Chapter 7

SALINITY PROBLEMS

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INTRODUCTION

The basic sources of salt-water pollution are the ocean, industry, and the soil. The ocean is responsible for the intrusion of salt water into rivers, canals, and lakes, and for infiltration of sea water into aquifiers which are tapped by wells. Industry causes salt-water pollution by discharging the brine of mines, oil wells, tanneries, and other industrial wastes into rivers and lakes. The soil is a source of salt-water pollution because of the run-off from chloride-bearing soils and the solution of soluble rocks. The most common and important source of salt-water pollution is the ocean, and is the only source considered in this paper.

NATURE OF SALINITY PROBLEMS

The types of salinity problems encountered are too numerous to permit coverage in a single paper; however, the most important are those pertaining to pollution of municipal, industrial, and irrigation water supplies, and to shoaling of navigation channels and harbors because of precipitation of suspended or dissolved solids which would otherwise pass out to sea. The subsequent parts of this paper define the above problems in more detail, describes methods which have been proposed or adopted for the solution of similar problems, and describes certain hydraulic model investigations of salinity problems. A selected bibliography is included which presents references to the most important literature available to the writer. References listed in the bibliography can be obtained on loan from the Research Center Library, Waterways Experiment Station, Vicksburg, Mississippi.

Pollution of water supplies

Salt water does not constitute a health hazard, but its taste in drinking water is very objectionable. The USPH "Treasury Standard" therefore limits the amount of chlorides to 250 parts per million, which is the approximate concentration at which consumers will begin to complain of salty taste. Many industries require water of very low salinity, the maximum allowable in certain products being 10 to 15 parts per million of chlorides.

Problems relative to pollution of irrigation water supplies are generally similar to those of municipal and industrial supplies; however, the demand for irrigation water and the tolerable limits of salinity vary with the season of the year and the crops to be irrigated. The results of a study of the Pecos River Basin by the National Resources Planning Board indicated that: (a) for salinities up to 3000 parts per million total salts little injury to crops was evident; (b) between 3000 and 6000 parts per million growth was limited to salt-tolerant crops; (c) between 6000 and 10,000 parts per million salt-tolerant crops will grow but seldom thrive well; and (d) above 10,000 parts per million plant growth was limited to some grasses and shrubs.[1*]

The results of a study made by the Louisiana State Department of Conservation to determine tolerable limits of salinity in irrigation water for rice indicate that the allowable limit ranged from 560 to 2900 parts per million total salts, depending upon the stage of growth of the crops.[2] In the Sacramento-San Joaquin Delta in California, the tolerable limit was established as approximately 330 parts per million chlorides. Crops irrigated in this area consist primarily of asparagus, potatoes, sugar-beets, corn, beans, and other truck crops, and considerable acreage in fruit orchards. It is therefore evident that a tolerable limit of salinity for all irrigation supplies can not be established. The crop to be irrigated, the characteristics of the soil, the amount of irrigation water necessary, and the stage of growth of the crop all affect the salinity that may be used without harmful effects. Only a thorough study of local conditions, and experimental determination of allowable limits of salinity for all stages of growth of the crop to be irrigated, will indicate whether or not the water available is suitable for irrigation purposes.

Shoaling in rivers and harbors

A large part of the silt carried by some rivers is in the form of collodial or semi-collodial suspension or in solution. An important property of these particles of solids is that they exhibit no tendency to ball together and form deposits on the river beds, for the reason that each particle is charged with a negative electric potential. This potential being the same in all particles, the latter repel each other and a complete state of dispersion prevails so long as the water is fresh. Contact with salt water, however, causes a base-exchange reaction, whereby the electric potential is neutralized and a process of clotting, technically known as coagulation or flocculation, results. At first the flocs or lumps of coagulated material are quite small; however, as more and more particles are attached the lumps attain sufficient size and weight to sink to the bottom, thus effecting deposits on the river beds. Shoaling from this source appears to be most serious in the tidal sections of rivers draining from the Appalachian Mountains and discharging into the Atlantic Ocean and the eastern portion of the Gulf of Mexico.[3]

MANNER OF SALINITY INTRUSION

Intrusion of salt water from the ocean may occur as flow through open channels or by infiltration into ground water supplies. In many coastal areas the source of municipal and other water supplies consists of wells. In some cases such wells have been driven indiscriminately, and are being pumped at a rate greater than that at which the acquifier

*See references at end of chapter

is being replinished with fresh water. Under these conditions salt water may be drawn into the water-bearing strata and cause contamination of the entire supply. Occasionally, the ground water supplies of coastal areas may become polluted because of surface flooding by sea water. Many wells in New England were contaminated in this manner as a result of the 1943 hurricane; however, the contamination was only temporary, and continued pumping of the wells soon reduced their salinities to normal levels.[4]

The upstream movement of salt water in open channels is attributable to the greater density of salt water as compared to that of fresh water. The nature and extent of such intrusion in a specific channel is dependent upon the range of tide and salinity of the sea water at the mouth of the estuary, the physical and hydraulic characteristics of the estuary proper, and the volume of fresh water being discharged into the estuary from the fresh-water section upstream. The manner of intrusion may vary from the well-defined wedge which is typical of the lower Mississippi River to the salinity front which may be found in San Francisco Bay and Delaware Bay and River; likewise, any modification between these two extremes is possible if the proper physical and hydraulic conditions exist in an estuary.

The well-defined salt-water wedge, such as exists in the lower Mississippi River, is illustrated by Fig. 1. The range of tide at the mouth of the Mississippi River is so small that there is no reversal of flow in the river because of tidal action; therefore, the position of the wedge is governed almost entirely by the volume of fresh water flow. Flow within the salt-water wedge is always upstream because of its greater density, while flow in the fresh or semi-fresh water stratas above is always downstream. The interface between the salt and fresh water is fairly well defined, and along this interface the fresh water continually erodes the salt wedge. The amount of such erosion upstream from a given point is always equal to the upstream discharge of salt water at that point so long as the position of the wedge remains stable, or until the fresh water discharge changes. If the fresh-water flow decreases, the wedge slowly moves upstream; conversely, if the fresh-water flow increases, the wedge is forced downstream to a new position. As an example of the magnitude of intrusion in the lower Mississippi River, salt water is found 135 miles upstream from the mouth (entrance to Southwest Pass) following prolonged periods of low river discharge. On the other hand, the wedge is pushed entirely out of the river during periods of extremely high river discharge.

Salinity intrusion in Delaware and San Francisco Bays appears to be in the form of a salinity front rather than a salt-water wedge, and is illustrated by Fig. 2. Salinities decrease progressively as distance from the ocean increases, and there is but little difference between surface and bottom salinity at any given point in the estuary. The salinity front advances and retreats with both tidal fluctuation

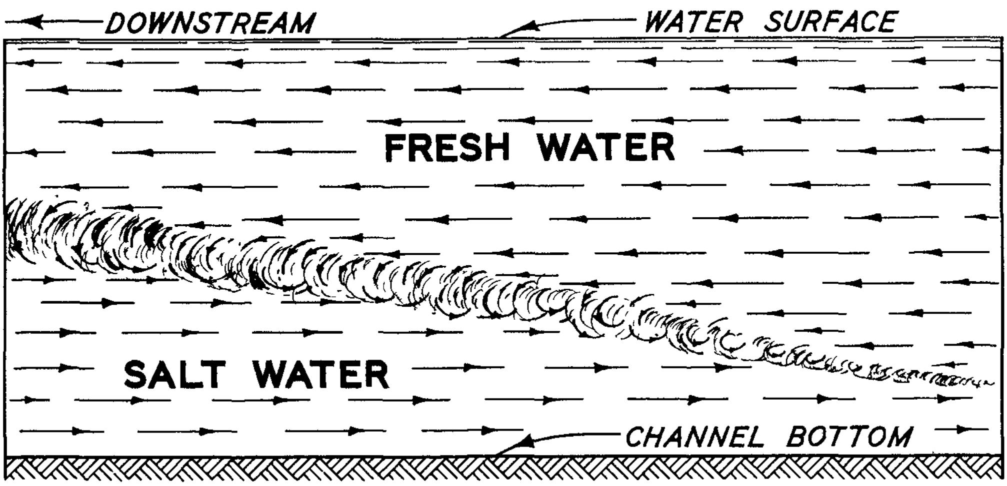

Fig. 1. This shows schematically the distribution of flow in an estuary having a well defined salt-water wedge (similar to lower Mississippi River). Flow in the wedge is always upstream, and flow in the fresh-water strata is always downstream. The thickness of the interfacial layer varies with the fresh-water discharge.

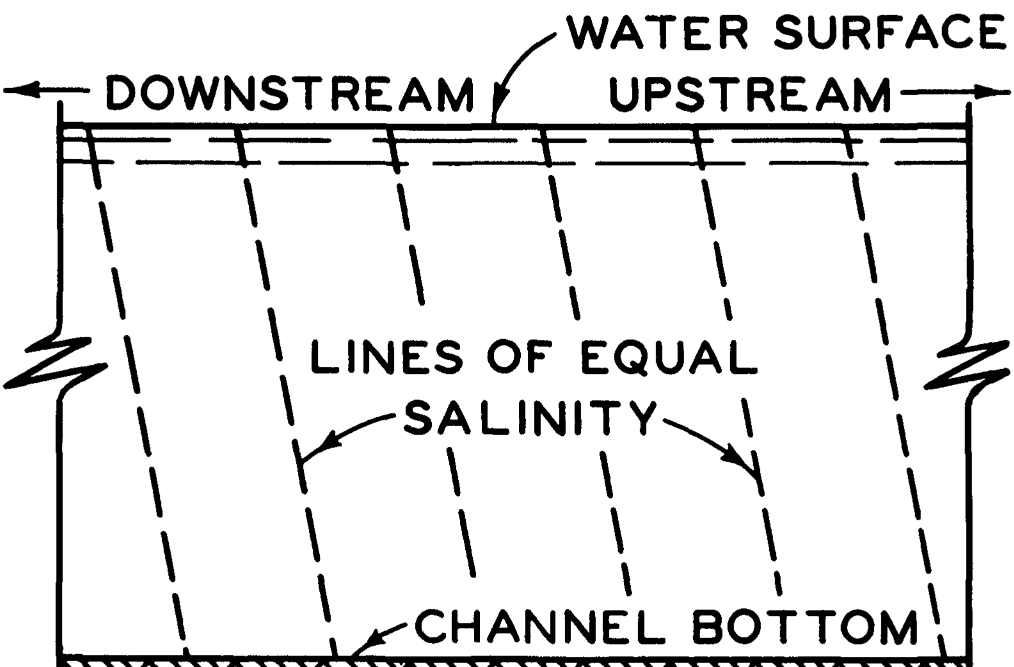

Fig. 2. This shows schematically the distribution of salinity in an estuary in which mixing caused by tidal turbulence does not permit formation of a well defined salt-water wedge (similar to San Francisco and Delaware Bays). The salt-water front advances and retreats with tidal action, but there is little difference in salinity from surface to bottom.

and change in fresh-water discharge, but the relation between surface and bottom salinity at all points in the estuary does not change appreciably.

Salinity intrusion in the Savannah River, Georgia, and the Cooper River in South Carolina might be classified as falling between the two extremes described above and is illustrated by Fig. 3. There is a definite salt-water wedge in these latter rivers; however, the direction of flow within the wedge reverses with change in direction of the tidal currents, and the transition layer between the salt water and fresh water is much thicker than that found in the lower Mississippi River. The advance and retreat of the salt-water wedge with tidal fluctuation in the Savannah and Cooper Rivers covers appreciable distances, and the upstream penetration of the wedge varies with the volume of fresh water being discharged into the estuary. The shape of the wedge at high-water slack, or at maximum penetration because of tidal fluctuation, is somewhat different from that at low-water slack, the wedge having an appreciably steeper front and a lesser range of salinity distribution from surface to bottom than is found at low-water slack.

It is the opinion of the writer that the different types of salinity intrusion described above can be attributed to the physical and hydraulic characteristics of the estuaries involved. The lower Mississippi River occupies a channel which is relatively narrow as compared to depth, there is but little tidal range at the mouth of the river, and the fresh-water discharge is relatively large as compared to tidal discharge. On the other hand, the deep-water channels of Delaware and San Francisco Bays are relatively narrow as compared to the total width of the estuaries (or the estuaries are relatively wide as compared to depth), the ranges of tide at the mouths of these estuaries are sufficient to produce reversals of flow with accompanying tidal currents of appreciable magnitude, and the fresh-water inflows are quite small as compared to tidal discharges. Physical and hydraulic conditions in these latter estuaries therefore contribute to the mixing of the salt and fresh waters, and since most of the fresh water enters the estuary at the upstream end, the salinity front type of intrusion exists rather than the wedge type. Conditions in the lower Mississippi River are such that but little mixing of the salt and fresh water takes place, and therefore salinity intrusion is in the form of a well-defined wedge. The other two rivers described, the Savannah and the Cooper, are similar in some respects to the lower Mississippi River and in other respects to Deleware and San Francisco Bays; therefore, the type of salinity intrusion in the Savannah and Cooper River have some of the characteristics of the former and some of the latter. The channels of the Savannah and Cooper Rivers are relatively narrow as compared to depth, the volumes of fresh water discharged into these estuaries are small as compared to tidal discharges, but the tidal ranges and accompanying tidal currents are sufficiently great to produce considerable mixing of the salt and fresh water. It is

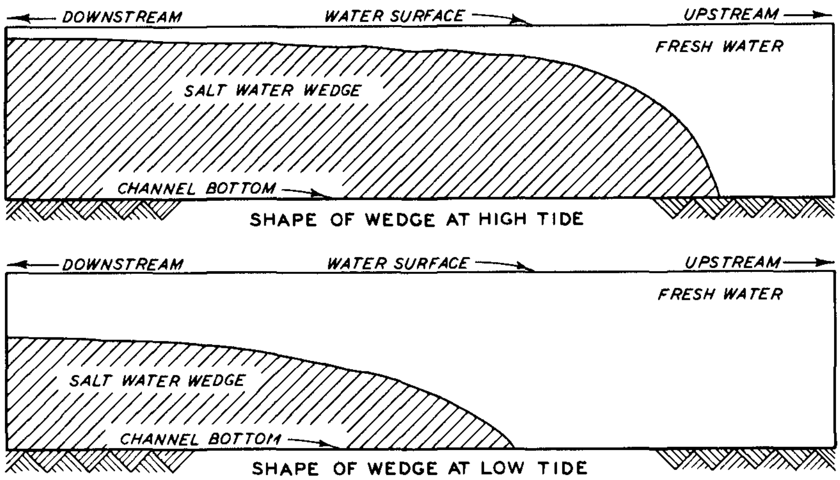

Fig. 3. This shows schematically the effect of tidal action on the salt-water wedge in an estuary having a well defined wedge but also having a sufficient tidal range to cause an appreciable advance and retreat of the wedge with tidal action (similar to the Savannah and Cooper Rivers). The wedge moves back and forth for considerable distances with tidal action, and the upstream face of the wedge is much steeper at high-water slack than at low-water slack.

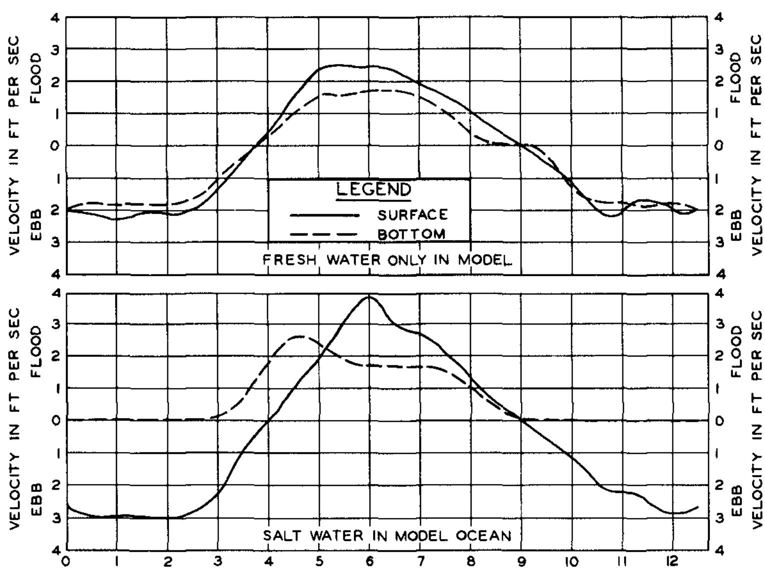

Fig. 4. This shows the effect on current velocities caused by using salt water in the ocean portion of the Savannah Harbor model. The upper plot consists of measurements made with only fresh water in the model, and the lower plot consists of measurements at the same station with salt water in the model ocean. The lower plot is similar to measurements made in the prototype for similar conditions of tide and fresh water discharge.

therefore the opinion of the writer that while the greater density of the salt water as compared to that of the fresh is the basic cause of salinity intrusion in all open channels, the type of intrusion to be found in a given channel is so modified by local physical and hydraulic conditions that but little similarity exists between salinity intrusion in any two estuaries. Salinity intrusion in each estuary should be considered and studied as an individual problem, and the reasoning applied with success to one estuary will probably fail completely when applied to another.

CONTROL OF SALINITY INTRUSION

It has been pointed out that most salinity problems are unique in nature which would therefore require that each such problem be studied individually. For this reason it is believed that no set rules or methods for the solution of salinity problems can be developed. Experience and sound judgement on the part of the engineer concerned with a specific problem are required to determine the exact nature of the problem, what factors are of greatest significance, and what solutions are feasible and economical. Some of the attempts that have been made to remedy salt-water problems, and some of the proposals that have been made but have not yet been attempted, are described below.

LOCKS AND GUARD LOCKS

Locks are usually constructed to facilitate navigation by making it possible to transfer a ship from one level to another. However, in the transit of a ship from a body of salt water to a body of fresh water, or in the opposite direction, salt water passing through the locks during a ship transit can cause pollution of the fresh water body. It is sometimes desirable, therefore, to design and construct the lock in such a manner that its chambers may be flushed with fresh water before the gates separating the lock chambers and the fresh-water pool are opened. This process reduces the salinity of the water in the lock chamber, thus reducing the source of pollution to the body of fresh water. This method has been used with success in operation of the locks of the Lake Washington Ship Canal, Seattle, Washington,[5] and has been proposed for the solution of similar problems in other locations, notable of which is the proposed New Jersey Ship Canal.[6] The design of such locks usually incorporates a deep sump adjacent to the entrance of the lock into the fresh water pool, the purpose of which is to collect, by virtue of its greater density, the salt water that succeeds in passing through the locks in spite of all precautions. A siphon located in the bottom of this sump returns the salt water collected therein to the salt water pool below the locks. This method can be made quite effective if a sufficient quantity of fresh water for flushing the locks is available.

Guard locks are usually constructed to prevent free flow through an open channel, and for this reason they provide an excellent means for preventing the movement of density currents. The use of guard locks, however, is usually limited to waterways in which flow is principally tidal, since, in the case of a waterway having an appreciable fresh water run off, the lock would impede drainage of flood waters. Notable examples of existing guard locks are the Great Bridge Lock in the Atlantic Intracoastal Waterway about 12 miles south of Norfolk, Virginia,[7] and the Calcasieu and Mermentau Salt-water Guard Locks in the Gulf Intracoastal Waterway in southwestern Louisiana.[8]

BARRIER DAMS

A large number of barrier dams have been proposed for the control of salinity intrusion; however, only a few such structures have actually been built. Barrier dams in open channels are of two general types: (a) a dam which effects a partial closure of a channel, thus concentrating the fresh-water flow into a relatively small cross section and increasing its effectiveness in combating salinity intrusion; and (b) a dam which effects a complete closure of a channel, thus creating a fresh-water pool at an elevation equal to or slightly greater than the salt-water pool downstream from the basin. Either of these types may be supplemented by locks for navigation or auxiliary openings for passage of large fresh-water flows. Examples of the former are the barriers proposed for control of salt-water intrusion in the lower Mississippi River,[9] and examples of the latter are the Goolwa Barrage across the lower Goolwa River in Australia[10] and the barrier across the Santa Ynez River at Camp Cooke, California.[11]

Several types of movable barriers have been designed for the control of salinity intrusion, and a few of these have been constructed and operated. A movable tidal gate was constructed across the Miami River Canal, Miami, Florida, and operated for some time to prevent salt-water intrusion into the canal.[12] One-way gates to prevent intrusion of salt water at high tide, at the same time permitting drainage of fresh water at low tide, have been used successfully in a number of cases. Such gates are usually relatively small and are installed in highway and railroad culverts; however, fairly large gates of this type have been utilized also. An example of the larger gates of this type is that used in Skagit County, Washington, which controls drainage from and prevents salt water intrusion into an area of about 6000 acres of highly productive farm land.[13]

REDUCTION OF SHOALING IN TIDAL WATERWAYS

The problem of flocculation of suspended or dissolved solids by salt water is further complicated by the effects of density currents on bottom velocities in estuaries. It has been pointed out that salt water tends to move upstream because of its greater density, sometimes underneath the fresh water and sometimes mixed with the fresh water in various degrees, and the net effort of this upstream movement is that bottom velocities in most estuaries are stronger during flood tide than during ebb tide. Surface velocities, on the other hand, are usually considerably stronger during ebb tide than during flood, since it appears that most of the fresh water run-off is carried to sea in the upper stratas, especially if the estuary is one in which little mixing of the fresh and salt water occurs. The importance of such effect on the vertical distribution of currents in an estuary is obvious, since it is extremely difficult for a deposit of material, once formed on the river bed, to be removed by natural forces and carried out to sea if the bottom currents moving upstream are normally predominant over the downstream currents. In fact, there is evidence that material flocculated in the lower reaches of some estuaries is thence progressively moved upstream by the predominant bottom currents to form shoals in the upper reaches of the estuary.

The usual plans adopted to reduce shoaling in tidal estuaries consist of proper channel alignment, the construction of training works to obtain good flow conditions in the navigation channel, removal of obstructions to the free run of the tide, elimination of channel bifurcation when possible to eliminate cross flows and eddy action, construction of jetties where required to concentrate flow, etc. It has also been proposed on numerous occasions that the construction of reservoirs in the fresh-water section upstream from the head of an estuary, the revetment of banks to eliminate bank caving and scour, and the dredging of sedimentation basins, either in the estuary proper or in the fresh water section upstream, might be effective in reducing the suspended load entering the estuary and therefore reduce the amount of solids available for flocculation by salt water. Sedimentation basins located in the fresh water section would probably be ineffective in reducing the suspended load, however, and the cost of constructing reservoirs and bank revetment is usually so great as to be prohibitive. Also, there is some evidence that suspended material in appreciable quantities can pass through one or more reservoirs without being deposited, only to be flocculated on coming into contact with the salt water of an estuary and contributing to shoaling of the navigation channels therein.

MODEL STUDIES OF SALINITY PROBLEMS

Hydraulic models have been used quite successfully during recent years for studies of salinity intrusion problems in open channels and in locks. Both theory and experience have shown that so long as gravity is the controlling force in the formation and movement of density currents, which is the case except in rare instances, models should be designed in accordance with Froude's model laws of similitude, and the salinity scale, model to prototype, should be unity. The reliability of a salinity scale of unity for model studies of salinity intrusion in open channels was recently confirmed by the results of an exhaustive study conducted by the National Bureau of Standards under the direction of Dr. Garbis H. Keulegan.

O'Brien and Cherno, in 1934, published the results of a study to determine a model law for use in the design of hydraulic models for the study of salinity problems.[14] The design criterion arrived at by Messrs. O'Brien and Cherno was:

$$L_r = D_r^{2.5} S_r^{0.5} \tag{1}$$

This equation was based on the assumption that inertia and friction were the controlling forces in movement of salinity currents, gravity being considered only insofar as the initial velocity was concerned. This condition exists only if a relatively small volume of salt water is released into a large body of fresh water as, for example, a slug of salt water entering a fresh water pool as a result of lock operation, and is therefore limited in scope.

It is usually necessary to reproduce salinity currents in estuary models for two reasons. First, some industries usually draw cooling water directly from estuaries, and any change in salinity, caused by changes in channel dimensions or other modifications of the estuary, may increase salinities to or beyond the danger point. Second, as stated previously, the action of salinity or density currents is such that the vertical distribution of currents in any cross section traversed by a salt-water wedge is appreciably different than would be the case if all fresh water or all salt water was moving in the cross section. The upper portion of Fig. 4 shows a plot of surface and bottom current velocities obtained in a model of Savannah Harbor, Georgia, with only fresh water in the model. The lower portion shows a plot of velocities at the same points with salt water in the model ocean and fresh water being discharged into the upstream end of the model estuary. These plots reveal the great differences between surface and bottom velocities at an identical point for the two conditions mentioned. The lower plot approximates very closely the velocity distribution found in the prototype for tidal and fresh-water flow conditions similar to those reproduced in the model at the time these measurements were obtained.

It is obvious that the movement of sediment in Savannah Harbor is affected appreciably by density currents, especially in that reach of the harbor in which these measurements were made. The observations obtained with salt water in the model ocean show an appreciable flood or upstream velocity on the bottom in this critical reach, but the ebb or downstream velocity is zero. The net effect of this difference in bottom velocity is that material deposited in the harbor because of flocculation or other causes may be moved upstream to form shoals in the navigation channel, but it can not be moved downstream and out to sea except during times of extremely high fresh water flows. It therefore follows that most of the material accumulated in critical reaches by this peculiar flow phenomena must be removed by dredging to maintain the desired channel depths.

In 1944-1945 a model study of salinity intrusion in the Calcasieu River, which is located in southwest Louisiana, was made by the Waterways Experiment Station, and this study may be used to illustrate the advantages of using hydraulic models in such investigations.[15] The problem involved was whether or not a proposed deepening of the Calcasieu River Ship channel, between the Gulf of Mexico and the Port of Lake Charles, La., from 30 to 34 ft at MGL would further aggravate an already serious salinity intrusion problem in the Calcasieu River and the Gulf Intracoastal Waterway east of the Calcasieu River. Water drawn from these streams, especially from the Intracoastal Waterway east of the Calcasieu River, is used for irrigating large areas used for rice cultivation.

One of the initial steps in planning the model study was the obtaining of sufficient and reliable hydraulic and salinity data upon which the adjustment of the model could be based. Tidal heights were obtained by automatic tide-recording gages in the Calcasieu River, Calcasieu Lake, and in the Intracoastal Waterway east and west of the Calcasieu River. Measurements of current velocity and salinity were made at six selected stations in the area to be reproduced. Fresh water discharges in the Calcasieu River and all tributaries were made daily for the duration of all tidal, velocity, and salinity observations. These data provided an accurate basis for adjustment of hydraulic phenomena and verification of salinity intrusion for the then-existing 30-ft channel.

A comprehensive study of salinity intrusion in the Calcasieu River area by means of a hydraulic model required that the model be so designed and constructed that both tidal and salinity currents be reproduced accurately throughout the problem area. Therefore, the model reproduced a portion of the Gulf of Mexico, Calcasieu Pass and Calcasieu Lake, 10 miles of the Lake Charles Deep Water Channel to the west of the Calcasieu, 10 miles of the Gulf Intracoastal Waterway to the east of the Calcasieu, the Calcasieu River in its natural state to a point about 5 miles above Lake Charles, and the remaining tidal portions of the Calcasieu River, Houston River, and English Bayou above this point in the form of a labyrinth. Fig. 5.

The model was of the fixed-bed type, all channel and overbank areas being molded in concrete. It was constructed to linear scale ratios, model to prototype, of 1:1000 horizontally and 1:50 vertically. The salinity scale used in the model was 1:1. Observed prototype tides were reproduced in the simulated Gulf of Mexico by means of an electro-mechanical tide reproducing apparatus, and the roughness values of the model bed and channels were so adjusted that the observed rise and fall of the tides, and the resulting strength and directions of tidal currents, were reproduced throughout the model. The fresh-water inflows, representing the fresh-water discharges of the Calcasieu and Houston Rivers, were introduced into the upstream end of the model by means of Van Leer weirs.

The water in the model gulf was maintained at the observed prototype salinity by the addition of common salt. The salt was added to the water-supply sump in the required quantities, and was dissolved by a circulating pump. Since the water which produced the rise and fall of the tide in the model circulated through this sump, the water in the model gulf was maintained at its correct salinity at all times.

Operation of the model for the verification test, and for tests of the various channel conditions for which information was desired, was begun with the river system filled with fresh water and the gulf filled with salt water, the two bodies of water being separated by a movable block located at the lower end of Calcasieu Lake. The tide control mechanism was then started and the block was removed, the fresh-water inflow weirs having been adjusted to reproduce the desired inflow for that particular test.

It is obvious that conditions in any tidal stream in nature represent an adjustment between the forces of fresh-water flow and those of tidal flow. It can be readily understood, therefore, that these forces in the model must be allowed to adjust themselves before a state of stabilization is reached. In the model, where factors affecting the adjustment between these forces are controlled, as they are not in the prototype, such a state of stabilization is characterized by the repetition of the action of the salt-water wedge during successive cycles of operation. When the position of the wedge becomes stable, or the advance and retreat of the wedge with tidal action is constant, the wedge may then be considered to have penetrated as far into the river as it will for the conditions reproduced.

For verification of the Calcasieu River model, the conditions of tidal action, fresh-water inflow, and gulf salinity were reproduced in the model in accordance with prototype data obtained during the field survey of the prototype previously mentioned. After the model was operated through the stabilization period, salinity samples were obtained at all stations and depths corresponding to the stations and depths at which prototype measurements were obtained. The results obtained from the model were then compared to data obtained in the prototype for similar

TABLE I

SALINITY MEASUREMENTS -- VERIFICATION TEST

Salinity values are expressed in parts per million
and represent average of all samples obtained during one tidal cycle

Salinity Station	Depth Sample Taken	Average Salinity for one Tidal Cycle: Model	Average Salinity for one Tidal Cycle: Prototype
1	0.0	2,360	3,280
1	-15.0	5,625	5,290
1	-30.0	14,790	12,670
2	0.0	500	430
2	-14.0	500	430
2	-28.0	12,340	9,740
3	0.0	400	330
3	-16.0	500	418
3	-31.0	14,520	7,150
4	0.0	75	73
4	-15.0	80	74
4	-30.0	85	76
5	0.0	400	320
5	-6.0	400	319
5	-12.0	400	322
6	0.0	700	657
6	-14.0	700	669
6	-27.0	2,000	1,968

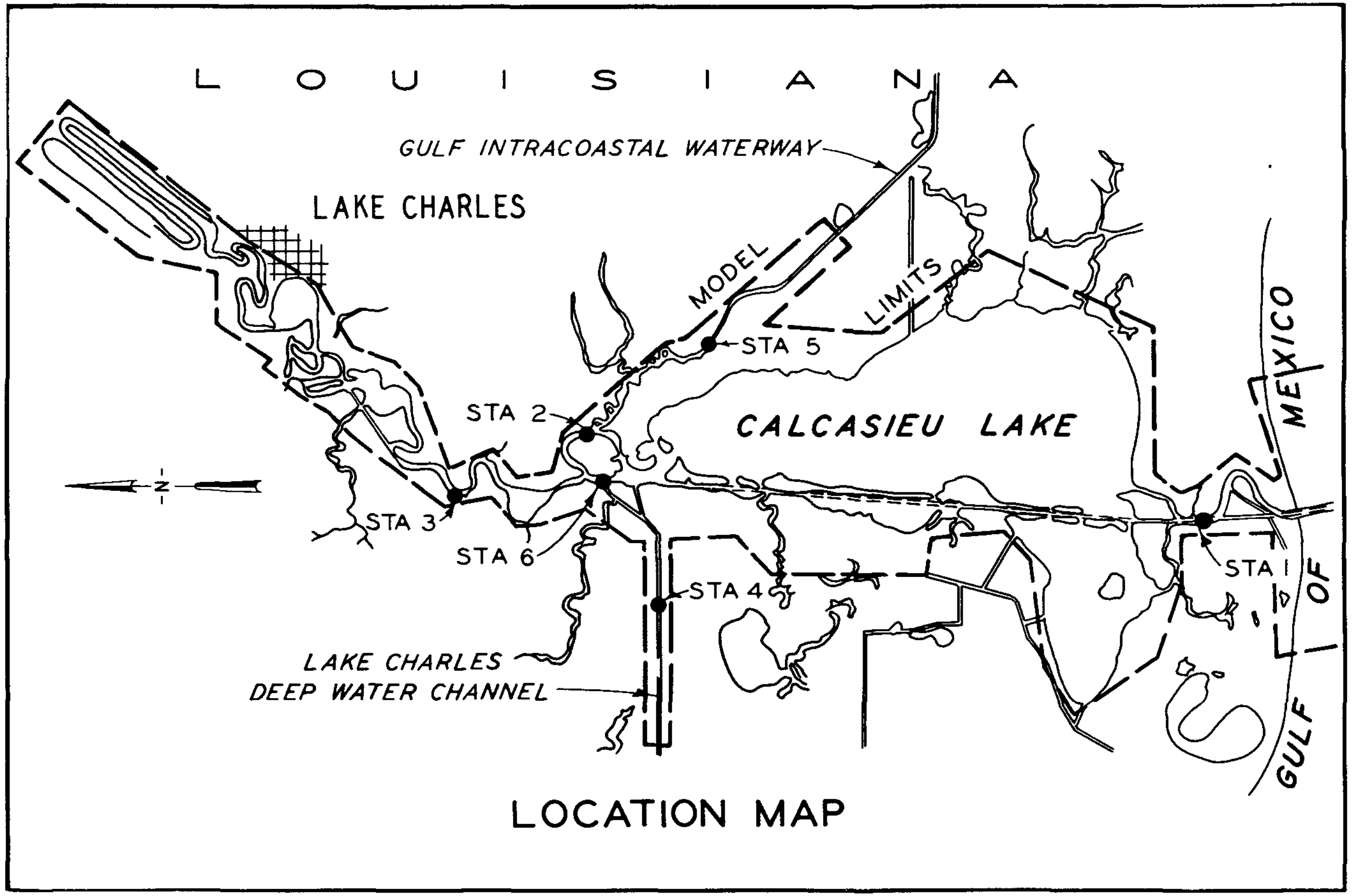

Fig. 5. This shows the location of the Calcasieu River, Louisiana, and connecting waterways, the limits of the Calcasieu River model, and the location of salinity stations at which comparable model and prototype salinity verification data were obtained.

conditions (table 1), and it was found that salinities in the model checked those obtained in the prototype with a remarkable degree of accuracy. The verification test was repeated several times to insure that identical and consistent results would be obtained.

After the verification of the model had been established, extensive salinity measurements were obtained for a series of fresh water river discharges and a series of eastward and westward flows in the Gulf Intracoastal Waterway. These various test conditions were selected with a view toward obtaining salinity data for any combination of flow which might be expected to occur in the prototype. Sufficient data were obtained during each test to serve as a basis for comparison of the results of later tests made after deepening the project channel. After all tests of the existing channel had been completed, the model channel was deepened to the new project and the series of tests was repeated. It was found that deepening the channel had very little effect on salinities in the Calcasieu River or in the Gulf Intracoastal Waterway east of the Calcasieu. Slight local differences were noted, usually occurring at middepth of the channel; however, there was no apparent overall change in salinities.

Following a thorough analysis of the results of all model tests, it was concluded that the proposed channel deepening would have no adverse effects on salinity intrusion in the Calcasieu River and the Intracoastal Waterway east of the Calcasieu. Since salinity intrusion for the 30-ft channel caused a serious problem at certain times, it was further concluded that a guard lock in the waterway should be constructed to alleviate this condition. A guard lock was constructed in the Intracoastal Waterway near Black Bayou, and it is the understanding of the writer that this lock has been very successful in preventing contamination of irrigation water therein by the intrusion of salt water from the Calcasieu River.

CONCLUDING REMARKS

This paper has covered only the general aspects of salinity problems and possible solutions, and was prepared to stimulate the thinking of other engineers in this respect rather than to show how salinity problems should be solved. The people of this country, especially the engineers, are constantly devoting more and more thought to water conservation and proper use of water, and it is the writer's opinion that salinity problems will receive more attention and study as inland sources of water are gradually developed to the fullest extent possible. The day may soon arrive when we, like the Dutch, will find it necessary or profitable to reclaim marginal land from the sea by the exclusion of salt water, and in doing so it is inevitable that new and startling engineering solutions will be developed.

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