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A NUMERICAL MODEL ANALYSIS OF MISSISSIPPI RIVER PASSES NAVIGATION CHANNEL IMPROVEMENTS

Report 5

THREE-DIMENSIONAL NUMERICAL MODEL RESULTS

by

D. R. Richards, D. P. Bach

Hydraulics Laboratory

DEPARTMENT OF THE ARMY
Waterways Experiment Station, Corps of Engineers
PO Box 631, Vicksburg, Mississippi 39181-0631

US Army Corps of Engineers

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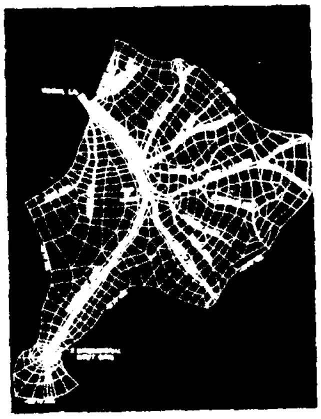

September 1988
Report 5 of a Series

Approved For Public Release, Distribution Unlimited

HYDRAULICS LABORATORY

Prepared for US Army Engineer District, New Orleans
New Orleans, Louisiana 70160-0267

88 10 31 161

Unclassified
SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION
Unclassified

1b. RESTRICTIVE MARKINGS

2a. SECURITY CLASSIFICATION AUTHORITY

2b. DECLASSIFICATION / DOWNGRADING SCHEDULE

3. DISTRIBUTION / AVAILABILITY OF REPORT
Approved for public release;
distribution unlimited

4. PERFORMING ORGANIZATION REPORT NUMBER(S)
Miscellaneous Paper HL-87-2

5. MONITORING ORGANIZATION REPORT NUMBER(S)

6a. NAME OF PERFORMING ORGANIZATION
USAEWES
Hydraulics Laboratory

6b. OFFICE SYMBOL *(If applicable)*
CEWES-HE-E

7a. NAME OF MONITORING ORGANIZATION

6c. ADDRESS *(City, State, and ZIP Code)*
PO Box 631
Vicksburg, MS 39181-0631

7b. ADDRESS *(City, State, and ZIP Code)*

8a. NAME OF FUNDING / SPONSORING ORGANIZATION
USAED, New Orleans

8b. OFFICE SYMBOL *(If applicable)*

9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER

8c. ADDRESS *(City, State, and ZIP Code)*
PO Box 60267
New Orleans, LA 70160-0267

10. SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT ACCESSION NO.

11. TITLE *(Include Security Classification)*
A Numerical Model Analysis of Mississippi River Passes Navigation Channel Improvements; Three-Dimensional Numerical Model Results

12. PERSONAL AUTHOR(S)
Richards, D. R.; Bach, D. P.

13a. TYPE OF REPORT
Report 5 of a series

13b. TIME COVERED
FROM ______ TO ______

14. DATE OF REPORT *(Year, Month, Day)*
September 1988

15. PAGE COUNT
22

16. SUPPLEMENTARY NOTATION
Available from National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

17. COSATI CODES

FIELD	GROUP	SUB-GROUP

18. SUBJECT TERMS *(Continue on reverse if necessary and identify by block number)*
Estuary
Mississippi River
Navigation channel
Numerical model

19. ABSTRACT *(Continue on reverse if necessary and identify by block number)*

Southwest Pass of the Mississippi River, where it meets the Gulf of Mexico, was modeled using a three-dimensional numerical model as a part of an extensive testing program to determine the effects of deepening the Mississippi River navigation channel. The three-dimensional finite element model, RMA-10, was used to duplicate the complex salinity and velocity conditions experienced at the Mississippi River entrance.

20. DISTRIBUTION / AVAILABILITY OF ABSTRACT
☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS

21. ABSTRACT SECURITY CLASSIFICATION
Unclassified

22a. NAME OF RESPONSIBLE INDIVIDUAL

22b. TELEPHONE *(Include Area Code)*

22c. OFFICE SYMBOL

DD Form 1473, JUN 86

Previous editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE
Unclassified

Preface

The study described herein was conducted during 1985-1987 for the US Army Engineer District, New Orleans, by personnel of the Hydraulics Laboratory (HL) of the US Army Engineer Waterways Experiment Station (WES) under the general supervision of Messrs. H. B. Simmons and F. A. Herrmann, Jr., former and present Chiefs, respectively, of HL, and R. A. Sager and W. H. McAnally, former and present Chiefs, Estuaries Division (ED). The study was performed and this report written by Messrs. D. R. Richards and D. P. Bach, ED. It is the fifth in a series of reports listed below.

COL Dwayne G. Lee, EN, is the Commander and Director of WES. Dr. Robert W. Whalin is the Technical Director.

Reports in this series:

Report 1: 55-Foot Channel Tests

Report 2: 45-Foot Channel Tests and Flow Diversion Schemes

Report 3: Bank Breaching Without Supplement 2

Report 4: Two-Dimensional Hydrodynamic and Sediment Transport Verification

Report 5: Three-Dimensional Numerical Model Results

Contents

Conversion Factors, Non-SI to SI (Metric) Units of Measurement

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

Multiply	By	To Obtain
cubic yards	0.7645549	cubic metres
feet	0.3048	metres
miles (US statute)	1.609347	kilometres

A NUMERICAL MODEL ANALYSIS OF MISSISSIPPI RIVER PASSES NAVIGATION CHANNEL IMPROVEMENTS

THREE-DIMENSIONAL NUMERICAL MODEL RESULTS

Introduction

1. Southwest Pass of the Mississippi River is the major navigation entrance serving the interior United States. Along with the vast amount of shipping that uses the main navigation channel comes drainage and sediment from the interior as well. Large amounts of dredging have been required historically to keep the Mississippi River open to navigation and this is illustrated clearly in the dredging quantities required in Southwest Pass. The annual dredging requirements averaged 22 million cubic yards* during the period 1975 through 1985.

2. Many engineering solutions have been attempted to minimize the shoaling problems in Southwest Pass. Pile dikes and bulkheads have been used extensively over the length of the pass to stabilize the banks and protect against blowouts (Figure 1). Nourishment of the banks with dredged material has assisted in minimizing erosion of the banks due to a variety of forces including wave attack and subsidence. Channel realignments have been attempted after they were suggested by some of the earliest physical model studies. Perhaps the most controversial studies recommend structures that reroute the main navigation channel itself or cause significant flow and sediment diversions from the existing flow distributions at Head of Passes. Each of these has its merits but must be weighed against the requirements of existing economic and environmental sensitivities.

3. The New Orleans District (NOD) developed such an engineering plan for Southwest Pass with these and other concerns in mind. It can loosely be identified as the Supplement #2 improvements which include provisions for the main navigation channel being deepened to -45 ft.** Once the plan was developed, the Hydraulics Laboratory was asked to evaluate the impacts of the plan

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* A table of factors for converting non-SI units of measurement to SI (metric) units of measurement is found on page 3.

** All elevations (el) cited in this report are in feet referred to the National Geodetic Vertical Datum (NGVD).

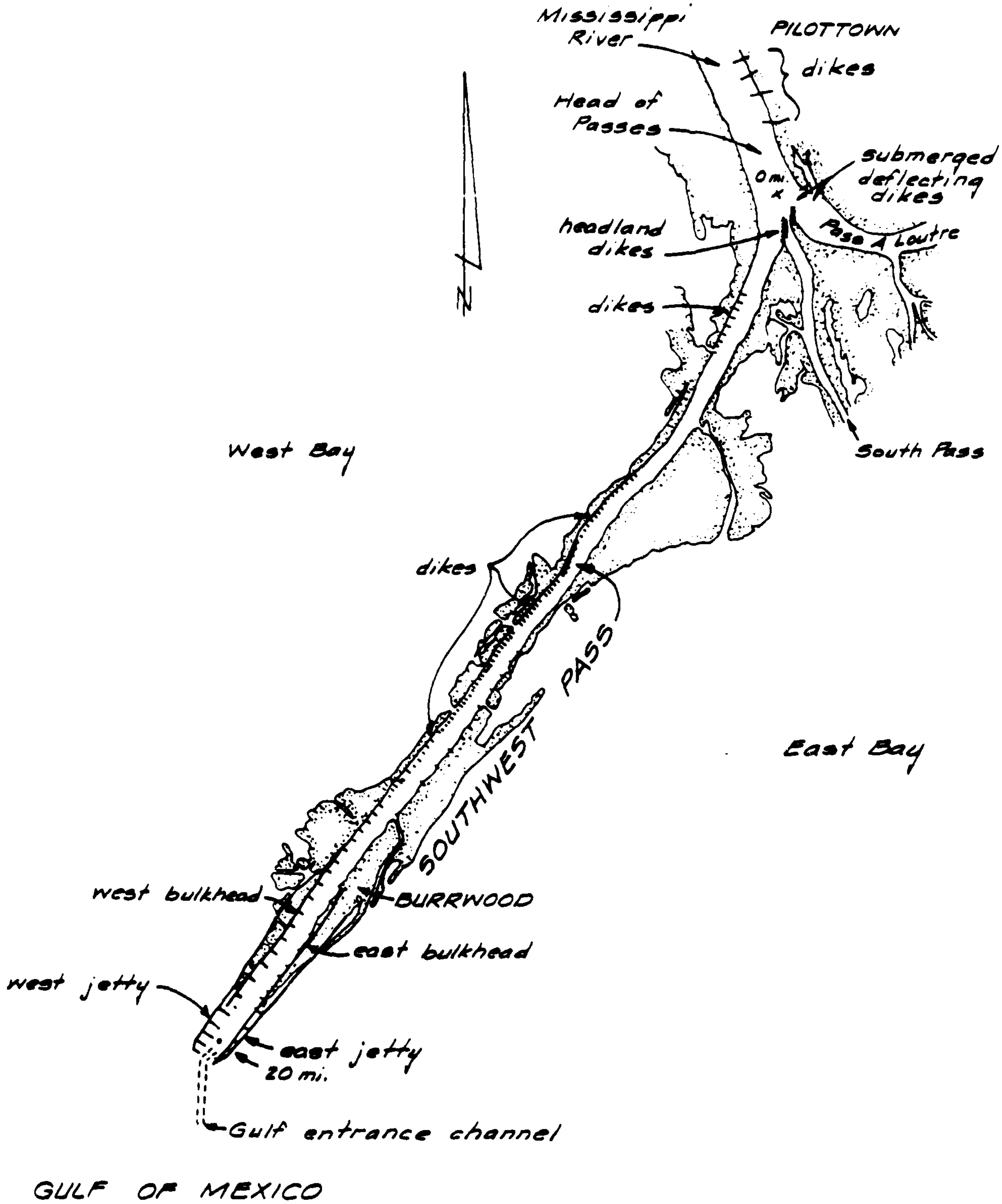

Figure 1. Southwest Pass

along with several alternatives on the hydrodynamic and sediment transport characteristics of the region. The problem was addressed using several modeling techniques including a physical model and two-dimensional (2-D) and three-dimensional (3-D) numerical models. The 2-D model RMA-2V addressed hydrodynamics in the global delta (Figure 2). This report addresses the lowest reach of Southwest Pass where it meets the Gulf of Mexico and the use of the 3-D numerical model RMA-10 in replicating 3-D hydrodynamics (Figure 2).

Prototype

4. The need for a 3-D treatment of Southwest Pass was caused by the physical processes there and by an engineering solution implemented to minimize shoaling in the entrance channel. As is the case in similar deltaic rivers, the Mississippi is able to carry its sediment load in suspension or moving on the bed until it loses flow through the outlets, enters the Gulf during high flows, or until it encounters the salinity wedge. These events result in shoaling that clogs the navigation channel. The engineering solution to minimize shoaling in the channel was developed after observations of a similar situation in South Pass. The plan involved realigning the channel seaward of the jetties so it did not bisect the zone of heaviest shoaling. In addition, the prevailing offshore currents of the Gulf of Mexico would carry a significant amount of the sediment to the west away from the channel thereby decreasing shoaling. The plan was effective but introduced an additional level of difficulty in numerical modeling of the hydrodynamics of the region.

5. For the flow conditions of interest to NOD, namely floods ranging from a yearly high to the flood of record, Southwest Pass is the most stratified major river in the United States. It approaches the classic case of an arrested saline wedge that has been studied in laboratory flumes in some detail. The trouble is that this already difficult modeling problem was accompanied by the oblique orientation of the channel to the predominant flood flows. In short, saline density currents followed the bottom in a northwesterly direction while opposed by upper currents in southwesterly direction. Currents from the physical model illustrate this point. Radical changes in depths in the region near the navigation channel cause the variations in current and salinity gradients to be abrupt rather than smooth from one portion of the region to another. Any numerical model that could accurately reproduce

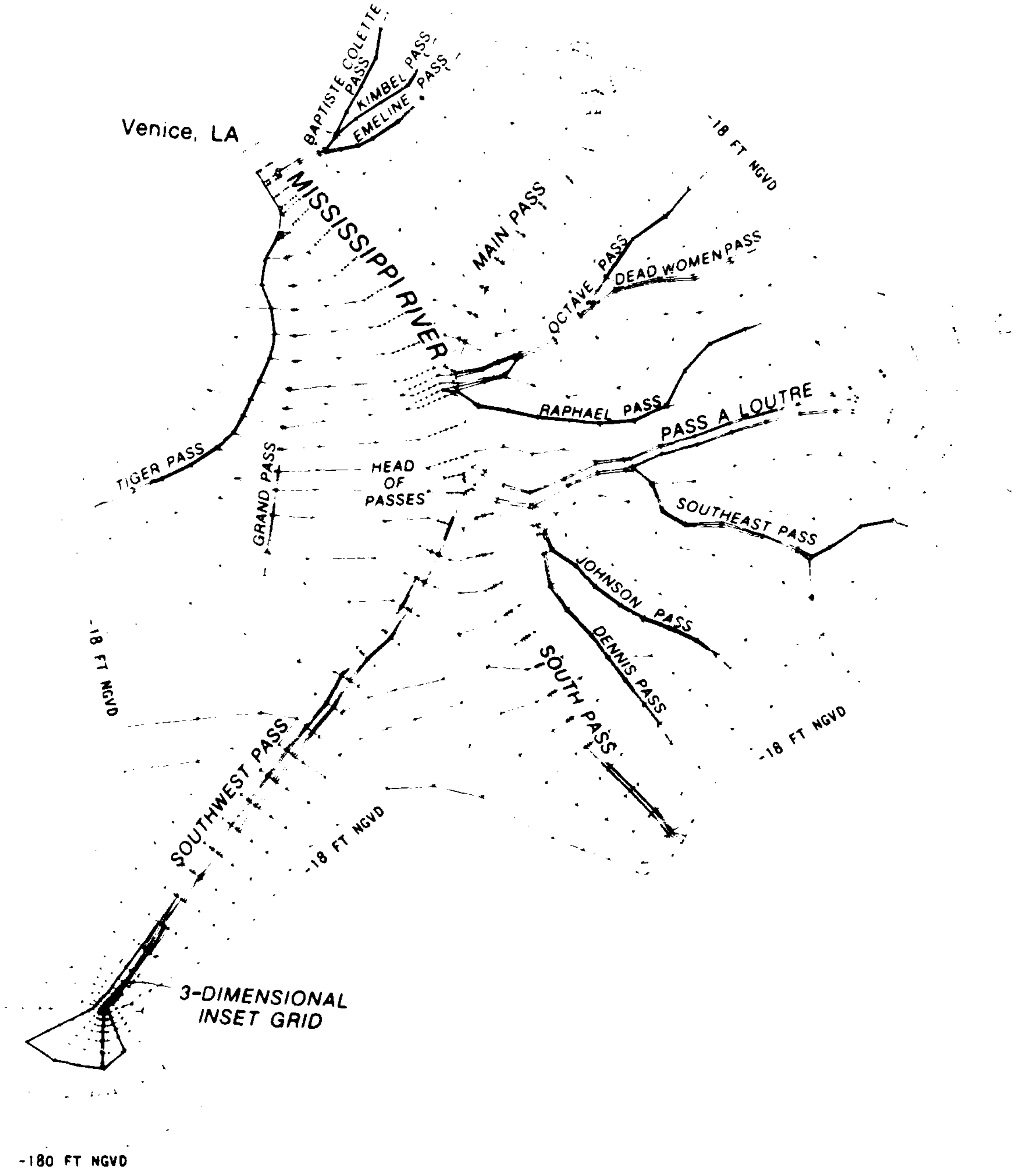

Figure 2. Mississippi River Passes 2-D numerical model grid

these gradients would have to be highly resolved with accurate boundary condition data.

Numerical Model Description

6. The 3-D numerical model RMA-10 was originally developed by Resource Management Associates (RMA) of Davis, California. Modifications have been made by the Hydraulics Laboratory for use in this particular problem, most notably in making the code compatible with the Hydraulics Laboratory's contracted Cyber 205 supercomputer. Documentation of the model, including a description of the governing equations and the finite element formulation is presented in an unpublished report by Ian P. King of RMA dated May 1982 ("Finite Element Model for Stratified Flow: RMA-10").

7. RMA-10 solves the Reynolds form of the Navier-Stokes equations in stratified flow conditions. The hydrostatic distribution of pressures in the vertical is assumed. The general approach to the formulation of RMA-10 is similar to that used in the 2-D vertically averaged model RMA-2V used for the analysis of the impacts of Supplement #2 in the global model of the Mississippi River delta. They are similar in that they both use the Newton-Raphson method of iteration, the Galerkin Method of weighted residuals, and a modified Crank-Nicholson scheme for time-stepping. As with RMA-2V, the quadratic basis elements can be either triangles or quadrilaterals. Velocities are interpolated with a quadratic scheme while head is interpolated with a linear representation. It is important to note that all simulations attempted in the course of this study were made in steady-state rather than time-varying mode.

Modeling Approach

8. Based on experiences in numerical and physical flumes and data from the physical model of Southwest Pass, a grid was designed that would accurately answer the questions posed. The lateral limits of the 3-D grid in the Gulf were located, based on the 2-D numerical modeling results, in an alignment where the currents either were parallel to the boundary or in very low velocity zones. It contained 423 horizontal elements and 4 vertical elements (Figure 3). Initial runs using this grid proved to be too costly for initial spinup and verification since the model had not yet been optimized for minimum

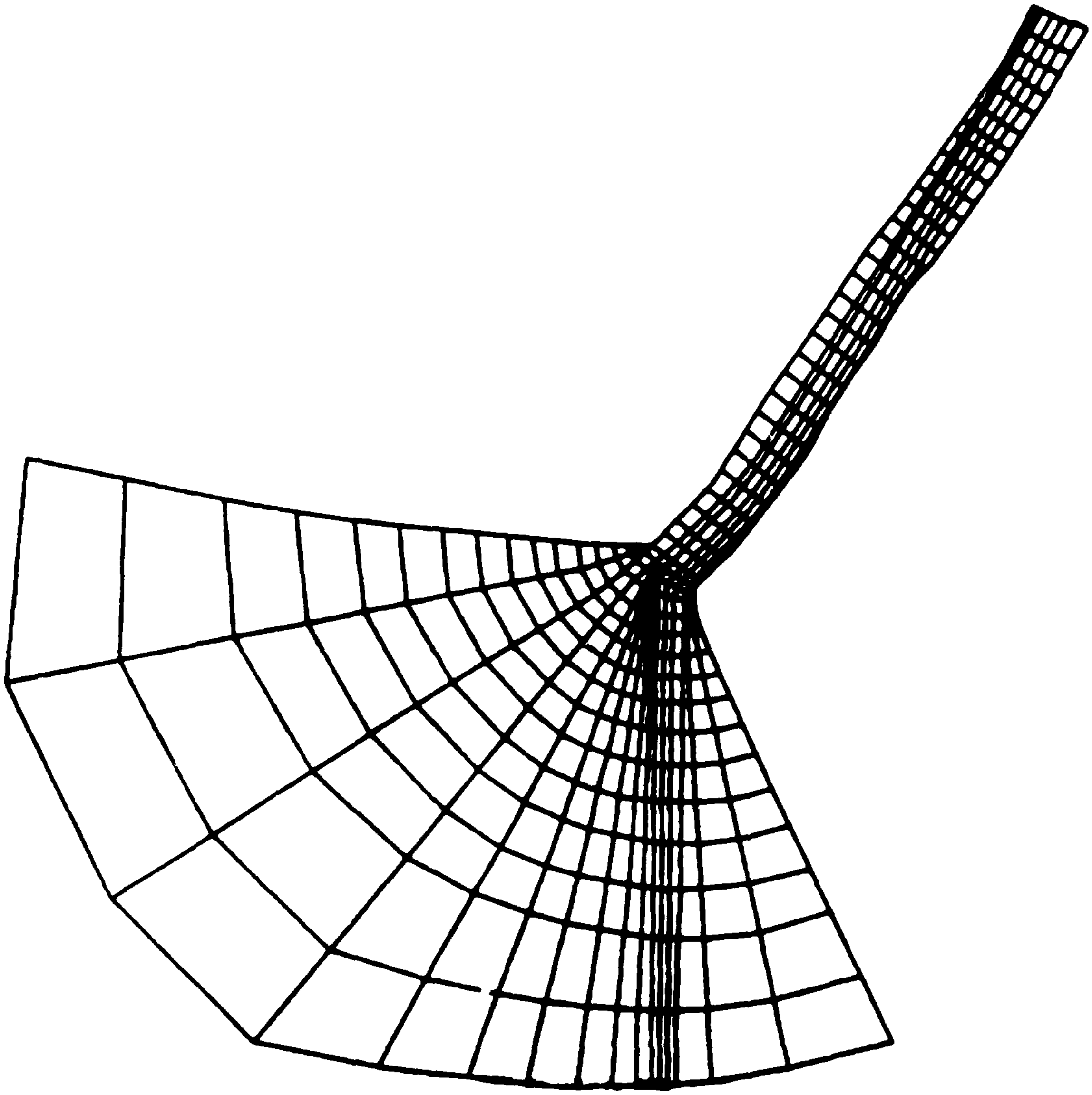

Figure 3. Southwest Pass 423 element 3-D grid

cost. Therefore, a grid with less resolution (76 by 4 elements) was developed for use in determining optimum verification coefficients and the most economical means of initializing a 3-D simulation (Figure 4). Although the original study plan called for final runs to be made on the 423 element grid, this became impossible due to time and cost constraints. The results presented herein were obtained from the schematic 76 element grid of Southwest Pass. This grid was developed from available bathymetry of Southwest Pass but is too coarse to duplicate every velocity and salinity gradient that occurs in the prototype or for that matter the physical model. It is important to note, however, that this coarse level of resolution reproduced some rather dramatic features that are seen in Southwest Pass.

Model Results

9. The boundary conditions used for the 3-D simulations were taken from the global RMA-2V grid of the delta. These included freshwater flows from the nominal 640,000-cfs discharge at Venice, minus losses in the overbank and to the other passes that were determined for the Supplement #2 conditions with the 45-ft channel depth and existing widths. A Gulf salinity of 34 ppt was specified with a slight stratification on the boundary similar to that found in the physical model. A constant Gulf water level was specified.

10. Stable solution were achieved for these boundary conditions early in the verification process, but the salinity solutions tended to be too smeared. This was caused by a combination of insufficient resolution to model the actual gradients and artificially high eddy-viscosity and diffusion coefficients that were required to maintain model stability for such a coarse model with the substantial variations in bathymetry. Once the coefficients were relaxed to a point where reasonable gradients were forming, problems were encountered in spinning up to and maintaining stable solutions in both velocities and salinities. The fact that RMA-10 solves for these in a coupled fashion makes stability difficult to maintain when the initial conditions are far from the desired solution. Attempts at decoupling the salt and velocity solutions in a fashion similar to most finite-difference models provided more stable solutions but unacceptable accuracies.

11. After considering the tradeoffs that were encountered in the various runs performed, and these are indeed encountered in most numerical

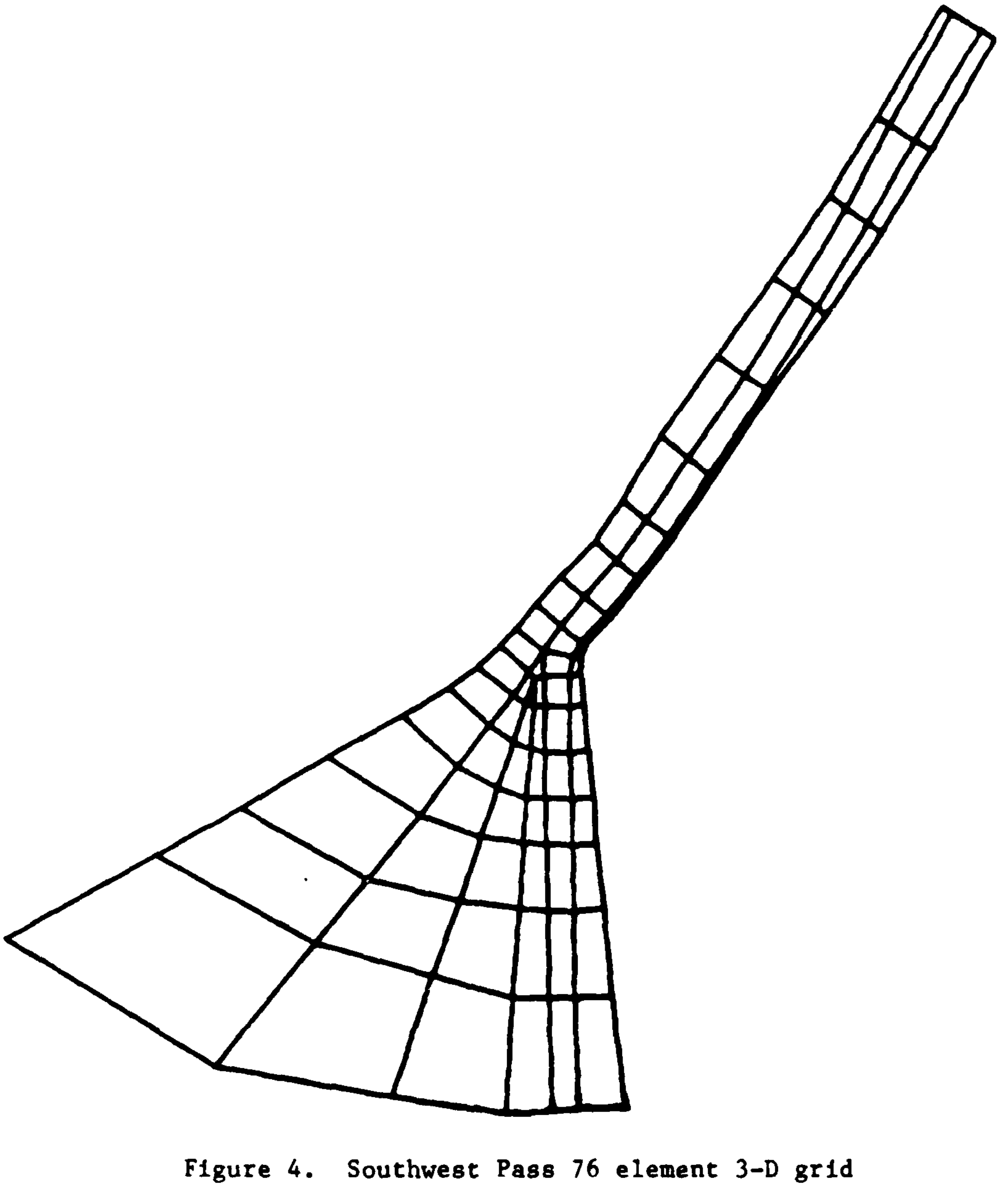

Figure 4. Southwest Pass 76 element 3-D grid

studies if not to this degree, the most realistic results were selected and they are presented herein. They demonstrate a high level of salinity stratification along with significant lateral and vertical variations in the velocity field. Plots were developed from the RMA-10 results and are presented for review.

12. A clear indication of the lateral velocity gradients can be seen in Figures 5 and 6. On the surface, a well-defined jet leaves the channel at the tip of the jetties and shoots out across the shallows formed by sediment deposition directly out from the jettied entrance. In contrast, the bottom velocities indicate that there are significant salinity density currents in the entrance channel and naturally deep water to the east. The bottom currents in the shallow bar just off the jetties still follow the direction defined by the surface jet, but this is reasonable since the water is shallow and is dominated by the freshwater flows leaving the pass. Notice that upstream of the salinity wedge the bottom currents move downstream, while beyond the jetties the bottom currents are moving upstream in the navigation channel.

13. The salinity results are consistent with the current observations. Figures 7 and 8 gives isohalines for the surface and bottom. Significant lateral variations occur in the surface and bottom values as well as variations in the amount of depth-averaged salt. The results agree with the current fields described in the previous figures. Figure 9 presents the profile of the vertical salinity structure along the navigation channel, exhibiting a highly stratified condition at the ends of the jetties. Significant improvements in the vertical distribution of salinity could be made to these results given additional time and funding. For example, an entirely different treatment of vertical eddy viscosity was developed and used during the course of this study. The vertical formulation had a Richardson number dependency that resulted in significantly improved results. However, time and funds did not allow for the improvements to be further developed.

Conclusions

14. The RMA-10 numerical model of Southwest Pass demonstrated truly 3-D current and salinity distributions. The results showed a vertical salinity stratification with flow reversals surface to bottom due to density differences. In addition, the longitudinal location of the salt wedge approximated

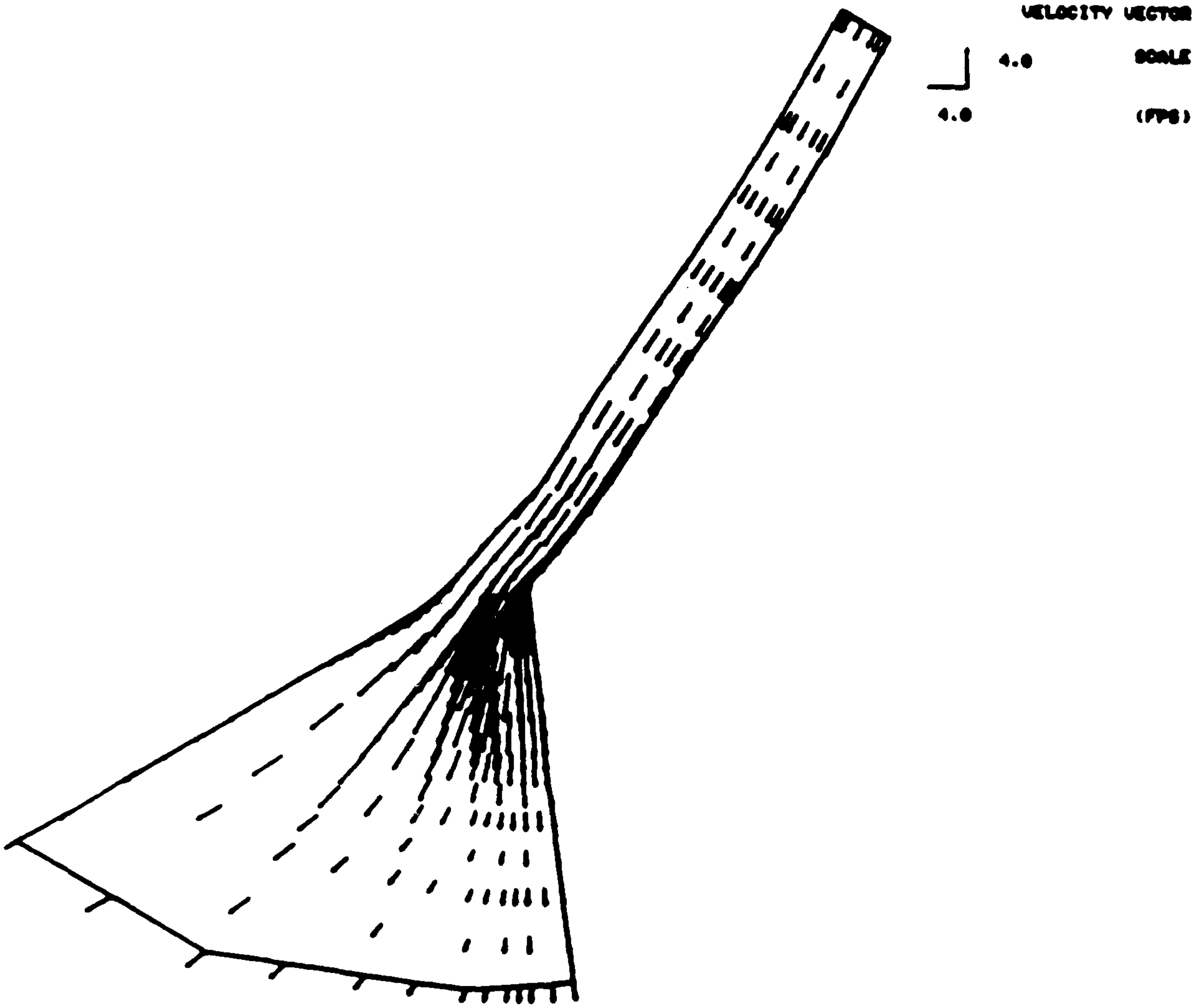

Figure 5. Southwest Pass 76 element grid
surface velocity results

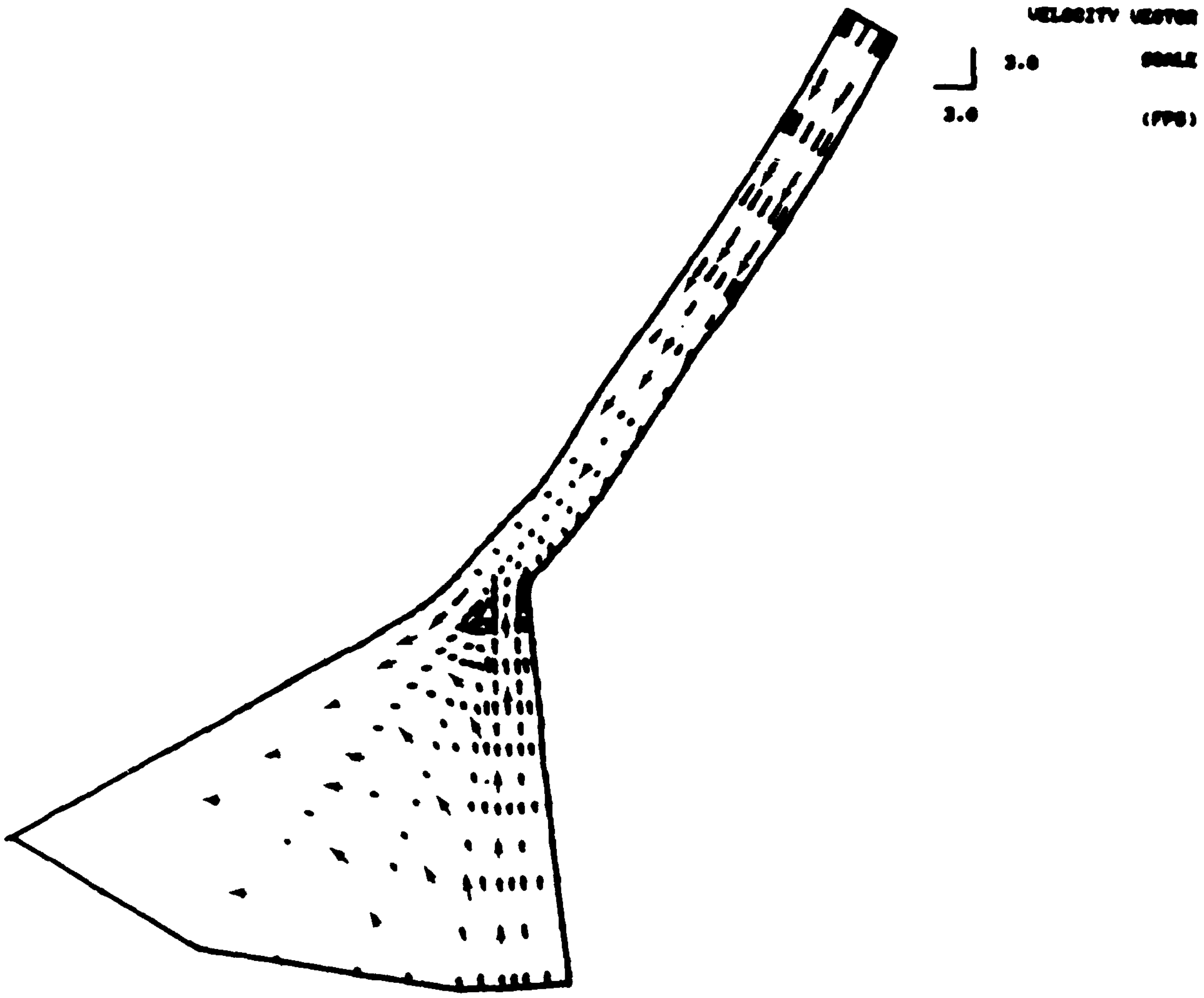

Figure 6. Southwest Pass 76 element grid bottom velocity results

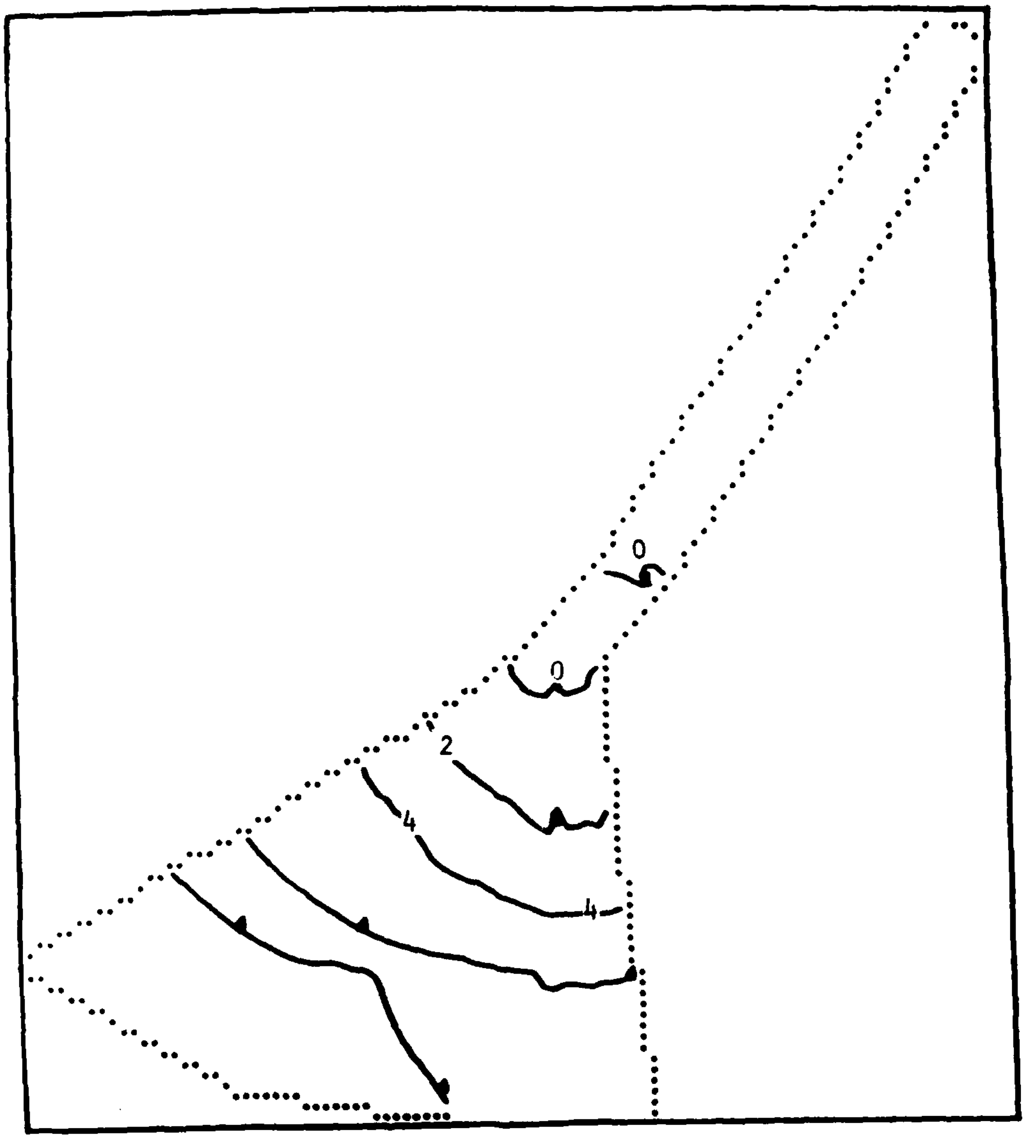

Figure 7. Southwest Pass 76 element grid surface salinities

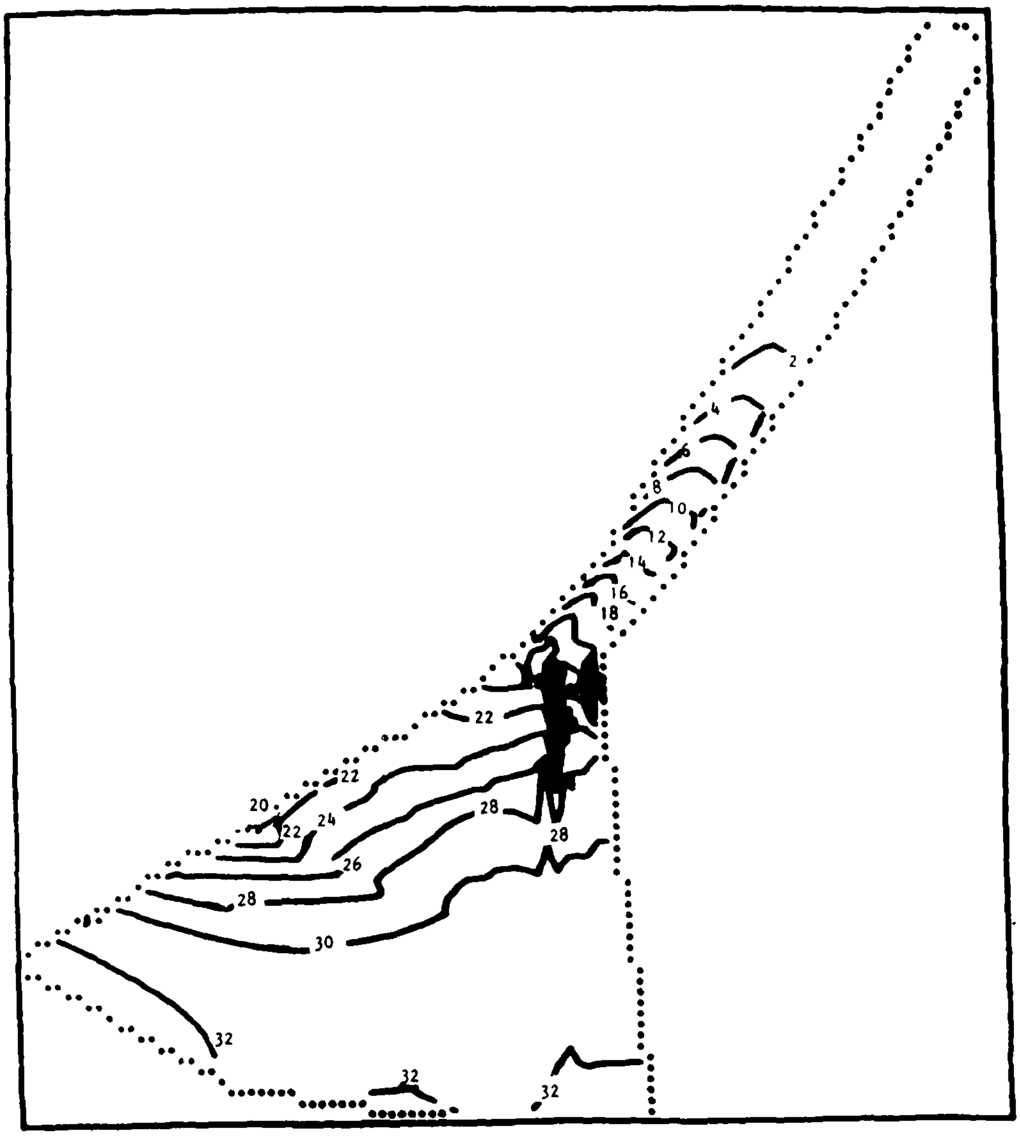

Figure 8. Southwest Pass 76 element grid bottom salinities

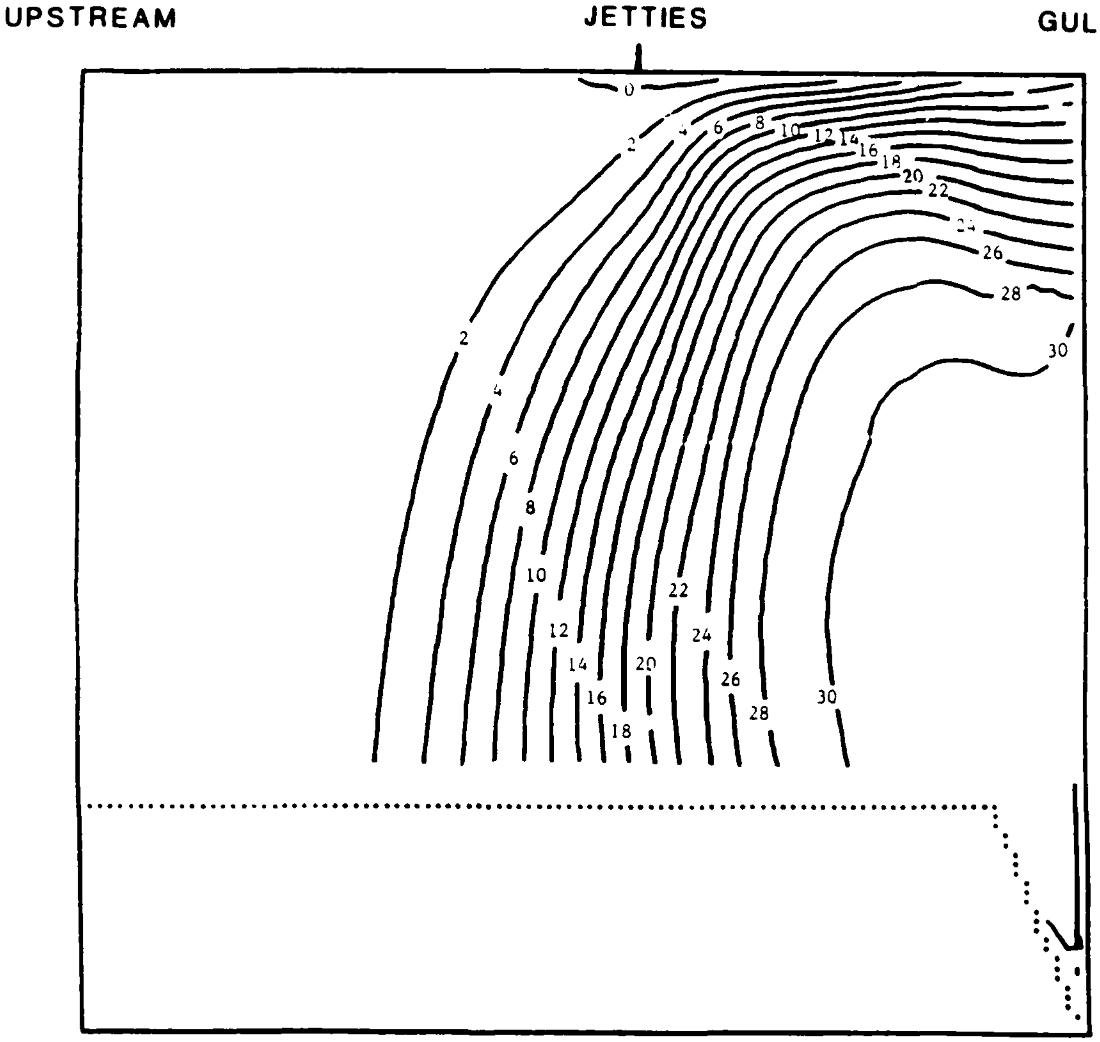

Figure 9. Channel profile of vertical salinity structure

that observed in the physical model. Also, the lateral variation of the vertical velocity structure in the Gulf was consistent with field observations and the physical model results. This was demonstrated despite using a coarse grid. A more highly refined grid and more rigorous verification were not pursued. Improvements to the presented results are possible with additional effort.