNEL AND HURRICANE SURGE CONTROL STRUCTURES

HIGH FRESHWATER INFLOW YEAR

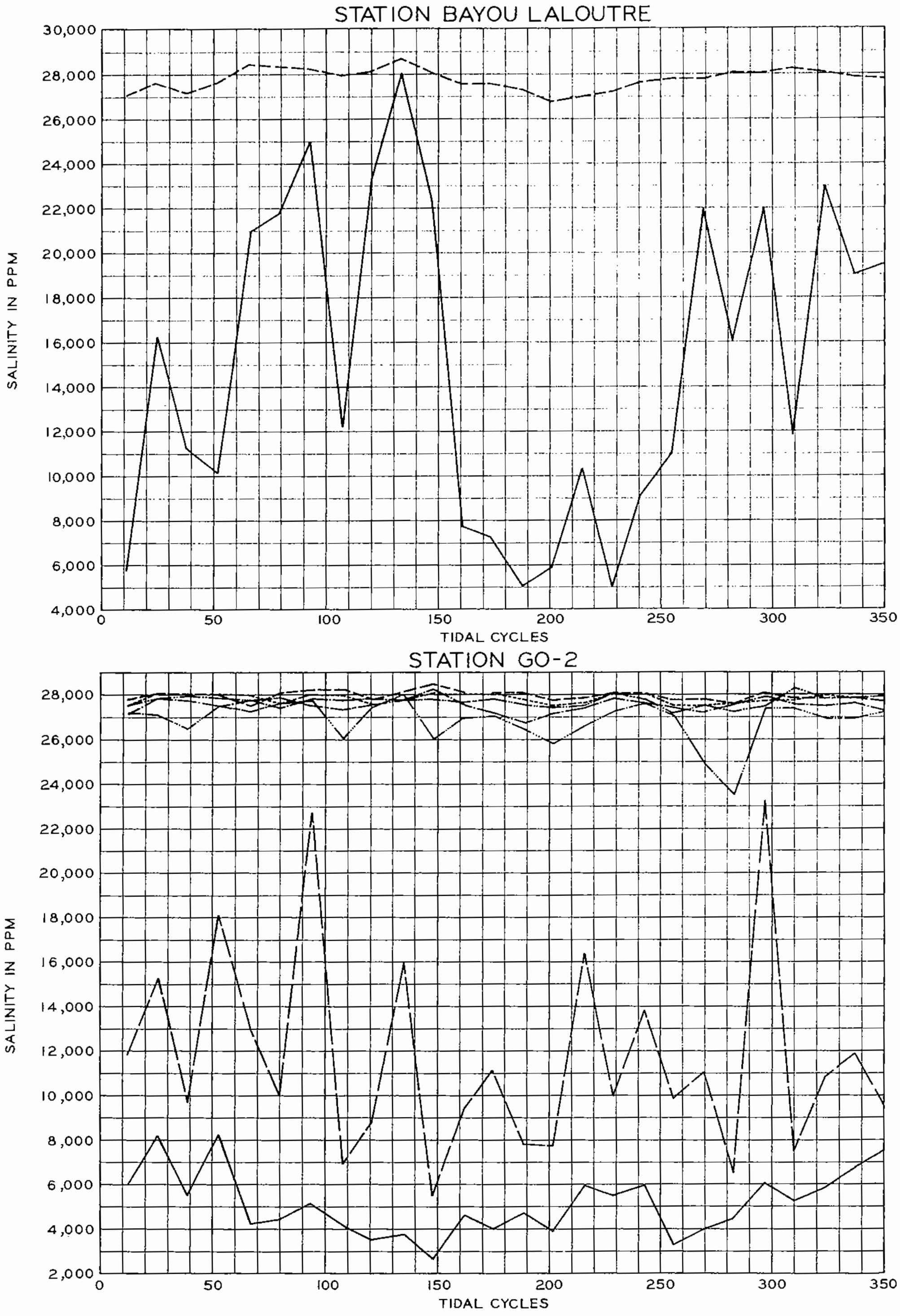
STATIONS PARIS ROAD AND NAVIGATION CANAL



EFFECTS OF ONE-THIRD REDUCTION IN DISCHARGE BETWEEN LAKE PONTCHARTRAIN AND GULF OUTLET CHANNEL WITH STRUCTURES IN THE PASSES

HIGH FRESHWATER INFLOW YEAR

STATIONS GO-1 AND POINTE-EN-POINTE BAYOU



LEGEND

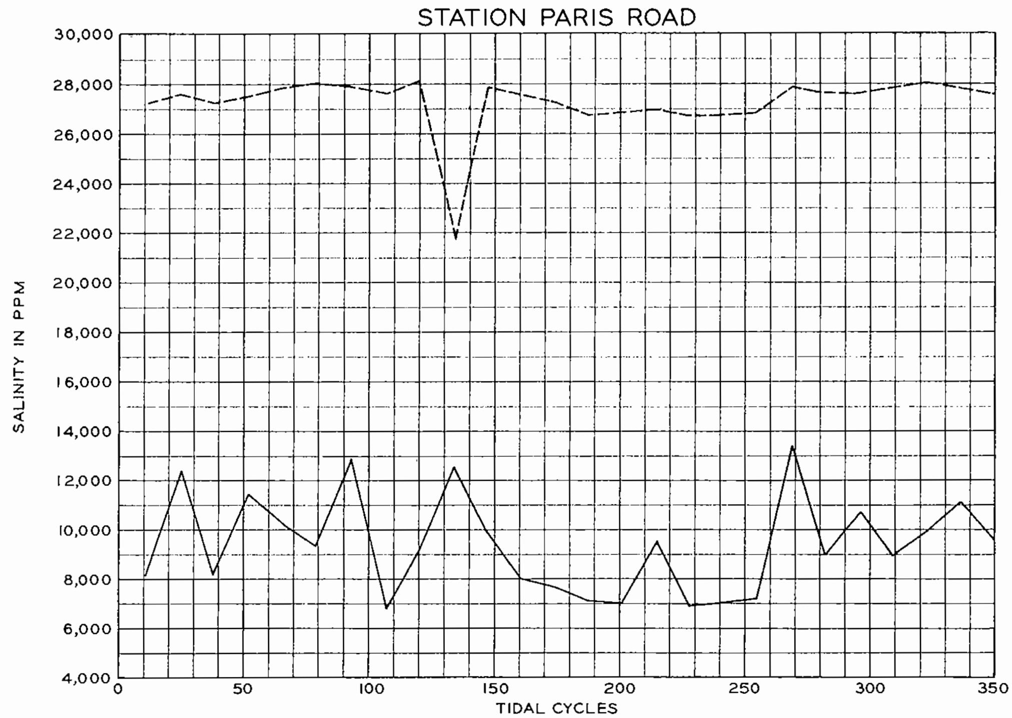
- SURFACE
- 6-FT DEPTH
- 12-FT DEPTH
- 18-FT DEPTH
- 24-FT DEPTH
- 30-FT DEPTH
- BOTTOM

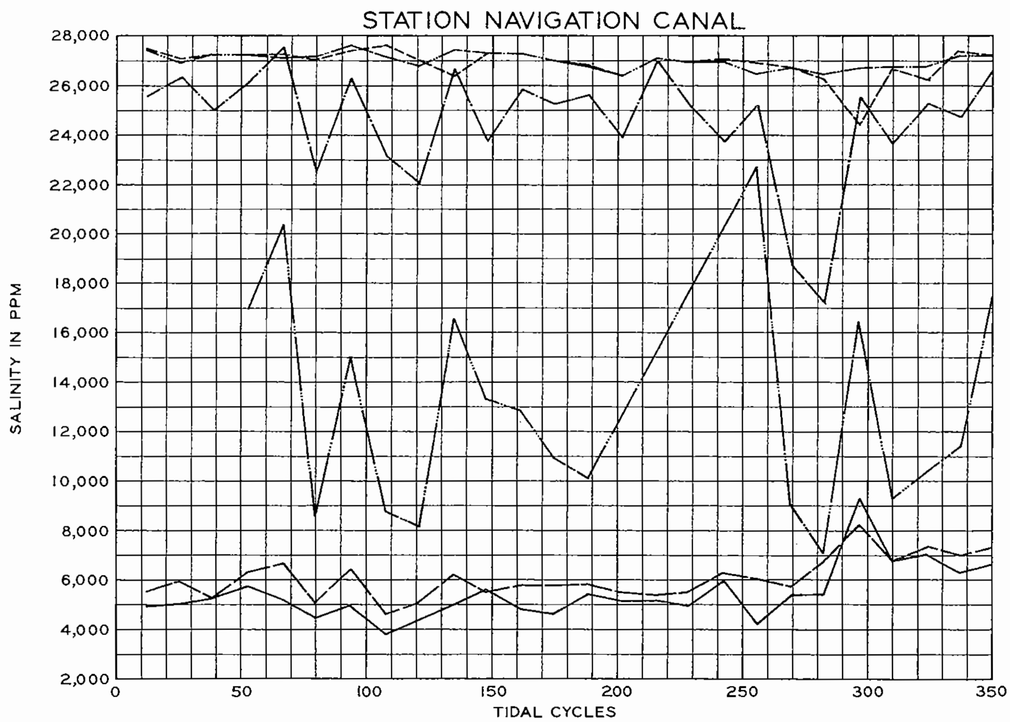
EFFECTS OF ONE-THIRD REDUCTION IN DISCHARGE BETWEEN LAKE PONTCHARTRAIN AND GULF OUTLET CHANNEL WITH STRUCTURES IN THE PASSES

HIGH FRESHWATER INFLOW YEAR

STATIONS BAYOU LALOUTRE AND GO-2

PLATE A14



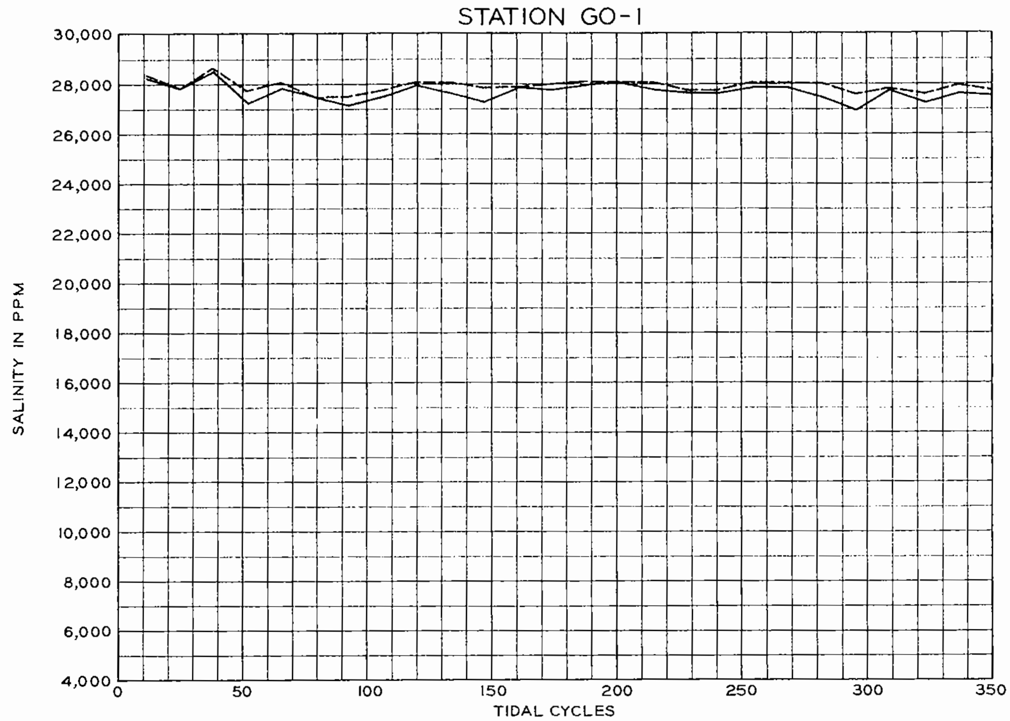


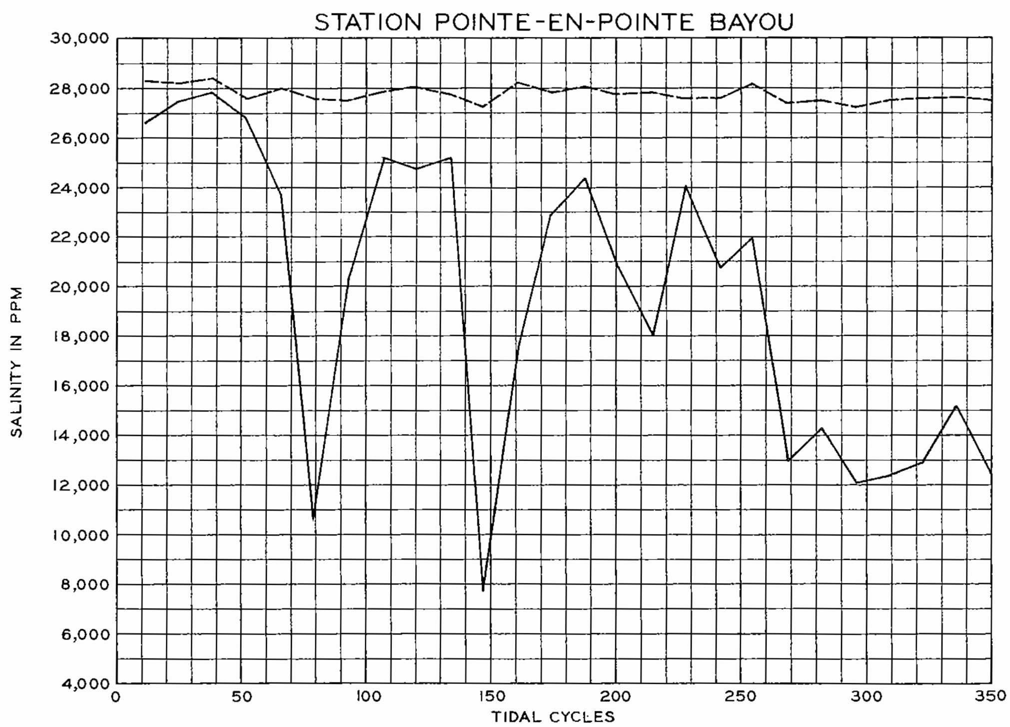
LEGEND

- SURFACE
- 6-FT DEPTH
- 12-FT DEPTH
- 18-FT DEPTH
- 24-FT DEPTH
- BOTTOM

EFFECTS OF ONE-THIRD REDUCTION IN DISCHARGE BETWEEN LAKE PONTCHARTRAIN AND GULF OUTLET CHANNEL WITH STRUCTURES IN THE PASSES

HIGH FRESHWATER INFLOW YEAR
STATIONS PARIS ROAD AND NAVIGATION CANAL



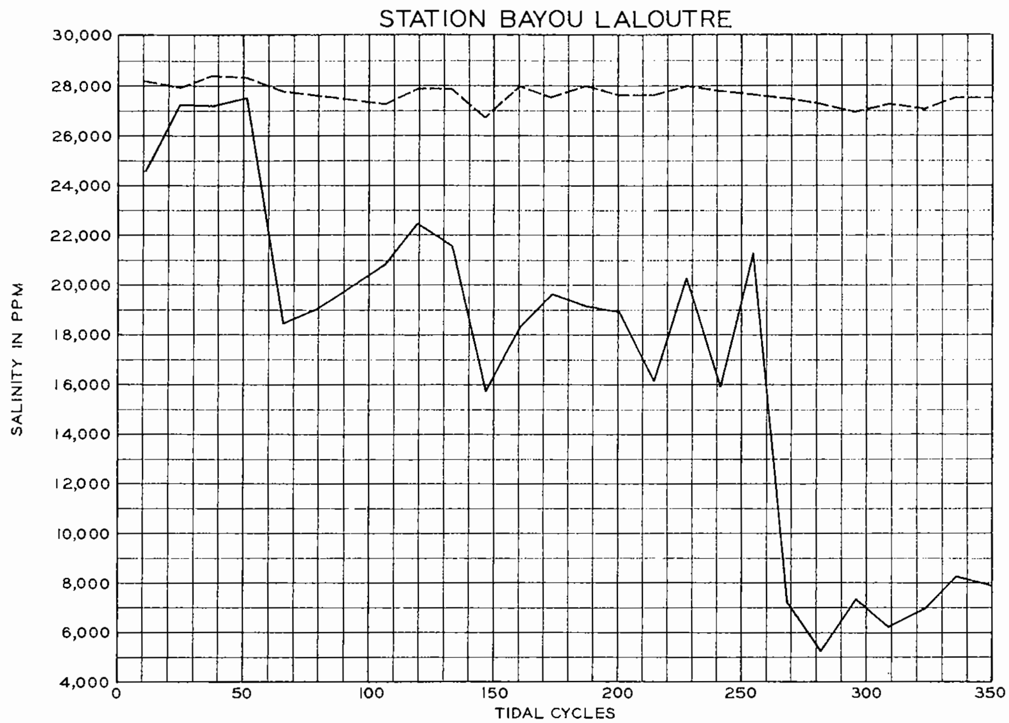


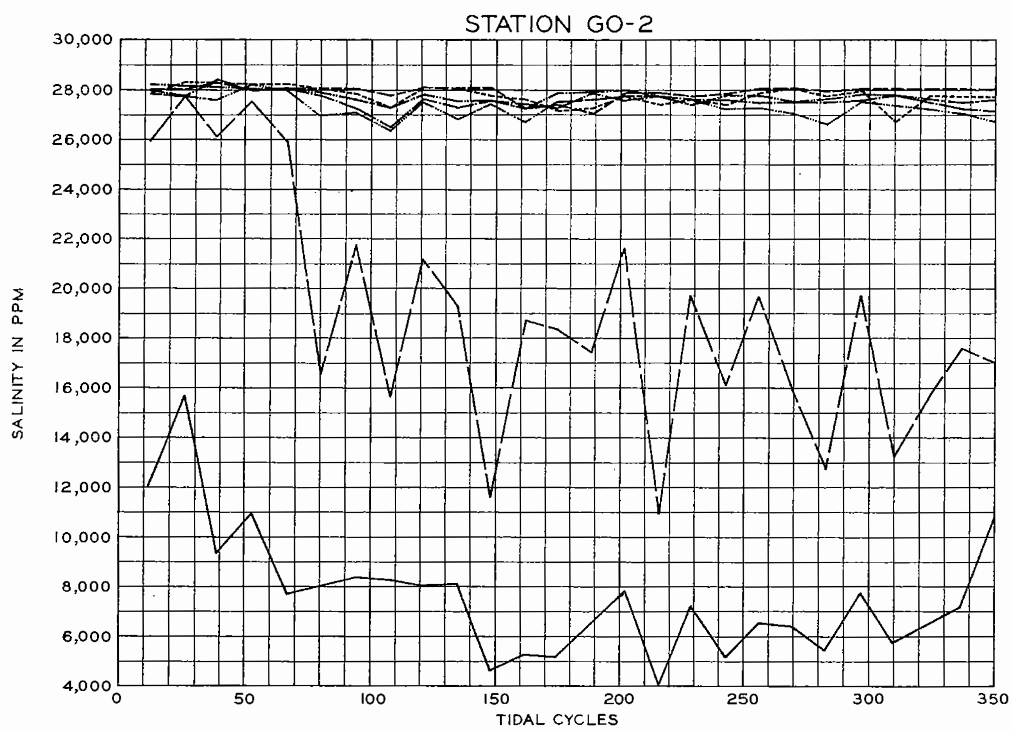
LEGEND
——— SURFACE
– – – – BOTTOM

EFFECTS OF TWO-THIRDS REDUCTION IN DISCHARGE BETWEEN LAKE PONTCHARTRAIN AND GULF OUTLET CHANNEL WITH STRUCTURES IN THE PASSES

HIGH FRESHWATER INFLOW YEAR

STATIONS GO-1 AND POINTE-EN-POINTE BAYOU





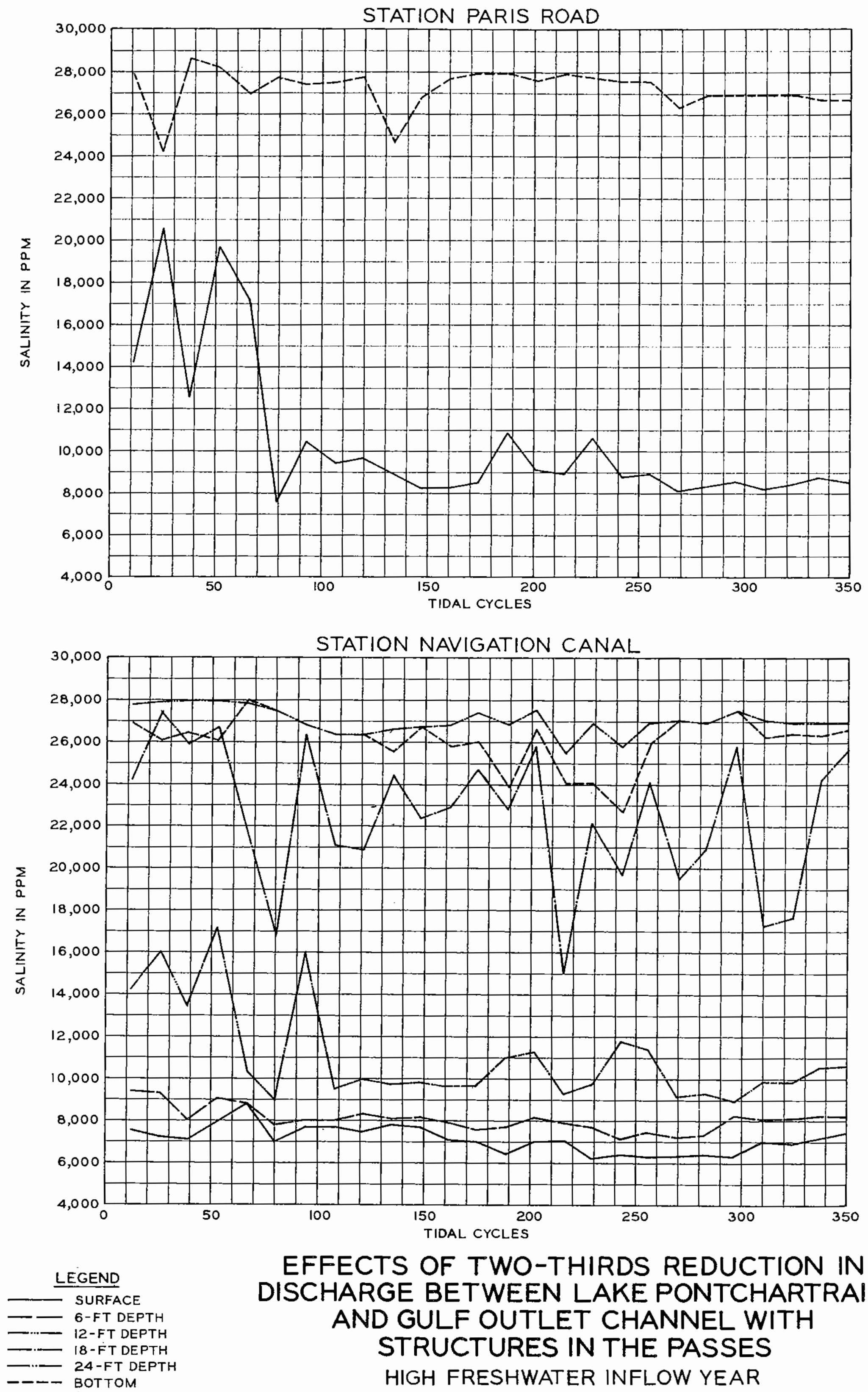
LEGEND

- SURFACE
- 6-FT DEPTH
- 12-FT DEPTH
- 18-FT DEPTH
- 24-FT DEPTH
- 30-FT DEPTH
- BOTTOM

EFFECTS OF TWO-THIRDS REDUCTION IN DISCHARGE BETWEEN LAKE PONTCHARTRAIN AND GULF OUTLET CHANNEL WITH STRUCTURES IN THE PASSES

HIGH FRESHWATER INFLOW YEAR

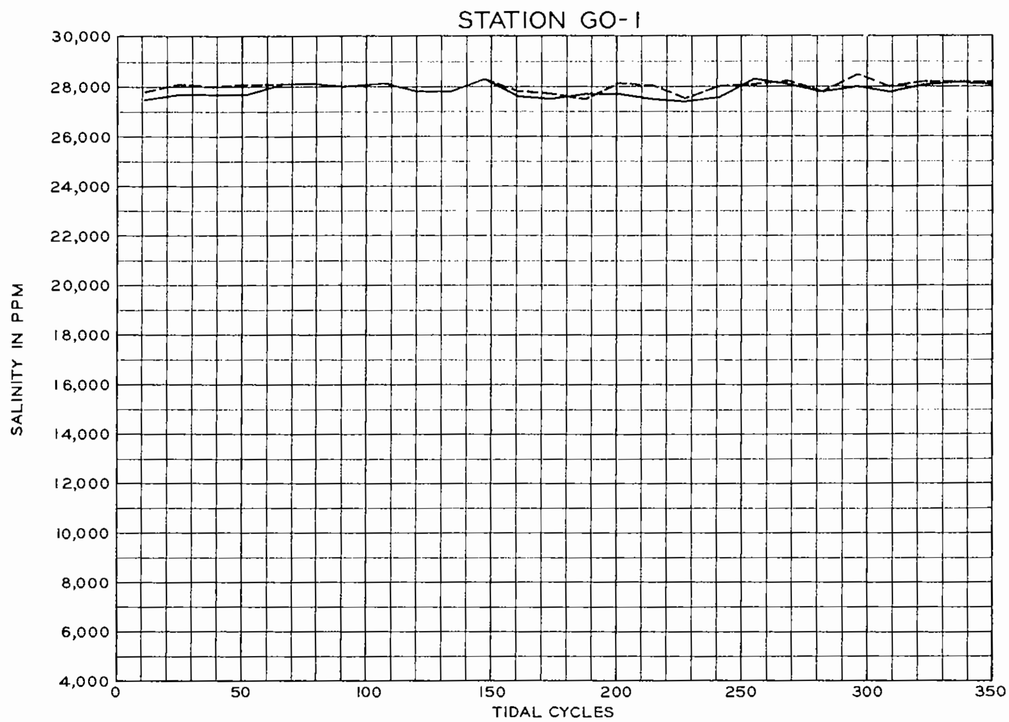
STATIONS BAYOU LALOUTRE AND GO-2

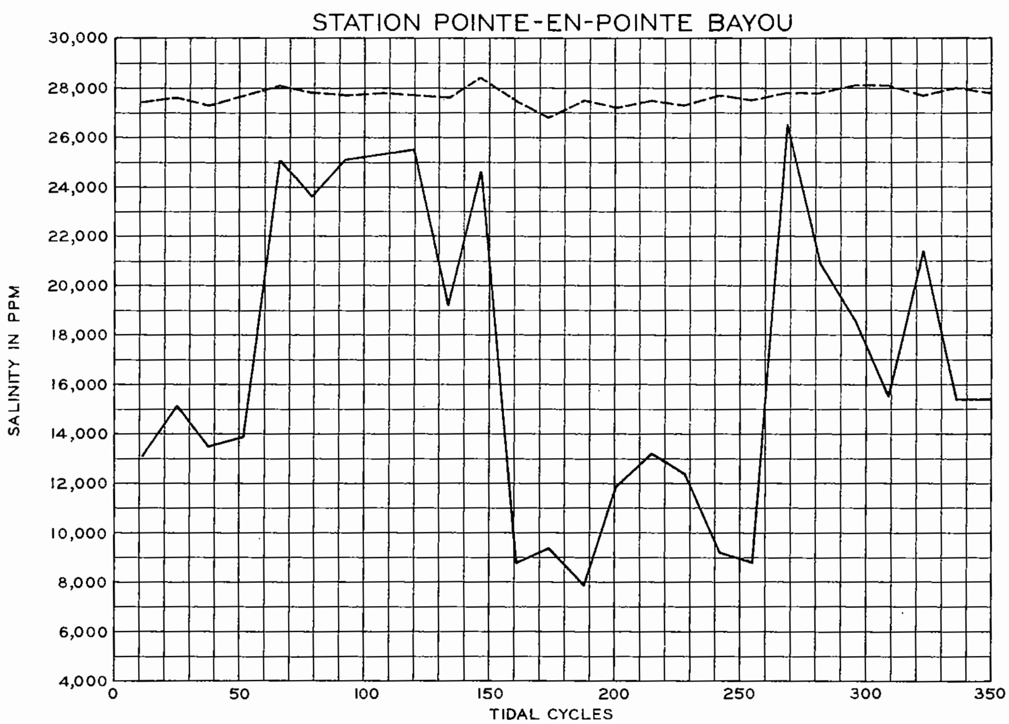


EFFECTS OF TWO-THIRDS REDUCTION IN DISCHARGE BETWEEN LAKE PONTCHARTRAIN AND GULF OUTLET CHANNEL WITH STRUCTURES IN THE PASSES

HIGH FRESHWATER INFLOW YEAR

STATIONS PARIS ROAD AND NAVIGATION CANAL



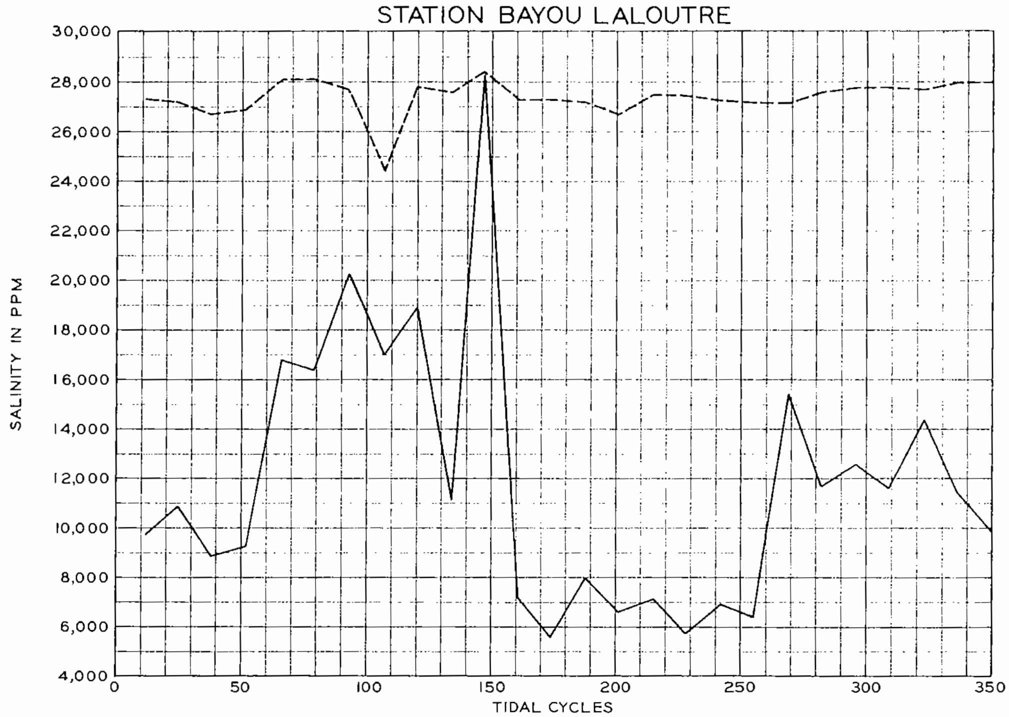


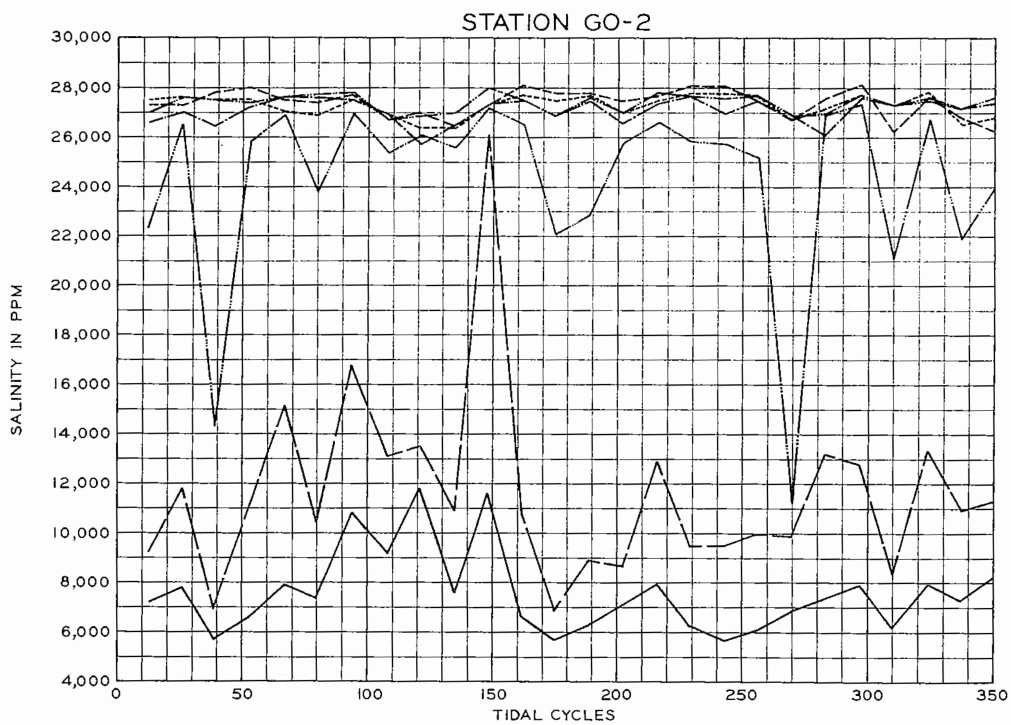
LEGEND
——— SURFACE
– – – – BOTTOM

EFFECTS OF COMPLETE CLOSURE OF ALL STRUCTURES DURING HURRICANE CONDITIONS

HIGH FRESHWATER INFLOW YEAR

STATIONS GO-1 AND POINTE-EN-POINTE BAYOU





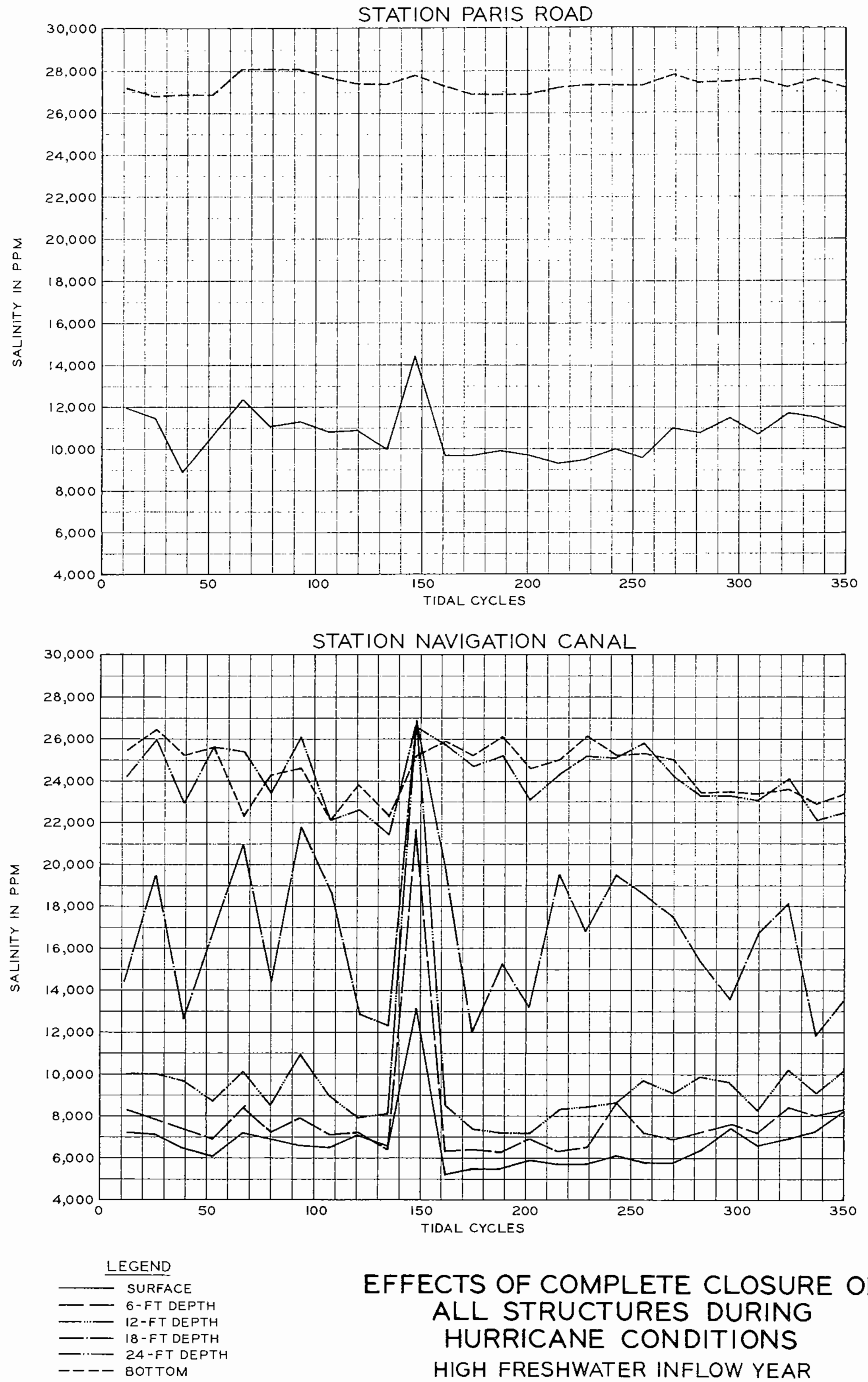
LEGEND

- SURFACE
- 6-FT DEPTH
- 12-FT DEPTH
- 18-FT DEPTH
- 24-FT DEPTH
- 30-FT DEPTH
- BOTTOM

EFFECTS OF COMPLETE CLOSURE OF ALL STRUCTURES DURING HURRICANE CONDITIONS

HIGH FRESHWATER INFLOW YEAR

STATIONS BAYOU LALOUTRE AND GO-2



EFFECTS OF COMPLETE CLOSURE OF ALL STRUCTURES DURING HURRICANE CONDITIONS

HIGH FRESHWATER INFLOW YEAR

STATIONS PARIS ROAD AND NAVIGATION CANAL