Chapter 25

DEVELOPMENT OF HYDRAULIC AND SHOALING CHARACTERISTICS OF SAVANNAH HARBOR, GEORGIA, BY PROTOTYPE STUDIES AND HYDRAULIC MODEL

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SUMMARY

Maintenance of Savannah Harbor became progressively more critical as the deepening of the channels caused heavy shoaling concentrations in a highly industrialized section of the harbor where spoil disposal areas are limited. Studies were performed to evaluate the shoaling and develop means of reducing the high cost of maintaining 31 miles of deep-water navigation channels. A hydraulic model investigation substantiated the conclusions reached through analysis of prototype data, greatly expanded the knowledge of hydraulic conditions and shoaling processes, and developed an improvement plan which involved a tide gate to induce the deposit of sediment in an off-channel sediment basin.

THE PROTOTYPE

DESCRIPTION OF THE PROTOTYPE

Savannah Harbor. Savannah Harbor is located on the South Atlantic Coast of the United States in the tidal estuary where the Savannah River empties into the Atlantic Ocean. The Harbor Entrance is about 32° 02' latitude and 80° 55' longitude.

The Port of Savannah is used for importing petroleum products, gypsum rock, raw sugar, fertilizer materials, and many other miscellaneous products. Principal foreign export commodities are wood pulp, paperboard, naval stores, and iron and steel scrap. During 1962 over 4.5 million tons of waterborne commerce was carried by 1611 ships entering and leaving the harbor.

The authorized channels which are maintained by the U. S. Army Corps of Engineers are shown on Figure 1. The project provides for 9.7 miles of channel 36 ft deep at mean low water and 500 ft wide from the 36-ft contour in the ocean to the harbor entrance; thence 18.8 miles, 34 ft deep and generally 400 ft wide; thence 2.5 miles, 30 ft deep and 200 ft wide to the upstream limit of the project. Four turning basins constructed at strategic locations are maintained to the project depth in the adjacent channel. The upper end of the harbor connects with the 9-ft channel in Savannah River which extends about 200 miles to the City of Augusta, Georgia, and the 12-ft Atlantic Intracoastal Waterway crosses the harbor about 8 miles below the City of Savannah. The city and industrial areas are located on the south side of Front River from 12 to 20 miles above the harbor entrance.

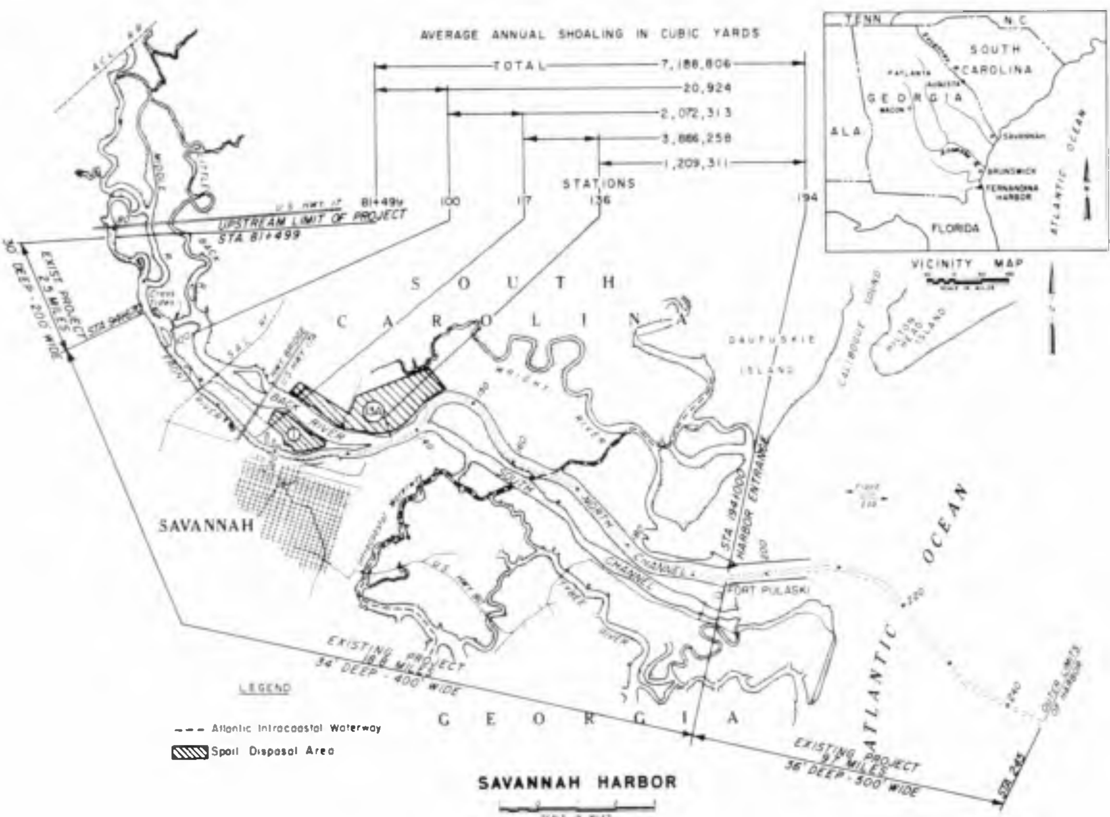


FIG. 1 - EXISTING PROJECT AND ANNUAL SHOALING

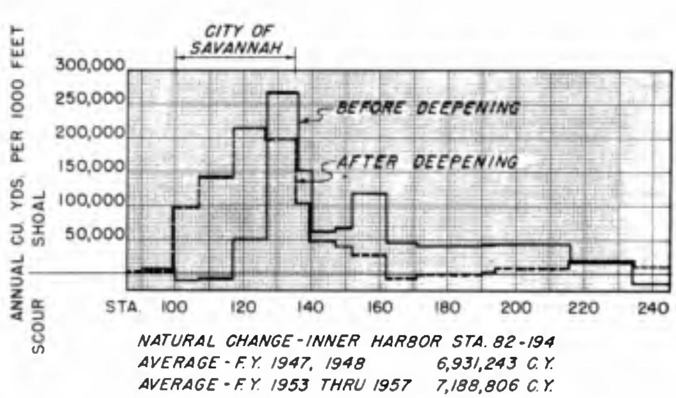


FIG. 2 - ANNUAL SHOAL AND SCOUR (NATURAL CHANGE) BEFORE AND AFTER DEEPENING NAVIGATION CHANNELS

Savannah River. The Savannah River, a heavy silt-bearing stream, has its source in the Blue Ridge mountains about 400 miles above the harbor and has a drainage area of 10,579 square miles. The river is tidal for a distance of about 50 miles upstream from the mouth. The index station for the harbor for the measurement of fresh water and sediment inflow is located 65 miles above the mouth. Two major reservoirs, which exercise significant control of the river flows, are located 238 and 305 miles above the mouth Normal fresh water inflow is about 7000 cfs and with regulation of flows by the two reservoirs, 16,000 cfs and 5800 cfs are considered the normal high and low flows to be expected during the year. An average annual sediment load transported into and deposited in the harbor by the Savannah River is equivalent to about 2,000,000 cu yds of shoal material.

EXISTING CONDITIONS

Tides and currents. The tides in Savannah Harbor are the semi-diurnal type with a tidal range of about 6.8 ft at the mouth and 7.4 ft at the City of Savannah. The maximum current velocities encountered in the navigation channels are of the order of 4 ft per second on flood and 5 ft per second on ebb tides.

Salinity. The water in the upper portion of Savannah Harbor is fresh while that near the ocean entrance is essentially sea water. The variation in the density of the water in the tidal reach of Savannah River causes a difference in the magnitude and phase of surface and bottom current velocities. This difference is more pronounced near the entrance, decreasing progressively upstream with decreasing salinities until the water becomes completely fresh. The degree of mixing of salt and fresh water and upstream extent of salt water intrusion in Savannah Harbor vary with the range and elevation of tides and the amount of fresh water discharge. With normal fresh water discharge the upstream limit of the salt water on the bottom extends from about Sta 140 to about Sta 100. (Channel locations refer to 1000-ft stations throughout the harbor).

Shoaling. The annual shoaling rate for the inner harbor, from the harbor entrance to the upstream limit of the project, averages about 7,000,000 cu yds. The greatest concentration occurs in the 3.6 mile reach above the juncture of Back River in the channels along the city and the industrial areas where over half of the total shoaling takes place. The annual shoaling in the bar channels amounts to about 700,000 cu yds.

Maintenance. A Government pipeline dredge is normally assigned to the district to maintain the inner harbor channels. The present maintenance program for the inner harbor costs over $1,000,000 annually.

Disposal of dredge spoil. Dredge spoil is disposed in marsh areas adjacent to the channel. Until recent years these areas were undiked; however, a diking program was initiated and has progressed as funds permitted and will continue whenever needed to prevent runback into the harbor channels. The depletion of spoil areas convenient to the channels especially in the reaches of heavy shoaling, necessitating locating spoil areas considerably more remote and requiring longer dredge discharge lines, has greatly increased the cost of channel maintenance.

Presentation of the problem. Maintenance of Savannah Harbor has become progressively more critical with each successive deepening of the channel which caused heavy shoaling to extend farther upstream into the highly industrialized section of the harbor where spoil areas are limited. The shoaling shifted upstream to its present location after the deepening of the channels to 34 ft in 1947-1948. Figure 2 shows a graphical comparison of the shoaling before and after the deepening. In the most critical City Front channel, not only is the total amount of shoaling serious but also the extremely rapid rate of occurrence. It is almost impossible to maintain the channel to the project depth of 34 ft at all times thereby diminishing effective utilization of the harbor. Due to the seriousness of the problem, extensive prototype investigations and engineering studies supplemented by a hydraulic model at the Waterways Laboratory, Vicksburg, Mississippi, have been made.

PROTOTYPE INVESTIGATIONS AND STUDIES

Purpose of the investigations and studies. The prototype investigations included operation of sediment sampling stations on the Savannah River to ascertain the fresh water contribution of silt, and exhaustive salinity and current velocity measurements at various points in the harbor. Studies were made to determine the shoaling characteristics and rates, composition of the shoal material, and the hydraulic characteristics of flow, and to evaluate dredging equipment and methods, and the utilization of spoil disposal areas.

Sources of shoaling. The studies indicated that the major portion of the shoaling material is supplied by the Savannah River with substantial amounts deriving from the ocean and runback from the spoil areas. The solids content of the industrial wastes, deposited in the harbor by several large industries, is negligible as a source of shoal material. The Savannah River sampling program which has been continuous since 1949 has shown that the annual total load of sediment transported into the harbor by the Savannah River is equivalent to about 2,000,000 cu yds of shoal material. This quantity is based on an average density of 1144 grams per liter (20 percent solids by weight) of the bulk of the material dredged from the rapid shoaling area. Of this quantity approximately 78 percent is suspended sediments which are deposited when velocities are reduced and 22 percent consists of colloidal clay and organic particles in solution which are flocculated by the electro-chemical action on contact with the sea water and deposited in the harbor.

Shoaling quantity and location. Shoaling is referred to also as natural change. Annual surveys of the entire harbor are used to determine the net change from year to year in total cross section area at each 1000-ft station. Shoaling quantities are derived from the summation of the net change and the gross quantities dredged during the year. The present annual shoaling rate is about 7,000,000 cu yds in the inner harbor and although the shoaling is distributed over all the inner channels, over half of the total concentrated along the city and industrial areas as shown on Figure 1.

The effect of the salt-water wedge on the location of shoaling. The salt water entering the harbor from the ocean, due to its greater density, moves along the bottom and extends into the river above the mouth somewhat in the shape of a wedge with the fresh water of Savannah River flowing downstream above it. This wedge moves upstream and downstream with the tide over a distance of several miles. The extent of travel varies with the range and height of tides and the amount of fresh-water inflow. The area of most severe shoaling coincides with the limit of travel of the salt-water wedge. This is evidence that the salt-water wedge condition is a factor in controlling the location of sediment deposition.

The effect of fresh water inflow on shoaling. The normal fresh water inflow is about 7000 cfs. With the regulation of flows by the two major reservoirs, Clark Hill and Hartwell, 16,000 cfs and 5800 cfs are considered the normal high and low flows to be expected during the year. The runoff from rainfall occurring in the lower Savannah River basin combined with the regulated flows from Clark Hill are expected to produce freshets of 16,000 cfs or greater each year. An inflow of this magnitude tends to shift the concentration of shoaling downstream. In 1964 a fresh water inflow of 20,000 cfs and more for a period of 4 months shifted the shoaling, and the salt-water wedge, as much as 8 miles downstream, and with 80,000 cfs which occurred during this same period, the shoaling moved to near the harbor entrance. This event has not been completely documented, but it can be seen that as the discharge decreased that the shoal material returned upstream to its normal location. Future studies will include determination of the quantity of shoaling which remained downstream.

The effect of the construction of the Clark Hill project on shoaling. The construction and operation of the Clark Hill project, completed in 1952, resulted in an annual decrease of about 400,000 cu yds in the quantity of shoal material transported into Savannah Harbor by the Savannah River. Construction of the dam was commenced 16 December 1946 and partial closure was made prior to commencement of the river sampling program in

October 1949 and may have had a diminishing effect on the quantity of sediment determined.

The effect of spring and neap tides on shoaling. The normal range of spring tides in Savannah Harbor is about 9 ft and for neap tides about 5 ft. During the neap tide periods the fluff, which is an indication of shoaling and will be discussed later, shifts upstream and during the spring tides it shifts downstream, and when a spring tide is accompanied by high fresh water discharge, a more pronounced downstream movement is experienced. This fluctuation of tidal range extends the area over which the shoaling occurs, although the effect on the quantity of shoaling is not apparent.

The effect of deepening of the channel on shoaling. The deepening of the channel from 30 to 34 ft in 1947-1948 caused the concentration of shoaling to shift upstream. An increase in the quantity also was observed at this time. The decrease in quantity contributed by the Savannah River due to the construction of Clark Hill project was countereacted by the increase from other sources. The increase may be only apparent since the principal sources of the shoaling material were not altered appreciably.

Conditions affecting shoaling rates. The annual shoaling rate of about 7,000,000 cu yds may be partially caused by certain operating practices which tend to increase the apparent quantity of shoaling.

a. The shifting of the shoaling upstream by the deepening necessitated the use of spoil disposal areas which have been inadequately diked. When this occurs a portion of the dredge material re-enters the channels and forms shoals.

b. The dredging process, due to the nature of the operation, causes material from the shoal to be placed in suspension and temporarily moved from the area by currents present in the area at the time. Hydraulic characteristics of the channel prevent the material from being carried out to sea and, in time, it consolidates and forms other shoals.

Surveys. Hydrographic surveys which are used as a basis for estimating dredged quantities are made by fathometer. The correlation of density data and the fathometer surveys indicate that generally the fathograms reflect a change in density and record a double bottom in the rapid-shoaling areas. The bottom line interpreted as firm bottom occurs at a density of about 1100 grams per liter. This material is generally stable and, except in extreme conditions, is not shifted by varying flows and tide conditions. The firm bottom material dredged from areas maintained regularly will be as much as 1200 grams per liter and averages about 1144 grams per liter, the density depending on the length of time it is allowed to consolidate. Fluff is the unconsolidated shoal material which overlays the firm bottom material and may be as much as 8 ft thick. The material is unstable and is shifted to an fro by varying flows and tide conditions. This material increases in density from one dredging operation to the next at a rate that depends on such factors as fresh water inflow and the location and type of dredging being performed in the inner harbor.

Dredging practices. Pipeline dredges are used to maintain the inner harbor. The present maintenance program requires the services of a 24-inch Government plant nearly full time. Dredging requirements are based on present maintenance policy which provides that dredging be performed when an area with authorized project depth of 34 ft has shoaled to about 30 to 32 ft; however, in the two most rapidly shoaling areas an additional 2 ft and 4 ft advanced maintenance is dredged to decrease the frequency of dredging. This has proven to be an effective means of increasing the time during which project depths are available.

Prototype tests made during experimental agitation dredging showed that the agitated material settles rapidly and is not permanently removed from the area. Based on this determination, in order to prevent agitation of the shoal material and the unconsolidated sediments overlaying the shoal, the cutter speed of the dredge has been reduced to 2 rpm and the swing speed controlled.

Numerous slips and wharves located adjacent to the channels experience rapid shoaling and maintenance of adequate depths in these areas is a serious problem to the owners. Required depths are maintained by dragging with a tug and I-beam. Since tests have shown that agitation dredging is not effective in removing the shoal material from the harbor, permits issued for dragging require that the Government be reimbursed for the material dragged into the channel.

Disposal of dredge spoil. Dredge spoil is disposed in marsh areas adjacent to the navigation channel. These areas are diked adjacent to the channel and a program is underway to completely enclose the areas with dikes of adequate height to produce ponding for complete settlement and retention of the solids. Studies have evaluated shoaling patterns and rates and provided means of estimating spoil area requirement so that timely acquisition of required areas is possible. Spoil area Number 1 (Figure 1) has been virtually filled necessitating acquiring and diking Area 13-A which is considerably more remote. Maintenance of some of the channel sections now requires more than 10,000 ft of dredge discharge line. Material dredged from the bar and jetty channels by hopper dredge is dumped at sea except in bad weather when the material is dumped in a previously dredged area adjacent to the channel between Sta 184 and 189, then rehandled by pipeline dredge and pumped ashore.

MODEL STUDY

THE MODEL

Purpose. The model tests were conducted to discover means of reducing or controlling the location of shoaling in the harbor, or otherwise improve navigation conditions and reduce the cost of maintenance.

Description. Approximately 413 square miles of prototype area were reproduced in the Savannah Harbor model including the Atlantic Coast from Hilton Head Island to Wassaw Sound and offshore areas well beyond the 40-ft contour in the ocean; up the Savannah River about 50 miles to the head of tidewater at Ebenezer Landing; the extensive system of tidal tributaries, salt-water creeks, and boundary marshes which affect tidal action throughout the harbor; and the Atlantic Intracoastal Waterway from Calibogue Sound through Skidaway River. Figure 1 shows most of the area reproduced. The model was constructed on scale ratios, model to prototype, of 1:800 horizontally and 1:80 vertically. It was equipped with necessary appurtenances to reproduce and measure all pertinent phenomena such as tidal elevations, salt-water intrusion, current velocities, fresh water inflow, pollution and shoaling. The model was constructed to conform to the prototype conditions that existed in 1950. Hydraulic and salinity verification was based on extensive prototype measurements made in 1950 and 1951. Shoaling verification was based on the quantitative distribution for the years 1953-1954 which is representative of prevailing conditions for the existing 34-ft project depth.

Plan of model tests. The tests conducted include general investigations, fresh water diversions, channel realignments and sediment basin. Significant results of these tests are discussed in this paper with emphasis on the sediment trap-tide gate plan which is considered the most favorable improvement plan developed.

GENERAL INVESTIGATIONS

Purpose. The principal purpose of the general investigations was to provide basic hydraulic, salinity, and shoaling data for use in evaluating the probable effectiveness of proposed improvement plans. As the condition of an estuary is never static, observation at any particular moment shows conditions of salinity, current, pollution, or shoaling that are the end products of a long series of changing tides and fresh-water flows. A static condition can be set up in a model, however, and the effect of a single variable can be studied.

Effects of tidal range and fresh water discharge. Tests to determine the effects of tidal range involved reproducing neap, mean, and spring tides and a fresh water discharge of 7000 cfs. Tests to determine the effects of fresh water discharge involved reproducing discharges of 7000 cfs and 16,000 cfs for both mean and spring tide conditions. The salinity profile, Figure 3, show that the salt-water penetration upstream was greatest for neap tides and least for spring tides. The high salinity encountered at the entrance to Savannah Harbor gradually diminishes in an upstream direction as the salt water encounters fresh water and is mixed with it by the tidal currents.

The effect of the tidal range on the mixing environment in the harbor is reflected in the predominance of flow in one direction or the other at surface and bottom. "Predominance of flow" is a single expression that combines analyses of velocities, directions, and durations of currents at a specified location and depth (surface, middepth, and bottom). It is expressed in percent of total flow in the direction of flood or ebb. Plots of predominance of flow for neap, mean, and spring tides are show on Figure 4. It is an important factor in determining the location of shoaling that predominance of downstream flow at the bottom extended from the upper harbor to Sta 121 for neap and mean tides and to Sta 130 for spring tides. Similarly the greatest shoaling concentration was found to extend farther upstream for neap tide and farther downstream for spring tide. Increasing the fresh water discharge from 7000 cfs to 16,000 cfs was found to have a marked effect on salinities, predominance of flow and shoaling in that equivalent salinities were shifted downstream, the point of balanced flow was shifted downstream, and shoaling was moved downstream by the higher discharge. These effects were more pronounced when the high discharge was accompanied by spring tide.

The effects of channel deepening. A review of future harbor development and the trend of increased draft of vessels indicate that a channel depth of 40 ft may be required in the foreseeable future. Model tests were, therefore, conducted for the deeper channel, as well as for the 34-ft depth presently authorized. Channel depths of 36 ft and 40 ft were tested initially and later channel depths of 38 ft with widening in the downstream reaches were tested. Emphasis in this paper is placed on the 40-ft channel depths, which at present is considered maximum, and the 38-ft channel depths with widening in the downstream portions which has been justified and recommended in a review report prepared for Savannah Harbor and which probably will be authorized in the near future.

The deepening to 40 ft caused a lowering of the low water plane of about 0.5 ft throughout the harbor. Salinities were increased throughout the harbor, with the principal increases occurring at the upper end. Total shoaling was increased about 5 percent; however, shoaling in the upper harbor above Sta 135 was decreased about 22 percent, and that downstream from Sta 135 was increased about 30 percent. Flow predominance computations indicate that the degree of predominance of upstream flow at the bottom was increased; however, computations of the total flood

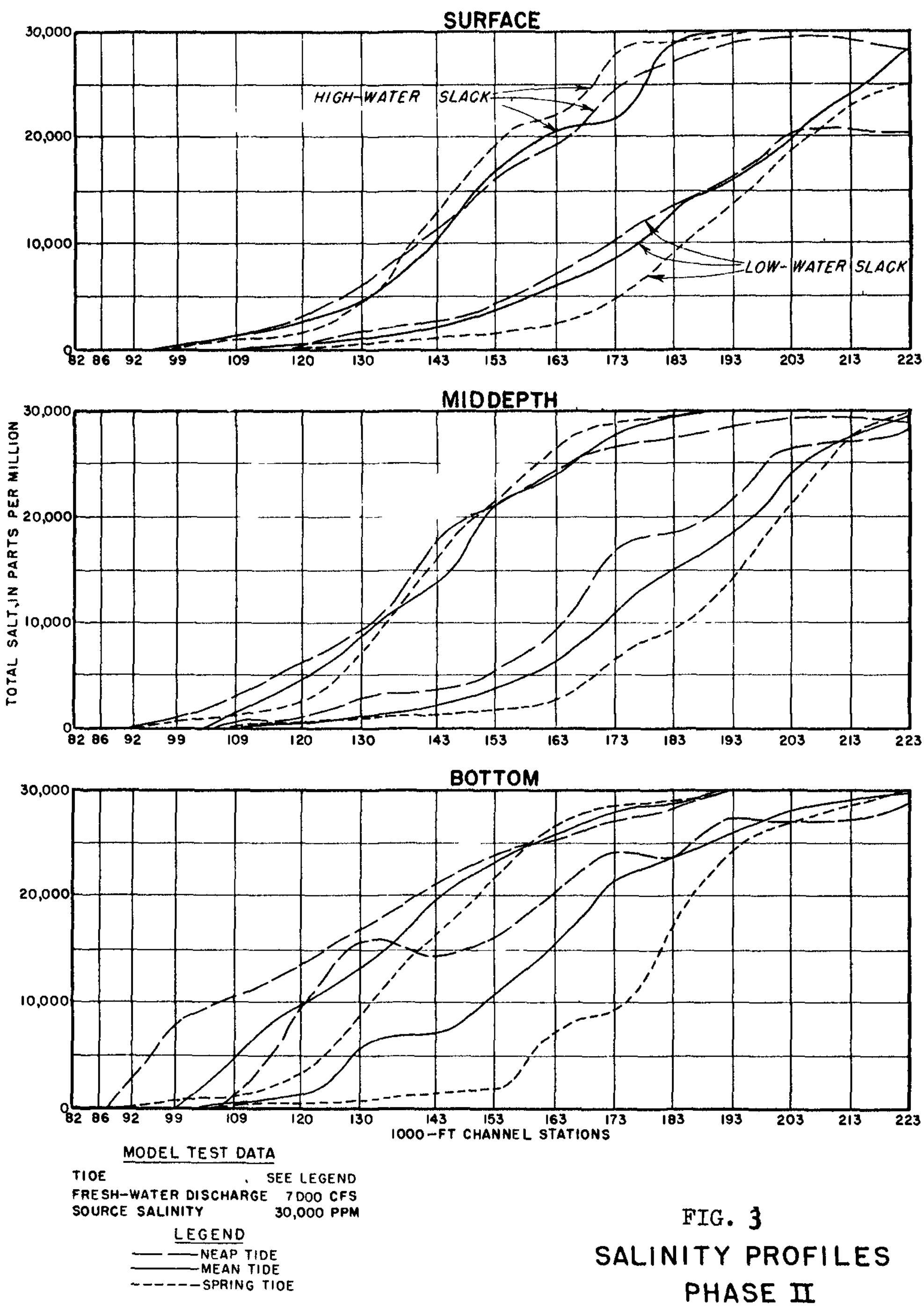
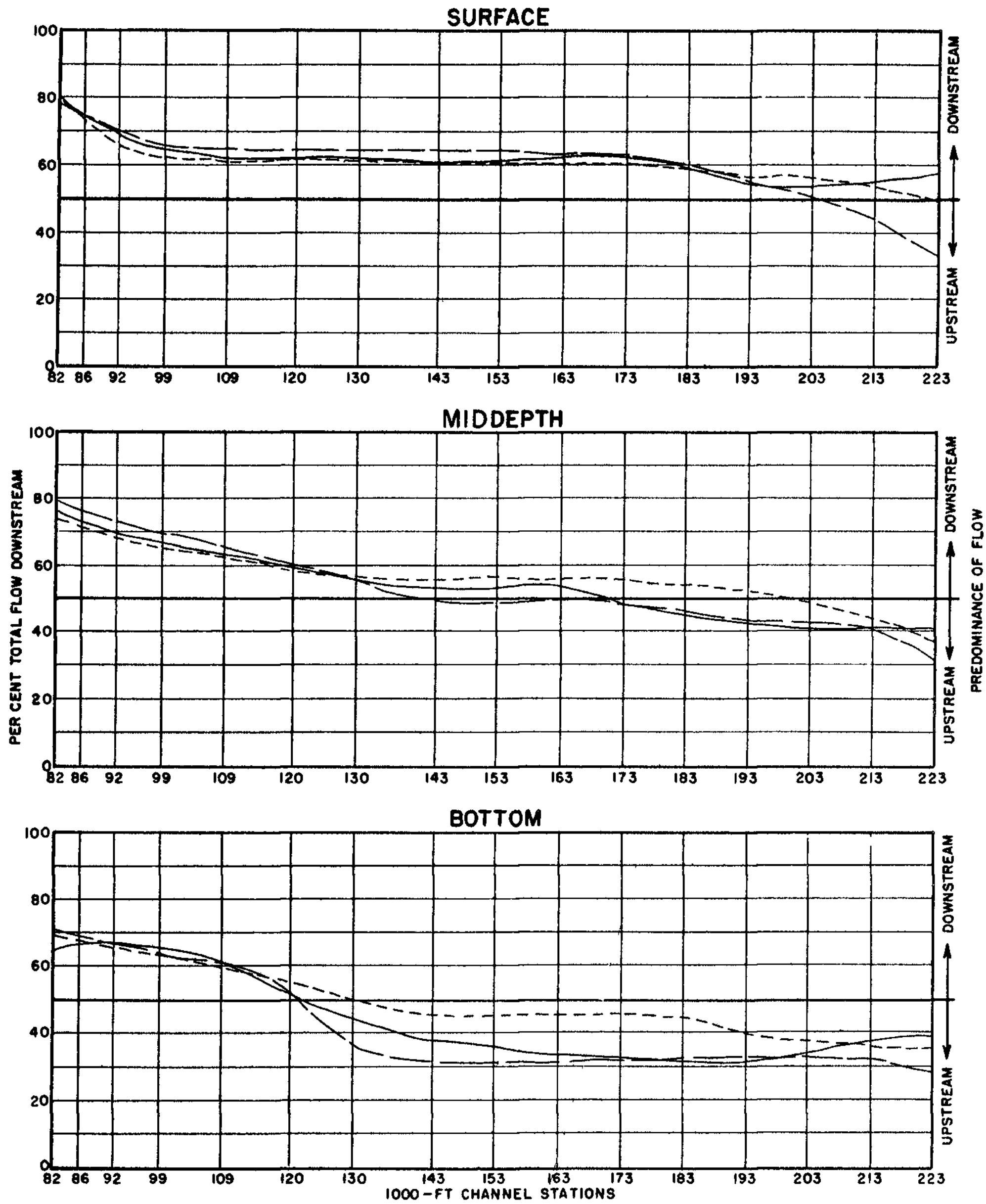


FIG. 3
SALINITY PROFILES
PHASE II
EFFECT OF TIDES
PRESENT PROJECT 34 FT



MODEL TEST DATA

TIDE . SEE LEGEND
FRESH-WATER DISCHARGE 7,000 CFS
SOURCE SALINITY 30,000 PPM

LEGEND

— — NEAP TIDE
—— MEAN TIDE
-------- SPRING TIDE

FIG. 4

PREDOMINANCE OF FLOW
PHASE II

EFFECT OF TIDES
PRESENT PROJECT 34 FT

and ebb flows at the bottom indicate that both were reduced appreciably by the deeper channel. The redistribtuion of shoaling observed during this test is attributed to the drastic reduction in the bottom flood currents. The sediments which reach the bottom in North Channel during the flood tides tended to remain there since the reduced flood currents on the bottom were not sufficient to resuspend and move the sediments progressively upstream during subsequent tidal cycles. These model shoaling test results, using gilsonite as the silting agent, might be somewhat different than shoaling in the prototype where even the very low velocities could be sufficient to move the light fluff material.

The deepening of the channel to 38 ft with the recommended widening from 400 ft to 500 ft in the lower reaches and 40 ft deep and 600 ft wide in the entrance channels caused little change in the low water plane and the time of the tidal events; however, salinity was increased greatly in the upper reaches and to a lesser degree near the entrance. The resulting salinities are shown on Figure 5. Predominance of flow is moderated. Resulting data are shown on Figure 6. The significance of the data is that bottom predominance is upstream to the extent that the sediment trap plan will be effective with the deeper channels and also that without this plan critical shoaling will continue in the same general locations as presently encountered. The tests indicate that the quantity of shoaling will be increased by about 20 percent; however since the shoaling sources were not altered by the plan the increase may not be completely valid but some increase can be expected with the wider channels.

FRESH WATER DIVERSION

The effects of fresh water diversion. The concept of complete diversion of fresh water as a means for reducing shoaling in Savannah Harbor, or relocating the major shoal areas, was based on two major factors:

a. Available information indicated that the fresh water flow in the Savannah River is a known source of sediment to the harbor.

b. The fresh water discharge is responsible for the density currents which amass 80 percent of the shoaling in the lower four miles of Front River. It was visualized that complete diversion of fresh water would eliminate the Savannah River source of sediment and at the same time eliminate density effects which are responsible for concentration of sediment in lower Front River. It would also eliminate the bottom density currents near the harbor mouth. The only currents remaining there would be tidal currents which should be approximately the same on flood and ebb. A large portion of the material carried in on the flood tide would most likely be carried out on the ebb. Several plans of diversion were tested, all of which were relatively successful in controlling the shoaling; however, all plans greatly reduced the

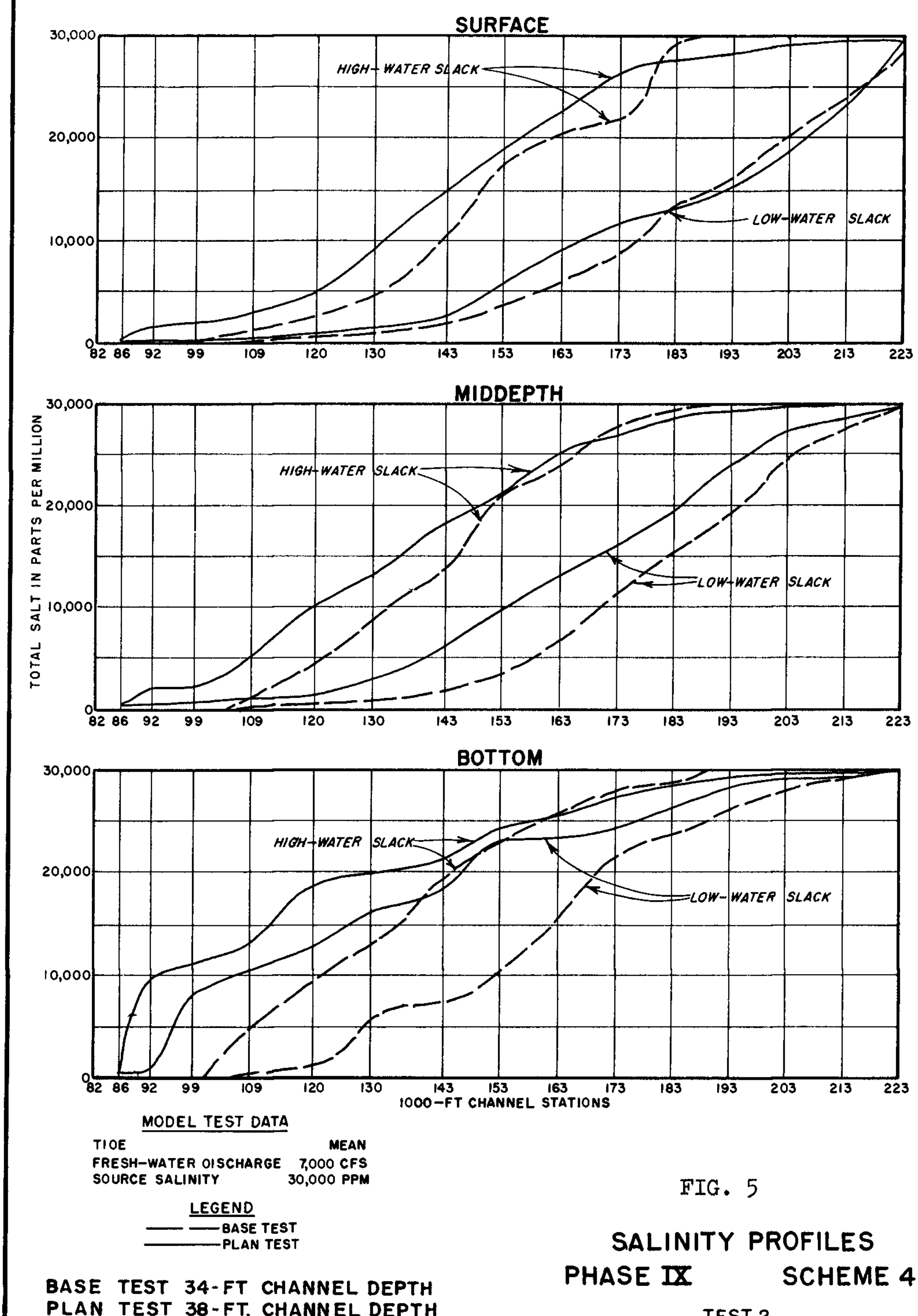
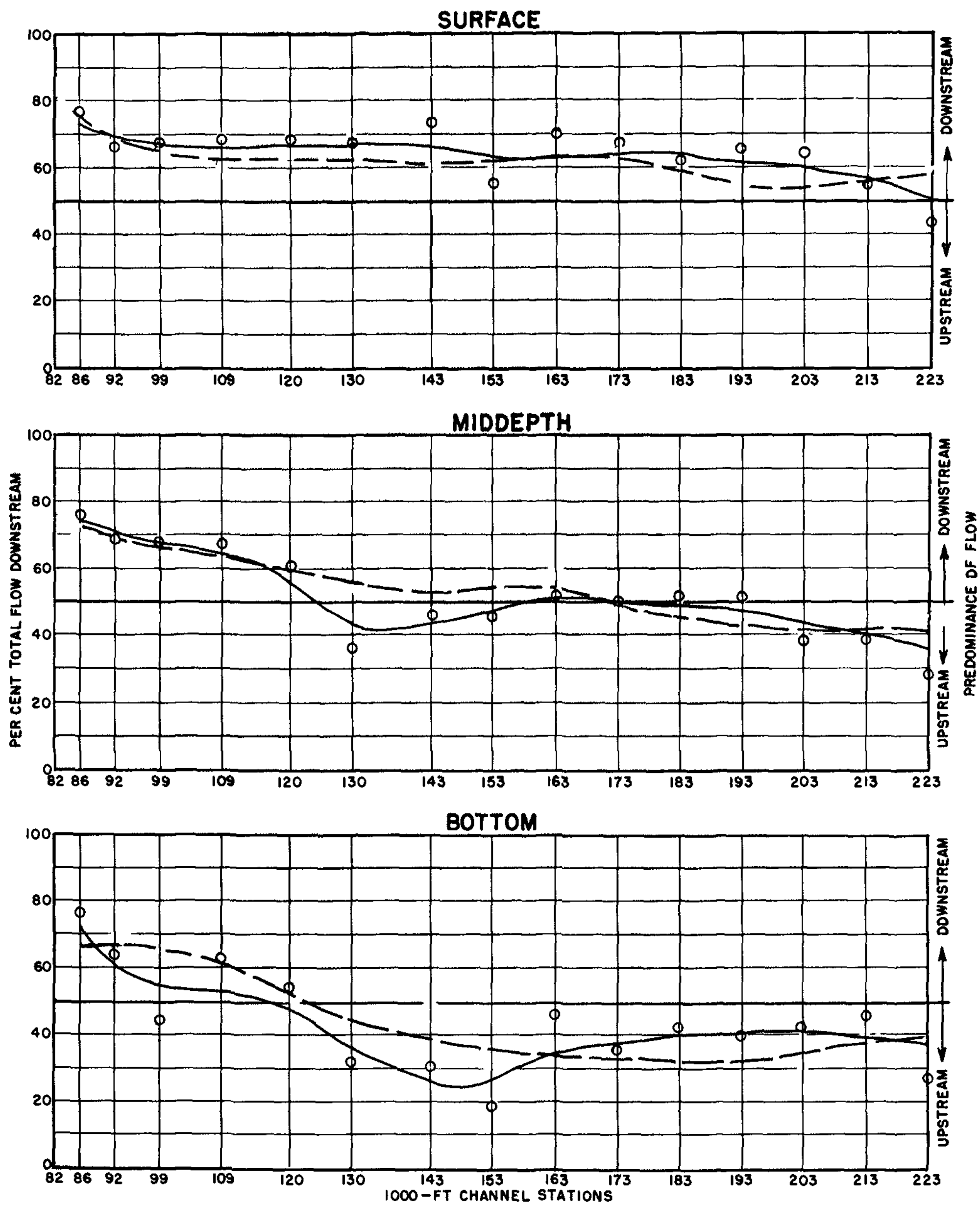


FIG. 5

SALINITY PROFILES
PHASE IX SCHEME 4
TEST 2



MODEL TEST DATA

TIDE MEAN
FRESH-WATER DISCHARGE 7,000 CFS
SOURCE SALINITY 30,000 PPM

LEGEND

BASE TEST
PLAN TEST

BASE TEST 34-FT CHANNEL DEPTH
PLAN TEST 38-FT CHANNEL DEPTH

FIG. 6

PREDOMINANCE OF FLOW
PHASE IX SCHEME 4

TEST 2

quantity of available dissolved oxygen in the Front River channel caused by the removal of the fresh water, and caused a reduction in ebb velocities. Under these conditions the industrial wastes and sewage deposited in the harbor would cause an extreme nuisanc condition in the vicinity of the City of Savannah, the prevention of which would be very costly and greatly reduce the overall mone tary benefits of the plan. Since another more favorable plan was developed by later studies, diversion of fresh water has not been adopted.

CHANNEL REALIGNMENT

Effects of channel realignment at Elba Island. This phase of the model study involved investigations to determine the effec of realignment of the navigation channel in the vicinity of the westerly end of South Channel on the hydraulic, salinity, and shoaling regimens of the harbor. The elements of the realigned channels and North Channel sediment basin are shown on Figures 7 and 8. The realignment at Elba Island was designed to improve navigation conditions by eliminating the sharp bend in the existing channel. The realigned navigation channel would connect the present channel at about Sta 160 and Sta 140. Tests were made foı the following purposes:

a. To determine the best alignment and entrance conditions for the new channel.

b. To determine the amount of contraction required in the intercepted reach of North Channel to prevent excessive shoaling in the realignment.

c. To determine the effectiveness of various sizes and shapes of openings into the intercepted reach of North Channel foı trapping and retaining sediment.

Hydraulic characteristics and shoaling were not materially affected by this plan which was envisioned only to benefit navigation. Tests, however, were made utilizing the abandoned portior of North Channel as a sediment basin, which was found to be effective if the entrances were restricted. Economies could be realize in dredging from the basin instead of the navigation channel but the benefits would be negligible since shoaling quantities in the critical channels were not affected and only those in the lower reaches where disposal areas are adequate were reduced.

SEDIMENT BASINS

Back River Sediment Basins. The results of the verification and preliminary tests confirmed the conviction that sediment basin might offer a possible means for reducing maintenance costs if the location, entrance, and hydraulic conditions of such basins could be designed to attain the maximum possible rate of shoaling in the and if the basins could be located adjacent to adequate spoil

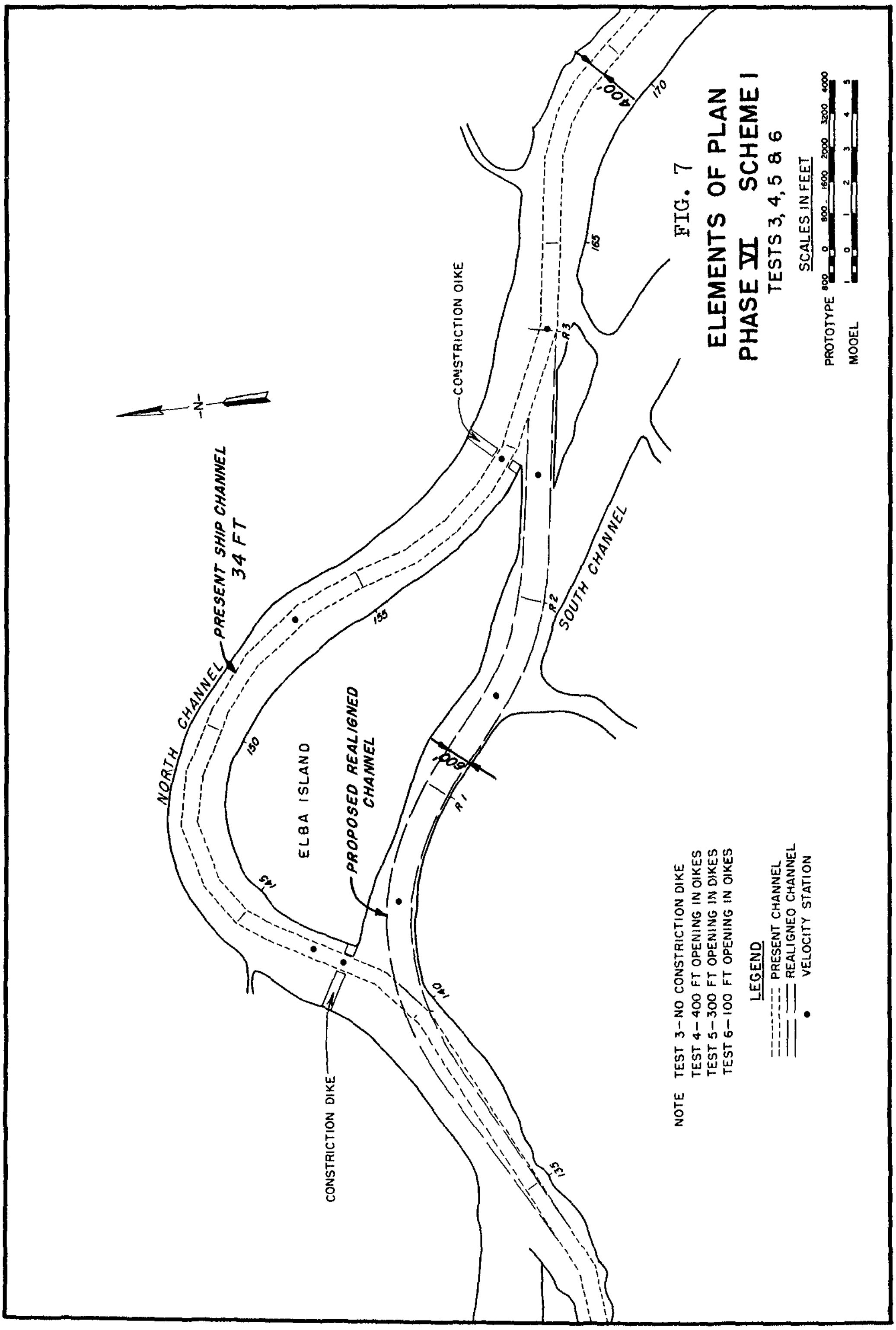


FIG. 7

ELEMENTS OF PLAN
PHASE VII SCHEME I
TESTS 3, 4, 5 & 6

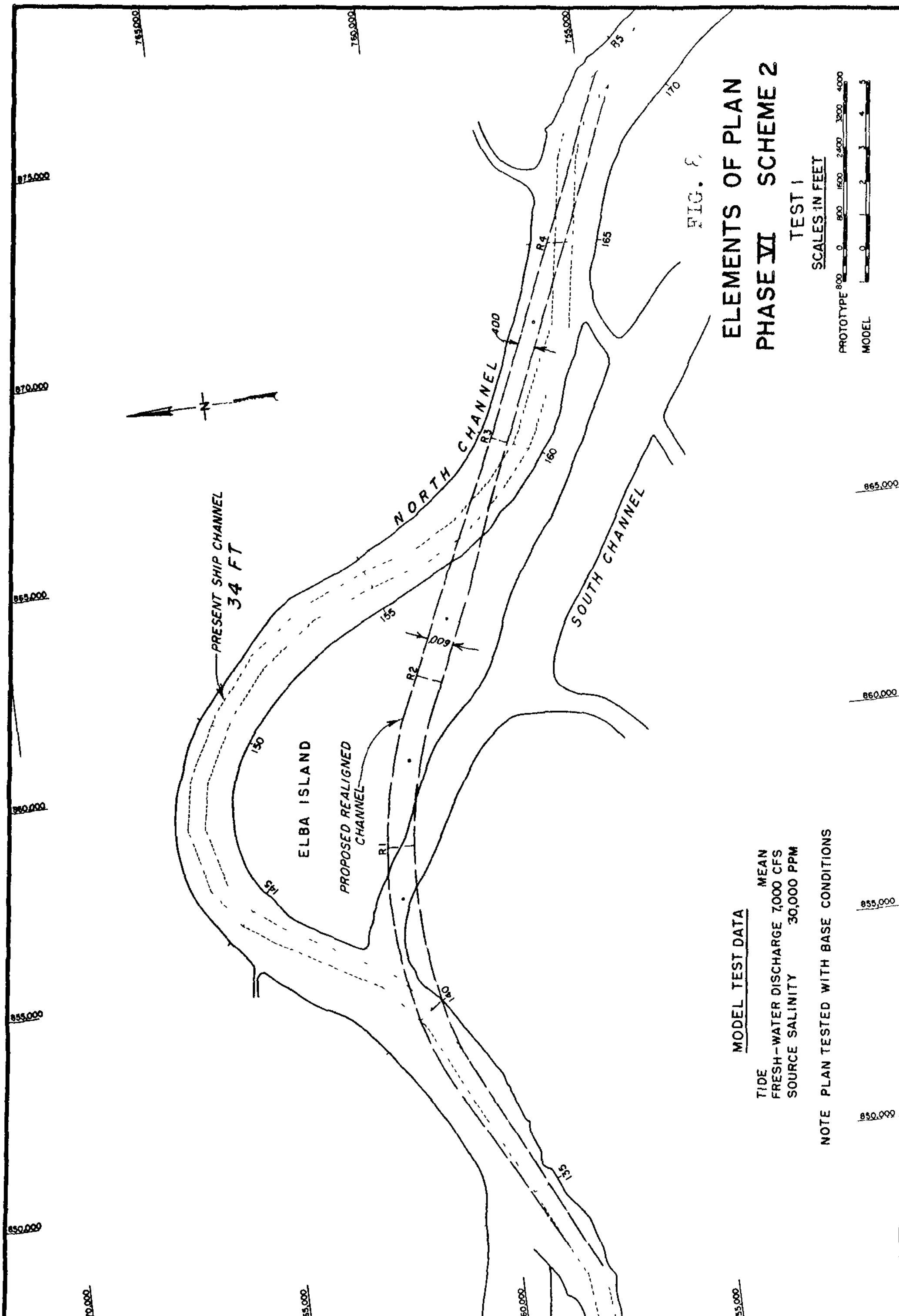

ELEMENTS OF PLAN
PHASE VI SCHEME 2
TEST 1
SCALES IN FEET
PROTOTYPE 800 0 800 1600 2400 3200 4000
MODEL 0 1 2 3 4 5
MODEL TEST DATA
TIDE MEAN
FRESH-WATER DISCHARGE 7,000 CFS
SOURCE SALINITY 30,000 PPM
NOTE PLAN TESTED WITH BASE CONDITIONS
NORTH CHANNEL
SOUTH CHANNEL
ELBA ISLAND
PROPOSED REALIGNED CHANNEL
PRESENT SHIP CHANNEL
34 FT
400
600
N

FIG. 8

disposal areas. Back River is ideally located for construction of a sediment basin. It has no commercial traffic, it is located near the major shoal area, it has no industrial development on either side, and the Government has perpetual spoilage easements on extensive diked areas adjacent to the proposed location for the sediment basin. A series of tests were made to determine the most favorable conditions for a sediment basin, and the effect of such a plan on the hydraulic regimen of the harbor.

Development of a Plan. The effectiveness of each plan was judged primarily by the ability of the plan to reduce shoaling in the Front River navigation channel between Sta 82 and Sta 135 and to concentrate shoaling in the sediment basin. The model tests of a sediment basin, located in the lower portion of Back River, 1500 ft wide and 2 miles long with an entrance channel in the mouth of Back River, reduced the shoaling in the navigation channel by about 20 percent. Since the reduction in channel shoaling occurred downstream from the entrance to Back River instead of in the critical shoaling area upstream from that point, little benefit would be realized.

The tide gate structure. The tide gate structure was provided across Back River at the SAL Bridge to increase the efficiency of the sediment basin by reducing ebb flows through the basin. A 500-ft gated opening was provided in the structure which opened automatically to allow flood flows to pass through but which was closed during the ebb periods. A canal was provided to drain the Back River tidal prism above the tide gate structure into Front River thus increasing ebb flows in Front River to reduce shoaling in that section.

It was determined by further tests that the sediment basin could be reduced to a width of 600 ft and still be reasonably effective. Tests incorporating deepening of the channels to 40 ft showed that ebb velocities in Front River were inadequate to maintain the channel to 40-ft depth. The tide gate was then shifted to the vicinity of the U. S. Highway 17A Bridge. It was found that a 100-ft opening was required in the tide gate to prevent excessive velocities in Front River during spring tides as long as the 34-ft channel was maintained. This reduced the efficiency of the sediment basin; however, the effect could be minimized by a controlled opening to be used only during spring tide periods.

The sediment trap-tide gate plan. The most effective plan was Phase VIII, Scheme 6, Test 4, (Figure 9) which requires a sediment basin in Back River 600 ft wide, 40 ft deep, and about 2 miles long; a tide gate in the vicinity of Highway 17A; and a canal connecting Back River to Front River in the upper portion of the harbor. The entrance channel to the sediment basin is 300 ft wide and 34 ft deep. During the shoaling tests, at the end of the prescribed number of tidal cycles, a stable condition

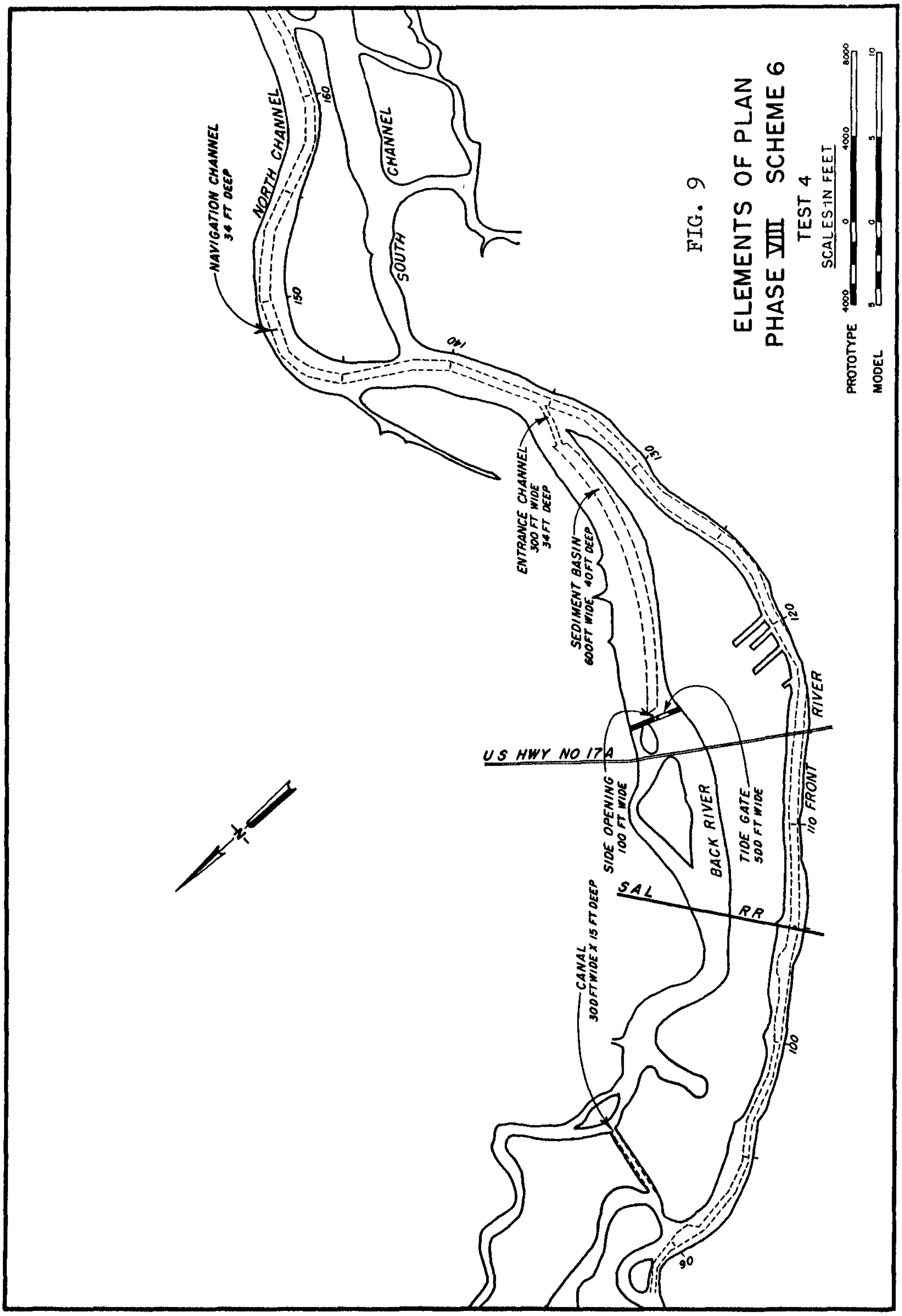


FIG. 9
ELEMENTS OF PLAN
PHASE VIII SCHEME 6
TEST 4

had not been reached in the navigation channels and sediment was still actively entering the sediment basin, whereas, in other tests the sediment had stabilized. Test 10 was then performed which extended the shoaling test until stability was reached. This plan reduced the shoaling between Sta 82 and Sta 135 from 77 to 5 percent and between Sta 135 and Sta 205 from 23 to 9 percent.

The 38-ft channel - with and without sediment basin. The 38-ft deep 500-ft wide channel which is being recommended for construction was tested with the Back River sediment basin and the results indicate that the plan will be successful. The model test data has been prepared to indicate a comparison of the 38-ft channel with and without the sediment basin.

The effects of the sediment trap on salinity throughout the harbor are shown on Figure 10. The only significant changes occurred in Front River where surface and middepth salinities were increased and bottom salinities were reduced; these changes were caused by the higher current velocities and more intense vertical mixing in Front River associated with the increased ebb discharge created by the plan.

Detailed velocity data were obtained; however, only the predominance of flow is presented. Figure 11 shows that in the bottom strata the predominance of flow is downstream from the upper limit of the harbor to about Sta 132 and upstream in the lower reaches as required to insure the maximum effectiveness of the sediment basin.

The effects of the sediment trap on shoaling are shown by Figure 12. Total shoaling in the navigation channel was increased by about 3 percent; however, shoaling of Front River was reduced to a great extent. This channel accounted for 57 percent of the total shoaling for the base test (without the sediment basin) but only 18 percent of the total shoaling with the sediment basin plan. Shoaling of the channels downstream from the confluence of Back River and Front River was not changed appreciably. The sediment basin retained 36 percent of the total shoaling. As was the case during previous tests of the sediment trap for other channel conditions, sediment was still moving into and depositing in the basin at the end of the test period. Therefore, had the tests been continued for a longer period of time, the results would have shown a much greater reduction in shoaling of the navigation channel. Previous tests indicated that 89 percent of the total shoaling material would be deposited in the basin if the tests were run until stability was reached.

In evaluating the results of this test, it should be kept in mind that the shoaling base test in the model represents the results of introducing a fixed amount of material into the model and operating for a fixed number of tidal cycles after injection

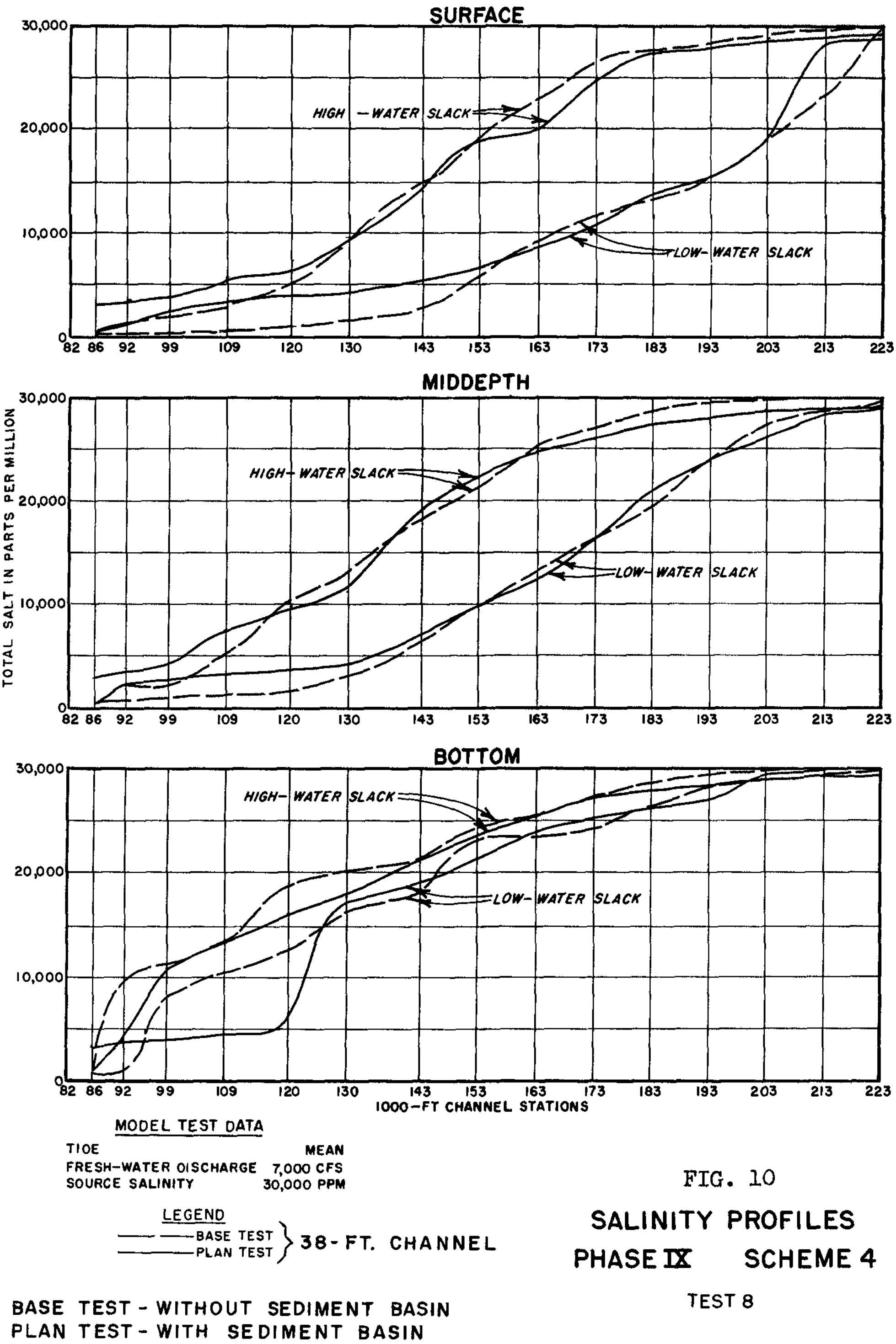
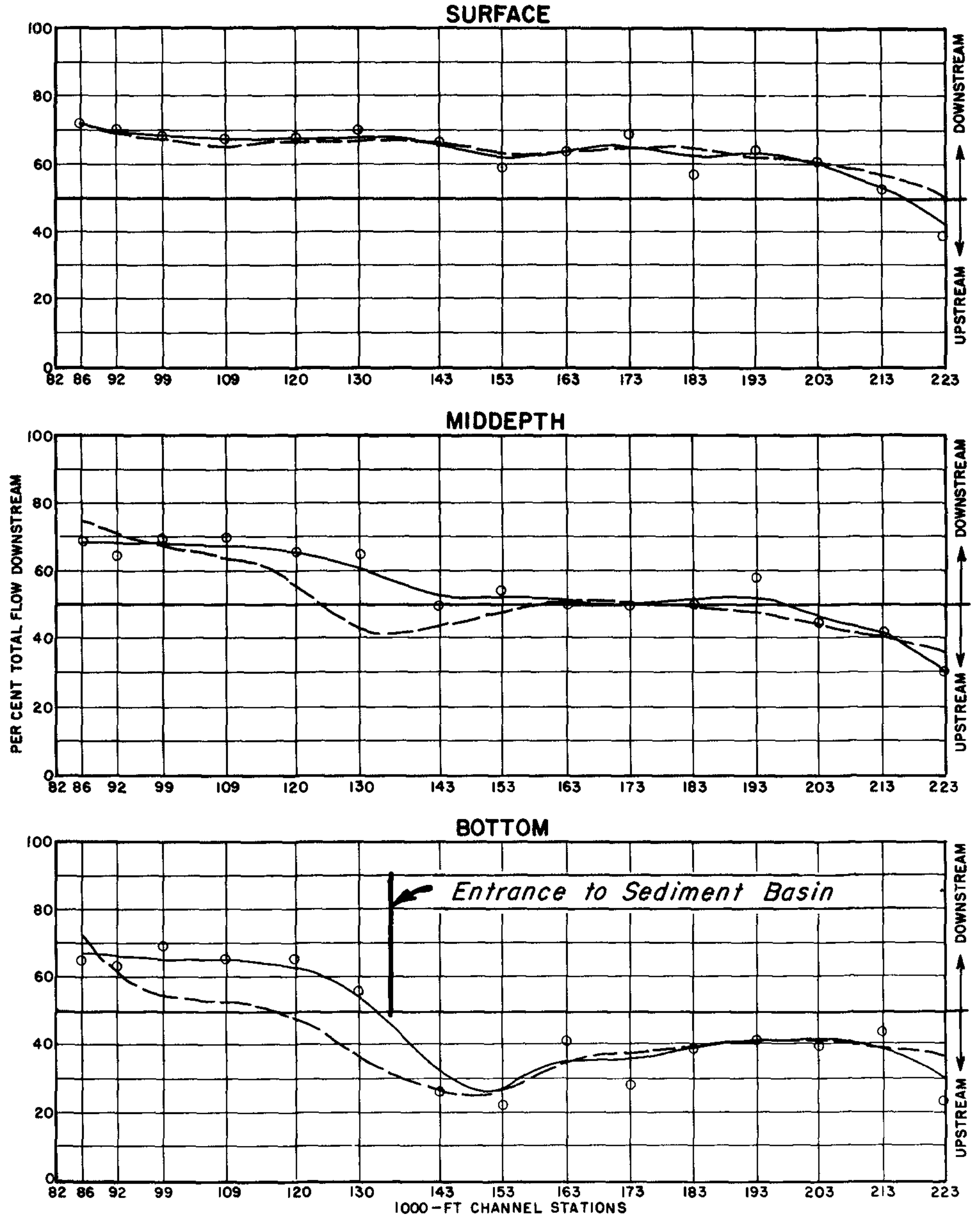


FIG. 10

SALINITY PROFILES

PHASE IX SCHEME 4

TEST 8



MODEL TEST DATA

TIDE . MEAN
FRESH-WATER DISCHARGE 7,000 CFS
SOURCE SALINITY 30,000 PPM

FIG. 11

PREDOMINANCE OF FLOW
PHASE IX SCHEME 4
TEST 8

LEGEND
38-FT. CHANNEL

– – – – BASE TEST - WITHOUT SEDIMENT BASIN
———— PLAN TEST - WITH SEDIMENT BASIN

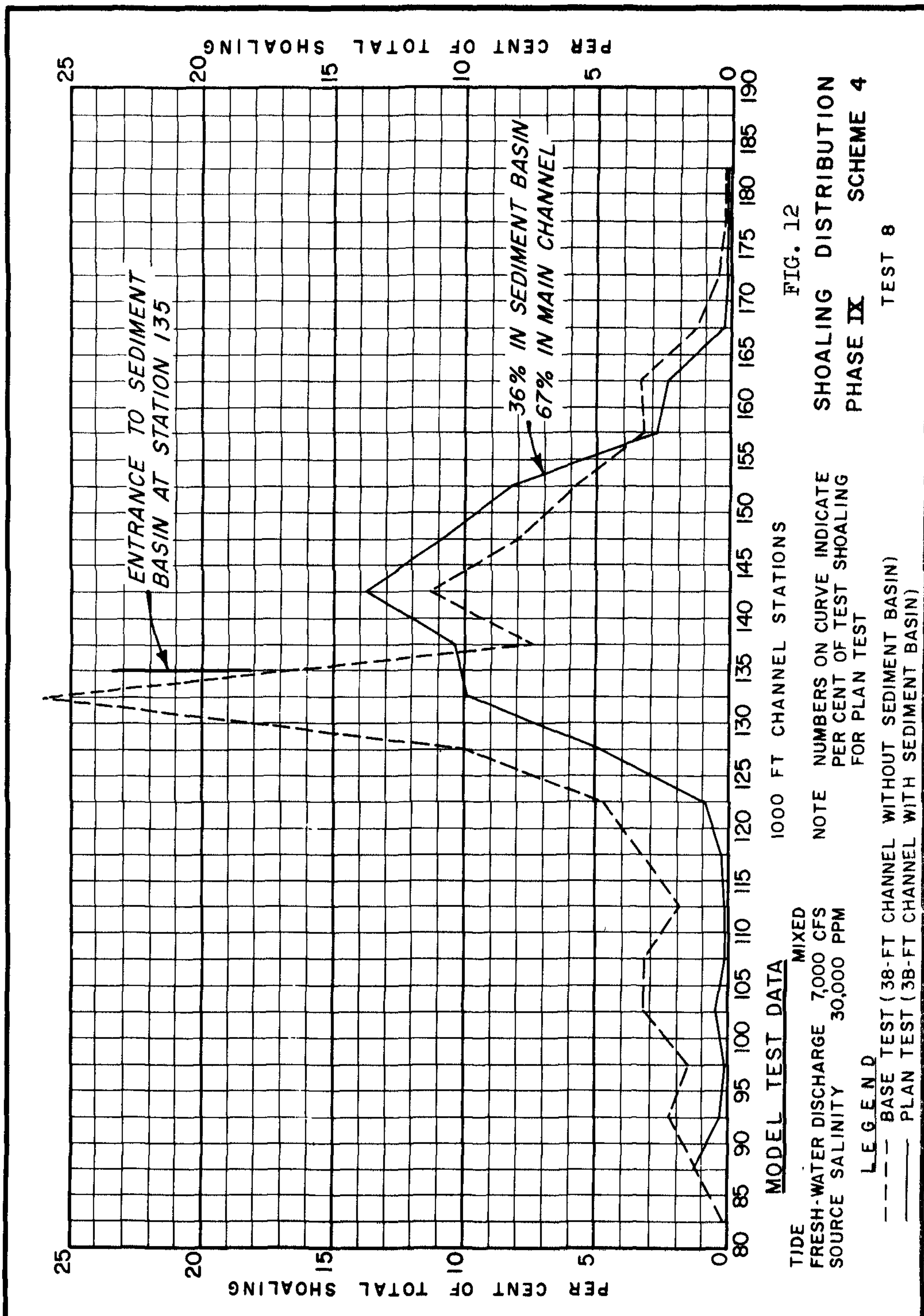


FIG. 12

SHOALING DISTRIBUTION

PHASE IX SCHEME 4

TEST 8

of the material. In the prototype, however, it is probable that shoaling material arrives in the problem area more or less continuously, although the rate of supply at certain times may vary. Of special importance is the fact that for higher fresh water discharges the effectiveness of the sediment trap would be temporarily reduced since much of the deposition would probably occur in the navigation channel downstream from the entrance to the sediment basin. For these reasons, it seems likely that the effectiveness of the plan is greater in the model than it would be in the prototype. After evaluation of this shoaling factor and the extended model tests, it was concluded that at least 60 percent of the total shoaling material would be deposited in the sediment basin. This has been used in economic analyses of the plan.

Sediment basin maintenance. Based on the present harbor shoaling rate and the model shoaling tests, it will be necessary to dredge about 6 million cu yds annually from the sediment basin. To retain the effectiveness of the sediment basin, it will be necessary to dredge it annually, or probably continuously, with periodic maintenance dredging in the navigation channels. The redistribution of the shoaling material is expected to produce considerable savings over the present maintenance cost because:

a. If a conventional pipeline dredge is used, reasonably short pipelines would be required since the spoil area is located adjacent to the basin, whereas, long lines are now required to maintain navigation channels.

b. Fixed pipelines could be utilized to eliminate much labor in handling.

c. The dredge would be out of the navigation channel which would eliminate loss of time permitting vessels to pass.

d. The operation of the dredge would be confined to limits of the sediment basin, eliminating the costly movement of the dredge over many miles of navigation channel.

e. It would be possible to let the sediment consolidate to an optimum density for efficient removal from the basin, whereas the present specified depths in the navigation channel which must be maintained often necessitates dredging material which has not consolidated sufficiently for economical removal.

The savings in labor and increased efficiency of dredging the material from the sediment basin would produce appreciable reduction in the maintenance cost. Preliminary economic studies for the plan indicate a favorable benefit-cost ratio. Although no specific plans have been made, it is contemplated that some means other than a conventional pipeline dredge can be devised to maintain the sediment basin, such as a simple arrangement of pumps on barges with drags similar to the hopper dredge or dust-pan type intake, or semi-mobile dredge powered by electricity.

Since the preliminary economic studies have been based on the maintenance of the sediment basin with a conventional pipeline dredge, it is almost certain that final studies will indicate a more favorable benefit-cost ratio for the plan.

Review of findings. When the deepening of channels caused shoaling to be shifted to the section of Savannah Harbor where disposal areas are limited, prototype investigations and a model study were undertaken to determine means of reducing the high cost of maintenance.

The prototype studies determined that the Savannah River is a major source of shoaling material and contributes about 2,000,000 cu yds annually; the stratified condition caused by the mixing of the fresh and the salt water produces a hydraulic mechanism that controls the location of shoals, which in turn is affected by the fresh water discharge, tidal range, and dredging methods; the diking of spoil disposal areas is necessary to prevent the runback of spoil into the channel; and the dredging method would be improved by reducing the cutter speed and controlling the rate of swing.

Data and knowledge of existing conditions was obtained from the prototype studies for verification of the hydraulic model of Savannah Harbor. The general investigations in the model confirmed the prototype findings and depicted in detail existing prototype hydraulic, salinity, and shoaling conditions throughout the harbor with random or sporadic factors eliminated.

The model tests of improvement plans showed that plans to reduce shoaling by fresh water diversion were successful, but they created problems of pollution of a scope which would make their adoption questionable. Plans of channel realignment tested in the model proved to be beneficial to navigation but would be of little benefit to harbor maintenance. They also indicated that the deposit of shoal material could be induced in a sediment basin. A sediment basin in Back River with a tide gate to increas its effectiveness was the most desirable improvement plan tested. Tests developed hydraulic and shoaling conditions for proposed harbor deepening and determined that the Back River sediment basin plan would induce about 60 percent of the total shoaling quantity in the basin and that other aspects of the plan would be favorable.