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Underwater Sill Construction for Mitigating Salt Wedge Migration on the Lower Mississippi River

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WES

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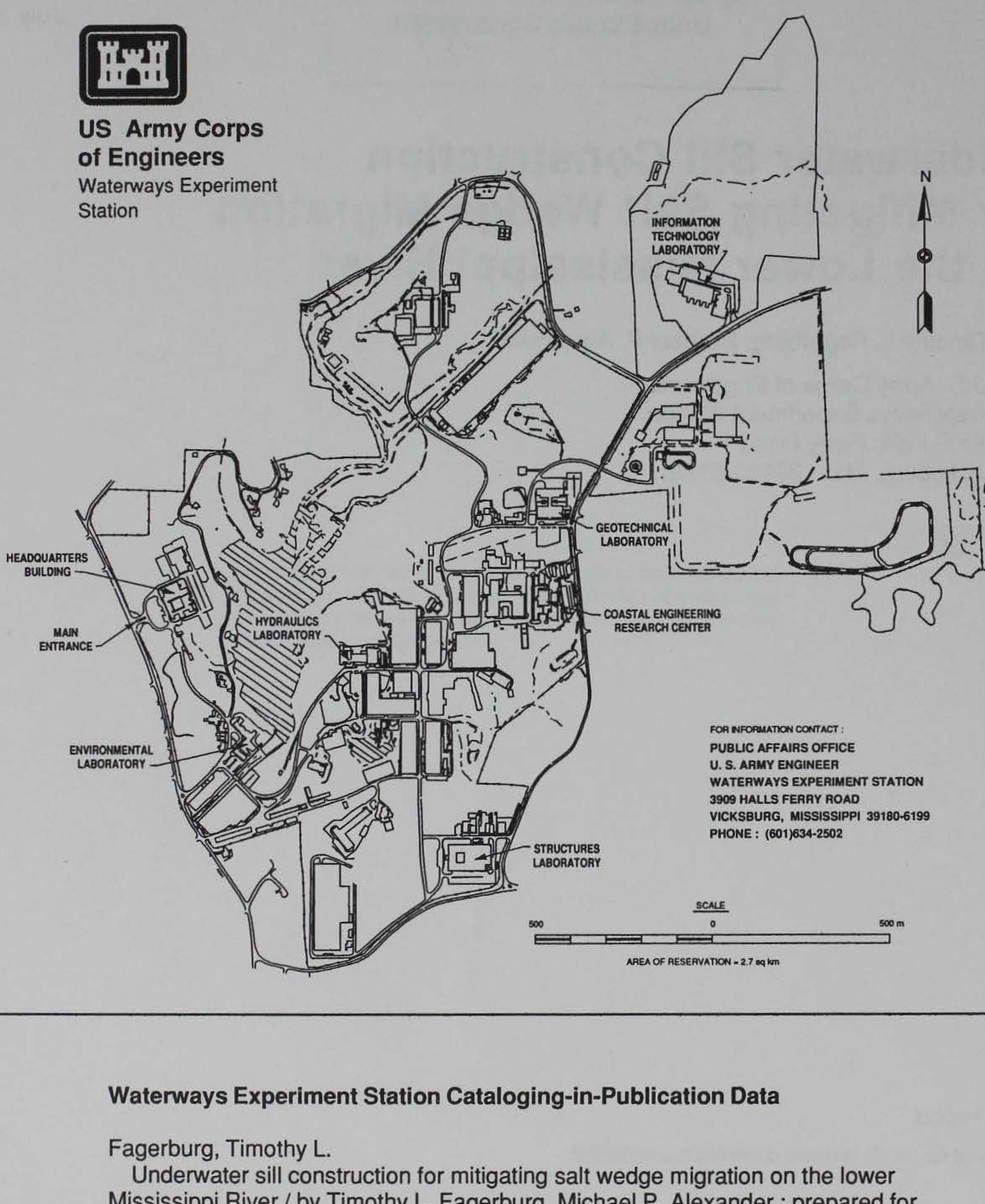

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Contents

Preface

The report herein was compiled during October 1990-October 1991 by the U.S. Army Engineer Waterways Experiment Station (WES), Vicksburg, MS, as part of CWIS Work Unit 32456, "Salinity Intrusion and Mitigation." This effort was funded by the U.S. Army Corps of Engineers Navigation Hydraulics Research Program.

Personnel of the WES Hydraulics Laboratory (HL) Estuaries Division (ED) Estuarine Processes Branch (EPB) and Estuarine Engineering Branch (EEB) performed the work under the general supervision of Messrs. F. A. Herrmann, Jr., Director, HL; R. A. Sager, Assistant Director, HL; W. H. McAnally, Chief, ED; G. M. Fisackerly, Chief, EPB; W. D. Martin, Chief, EEB; and T. J. Pokrefke, Navigation Hydraulics Research Program Manager. Technical Monitor of the Navigation Hydraulics Research Program was Mr. Glenn Drummond, Headquarters, U.S. Army Corps of Engineers. The report was prepared by Messrs. T. L. Fagerburg, EPB, and M. P. Alexander, EEB.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Bruce K. Howard, EN.

Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
cubic feet	0.02831685	cubic meters
feet	0.3048	meters
gallons (U.S. liquid)	3.785412	cubic decimeters
miles (U.S. statute)	1.609347	kilometers

1 Introduction

The Mississippi River discharges into the Gulf of Mexico through three major outlets or passes (Figure 1). The navigation depth maintained through Southwest Pass makes it the primary avenue of salt water intrusion toward New Orleans, LA. Because salt water is more dense than fresh water, it moves upstream in the form of a wedge along the bottom of the Mississippi River channel. Prior to 1987, the Mississippi River channel through Southwest Pass was maintained at a depth of 40 ft[1] below mean low water (mlw). Plans were developed in the early 1980's to provide deeper draft access to the ports of New Orleans and Baton Rouge, LA, and Southwest Pass was deepened from -40 ft mlw to -45 ft mlw in 1987. Historical evidence identifies channel deepening as a major cause of increases in frequency and duration of salinity intrusion events[2] along the Lower Mississippi River channel. The potential effects of salinity intrusion on water supplies were recognized, and engineering measures capable of mitigating water quality problems were included with channel deepening design studies. The most feasible plan to prevent severe water supply degradation was determined to be an underwater berm, or sill, constructed across the riverbed.

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[1] A table of factors for converting non-SI units of measurement to SI units is found on page v.

[2] C. W. Soileau, B. J. Garrett, and B. J. Thibodeaux. (1989). "Drought-induced saltwater intrusion on the Mississippi River," US Army Engineer District, New Orleans, New Orleans, LA.

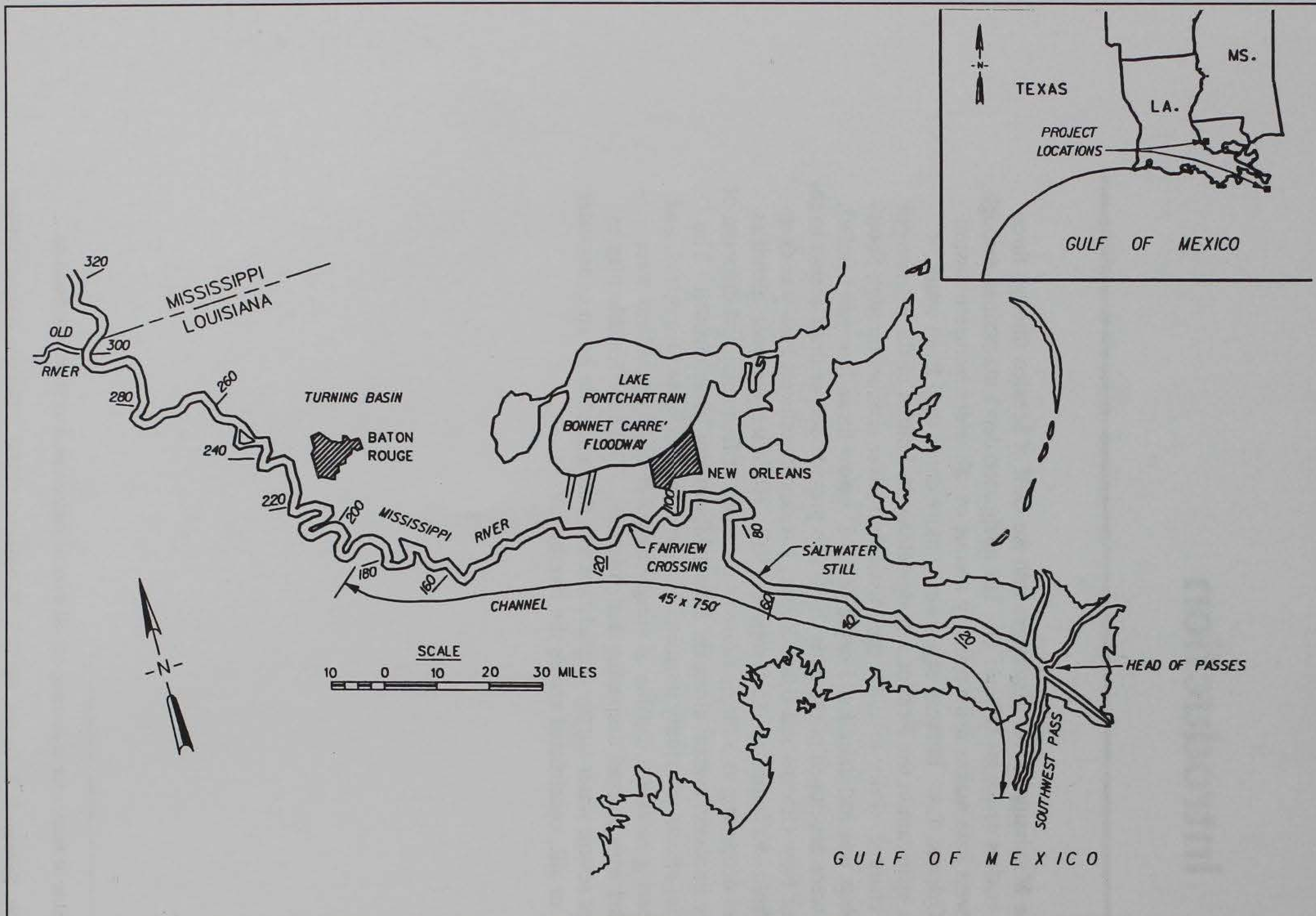

Figure 1. Project location map

2 Salinity Intrusion

Salt Wedge Migration

Many factors can influence the distance up the Mississippi River that a saltwater wedge moves, but the most significant variable effect on salt wedge migration is the volume of riverflow. Movement of the salt wedge has been correlated to the volume of riverflow using historical low-flow events. Discharges of 300,000 cfs or greater will prevent saltwater intrusion into the entrance of Southwest Pass. As flows drop to around 250,000 cfs, salt intrusion will reach the Head of Passes, which is the point of major trifurcation along the Lower Mississippi River (Figure 1). Distances are commonly measured in miles above the Head of Passes (AHP). Figure 2 relates minimum river discharge and salt wedge migration. Flow durations were not factored into this plot, but it serves as a useful estimate for forecasting saltwedge migration.

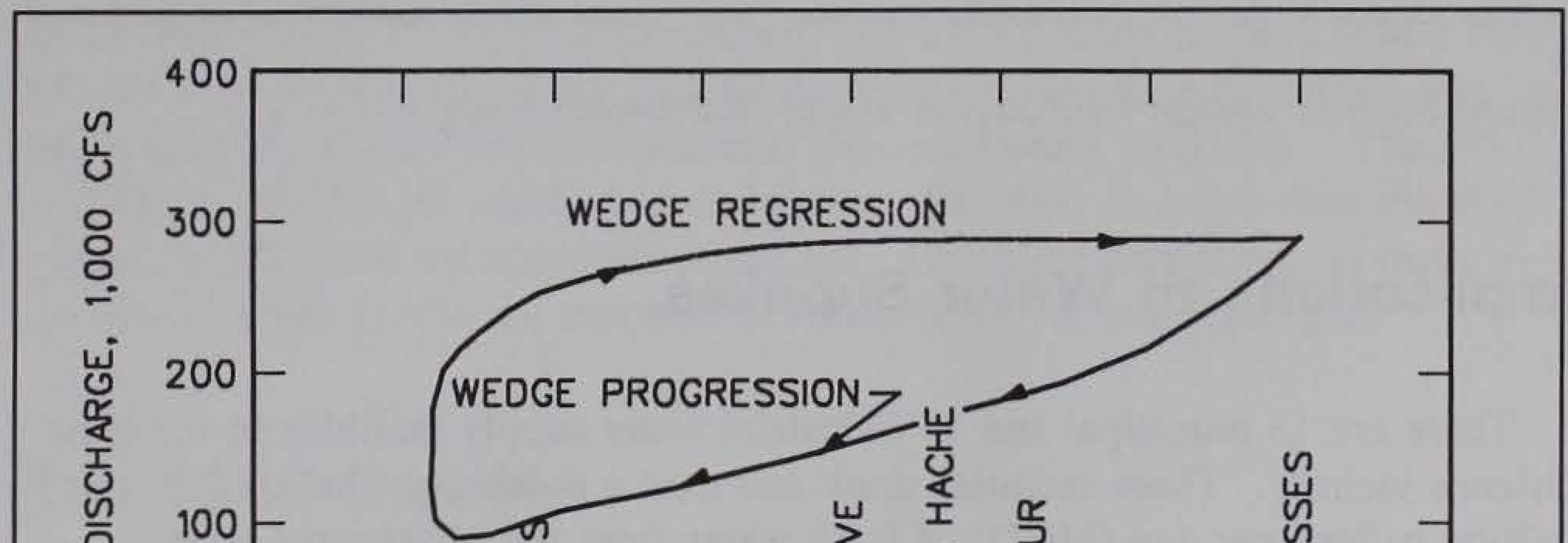

Figure 2. Salt wedge position in relation to low riverflow

Because the mixing between salt and fresh water at Southwest Pass is relatively slight, the interface between the salt and fresh water along the channel is very distinguishable. In this regard, Southwest Pass is an example of a highly stratified estuary. Figure 3 depicts the characteristics of flow stratification at Southwest Pass. At point A in Figure 3, the direction of flow is toward the Gulf of Mexico throughout the vertical profile. Downstream to point B, the flow in the upper water column is still toward the Gulf, but the lower levels comprise a zone of upstream saltwater flow. There is a constant upstream flow in the salt zone, even when the wedge location is stable. This is due to the constant downstream current at the freshwater-saltwater interface.

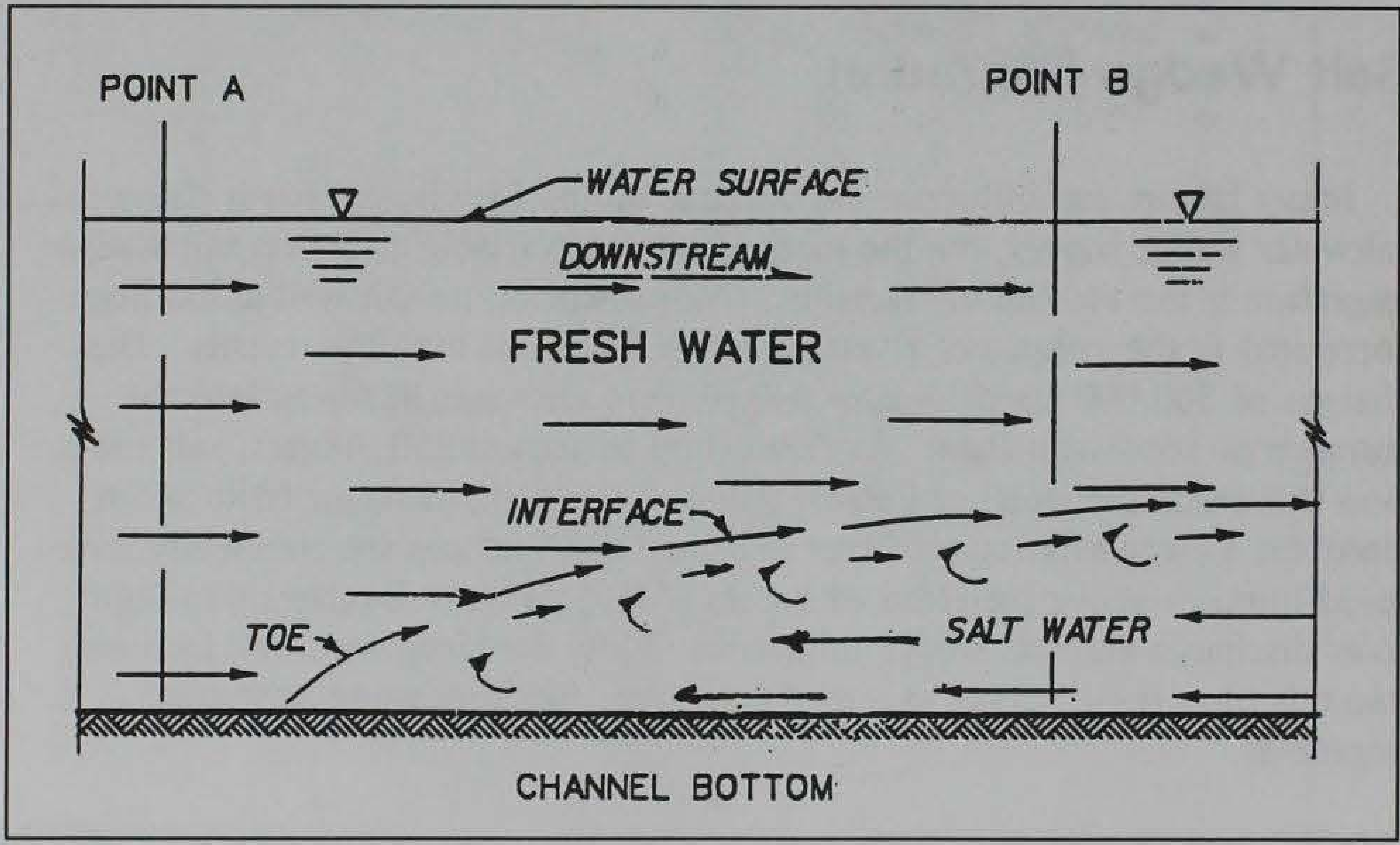

Figure 3. Salt wedge hydrodynamics at Southwest Pass

Implications to Water Supplies

There are 13 municipal and 15 industrial water supply facilities in the New Orleans vicinity. These facilities draw and treat a combined total of 468 million gallons per day (MGD) of fresh water from the Mississippi River. Desalinization procedures are very expensive, and none of the treatment plants incorporate salinity removal. The Federal drinking water standard for salinity is set at 250 parts per million (ppm) of chloride ion (Cl^-). Treatment plant water intakes are located near the water surface of the river, and the drinking water salinity standard is reached at the river surface at a distance of approximately 20 miles downstream from the salt wedge toe (Figure 3). During extreme low flows on the Mississippi, salinity intrusion up to the New Orleans area has the potential to create serious water supply problems.

3 Salinity Intrusion Mitigation

Sill Design

The contingency plans for a saltwater barrier sill were developed based on studies at the US Army Engineer District, New Orleans, and at the US Army Engineer Waterways Experiment Station. The effectiveness of a salt barrier sill was evaluated from a numerical model of the Lower Mississippi River using pre- and post-channel-deepening conditions in conjunction with the then-proposed 45-ft channel project. The sill height was designed to create a large reservoir to collect and hold saltwater for a period of time equal to the increase in duration of salt water intrusion caused by channel deepening. The numerical model was verified using hydrologic and hydrographic data collected in 1981. Historical salinity intrusion events were then used to develop a salinity intrusion mitigation plan using an underwater sill. Modeling results were consistent with each historical event modeled. Figure 4 shows the results from a model repeat of the 1953-54 drought year hydrograph for a 40-ft-deep channel, a 45-ft-deep channel, and a 45-ft-deep channel with a sill located at mile 63 AHP. The original design crest elevation of the sill was -60 ft referred to the National Geodetic Vertical Datum (NGVD). The sill with the 45-ft channel resulted in an intrusion of lesser duration than the 40-ft channel at all locations upstream of the sill. Complete details on the numerical model development are reported in Johnson, Boyd, and Keulegan.[1]

The 1988 Drought

A full-scale test was planned to verify sill performance in the river and to convince local governments that the salt wedge mitigation plan was both feasible and effective. A successful test would also assure local governments that implementation procedures could result in timely construction. However, the first water level decline following channel deepening that warranted a sill test was associated with the 1988 drought. Figure 5 shows the six worst

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[1] B. H. Johnson, M. B. Boyd, and G. H. Keulegan. (1987). "A mathematical study of the impact on salinity intrusion of deepening the Lower Mississippi River Navigation Channel," Technical Report HL-87-1, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

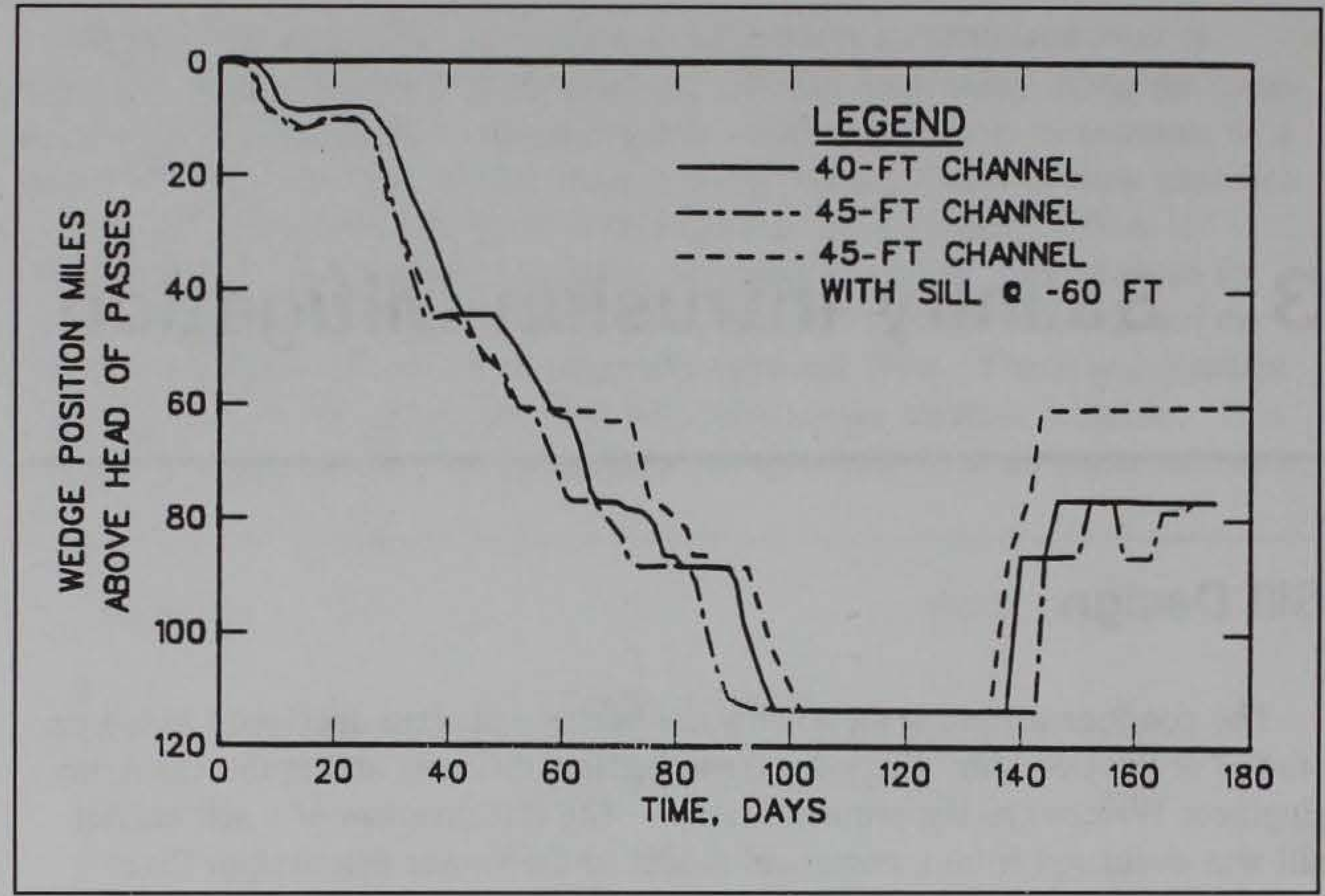

Figure 4. Model results of salt wedge position for project depths with and without the salt barrier sill

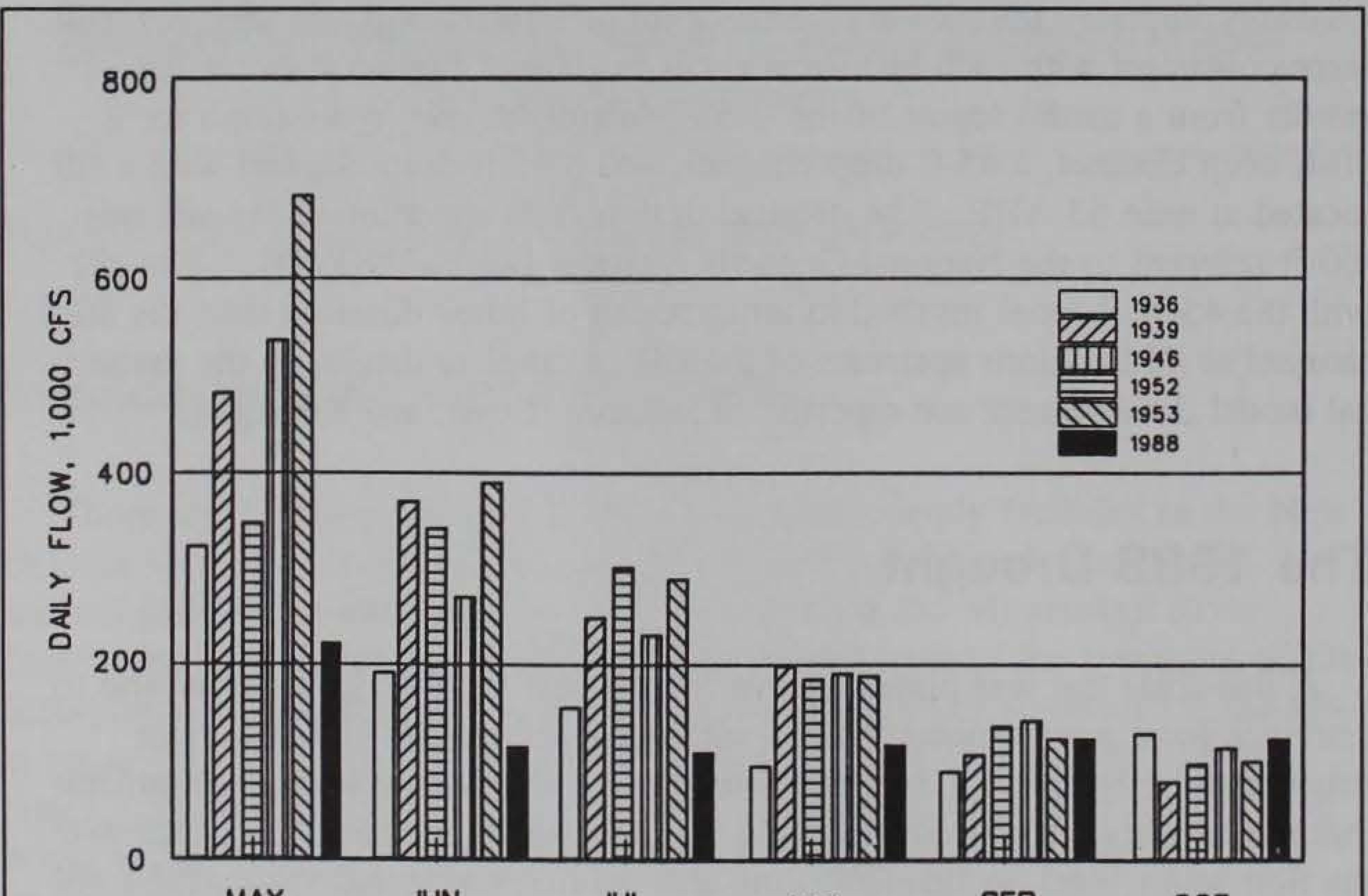

Figure 5. Records of the six worst low-flow events on the Mississippi River

low-flow events of record along the Lower Mississippi River. The 1988 event produced the lowest average monthly flows for May, June, and July, and was only slightly surpassed by the 1936 event for the months of August and September. The 1988 drought also caused the longest duration of low flows compared with other low-flow events. The 1988 drought proved to be a challenging field verification for any salt wedge migration abatement plan. This event caused the field verification to become an emergency mitigation measure.

Essential Elements for Sill Construction

Construction time for the sill was estimated at 4-6 weeks. The key factor in the plan was to commence and complete construction in enough time to intercept the salt wedge. The decision to implement the plan would be based on river stage predictions that indicated imminent water quality problems. Reliable river stage forecasts can be made for periods of up to 10 days with an estimated outlook for about another 20 days.[1] Since the toe of the salt wedge can advance 2-3 miles per day, it was necessary to have contractual and logistical arrangements completed quickly. The sill location had to be planned to successfully intercept saltwater flow, and the sill also had to be located near an adequate borrow area, preferably containing medium to coarse sand.

Underwater Sill Specifications

The New Orleans District began monitoring salinity intrusion in May of 1988. By June, it was obvious that the salt wedge was migrating upstream at an alarming rate and that mitigation plans should be enacted. On 25 June 1988 the decision was made to construct the sill at river mile 63 AHP, and dredging began on 1 July. At this time the salt wedge toe had migrated to river mile 80, well above the sill location. Since the sill location at 63 miles AHP was designed to precede salt wedge arrival, the original sill design elevation of -60 ft NGVD was raised to -55 NGVD to shut off saltwater flow and stabilize the upstream salt wedge location. On 6 July the Governor of Louisiana declared the area to be in a disaster status and requested the Corps to further increase the height of the sill to assure complete saltwater containment below the sill. Corps representatives agreed, provided that the sill height would not impede navigation, additional construction funds could be authorized, and sufficient borrow material was available. On 8 July 1988 orders were issued to the contractor to continue sill construction to a height of -45 ft NGVD. The sill height was completed to -55 ft by 10 July and to -45 ft on 22 July. Full crown width was completed on 1 August. Figure 6 depicts the sill across the river bottom. Sill specifications were as follows:

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[1] C. W. Soileau, B. J. Garrett, and B. J. Thibodeaux, op. cit.

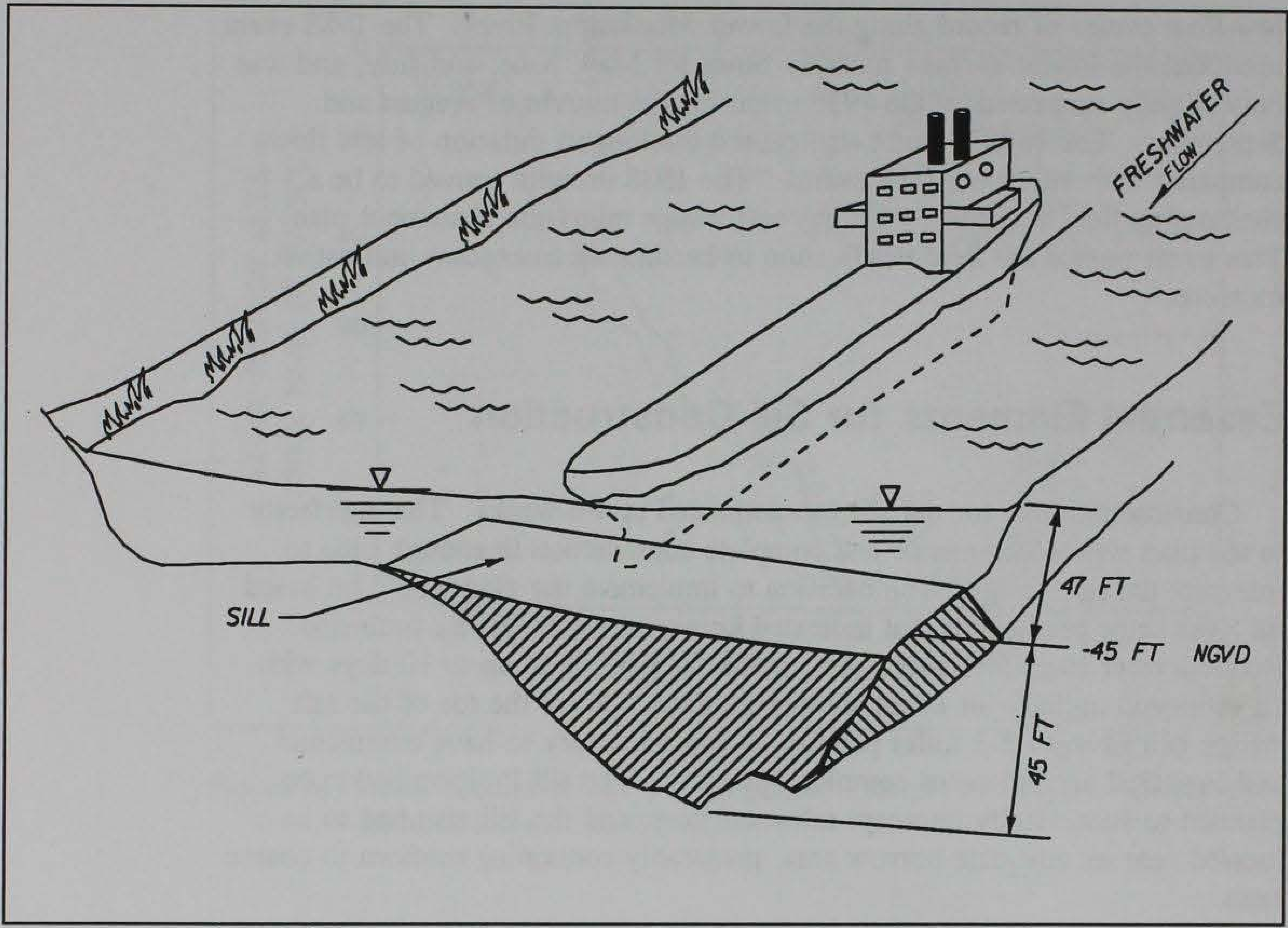

Figure 6. Salt barrier sill in the Mississippi River

Top Elevation	-45 ft NGVD
Overall Length across Crown	1,670 ft
Average Height above River Bottom	25 ft
Maximum Height above River Bottom (See Figure 6)	45 ft
Crown Width	30-115 ft
Average Side Slopes	1V:7H
Volume of Material Pumped to Sill	850,000 cu yd
Volume Retained in Sill	470,000 cu yd
Cost of Construction	$790,000

Underwater Sill Project Success

The toe of the salt wedge was arrested at river mile 104.5 AHP on 11 July. Sill construction was still in progress, but the sill height at this time was up to -55 ft NGVD. The arrested salt wedge toe location was adjacent to water intakes serving approximately 1 million people. At this time and with continued construction to -45 ft NGVD the sill had effectively shut off upstream salt wedge migration. The wedge began to recede by 14 July and became discontinuous above the sill by 11 August. The toe of the wedge was difficult to locate at this time because of pockets of salt water trapped in deeper holes along the channel thalweg. The sill had effectively preserved water quality for the New Orleans vicinity.

Sill Stability

Original design concerns included possible sill erosion due to river currents. The original design was evaluated with a sediment transport model to determine its stability.[1] Model analyses included steady-state discharges ranging between 200,000 and 800,000 cfs simulated for periods of 150 days. The following depths of material were eroded off the crest of the sill:

Discharge, cfs	Erosion, ft
200,000	0.02
300,000	1.4
400,000	2.0
450,000	5.0

The sill was considered stable for discharges below 400,000 cfs. Between 31 July and 14 November 1988 there was no significant loss of height or other impairment to the sill function due to erosion. It was not until higher river discharges recurred in late November that the sill began to erode. This postdrought sill erosion was intended to prevent any backwater effects during flood events.

Barging Water to Communities Downstream of the Sill

It was not practicable nor possible to prevent salinity intrusion to all water intakes along the Lower Mississippi River, but plans were made to barge sufficient volumes of fresh water to these communities for diluting their supply within acceptable drinking water standards or for direct treatment. These users are located at miles 49 and 18.6 AHP. At the same time that the sill contract was awarded, a sufficient number of certified water barges were secured for transporting salt-free river water to the downstream communities.

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[1] R. W. Copeland, 1983, "Sill Stability Results," Memorandum for Record, Hydraulics Laboratory, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

The barges were filled at the New Orleans District reservation and then transported downstream. The freshwater barging operation fully met the municipal water needs for downstream communities.

4 Conclusions

The mathematical model predictions of sill performance were accurate and the sill design and construction resulted in successfully preventing contamination of the New Orleans water supplies. The sill stability predictions were also accurate, and the project demonstrated that the sill will remain stable through sustained drought-induced low flows. This chronology of modeling, design, and construction can confidently be applied to other stratified estuarine systems when similar salinity intrusion problems develop.

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13. ABSTRACT *(Maximum 200 words)*

The Mississippi River is a major navigable waterway between New Orleans, LA and the Gulf of Mexico. The navigation channel through the delta area of the Mississippi River is through Southwest Pass, and the channel depth maintained for navigation makes it the primary avenue of saltwater intrusion from the Gulf toward New Orleans. Salt water is more dense than fresh water and moves upstream along the bottom in the form of a wedge. Historical evidence indicates that channel deepening increases the frequency of salinity intrusion events. Decreased river discharges during drought periods also contribute to the duration and distance upstream of a saltwater wedge intrusion unless efforts are taken to mitigate the event. The report presents a brief summary of the causes of the 1988 salinity intrusion event that threatened the water supplies of New Orleans, the emergency efforts undertaken to halt the salt wedge migration, and the success of those efforts.

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