USE OF HYDRAULIC MODELS FOR WATER QUALITY INVESTIGATIONS

by

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In our modern and complex civilization, the term "Water Quality" has different meaning to those having different primary interests. For example, those concerned with providing adequate supplies of water for potable, industrial, and irrigation uses are often concerned about possible contamination of freshwater sources by sea water. On the other hand, the marine biologist who is concerned with establishing and maintaining the optimum brackish water environment to serve as breeding and nursery areas for fin and shell fishes may be equally concerned about possible contamination of such areas by fresh water. Thus, good quality water to one interest or group of interests may be poor quality water to other interests, and vice versa.

Hydraulic models have been used for many years for a wide variety of purposes, and use of models for estuary studies dates back to 1887 when Professor Osborne Reynolds constructed and operated a small-scale model of the Mersey Estuary in England as an aid in designing a comprehensive plan of training works to maintain depths adequate for navigation at the entrance to this estuary. Navigation and channel maintenance problems are among the more important ones studied in modern estuary models, although model techniques and procedures have now been refined to such extent that such models can also be used to investigate saltwater intrusion, the diffusion, dispersion, and flushing of contaminants, hurricane surge phenomena, and many other problems.

At the U. S. Army Engineer Waterways Experiment Station in Vicksburg, there are presently comprehensive hydraulic models of a number of major estuaries. These include New York Harbor and the Hudson River; the Delaware Estuary; the James River; Charleston Harbor; Savannah Harbor; Brunswick Harbor; the Galveston Bay complex; the Umpqua River in Oregon; and the lower 52 miles of the Columbia River. A model of San Diego Bay is presently under construction, and a model of Grays Harbor in Washington will be built next year. In addition, a model of the San Francisco Bay complex has been constructed in the bay area by the U. S. Army Engineer District, San Francisco, and a model of the entire Chesapeake Bay system is in design by the Waterways Experiment Station and will be constructed somewhere in Maryland by the U. S. Army Engineer District, Baltimore, within the next few years.

To acquaint you with the potentials of hydraulic models in water quality investigations, I would like to describe briefly and in non-technical terms two such investigations that have been carried out at the Waterways Experiment Station in recent years. The first of these was a study of the Vermilion Bay system in southwest Louisiana which was performed for the Louisiana State Department of Public Works. As most of you are aware, the principal agricultural crop of this region of Louisiana is rice, and the growing of rice requires large quantities of water for irrigation. The principal water supply to this rice-growing region is the Vermilion River; however, the water requirements for irrigation are so great that the quantity of water pumped from the river often exceeds the flow of the river, and when this occurs salt water is drawn rapidly upstream in the river from Vermilion Bay and sometimes reaches the irrigation pump intakes. When such an event takes place, the farmers have a choice of two undesirable actions: first, they can continue to irrigate and take the chance that salt concentrations in the irrigation water will not reach heavily damaging levels or, second, they can curtail irrigation and pray for rain.

It was noted by engineers of the Louisiana Department of Public Works that the salinity of Vermilion Bay is greatly reduced each spring during the period of high runoff from the Atchafalaya River, which discharges into Atchafalaya Bay to the east of Vermilion and Cote Blanche Bays. They noted further that, following the high inflow period, the intrusion of salt water from the Gulf of Mexico into Vermilion Bay occurred primarily through Southwest Pass, a direct connection between Vermilion Bay and the Gulf, rather than through the Atchafalaya Bay-Cote Blanche Bay system. This suggested the possibility that, if Southwest Pass should be closed, salinity concentrations in Vermilion Bay might either be reduced appreciably, or else the time of high salinity might be delayed until near or after the end of the irrigation season. Any reduction in the salinity of Vermilion Bay would result in a reduction of salinity of the water drawn upstream in the Vermilion River because of excessive pumping, and thus pumping could be continued longer without harm to the rice crop.

Since the effects of closure of Southwest Pass on the salinity of Vermilion Bay could not be determined analytically, the Louisiana Department of Public Works engaged the Waterways Experiment Station to conduct a model investigation to define the effects of the proposed closure. The model reproduced the area shown in Fig. 1 to a horizontal scale of 1:2000 and a vertical scale of 1:100. The model was first adjusted carefully so that tides and tidal currents throughout the entire area reproduced were in the proper scale relationships to those in nature. Next, the model Gulf of Mexico was filled with salt water of the proper concentration, the freshwater inflows of the Atchafalaya River, Vermilion River, and all other tributaries were reproduced for the period March through December 1955, and salinity observations were made during this period for comparison to observations made in nature in this same period to demonstrate the degree of accuracy with which the model reproduced prototype salinity conditions during this period. This procedure is called verification of the model, and the results proved that the model would accurately and faithfully reproduce salinity conditions of nature under identical conditions.

Since a year of low inflow from the Atchafalaya River produces the most unfavorable salinity situation in Vermilion Bay so far as water use for irrigation is concerned, the inflows representing a low inflow year were selected for test purposes. In the first test, the low inflow year was reproduced with Southwest Pass open to establish in detail the salinity situation in Vermilion Bay that would occur during such a year. Figure 2 shows the salinity distribution over Vermilion Bay at the time of maximum salinity for this test year, and it may be noted that salinity concentrations along the west and northwest shores of the bay were in the order of 10.0 to 15.0 parts per thousand, indicating the salinity of the water that would be drawn upstream in the Vermilion River because of excessive pumping for irrigation purposes. In the second test, which was identical in all other respects to the first, Southwest Pass was closed in the model and the low inflow test year was repeated. Figure 3 shows the salinity distribution over Vermilion Bay at the time of maximum salinity for this test, and it may be noted that maximum salinities along the west and northwest shores of the bay were in the order of 1.0 to 2.0 parts per thousand. Thus, the model tests demonstrated that closure of Southwest Pass, for conditions of a low inflow year, would reduce the maximum salinity that could be drawn to the irrigation intakes from about 15.0 parts per thousand to about 2.0 parts per thousand, which would greatly improve the quality of the water for irrigation purposes. It was also noted from the test results that the time of maximum salinity with Southwest Pass open occurred during the month of October, while some pumping for irrigation is still in progress; however, with the pass closed, the time of maximum salinity occurred during the month of January, or well after the end of the irrigation season. Thus, in addition to decreasing maximum salinities to an appreciable degree, the model tests demonstrated that the closure would also delay the time of maximum salinity until after the end of the irrigation season, which would further improve the quality of the water available for irrigation purposes.

For reasons unknown to the author, the closure of Southwest Pass has not been made to date. However, the documented results of the model investigation show conclusively the benefits that would be obtained from such closure, and the closure can be made at any future date desired with the assurance that the expected benefits to water quality will be realized.

The Lake Pontchartrain model study may be cited as a second example of use of a model for water quality investigations. The New Orleans District of the Corps of Engineers is presently designing a comprehensive plan for protection of New Orleans from inundation by hurricane surges, such as that which occurred during Hurricane Betsy in September 1965 and which resulted in extensive damage throughout the metropolitan area of New Orleans. One feature of the comprehensive plan will consist of a high levee extending from existing Mississippi River and other flood control levees south of the city in a northeasterly direction across the marsh lands separating Lake Pontchartrain and Lake Borgne and tying into high ground north of Chef Menteur Pass. The plan incorporates gated structures in Chef Menteur Pass and the Rigolets, the two channels connecting Lake Pontchartrain and Lake Borgne; the gates would remain open except in the event of an approaching hurricane, in which case the gates would be closed for the duration of the hurricane. The levee and gates would prevent the water level in Lake Pontchartrain from building up to such extent that wind setup and wave action in the lake could cause severe flooding of the city from the north.

Fish and Wildlife biologists reviewed the elements of the protection plan, and they expressed a fear that restriction of the two natural channels connecting Lakes Pontchartrain and Borgne by gated structures, even with the gates open for essentially all of the time, could reduce tidal interchange of waters between the two lakes and possibly cause a decrease in the salinity of Lake Pontchartrain. Since the normal salinity of the lake is somewhat lower than ideal for saltwater fishes, it was believed that any further reduction in salinity could be highly detrimental to sport and commerical fishing activities in the lake. The U. S. Army Engineer District, New Orleans, therefore requested the Waterways Experiment Station to construct a suitable hydraulic model of the lake system in order to determine the effects of the structures on the salinity regimen of Lake Pontchartrain.

The area reproduced in the Lake Pontchartrain model is shown in Fig. 4, and the model was constructed to linear scale ratios of 1:2000 horizontally and 1:100 vertically. Initially, there were no plans for reproducing in the model a portion of Breton Sound and the Mississippi River-Gulf Outlet Channel, which is a deep-draft navigation channel extending from deep water east of Breton Island to a terminal at New Orleans, since inclusion of these areas was not essential to a study of the effects of the proposed gated structures on the salinity regimen of Lake Pontchartrain. However, the terminal of the Mississippi River-Gulf Outlet Channel is connected to Lake Pontchartrain by the Inner Harbor Navigation Canal, and the opinion was expressed by Waterways Experiment Station engineers that the intrusion of salt water into Lake Pontchartrain through this channel system was likely to have a much greater effect on the salinity of Lake Pontchartrain than the gated structures of the hurricane surge protection plan. Accordingly, a portion of Breton Sound and the Mississippi River-Gulf Outlet Channel was constructed along with the remaining portion of the model, and separate studies were made to determine the effects of the gated structures and the Mississippi River-Gulf Outlet Channel on the salinity of Lake Pontchartrain.

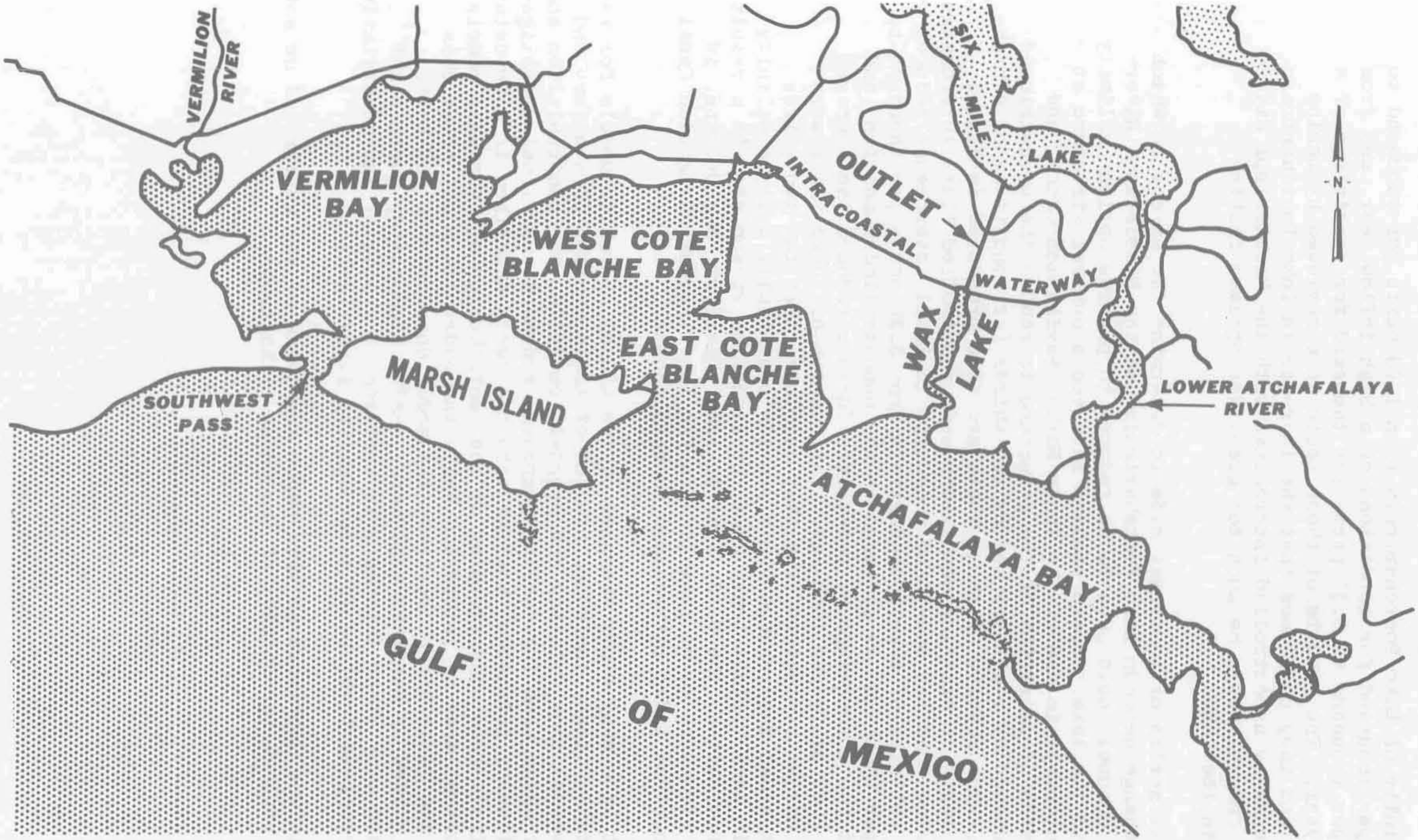
Prior to use of the model for actual tests, the model was adjusted and verified to reproduce existing conditions by the same procedures described previously for the Vermilion Bay model. Tests were first made of the gated structures in Chef Menteur and Rigolets Passes, for conditions of a year of high freshwater inflow to the lake system, since such an inflow year would indicate the maximum effect of the structures, if any, in reducing the salinity of Lake Pontchartrain. The results of these tests, shown in Fig. 5, showed conclusively that construction of the hurricane surge protection plan would have no measurable effects on the salinity of Lake Pontchartrain.

Tests of the Mississippi River-Gulf Outlet Channel were first made with the assumption that there would be no control of tidal interchange between this channel and Lake Pontchartrain through the Inner Harbor Navigation Canal, and such tests were made for conditions of both a high freshwater inflow year and a low inflow year. The results of these tests, also shown in Fig. 5, indicate that the Mississippi River-Gulf Outlet Channel would increase the average salinity of Lake Pontchartrain from 1.06 parts per thousand to 5.39 parts per thousand for conditions of a high inflow year, and from 2.28 parts per thousand to 8.41 parts per thousand for conditions of a low inflow year. The results of these tests were reviewed by marine biologists, and they concluded that the increase in Lake Pontchartrain salinity caused by uncontrolled interchange with the Mississippi River-Gulf Outlet Channel would be much too great for optimum fishing conditions in the lake.

The next series of tests was made to determine the extent to which tidal interchange between Lake Pontchartrain and the Mississippi River-Gulf Outlet Channel would have to be reduced to provide optimum salinity conditions in the lake. These studies involved a control structure at the Lake Pontchartrain end of the Inner Harbor Navigation Canal, and tests were made of operation of the structure to reduce the unrestricted tidal interchange by one-third and by two-thirds for conditions of a high inflow year. The results of these tests are also presented in Fig. 5, compared to tests of existing conditions and uncontrolled tidal interchange. It may be noted that the one-third reduction in tidal interchange reduced the average salinity of Lake Pontchartrain from 5.39 parts per thousand to 3.01 parts per thousand, as compared to the uncontrolled condition, and reduction of the interchange by two-thirds further reduced the average salinity to 2.62 parts per thousand. The results of these tests were analyzed by marine biologists, and they concluded that the two-thirds reduction in tidal interchange would provide essentially optimum salinity conditions in Lake Pontchartrain from the fisheries viewpoint. As a result of this determination, the U. S. Army Engineer District, New Orleans, is designing a structure to be installed in the Inner Harbor Navigation Canal which will control tidal interchange to this amount.

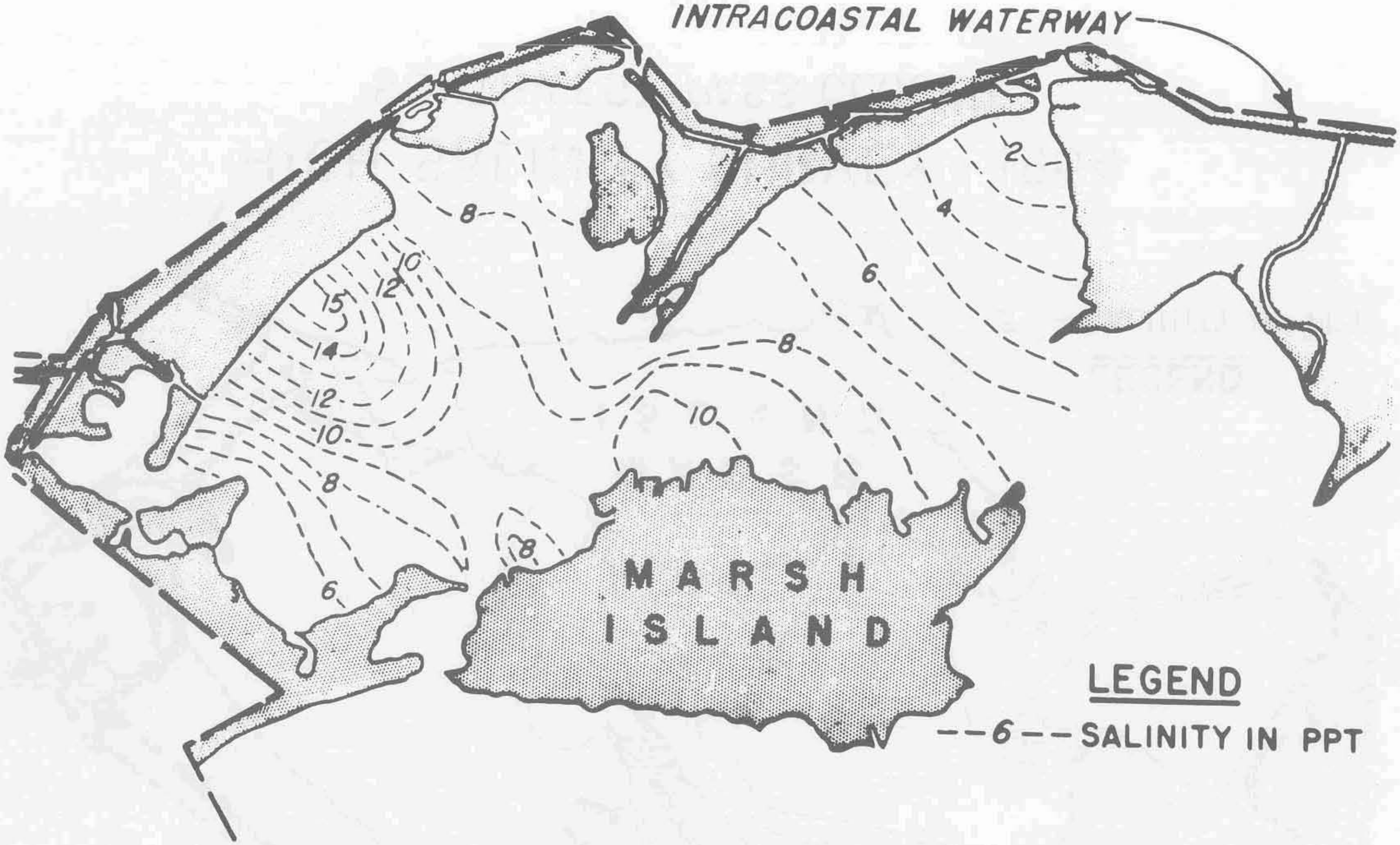
I could cite many other examples of the use of hydraulic models for water quality investigations, including studies of the diffusion of sanitary and industrial wastes from existing and proposed outfalls, the recirculation and diffusion of water used for cooling purposes, and many additional investigations of saltwater intrusion; however, the two cases described in some detail should provide a good understanding of the contribution of hydraulic models in this important area of interest. While the hydraulic model often does not provide the final answer desired, the model does provide the basic information needed by sanitary engineers, marine biologists, power plant engineers, and many other interests in arriving at practical and quantitative answers to problems involved in water quality investigations.

The opinions expressed in this paper are those of the author and do not necessarily reflect the opinion of the Corps of Engineers.



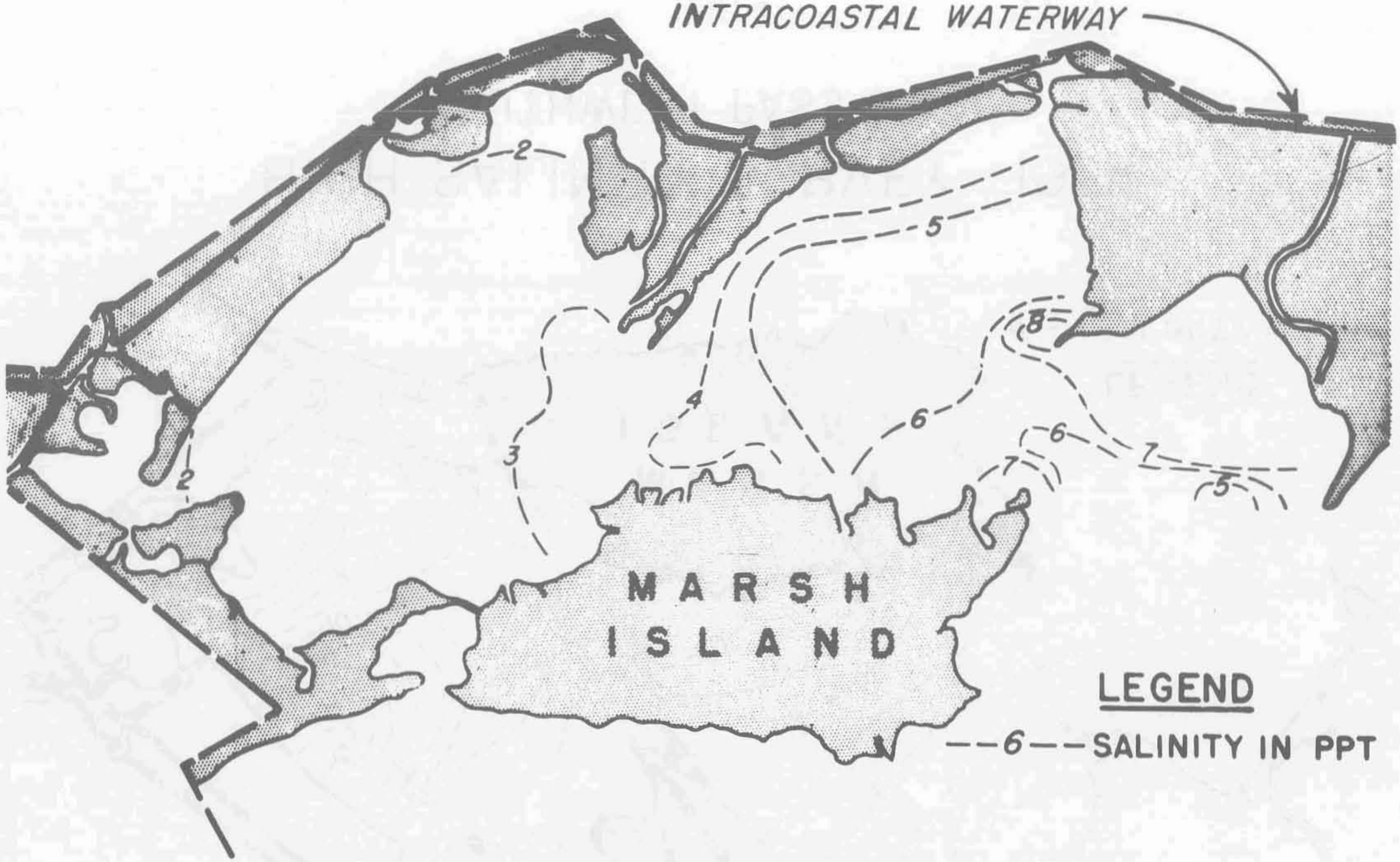
LOCATION OF PROBLEM AREA

Fig. 1



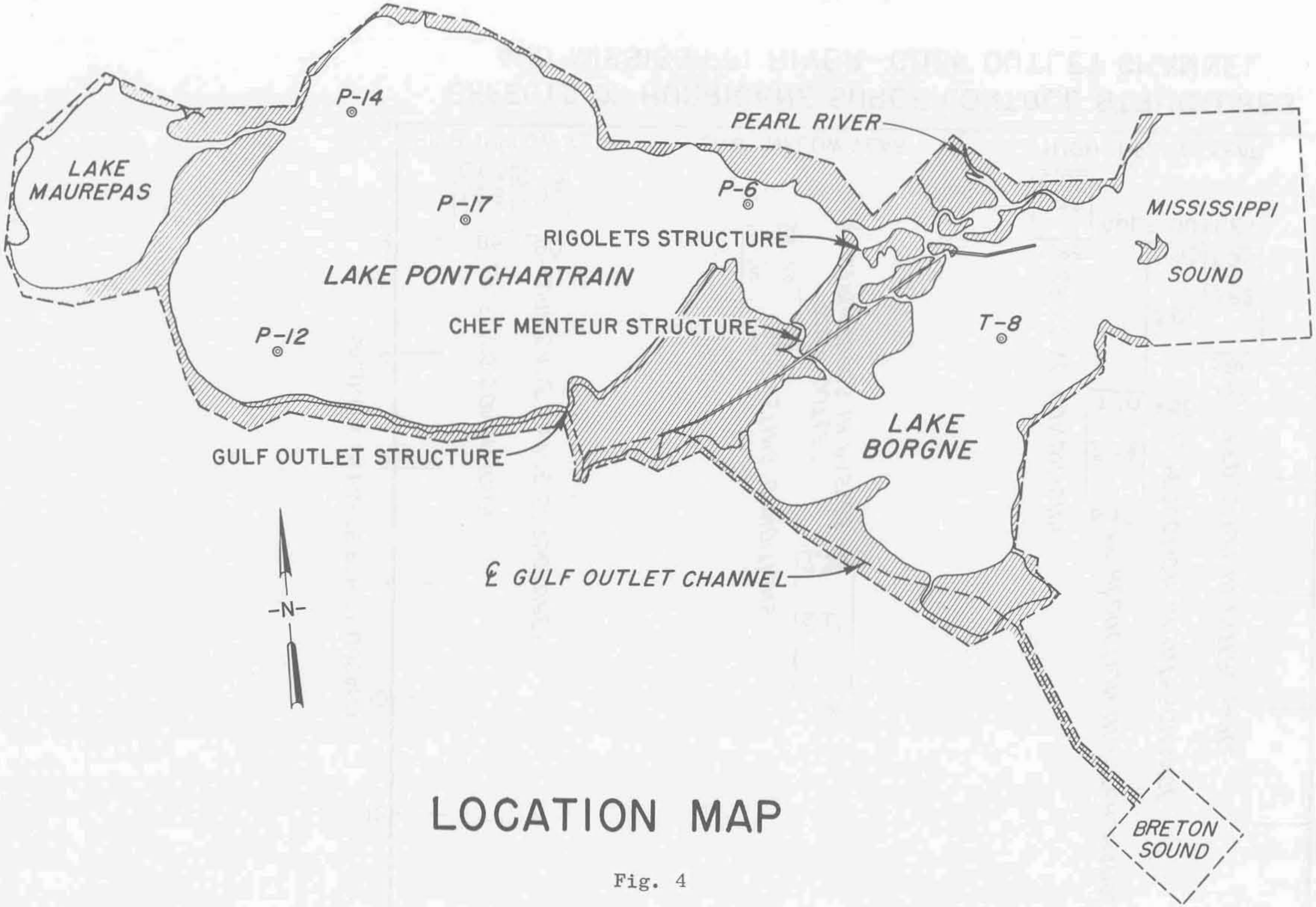
HIGH SALINITY SURVEY - 1954
SOUTHWEST PASS OPEN

Fig. 2



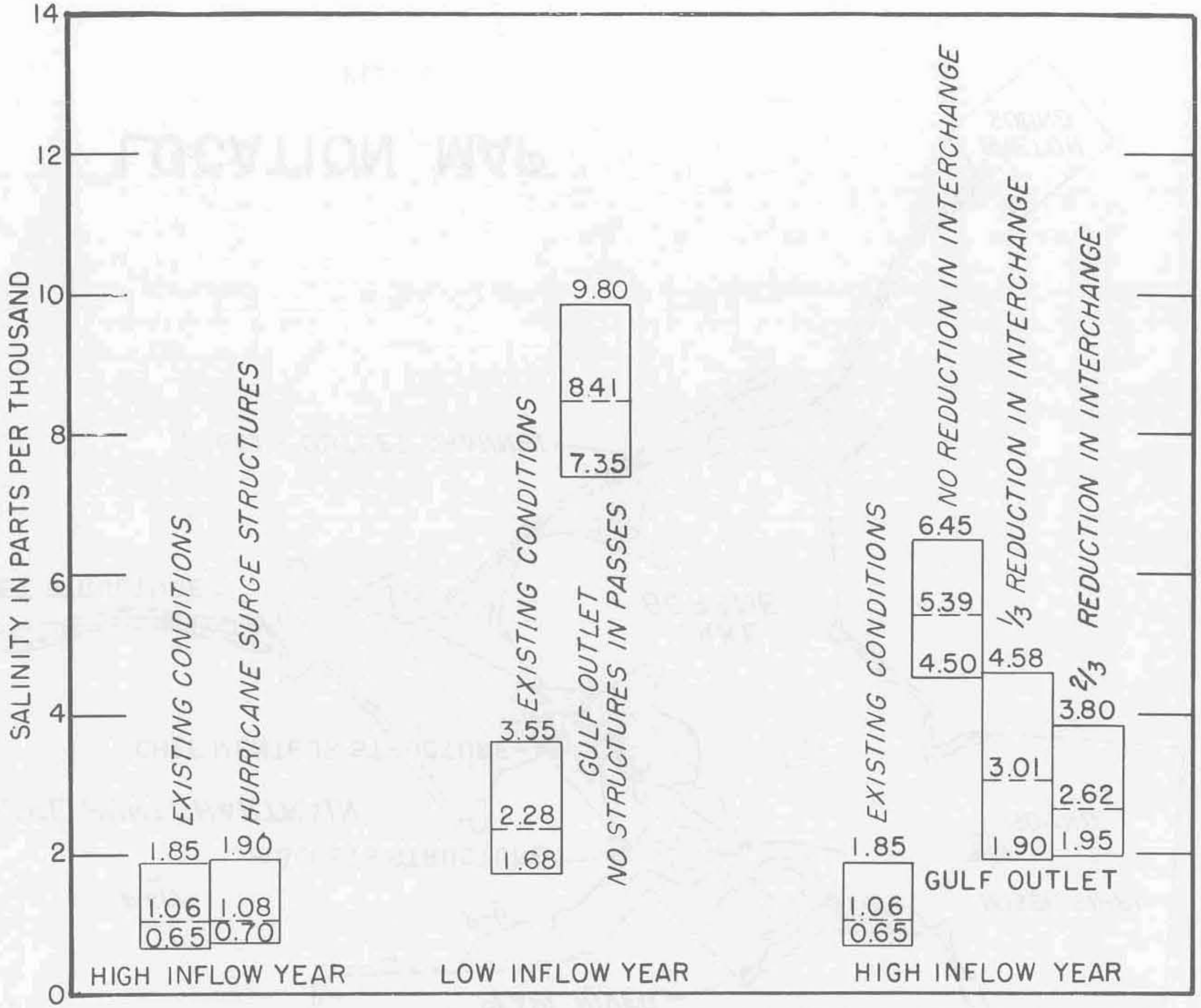
HIGH SALINITY SURVEY - 1954
SOUTHWEST PASS CLOSED

Fig. 3



LOCATION MAP

Fig. 4



EFFECTS OF HURRICANE SURGE CONTROL STRUCTURES AND MISSISSIPPI RIVER–GULF OUTLET CHANNEL

Fig. 5