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(2)

THE ATCHAFALAYA RIVER DELTA

Report 13

SUMMARY REPORT OF DELTA GROWTH PREDICTIONS

by

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13. ABSTRACT *(Maximum 200 words)*
Coastal Louisiana is experiencing dramatic and alarming land loss. The exception to this general trend is the Atchafalaya River delta, which has been experiencing dramatic deltaic growth during the past 20 years. This deltaic activity can be viewed as both a resource for development of coastal wetlands and as a threat for potentially aggravating flooding in communities upstream of the delta. In response to these concerns, the Corps of Engineers is conducting a thorough investigation to predict how the delta will evolve over the next 50 years, the impacts of the growth and the effectiveness of structures for controlling detrimental results. The investigation approach used several analytical and numerical techniques applied separately to arrive at independent predictions of delta growth. The approach was arranged to provide results from increasingly sophisticated techniques over the period 1980-1989. Each of the techniques are summarized and comparisons are made. The techniques included: analytical model, regression/extrapolation analysis of past behavior, generic
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analysis of similar deltas' growth patterns, a quasi-two-dimensional numerical model, and TABS two-dimensional numerical model. The results from these techniques indicated a wide possible range of 32 to 149 square miles of subaerial delta for year 2030. A regression analysis of all of these results predicted the subaerial delta area to peak at year 2035 with 89 square miles.

14. SUBJECT TERMS (CONCLUDED).

Louisiana deltas
Salinity intrusion
Sedimentation

PREFACE

The work reported herein was performed during the period 1980-1989 in the Hydraulics Laboratory (HL) of the US Army Engineers Waterways Experiment Station (WES) as a part of the overall investigation to predict the evolution of the Atchafalaya Bay Delta for the US Army Engineer District, New Orleans (LMN). Messrs. Cecil Soileau and Bill Garrett and Ms. Nancy Powell were LMN Engineering Division liaisons during this study. This report presents the comparisons of predictive delta evolution results between the two-dimensional numerical modeling technique and other techniques employed throughout the study.

The investigation was conducted under the direction of the following members of the staff, HL, WES: Messrs. F. A. Herrmann, Jr., Chief; R. A. Sager, Assistant Chief; W. H. McAnally, Chief, Estuaries Division; J. V. Letter, Jr., Chief, Estuarine Simulation Branch, and Technical Advisor; and Project Managers Messrs. McAnally and S. A. Adamec, Information Technology Laboratory, formerly HL, and Ms. B. P. Donnell, Estuarine Simulation Branch. The generic analysis work was performed by Drs. J. T. Wells and J. M. Coleman and Ms. S. J. Chinburg, Center for Wetlands Resources, Louisiana State University, Baton Rouge, LA. The extrapolation work was performed by Mr. Letter. The quasi-two-dimensional modeling was performed by Messrs. W. A. Thomas, Waterways Division, R. E. Heath, Math Modeling Group, J. P. Stewart, Office of Technical Programs and Plans, formerly Estuarine Division, and CAPT D. Clark, Estuaries Division. Mr. A. M. Teeter, Estuaries Division, contributed to the delta life cycle analyses. The analysis of a jet flowing into a quiescent bay was performed by Dr. F. C. Wang, Center for Wetlands Resources. The two-dimensional modeling work was performed by Ms. Donnell and Messrs. Letter and Teeter. Messrs. Adamec and D. P. Bach (previously HL) contributed to the two-dimensional modeling work.

Consultants to the project were Mr. H. B. Simmons, retired Chief, HL, L. R. Beard, Dr. R. B. Krone, Dr. C. R. Kolb (deceased), and Mr. F. B. Toffaleti (deceased). This effort was coordinated with the US Fish and Wildlife and the Center for Wetland Resources through the LMN.

Commander and Director of WES during preparation of this report was COL Larry B. Fulton, EN. Technical Director was Dr. Robert W. Whalin.

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
acres	4,046.873	square metres
cubic feet	0.02831685	cubic metres
cubic yards	0.7645549	cubic metres
feet	0.3048	metres
miles (US statute)	1.609347	kilometres
square feet	0.09290304	square metres
square miles	2.589998	square kilometres
tons (2,000 pounds, mass)	907.1847	kilograms

THE ATCHAFALAYA RIVER DELTA

SUMMARY REPORT OF DELTA GROWTH PREDICTIONS

PART I: INTRODUCTION

Objectives

1. The objectives of the Atchafalaya Bay investigation were to answer these questions:

   a. For existing conditions and no actions other than those already practiced (i.e., maintenance of navigation channels), how will the deltas evolve over the short-to-medium term (10-15 years) and the long term (50 years)?

   b. How will the deltas' evolution affect:

      (1) Flood stages?

      (2) Maintenance dredging of the navigation channel?

      (3) Salinity, sedimentation, and circulation in the Atchafalaya Bay system?

   c. What would be the impact of various alternatives on each of these conditions?

2. This report summarizes and combines results of the five predictive efforts completed during the Atchafalaya Bay investigation between the years 1980-1989. Its objective is to provide the Corps of Engineers with a single document that presents and compares the results of delta evolution concisely.

Background

3. The primary driving force for the system is the supply of water and sediment from the Atchafalaya River. The river captures about 30 percent of the latitude flow (combined flow of the Mississippi River and Red River at the latitude of 31 deg north) at the Old River Control Structure (near Simmesport, Figure 1) and carries with it an average of 100 million tons* of sediment (Keown, Dardeau, and Causey 1981) in suspension each year. Progressively, the sediment load has filled in the Atchafalaya basin floodway between its natural

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

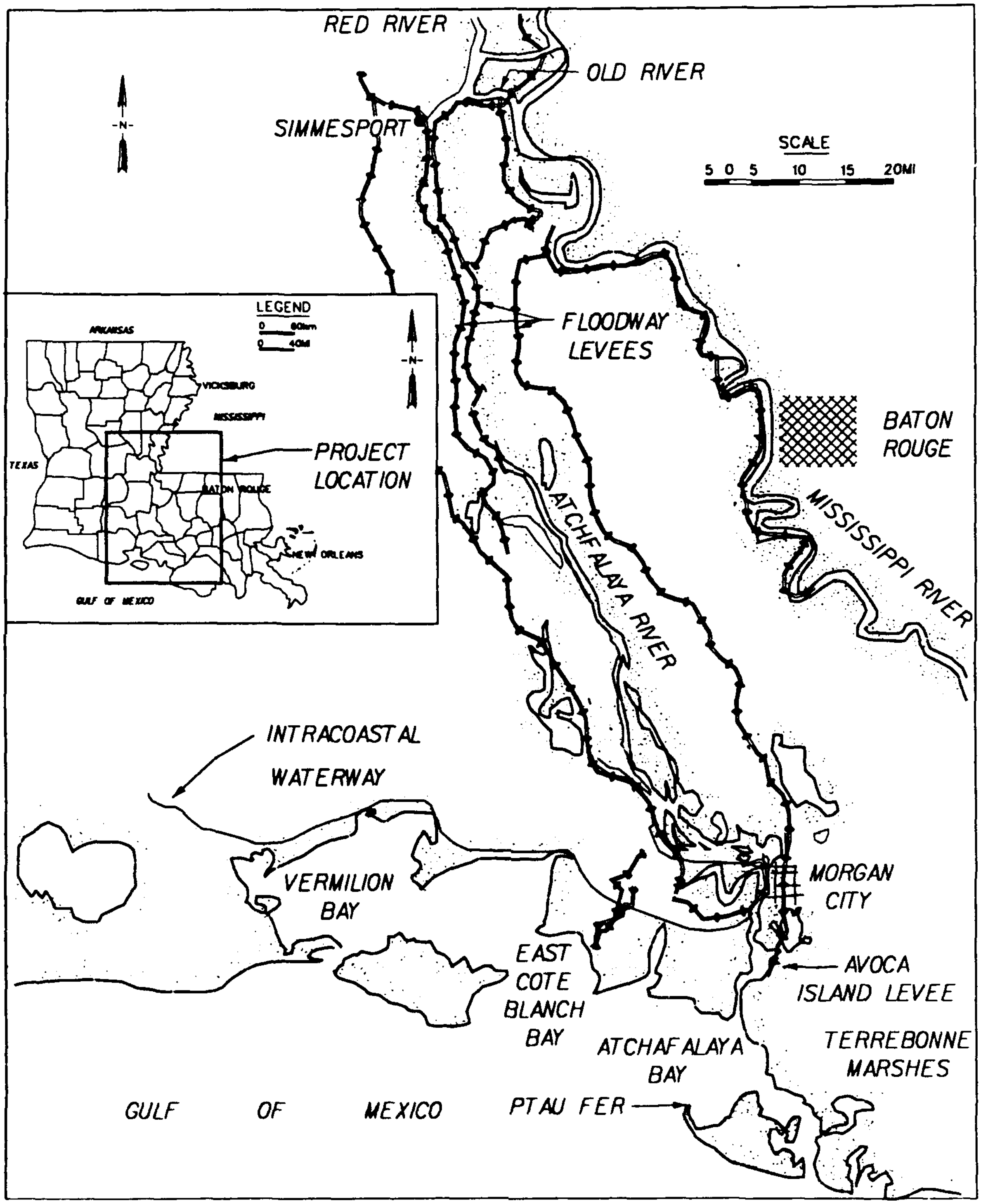


Figure 1. Project location

and manmade levee systems over the past several decades and is now depositing rapidly in Atchafalaya Bay (Figure 2 enlargement). As shown, there are two deltas forming in Atchafalaya Bay; at the mouth of Lower Atchafalaya River (LAR)* and Wax Lake Outlet (WLO). The evolving deltas became subaerial in 1973 and soon after vegetated and have since become one of the most dynamic currently active delta systems in the world. The evolving deltas have converted shallow bays into marshes and continue to generate a great deal of interest in deltaic processes. The primary benefit from these two deltas has been the addition of new land to the coast of Louisiana in areas that are otherwise experiencing land loss. The primary concerns with the evolving deltas have been sedimentation in the navigation channels and backwater flooding in the surrounding low-lying coastal parishes of southern Louisiana.

4. Phenomenal growth of the subaerial Atchafalaya River Delta (since 1972) and the emerging WLO delta led the US Army Engineer District (USAED), New Orleans, to request that the US Army Engineer Waterways Experiment Station (USAEWES) conduct a thorough model study to predict future growth of the deltas and effects of that growth.

5. The plan of investigation includes the following multiple techniques to predict delta growth.

a. Extrapolation of observed bathymetric changes into the future.

b. A generic analysis that predicts future delta growth by constructing an analogy between behavior of the Atchafalaya delta and other deltas in similar environments.

c. Analytical treatment of a sediment-laden jet discharging into a quiescent bay.

d. Quasi-two-dimensional (2D) numerical modeling of hydrodynamics and sedimentation processes considering a river flowing into a quiescent bay.

e. Two-dimensional numerical modeling of hydrodynamics and sedimentation processes considering riverflow, tides, Gulf levels, storm surges, wind-induced currents, wind waves, salinity, and subsidence.

Each of these builds upon prior work and employs a progressively greater degree of sophistication. A basic description of the overall plan is given by McAnally, Heltzel, and Donnell (1991) in Report 1 of this series. A list of

* For convenience, symbols and abbreviations are listed and identified in the Notation (Appendix A).

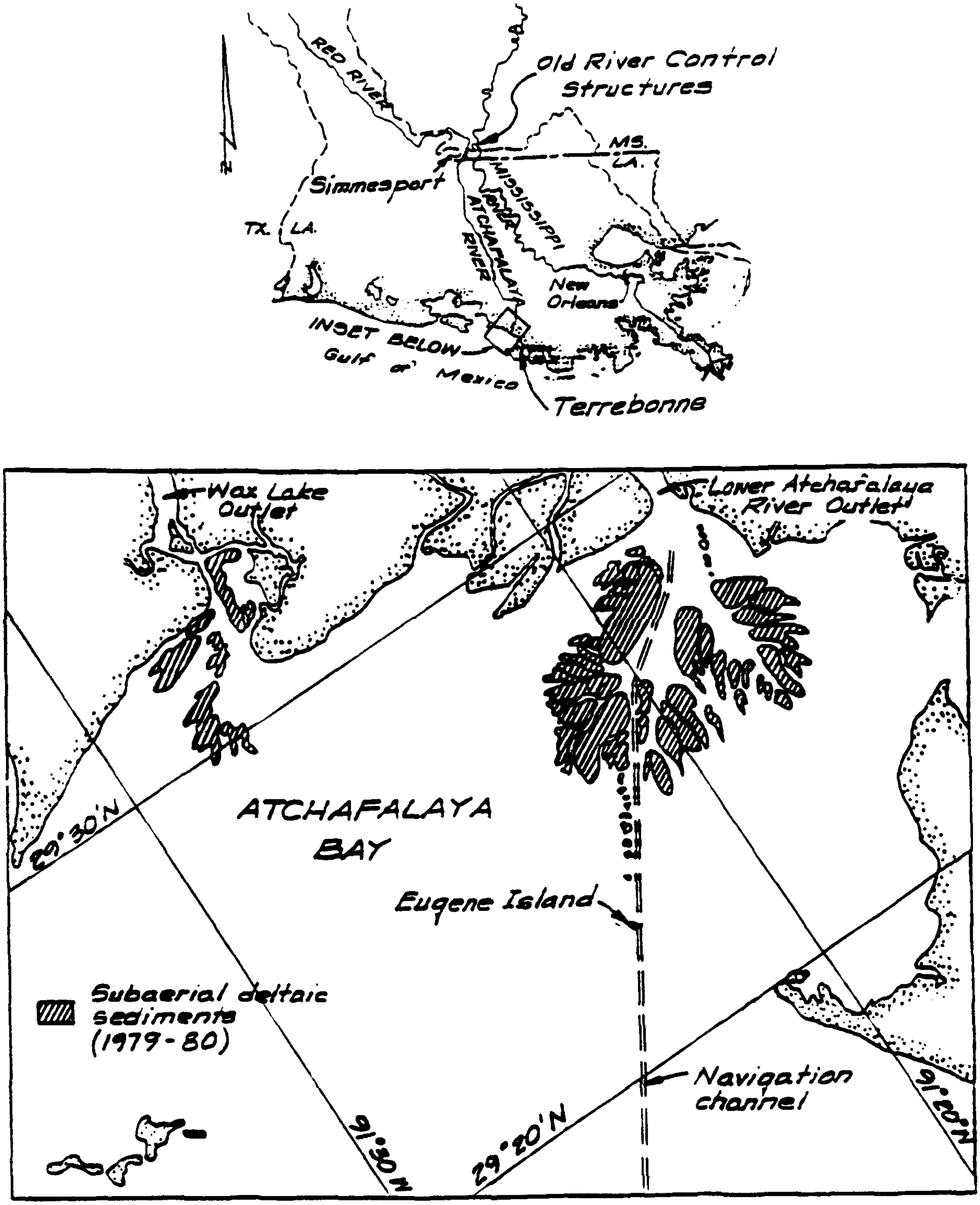


Figure 2. Vicinity sketch showing the Atchafalaya River and Wax Lake Outlet deltas

all reports of this series is found in Table 1 and the References section found at the end of the report.

6. Development of these techniques was seen to be a multiyear effort, and the implementation plan was designed so that results would be produced early and at regular intervals throughout the project. In the spring of 1981, the extrapolation results were completed, followed by the quasi-2D results in the winter of 1982. Next completed was the generic analysis in the spring of 1982. An interim summary report was written on the techniques mentioned in paragraph 5a-d (McAnally, et al. 1984). In 1985 the analysis of a jet flowing into a quiescent bay was completed. The 2D numerical modeling of delta evolution results were completed in stages from 1986 to 1989.

7. The purpose of this report is to summarize the results from all of the methods employed and to provide comparisons between the techniques where appropriate. In the interest of keeping this report as concise as possible, study results will only be presented for the purposes of comparisons between techniques. Detailed results will not be duplicated here, and the reader is referred to the complete report of the appropriate method (Table 1) for more information.

Table 1

Reports in this Series*

Report No.	Reference		Subtitle	Contents
1	McAnally, Heltzel, Donnell	1991	A Plan for Predicting the Evolution of Atchafalaya Bay, Louisiana	Methods and approach
2, Section 1	Coleman et al.	1988	Field Data: Atchafalaya Bay Program Description and Data [2 volumes]	Field data collection methods and presentation of data (4 Sections)
2, Section 2	Teeter and Pankow	1989	Field Data: Settling Characteristics of Bay Sediments	
2, Section 3	Pankow, Teeter, Donnell	1990	Field Data: Grain Size Analysis of Selected Bay Sediments	
2, Section 4	Bensen and Donnell	1990	Field Data: Terrebonne Marshes Program Description and Data	
3	Letter	1982	Extrapolation of Delta Growth	Analytical extrapolation of historical behavior
4	Wells, Chinburg, Coleman	1984	Generic Analysis of Delta Development	Comparison with similar deltas to identify stage of development and predict future trends
5	Thomas, Heath, Stewart, and Clark	1988	Quasi-Two-Dimensional Modeling of Delta Growth and Impacts on River Stages	Quasi-two-dimensional hydrodynamic and sedimentation river flow modeling

(Continued)

* All Atchafalaya reports in this series are published under the main title, "The Atchafalaya River Delta," Technical Report HL-82-15, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

Table 1 (Concluded)

Report No.	Reference		Subtitle	Contents
6	McAnally, Thomas, Letter, and Stewart	1984	Interim Summary Report of Growth Predictions	Summary and analysis of Reports 3, 4, and 5
7	Wang	1985	Analytical Analysis of the Development of the Atchafalaya River Delta	Analytical treatment of a simple jet discharging into a quiet bay
8	Ebersole	1985	Numerical Modeling of Hurricane-Induced Storm Surge	Two-dimensional modeling hurricane-induced storm surge
9	Ebersole	1985	Wind Climatology	Predictions of wind conditions over the bay
10	Jensen	1985	Wave Hindcasts (3 Appendices)	Modeling of locally generated wind waves
11	Donnell, Letter, Teeter	1991	Two-Dimensional Modeling (1 Appendix)	Two-dimensional finite element modeling of hydrodynamics, salinity, and sedimentation
12	Donnell and Letter	1992	2D Modeling of Alternative Plans and Impacts on the Atchafalaya Bay and Terrebonne Marshes	Employs the tools described in Report 11 and shows the effects of plans
13	Donnell and Letter (volume herein)	1992	Summary Report of Delta Growth Predictions	Summary and analysis of all delta growth predictions conducted during this investigation

PART II: METHODS USED AND RESULTS

Delta Growth Extrapolation/Regression Technique

8. The delta growth extrapolation method was the first attempt to predict an approximation of delta growth within this study. The basic approach was to identify and relate (by regression analysis) observed historical phenomena to deposition within the bay, then to use that relationship to predict future delta growth from an initial bathymetric condition. For details of the work, refer to Letter (1982).

9. Figure 3 illustrates the extrapolation approach. Figure 4 shows the limits of the extrapolation window for the regression analysis (the smaller of the two windows). The southwest corner of this window is presented in Louisiana state grid coordinates of x = 192,200 and y = 203,000, and the northeast corner of x = 2,037,000 and y = 330,000 ft. Considerable effort was expended in compiling and checking the quality of the prototype data used in this analysis and to structure the technique so that new field data and insights could be incorporated into the regression. The regression work was performed using the Statistical Package for Social Sciences (SPSS) system on the WES G635 computer. The regression incorporated those parameters with sufficient field data to reliably measure variation and those felt to be of significance to delta evolution. Each parameter was selected based upon its correlation coefficients performance in a simple regression. A number of different sets of variables were tested in various forms. However, the final independent variables included in the regression were:

- a. Mean river discharge at Simmesport (in thousands of cubic feet per second).
- b. Annual sediment yield for the period (in million tons per year).
- c. Location in the bay (in thousands of feet).
- d. Center of mass of the delta (in thousands of feet).
- e. Depth at the location in the bay (in feet).

10. The regression model (Equation 1) was first applied to the historical data to confirm its ability to extend an initial condition forward in time with reasonable success. Three confirmation sequence runs were made using an initial prototype bathymetry and extrapolating to obtain a 1977 bathymetric prediction. The regression coefficient, R , for the overall regression was

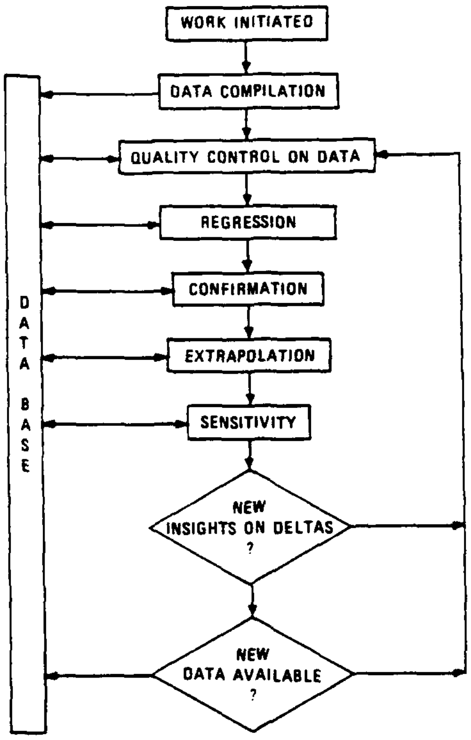


Figure 3. Approach for extrapolation study

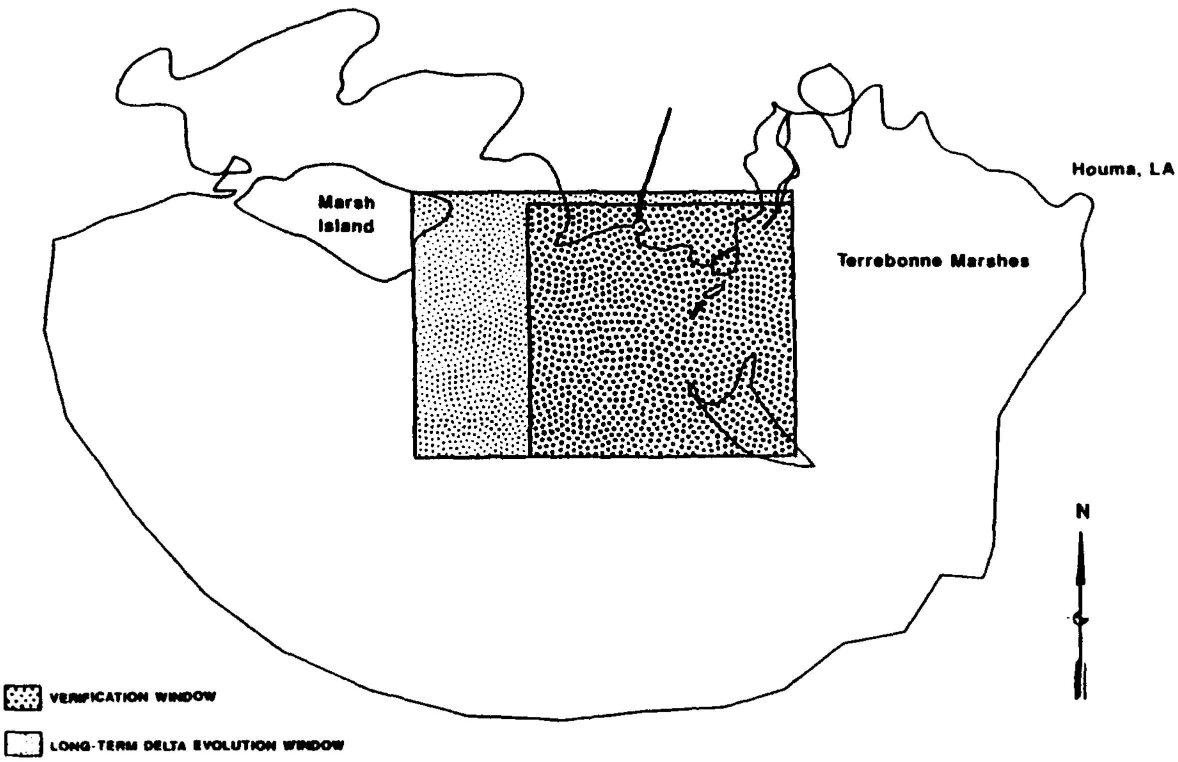


Figure 4. Numerical model extrapolation windows

0.465, which gives an R^2 of 0.216. This implies that the overall regression equation accounts for only about 22 percent of the total variance, indicating that the basic data contained significant randomness relative to those variables. However, the quality of confirmation was satisfactory and within the limits imposed by the method. This randomness is associated with details of deltaic evolution which cannot be addressed within the limits of the regression model. These details are left for the more sophisticated techniques to follow.

11. The regression equation used was of the form:

$$\text{Deposition Rate} = G * M - \text{Shift} \tag{1}$$

where

$$G(x,y,xo,yo,Qm) \text{ is the distribution function} \tag{1a}$$

$$= \exp\left[\frac{1}{2SX^2}(x - xo + AQm)^2\right] * \exp\left[-\frac{1}{2SY^2}(y - yo + BQm)^2\right]$$

and

SX = 30 (thousands of feet)

SY = 40 (thousands of feet)

A = 0.037 (1,000 ft per 1,000 cfs)

B = 0.094 (1,000 ft per 1,000 cfs)

(xo,yo) = coordinates of the centroid of delta mass (thousands of feet)

(x,y) = coordinates of desired position

and where

$$M(Qm,S,d) = \exp\left[C + D * Qm^2\right] * S * Qm^{0.316} * d^{0.592} \tag{1b}$$

and

Qm = mean freshwater discharge in 1,000 cfs

S = sediment yield in million tons per year

d = water depth in feet

C = -7.64

$$D = 0.00000355$$

and where

$$\text{Shift} = 0.26 \text{ ft/year} \tag{1c}$$

and where

$$S = [\sum_{i=1}^{N} f_i * Qs_i/DUR] * C \tag{1d}$$

and

Qs_i = suspended sediment discharge in 1,000 tons per day (computed by Equation 1e)

DUR = duration of period in days

C = 0.365 (conversion factor from thousands of tons/day to millions of tons/year

f_i = number of days at occurrence of river discharge Qw_i

and where

$$Qs_i = 0.0728\ Qw_i^{1.444} \tag{1e}$$

and

Qw_i = water discharge in 1,000 cfs

The shift was applied to the input data so that small degrees of erosion could be included within the analysis.

12. The regression model was then applied to the 50-year extrapolation hydrograph, shown in Figure 5, (with a flow split of 70 percent and 30 percent between the LAR and WLO, respectively) using the New Orleans District's 1977 survey bathymetry and the National Oceanic and Atmospheric Administration-National Ocean Survey Chart No. 11351, 1979 edition, as an initial condition. The extrapolation 50-year hydrograph was based on the Atchafalaya River hydrograph at Simmesport, LA, which was developed by the New Orleans District for

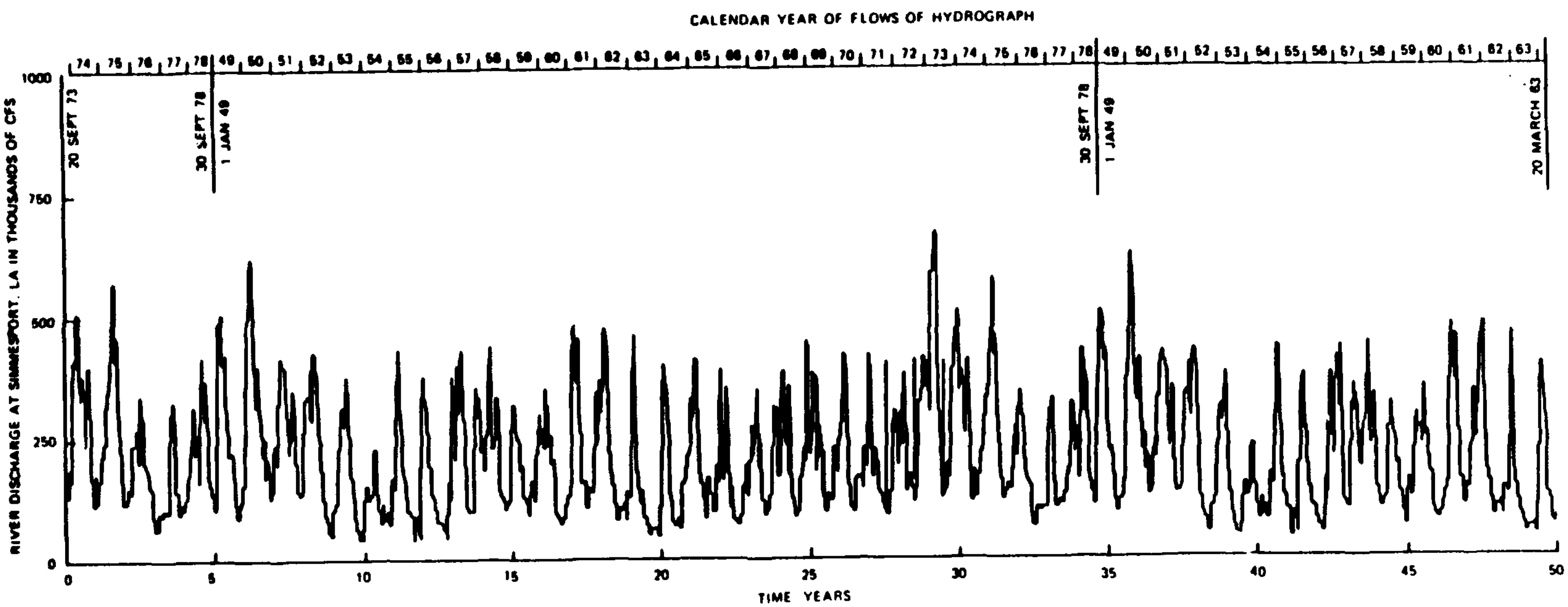


Figure 5. Fifty-year extrapolation hydrograph for Simmesport (Letter 1982)

use in one-dimensional (Hydrologic Engineering Center (HEC)-2 Water Surface Profile Model and HEC-6 Sediment Transport Model) models of the Atchafalaya River basin and bay. The method did not allow a negative deposition rate below the generally accepted subsidence rate of -0.03 ft/year (1 cm/year). An upper limit on delta elevation was assumed to be el +3 ft NGVD.* The time step for the extrapolation sequence was 2-year intervals with the predicted delta condition reported at 10-year increments.

13. The regression analysis predicted a nearly linear trend of delta subaerial growth with 19 mi^2 at year 10 and 87 mi^2 at year 50. Projected delta volume (material above -3 ft contour) at year 50 was 17.6 billion cubic feet. Sensitivity tests were made with the regression model (see Table 2) which determined that the sequencing of hydrologic events had essentially no impact on the resultant 50-year condition, provided the total water and sediment entering the bay remained unchanged by resequencing events. However, if the 1973 flood was eliminated or duplicated, there was a noticeable change in the total volume in the delta mass and the amount of subaerial land. Figure 6 presents the results of the sensitivity test for delta volume (range 12.6-22.2 billion cubic feet). The projected 50-year delta configuration for the selected sequence is given in Figure 7. It was concluded that within 50 years, the delta should grow gulfward of Eugene Island.

Table 2

Summary of Sensitivity Analysis Extrapolation Technique

Year 50 Delta

Test	Delta Volume (10^9 cu ft)	Subaerial Land (sq mi)
Original sequence	17.6	87
Reverse sequence	18.4	91
1973 flood first	17.3	83
1973 flood last	18.0	90
No 1973 flood	12.6	71
1973 flood twice	22.2	131
Average	17.6	92
Variation	43%	65%
Standard deviation	2.8	18.6

* All elevations (el) cited herein are in feet referred to the National Geodetic Vertical Datum (NGVD) of 1929.

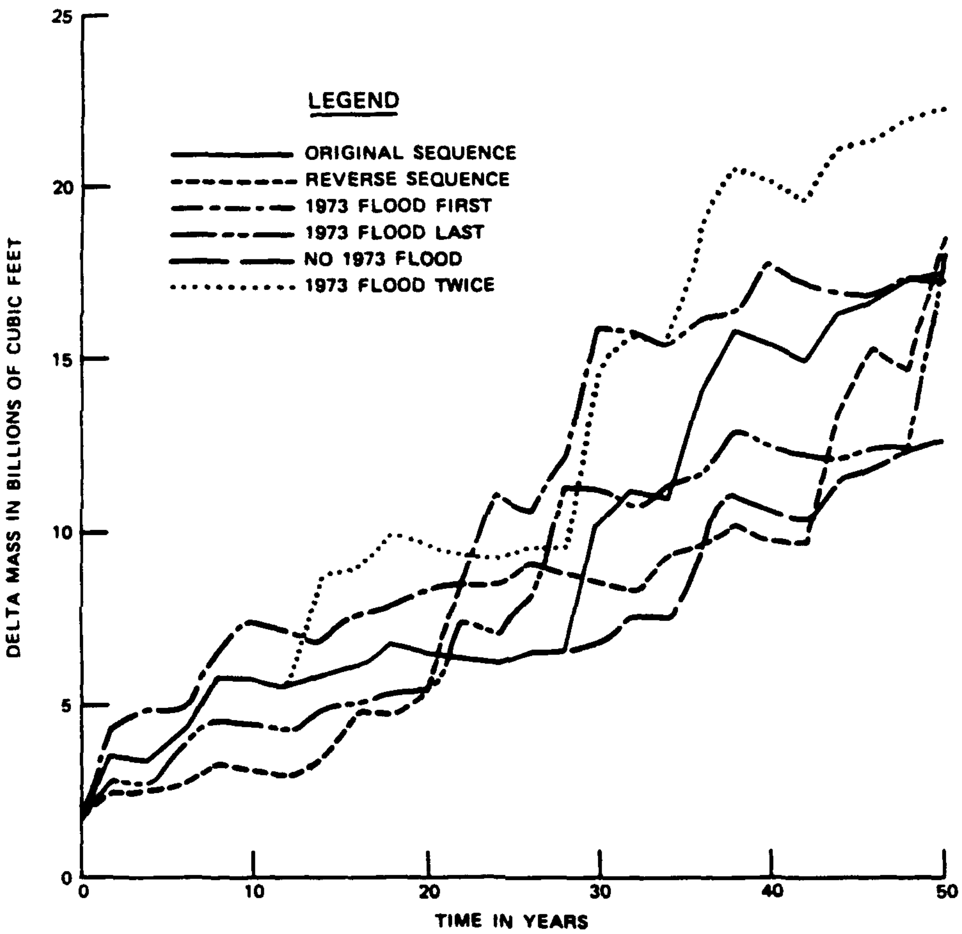


Figure 6. Sensitivity test results for delta volume (above -3 ft contour) (Letter 1982)

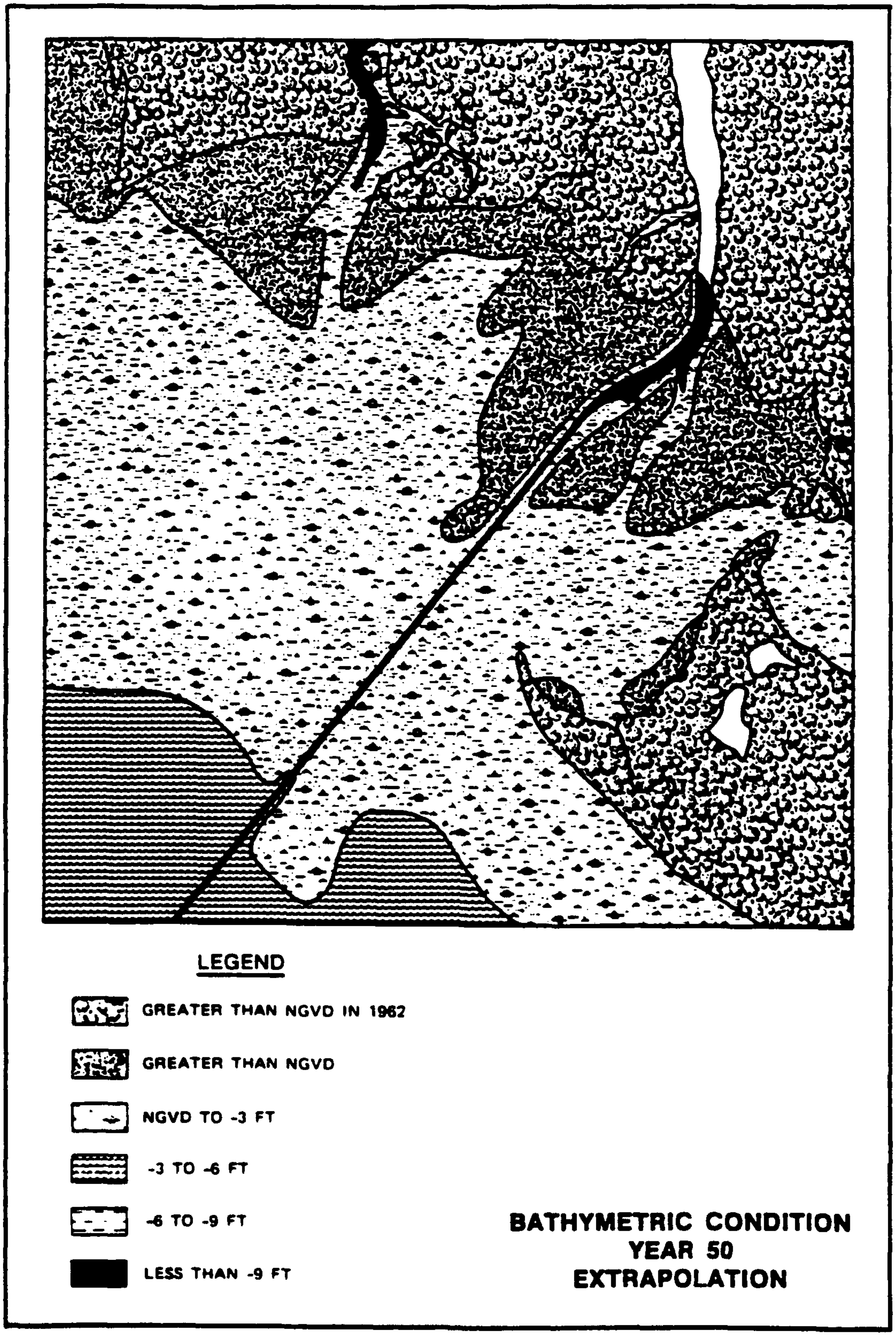


Figure 7. Predicted year 50 bathymetry for the selected extrapolation sequence from regression analysis (Letter 1982)

14. The following are strengths of the regression analysis: the method was based upon field data and easy to perform sensitivity analysis. The limitations of the regression analysis were as follows: the method was a statistical tool rather than a dynamic model, the results were only as good as the quality of the input data, all input field data were obtained from the protected bay and were not exposed to a severe wind climate, the method was incapable of addressing the impact of delta growth on hydrodynamics, and the predicted size and shape of the delta was heavily dependent on the initial condition.

Generic Analysis

15. The generic analysis task predicted Atchafalaya Bay Delta growth by comparing it with deltas formed under similar environmental conditions. It also served to provide a geologic framework for the investigation so that 50-year predictions could be viewed in comparison with the longer-term processes involved. Details of the work are found in the study by Wells, Chinburg, and Coleman (1984).

16. The generic analysis effort quantitatively predicted the growth and decay of the Atchafalaya River Delta by analyzing data from 10 deltas in three geographic categories and five environmental settings. A data base was formed by studying published and unpublished accounts of delta growth, analyzing maps, survey sheets, aerial photographs, dredging records, and LANDSAT images. The most accurate information was for the four Mississippi river subdeltas: Baptiste Collette, Cubits Gap, West Bay, and Garden Island Bay. Considerable effort was made to screen and remove suspect maps that did not directly match a known survey period. Subaerial land areas for these deltas were computed by digitizing the land-water boundaries and adjusting for tidal elevations. Accumulated sediment volumes were computed using a contour-area method. The rate of depth-contour advancement was calculated by measuring the linear progradation of the land-water boundary normal to the delta apex.

17. The actual generic analysis predictions for the Atchafalaya River Delta were patterned from the Mississippi River subdeltas because of their similarity and excellent data base extent. Results obtained from the data base indicated that there were five features common to the Mississippi River subdeltas:

a. Initiation of growth by crevasse or break in the natural levee system.

b. A well-defined life cycle that includes both growth and deterioration.

c. A life of approximately 115 to 175 years.

d. Continuous infilling and linear growth throughout the destructional phase of the subaerial life cycle.

e. A pulse of subaerial growth between the multiflood years of 1971 and 1978.

18. The life cycles of the Mississippi Deltas studied appear to be highly dependent on the cessation of sediment delivery and a moderate-to-high subsidence rate. (For a complete discussion of subsidence, refer to Report 11, Appendix A, of this series (Donnell, Letter, and Teeter 1991).) Results of normalized and smoothed delta growth and deterioration of the four Mississippi River subdeltas are given in Figure 8. Note that the average time for maximum delta growth is 66 years.

19. Results of the LANDSAT analysis provided the rates and patterns of subaerial growth (MSL) for both deltas in Atchafalaya Bay since subaerial emergence began in 1973. These results are given in Figure 9. The 1980 total subaerial land is bounded by the observed value of 8.0 sq m or 20.8 sq km and the least squares estimate of 11.1 sq m or 28.8 sq km. By averaging the four subdeltas percentage of expected growth presented in Figure 8 and using the upper and lower bounds of subaerial land presented in Figure 9, a band for the future predicted subaerial land was obtained (Figure 10).

20. The final step in the generic analysis was to plot the land configuration for year 2030 (50 years) based upon several different rates of growth. Figure 11 provides estimates based upon the upper (80.3 square miles or 208 sq km) and lower (57.9 square miles or 150 sq km) bounds (Figure 10) and an extreme value (130.1 square miles or 337 sq km) based upon the highest growth rate (1972 to 1975) over the 8-year period presented in Figure 10. The generic analysis predictions had a variation of 81 percent.

21. Wells, Chinburg, and Coleman (1984) concluded that the upper bound of 80.3 square miles or 208 sq km of subaerial growth (1.6 square miles/year or 4.2 sq km/year) by year 2030 is the most reasonable estimate under normal flood conditions. They concluded that the Wax Lake Delta will continue to grow at a faster rate than the Lower Atchafalaya River Delta, but the two deltas will not merge within 50 years unless an extreme flood event occurs.

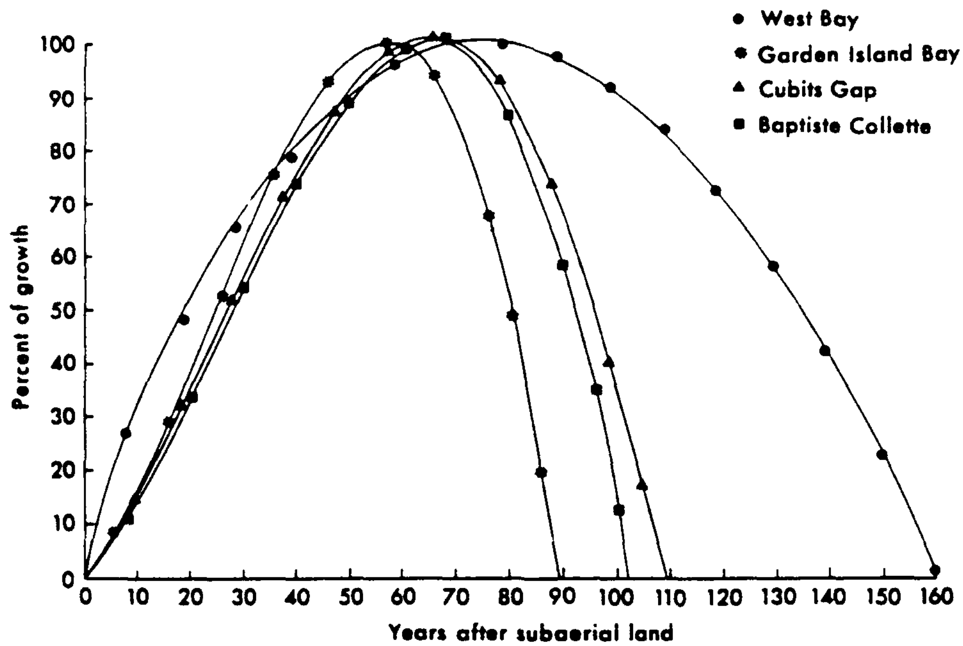


Figure 8. Normalized and smoothed curves showing growth and deterioration of the four Mississippi River subdeltas (Wells, Chinburg, and Coleman 1984)

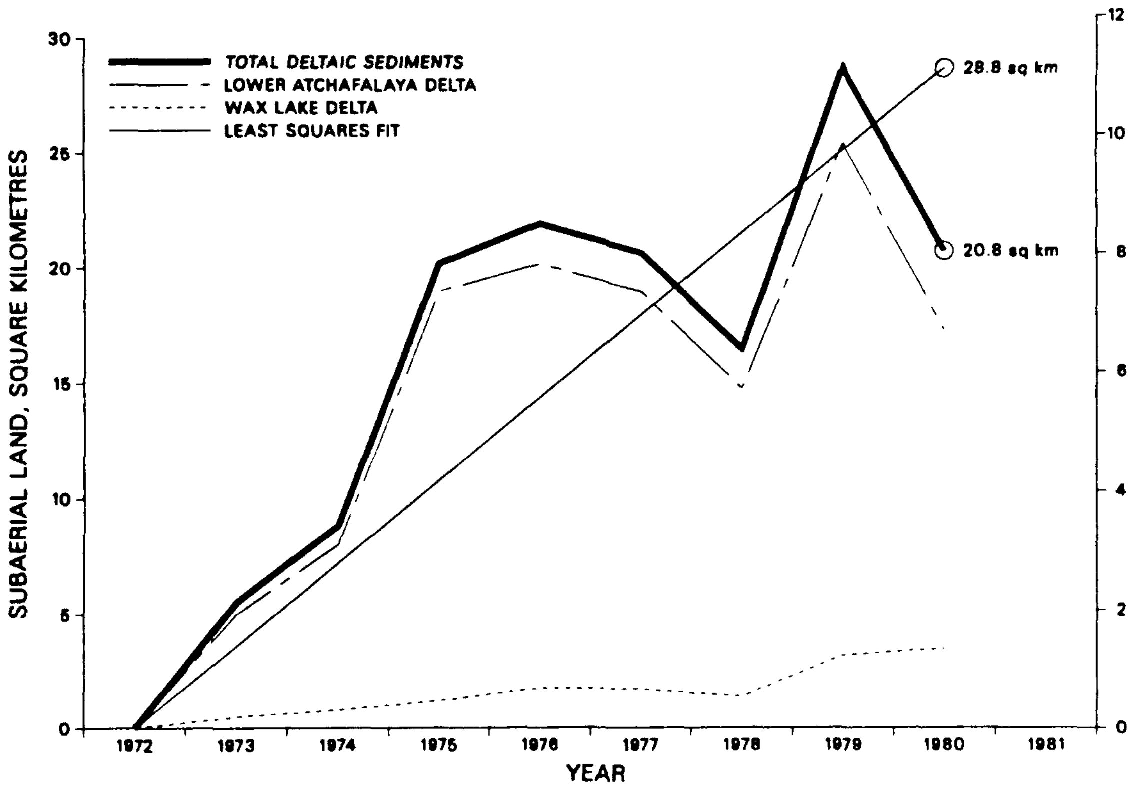


Figure 9. Prototype subaerial land growth curves with a least squares fit (Wells, Chinburg, and Coleman 1984)

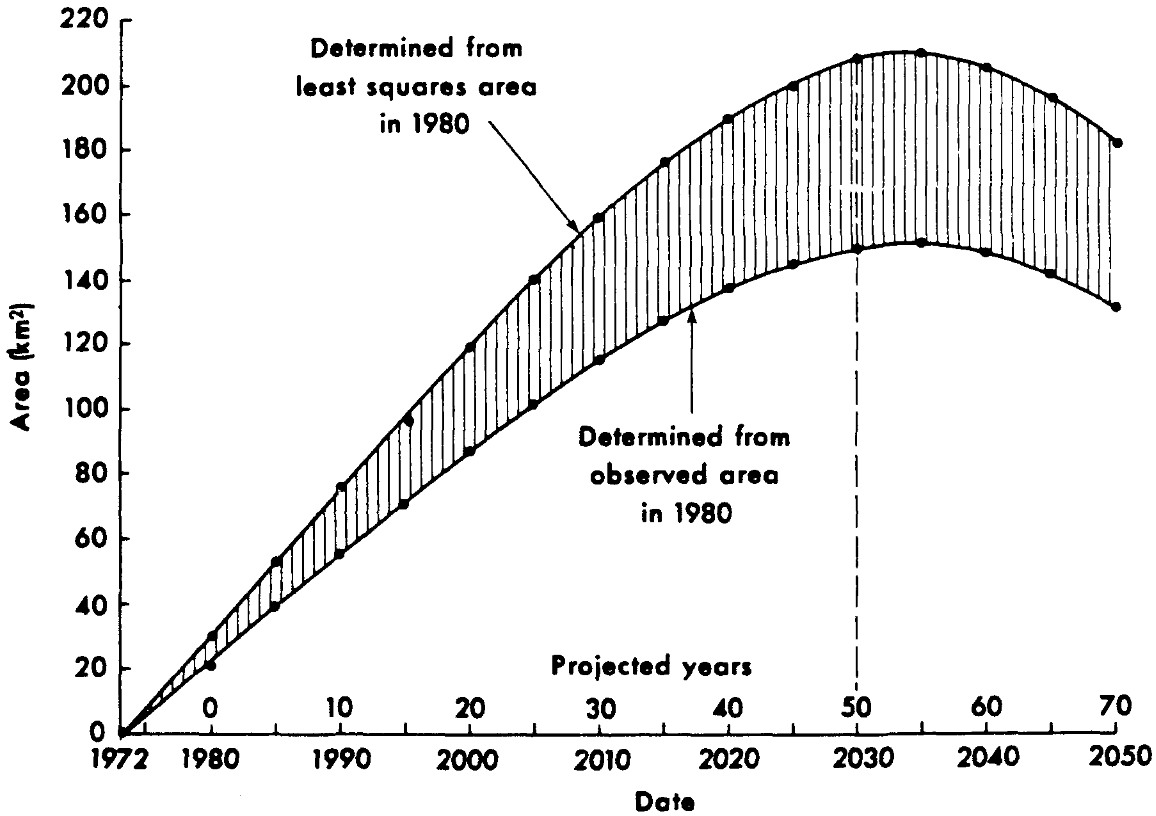


Figure 10. Growth curves predicting subaerial land in Atchafalaya Bay in the year 2030. Determinations made from growth curves of Mississippi River subdeltas assuming 28.8 km^2 of land (upper curve) and 20.8 km^2 of land (lower curve) in Atchafalaya Bay in 1980 (Wells, Chinburg and Coleman 1984)

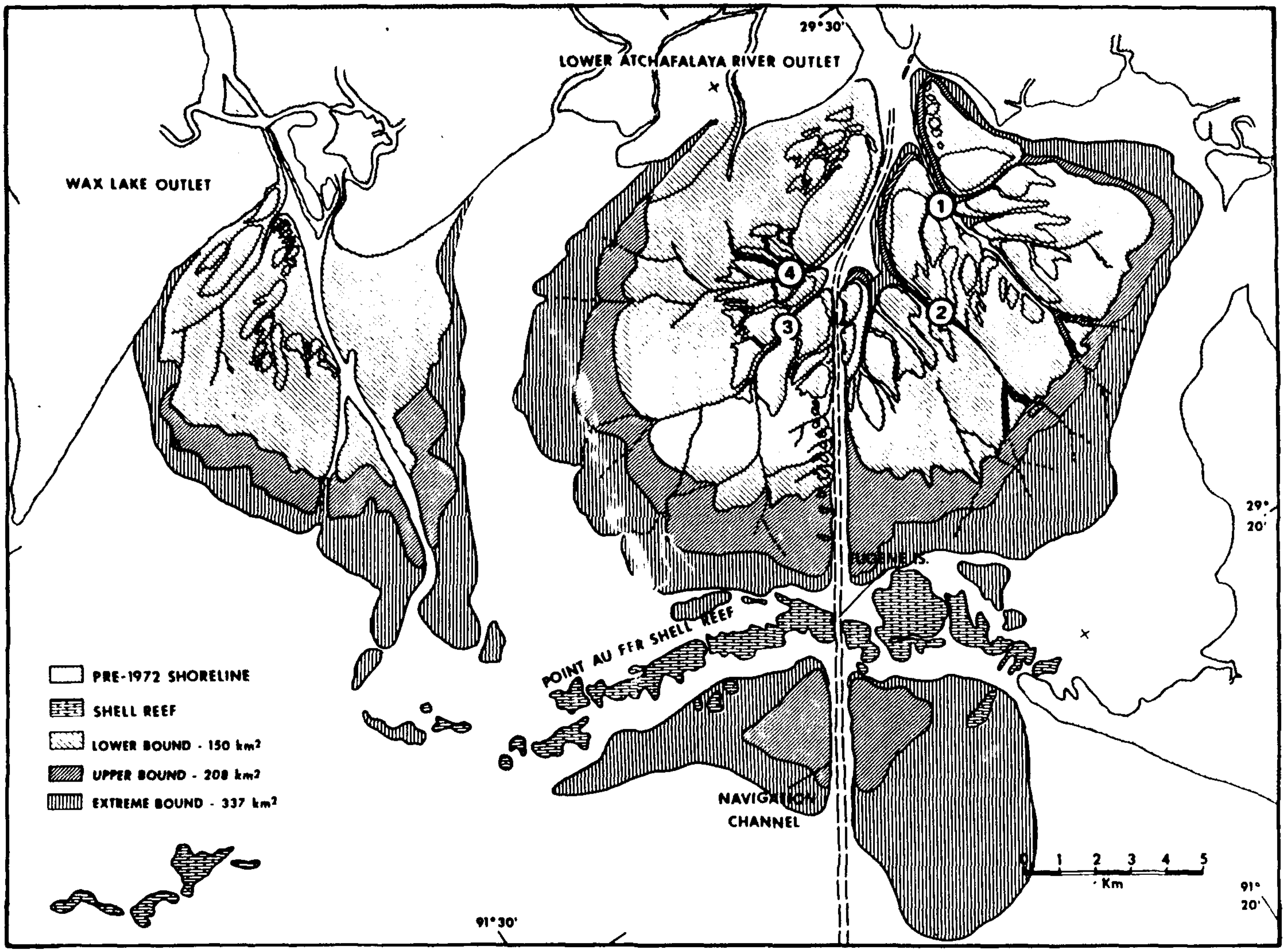


Figure 11. Configuration of subaerial land in Atchafalaya Bay in the year 2030 assuming total areas of 150 km^2, 208 km^2, and 337 km^2 (Wells, Chinburg, and Coleman 1984)

In addition, the life cycle of the delta is expected to resemble a Gaussian distribution and peak after 66 years of growth (year 2039). The predicted deltaic volume (above -3 ft contour) was to grow at a rate of 18.3 million cubic yards per year or 14 million cubic meters per year.

22. The strength of the generic analysis rests in the fact that the procedure was based upon historical events which have previously occurred in southern Louisiana. The following were weaknesses of the generic analysis: inability to determine the effect of delta growth on hydrodynamics, lack of consideration for waves or wind-driven currents, and an inability to compensate for the man-excavated barrier shell reef or other man-induced changes to the system.

Quasi-Two-Dimensional Numerical Model

23. The first numerical modeling task in this investigation used the general-purpose computer program HAD-1 to compute flows and sediment transport, deposition, and erosion in the bay. Flood stages and flow distribution changes resulting from delta growth were modeled with the generalized computer program named Simulated Open Channel Hydraulics in Multiple Junction Systems (SOCHMJ). The required information for both the sediment movement model (HAD-1) and the flood routing model (SOCHMJ) included: basin, bay and marsh geometry, hydrologic data, sediment data, land/water use data. The approach was verified to historical bed deposition and scour and employed to forecast delta growth for the next 50 years. Details of the model's application are provided by Thomas et al. (1988).

24. As stated in Report 6 of this series (McAnally, Thomas, Letter, and Stewart 1984):

> "The program HAD-1, quasi-two-dimensional computations, was developed by substantially modifying the one-dimensional program HEC-6 to allow lateral transport of sediment. In HAD-1, the flow area is partitioned into strips of similar hydraulic properties and sediment can move both down a strip and laterally from one strip to another. Hydraulic computations are one-dimensional for energy loss and distributed among the strips based on their relative conveyance. Lateral water and sediment movement satisfies mass continuity. The sediment moves either in proportion to water flow or in a ratio of water movement based on calculated vertical concentration profiles."

The HAD-1 computation grid is presented in Figure 12. The grid is composed of 20 lateral segments each divided into 7 longitudinal strips. The grid spans from beyond Eugene Island in the gulf northward to river mile 87 and spans laterally from the entrance of East Cote Blanche Bay to the Pt au Fer Island boundary.

25. Beginning with the 1961 survey date as an initial condition, a continuous, time-dependent record of each boundary variable is coded up to the time of the second survey (1977). The boundary variables were sediment discharge rate (cohesive and noncohesive), and river discharge combined by joint probability with gulf stages. The calculated 1977 bathymetry (uniformly adjusted for subsidence) was compared to the 1977 survey for verification of the model.

26. Once the delta growth had been calculated by HAD-1, SOCHMJ was used to determine water-surface elevations resulting from deltaic revisions. SOCHMJ solves the St. Venant equations describing unsteady, one-dimensional channel flows. The SOCHMJ application for the Atchafalaya River is called the Multiple Channel Model (MCM) and its computational network is presented in Figure 13. Both the Mississippi Basin Physical Model (MBM) and prototype water-surface elevations were used in the water-surface profile verification. Tested riverflows consisted of 350,000 cfs, 800,000 cfs, and 1,500,000 cfs (the 58AEN project design flood).

27. Forecasts of delta development and resulting water-surface elevations were made at 10-year increments from 1977 to 2030 (a cumulative 53 years) both with 1.3 cm/year constant subsidence rate. (Later a sensitivity test was conducted with a lower subsidence rate of 1.0 cm/year.) Figure 14, shows the surface area and volumes associated with the predictions which included subsidence. A maximum subaerial delta of 33 square miles was predicted at year 40. Note that the predictions are relative to a zero value at year 0, when in actuality there was subaerial delta growth present in 1977. Figure 15 shows the calculated delta configuration. Subsequent to model testing, a survey of the bay verified that the barrier reef near Pt au Fer was completely gone; however, this model contained the reef throughout the 50-year simulation.

28. The model predicted a peak in subaerial growth at year 40. When a subsidence rate of 1.0 cm/year is used, the growth curve for area peaks at year 40, also, but with 47 square miles. A constant subsidence rate of

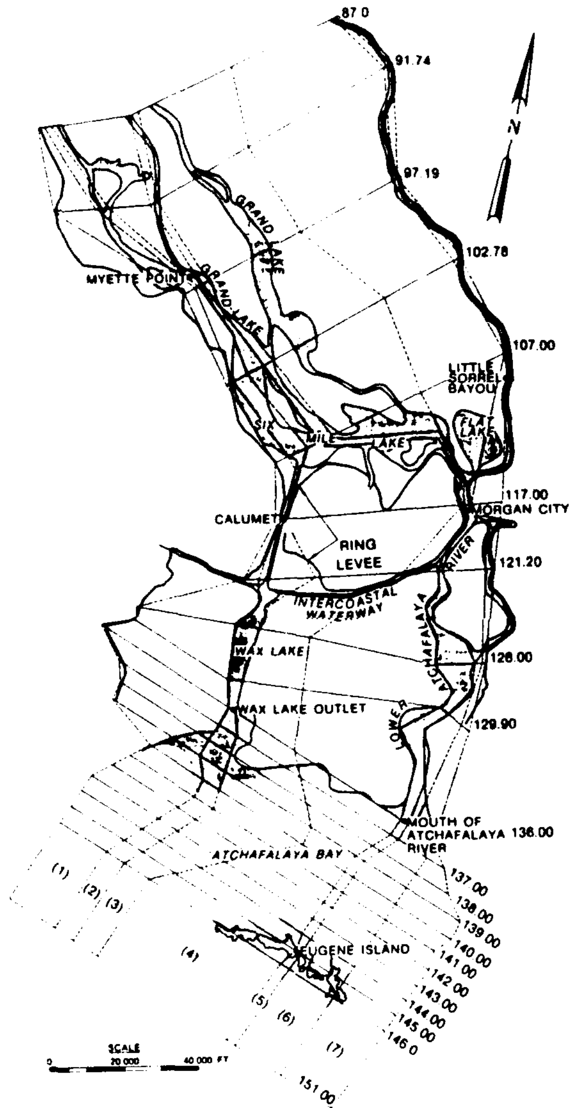


Figure 12. HAD-1 computational grid (Thomas, Heath, Stewart, and Clark 1988)

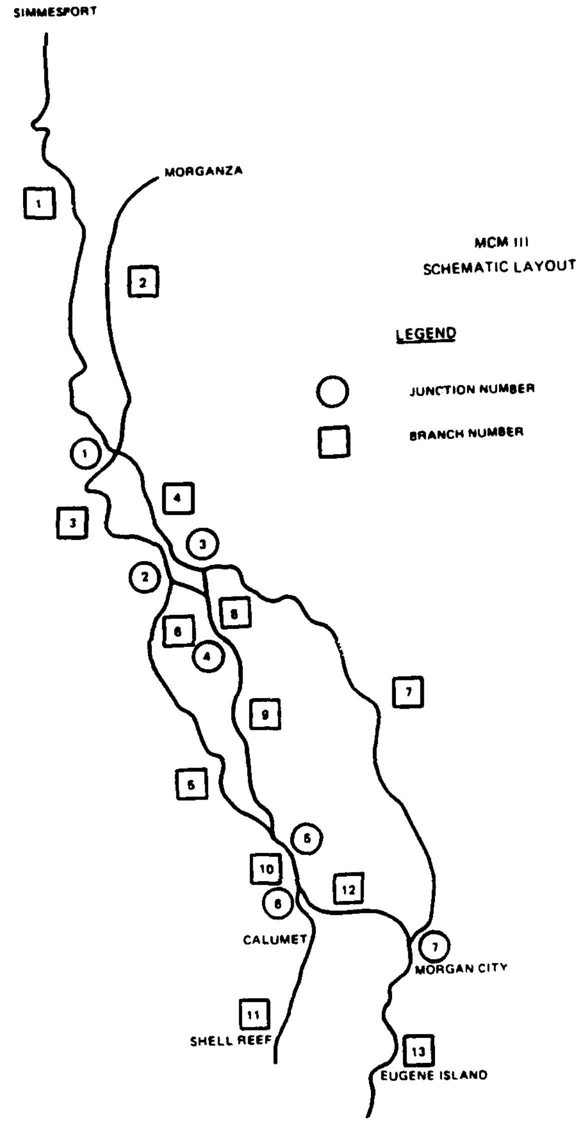
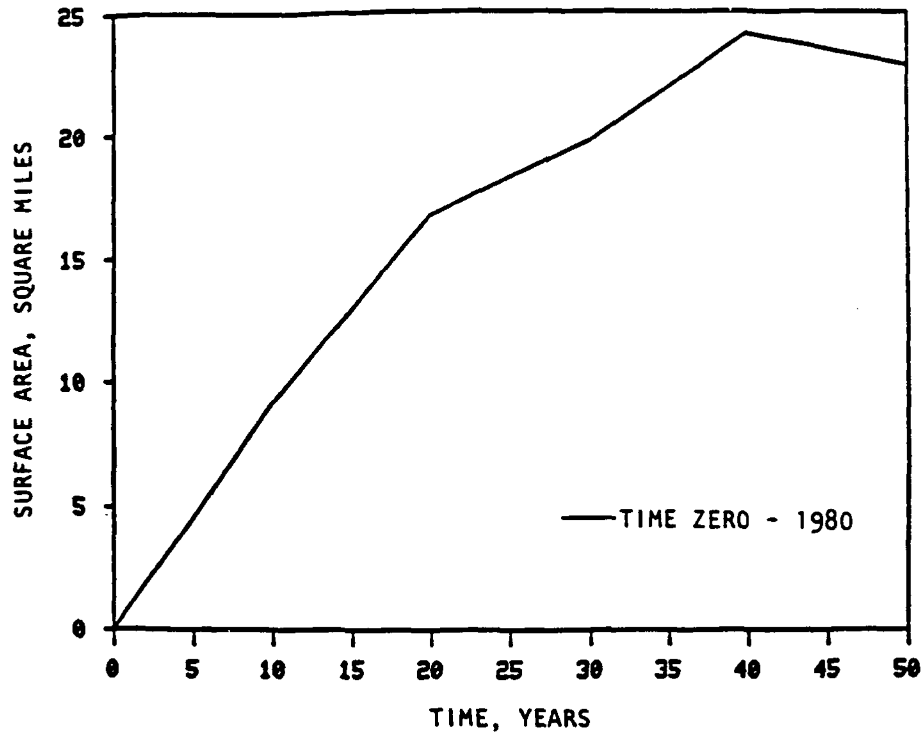
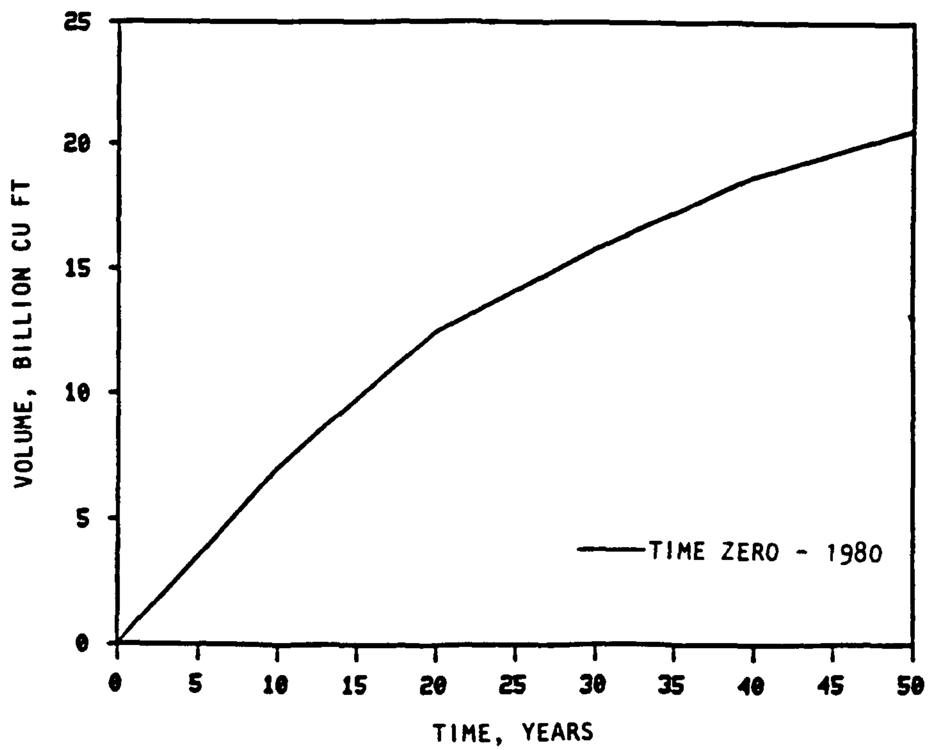


Figure 13. MCM network (Thomas, Heath, Stewart, and Clark 1988)



a. Predicted surface area



b. Predicted volume of deposition

Figure 14. Quasi-2D predicted delta growth in terms of new subaerial land and volume of deposition in the bay (Thomas, Heath, Stewart, and Clark 1988)

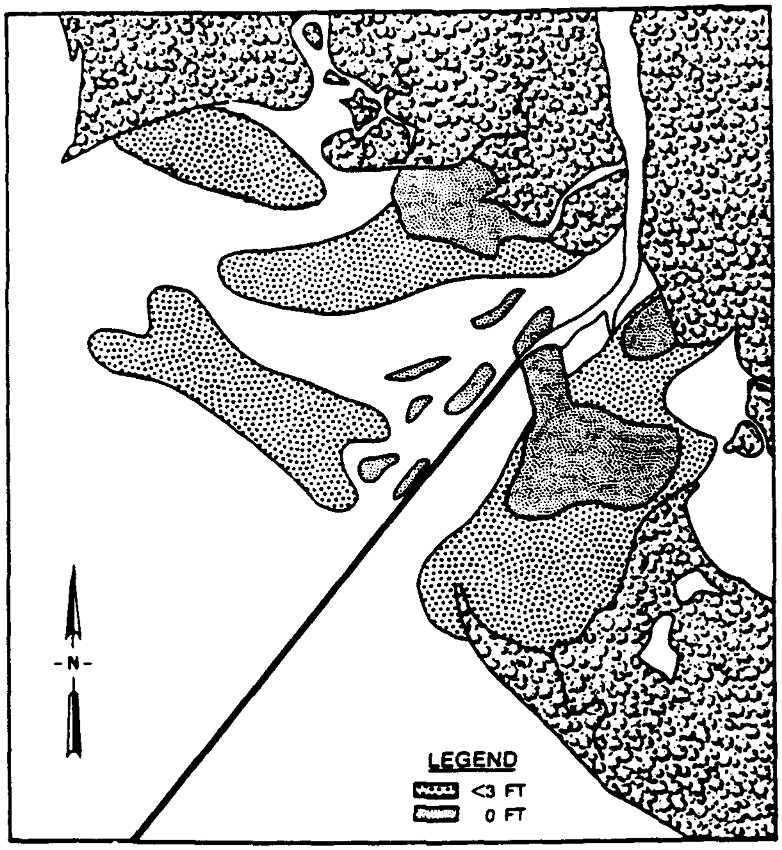


Figure 15. Quasi-2D calculated 50-year delta configuration (Thomas, Heath, Stewart, and Clark 1988)

1.0 cm/year is believed to be the better estimate of a baywide average value (Letter 1982). Therefore, the 47-square-mile delta subaerial extent is believed to be the more appropriate of the two runs made for the quasi-2D model.

29. The following are strengths of the quasi-2D model: it was a dynamic model incorporating multiple grain sizes, the study domain included the upper basis, and it utilized a real time hydrograph with many different flow conditions. The weaknesses of the quasi-2D model were as follows: the assumption that the shell reef had not been removed, the inability to incorporate wind and wave effects, the limited study area within the bay proper, the application of a constant uniform value of subsidence throughout the study domain, the inability of the model to erode or cut through a predicted subaerial lobe formation, the fact that the general flow directions are predefined, and the model did not allow for changes in flow direction as the delta emerges.

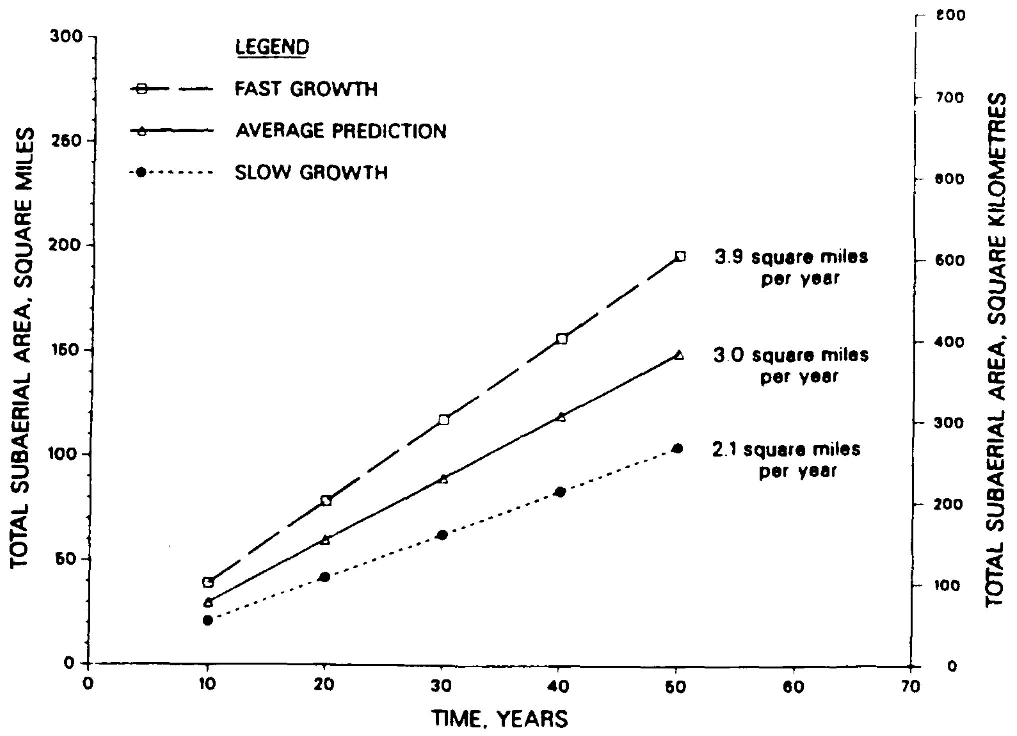
Analytical Prediction of Future Delta Growth

30. An analytical study of the various phenomena associated with turbulent plane jets issuing from river outlets into a quiescent bay was conducted in parallel with the quasi-2D study. Wang (1985 described it as, "An integrated form of the hydrodynamics equations of flow continuity and momentum balance, coupled with the advection-diffusion mass transport equation, have been formulated into a two-dimensional spatial and quasi-steady state temporal domain. Closed-form analytical solutions are obtained with the aid of similarity functions for the velocity and sediment concentration profiles." For a detailed account of the analysis see Wang (1985).

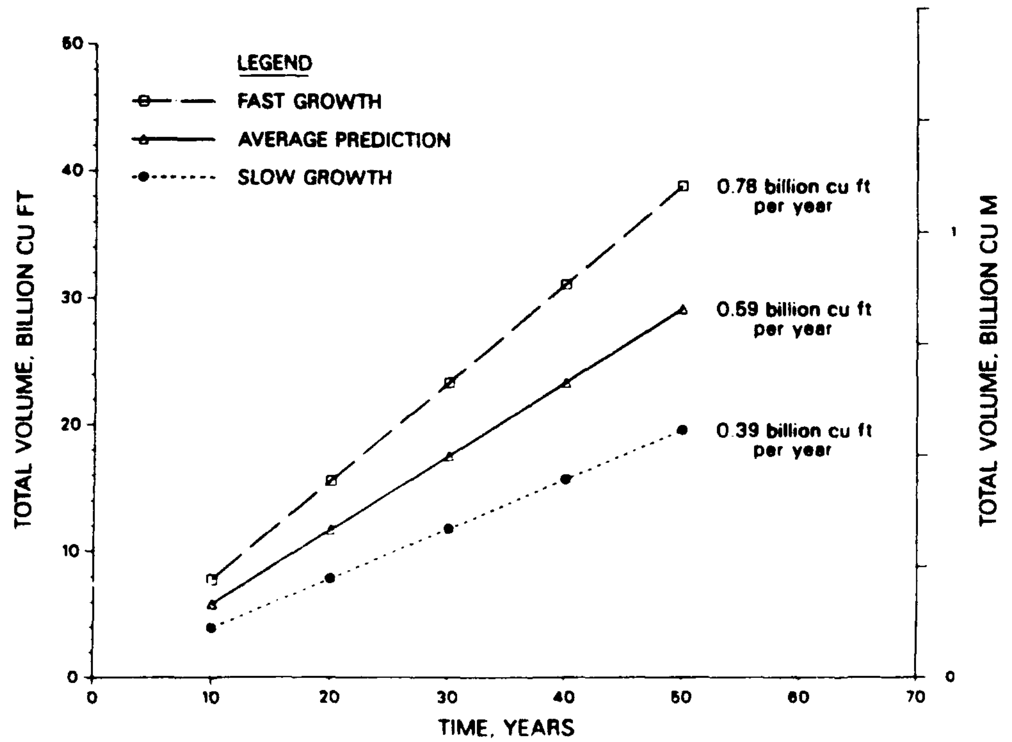
31. The delta growth prediction (Figure 16), based upon analytical results, showed an average growth rate of 3.0 square miles/year or 7.7 sq km/year (5.1 sq km/year for LAR and 2.6 sq km/year for WLO) bounded by a range of 5.4 to 10.1 sq km/year for the slow- and fast-growth environments. The average volume of total sediment deposition was 16 million m^3/year with a range of 12 to 23 million m^3/year for the slow- and fast-growth conditions. A contour map for approximate delta front advancement is depicted in Figure 17. Wang's prediction of total growth of subaerial land of the Atchafalaya River Deltas is expected to be 7.7 sq km/year. Sensitivity tests were performed to bound the projected 50-year delta area (150 square miles) by 105 and 195 square miles, a 60-percent variation.

32. Because of the parameter selection used in the analytical projections, the 105-square-mile slow growth delta prediction is the most appropriate projection for incorporation into the overall study. The fast-growth test (195 square miles) is not believed to be plausible and is omitted from additional analysis.

33. The strength of the analytical tool lies in its simplicity to provide an exact solution to the problem after a set of approximations. However, the weaknesses of the analytical method are numerous and are listed: tide and wave action was ignored, all input parameters were long-term averages within the protected bay, erosion and subsidence were not allowed in the computation, the thickness of the deposited sediment layer was assumed to vary linearly with time, and the basic jet theory breaks down as the depths became subaerial.



a. Analytical prediction of subaerial area



b. Analytical prediction of delta volume (above -3 ft contour)

Figure 16. Analytical delta growth predictions (Wang 1985)

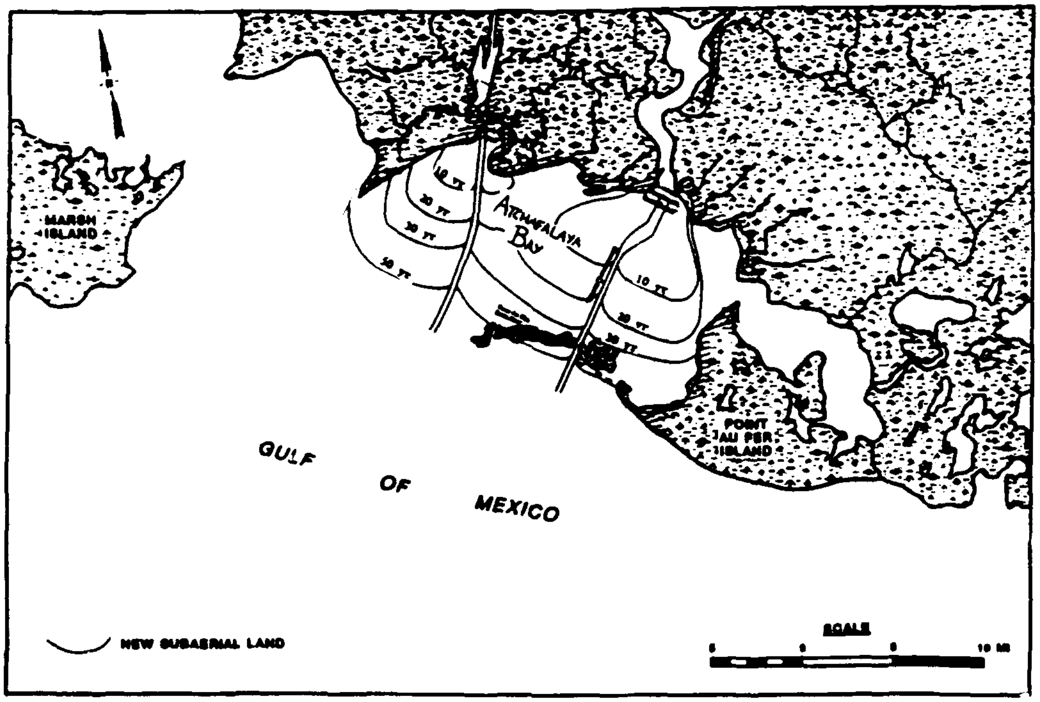


Figure 17. Predicted Atchafalaya Bay subaerial delta configuration by the Analytical method (Wang 1985)

Two-Dimensional Numerical Model

34. A generalized model of Atchafalaya Bay and Terrebonne Marshes was developed using the TABS-2 two-dimensional finite element numerical modeling system. It was the most sophisticated delta prediction attempt and incorporated knowledge obtained from all of the studies and field exercises conducted within this investigation. The TABS-2 system is a well-documented set of three generalized computer programs used to model 2D hydrodynamics (RMA-2), constituent transport (RMA-4), and sediment transport (STUDH), plus numerous utility programs. For a detailed account of the theory, governing equations, and instructions refer to Thomas and McAnally (1985).

35. The computationally intensive TABS-2 modeling simulations were conducted on both Cray-1 and Cyber-205 supercomputers. The two-dimensional modeling approach was extensively verified to available short-term and long-term prototype data. The numerical model extrapolation technique was verified to the 1967-1977 delta evolution. The approach was to calculate hydrodynamics and corresponding sediment transport to predict delta evolution. An iterative loop (beginning with the 1980 bathymetric condition with no barrier reef) for

using the predicted bathymetry to calculate updated hydrodynamics and sediment transport at delta evolution times of 0-, 15-, 30- and 50-years was incorporated. The approach permitted the statistical combination of multiple events which calculated hydrodynamics in response to deposition, erosion, dredge material placement, and delta lobe formations. The run-composite-extrapolate-run process is presented in Figure 18. For a detailed account of the verification process, sensitivities, spatial variations of subsidence, and the existing condition (BASE), delta predictions refer to Donnell, Letter, and Teeter (1991). Alternative operating procedures tested and their impacts on the system are presented, compared, and discussed by Donnell and Letter (in preparation) in Report 12 of this series.

36. The final computational mesh used in the delta evolution simulations is presented in Figure 19. One major difference between the TABS-2 two-dimensional delta evolution predictions and the other techniques was the increased size of the predictive 'window'. The extrapolation windows were compared earlier in Figure 4.

37. The TABS-2 two-dimensional modeling simulations with dredge disposal placement predicted that the subaerial size of the 50-year deltas will be bounded between 109 and 144 square miles (for the long-term extrapolation window). Corresponding 50-year delta volumes (above -3 ft contour) ranged between 19.35 to 24.13 billion ft^3. The variation in size is dependent on combinations of these factors (listed based upon relative significance): flow control (FCP) project on the Wax Lake Outlet, Avoca Island Levee extension to Deer Island (Figure 20), channel area, and lock operations. Table 3 presents a summary of the production runs tested. Plans D through H are presented in Figure 21 for comparison. Because of the impact of the delta evolution on stages in upper Terrebonne Marshes, the Bayou Boeuf Lock will have to remain closed at all river flows in the later years of delta evolution. Therefore, Plans G and H are viewed as the most likely two scenarios for with and without the levee extension. Figure 22, shows comparisons of the predicted subaerial land and deltaic volumes for plans G and H. None of the alternatives tested indicated a peak in delta growth within the first 50 years.

38. The following are strengths of the fully two-dimensional model: it used a realistic representation of the geometry, it provided continuous solution to the governing equations for both hydrodynamics and sediment transport, it allowed flexibility and ease in testing various alternatives, it

FLOWCHART OF LONG-TERM DELTA GROWTH PREDICTION

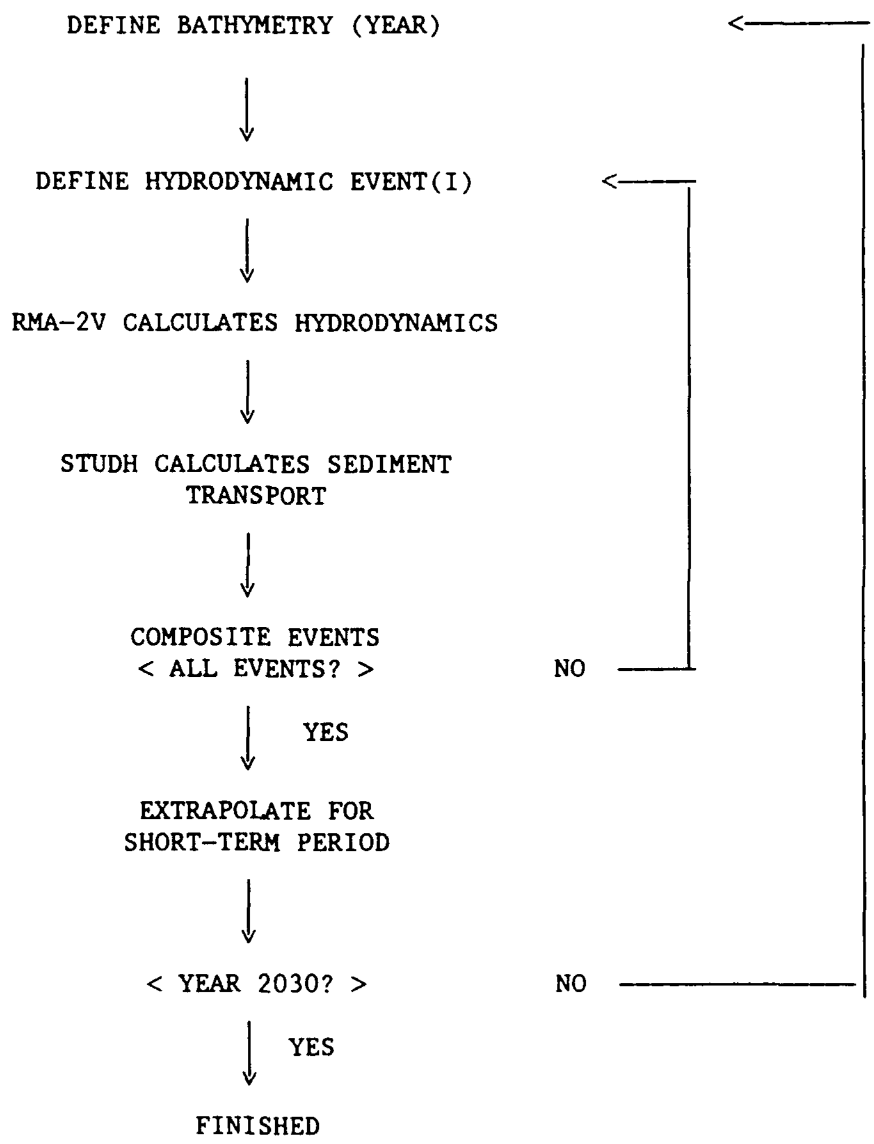


Figure 18. Flowchart of the run-composite-extrapolate-run process for long-term delta growth prediction

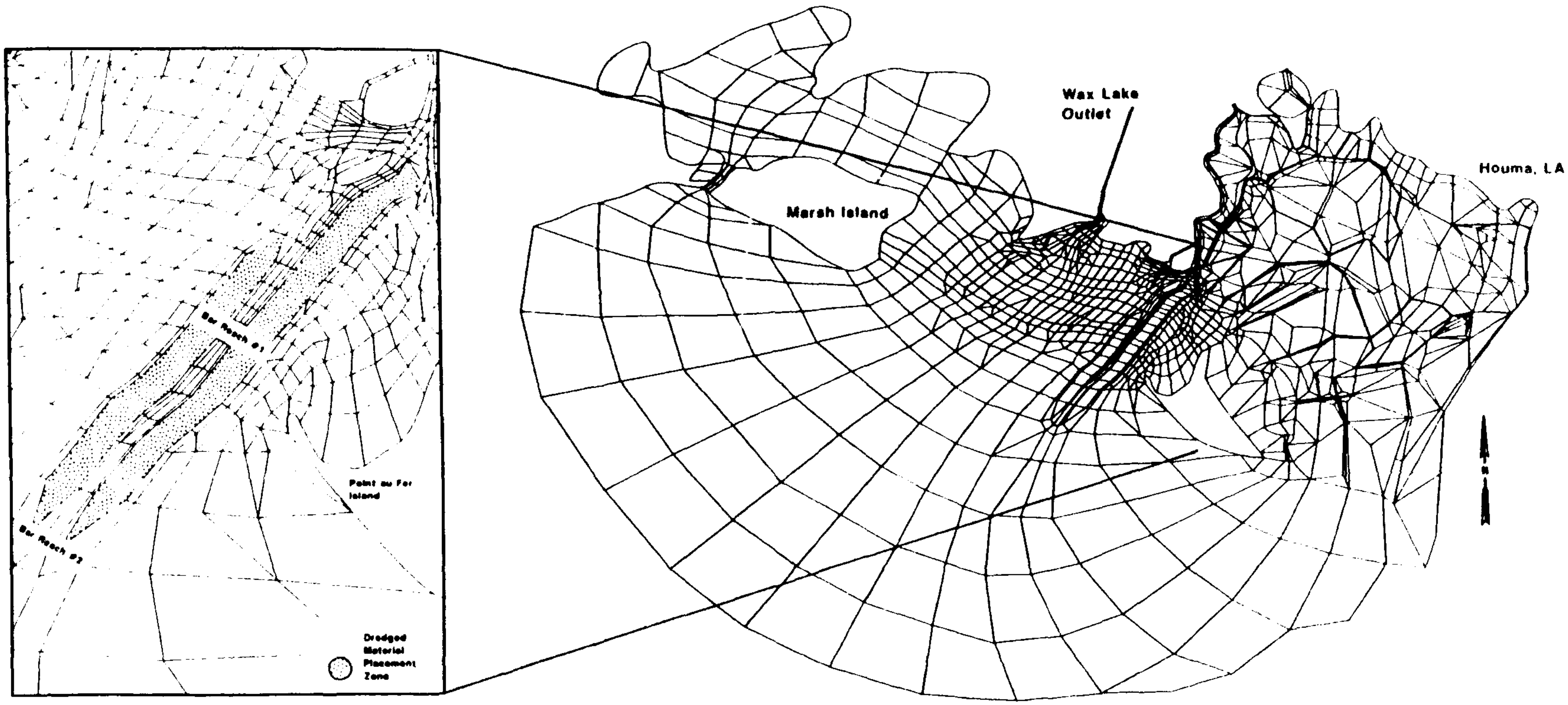


Figure 19. TABS numerical computational MESH8 for the Atchafalaya Bay and Terrebonne Marshes with a 6,000-ft-wide dredge disposal zone (Donnell, Letter, and Teeter 1991)

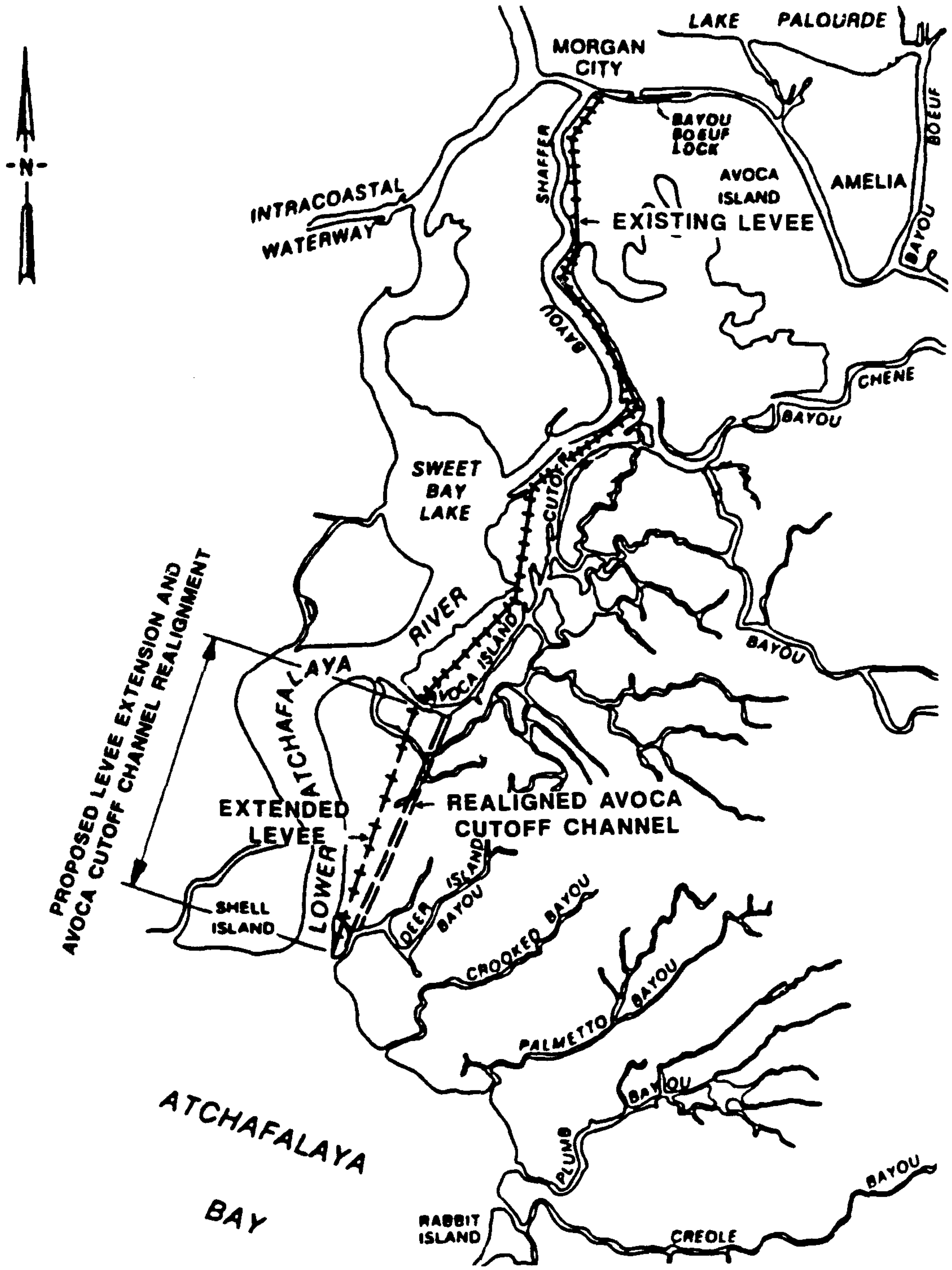


Figure 20. Avoca Island levee extension plan

Table 3

Elements of TABS Plans

Plan ID	Channel Maint	Levee Ext	WLO FCP	Dredge Disp Placement	B. Boeuf Lock
X	X	0	X	0	*
Y	X	2	X	0	*
C	0	0	0	0	*
D	X	0	X	X	*
E	X	2	X	X	*
F	X	0	0	X	*
H(30-50)	X+Er	0	X	X	Closed
G(30-50)	X+Er	2	X	X	Closed

* Bayou Boeuf Lock open for low discharges and closed for discharges above ~300,000 cfs.
X Indicates that the feature was activated.
0 Indicates that the feature was not activated.
Er Indicates that the LAR/WLO channels were allowed to erode.
2 Indicates that the Avoca Island Levee was extended to Deer Island (Reach 2)

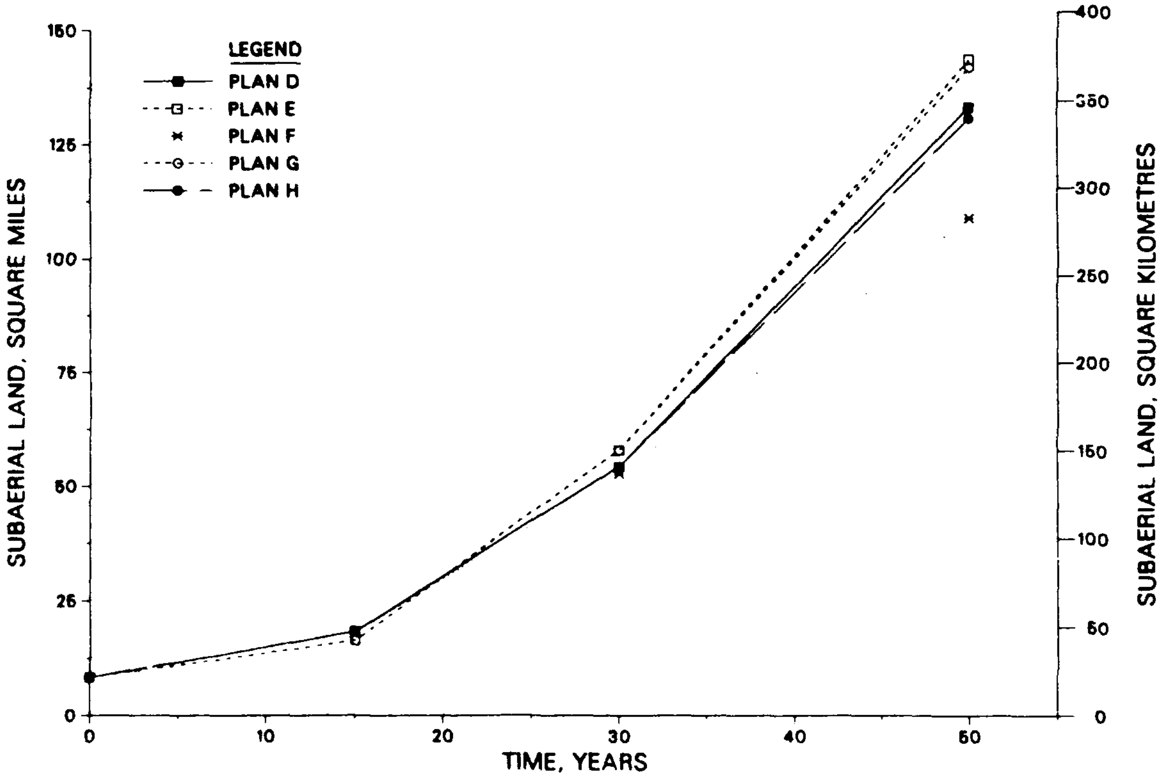
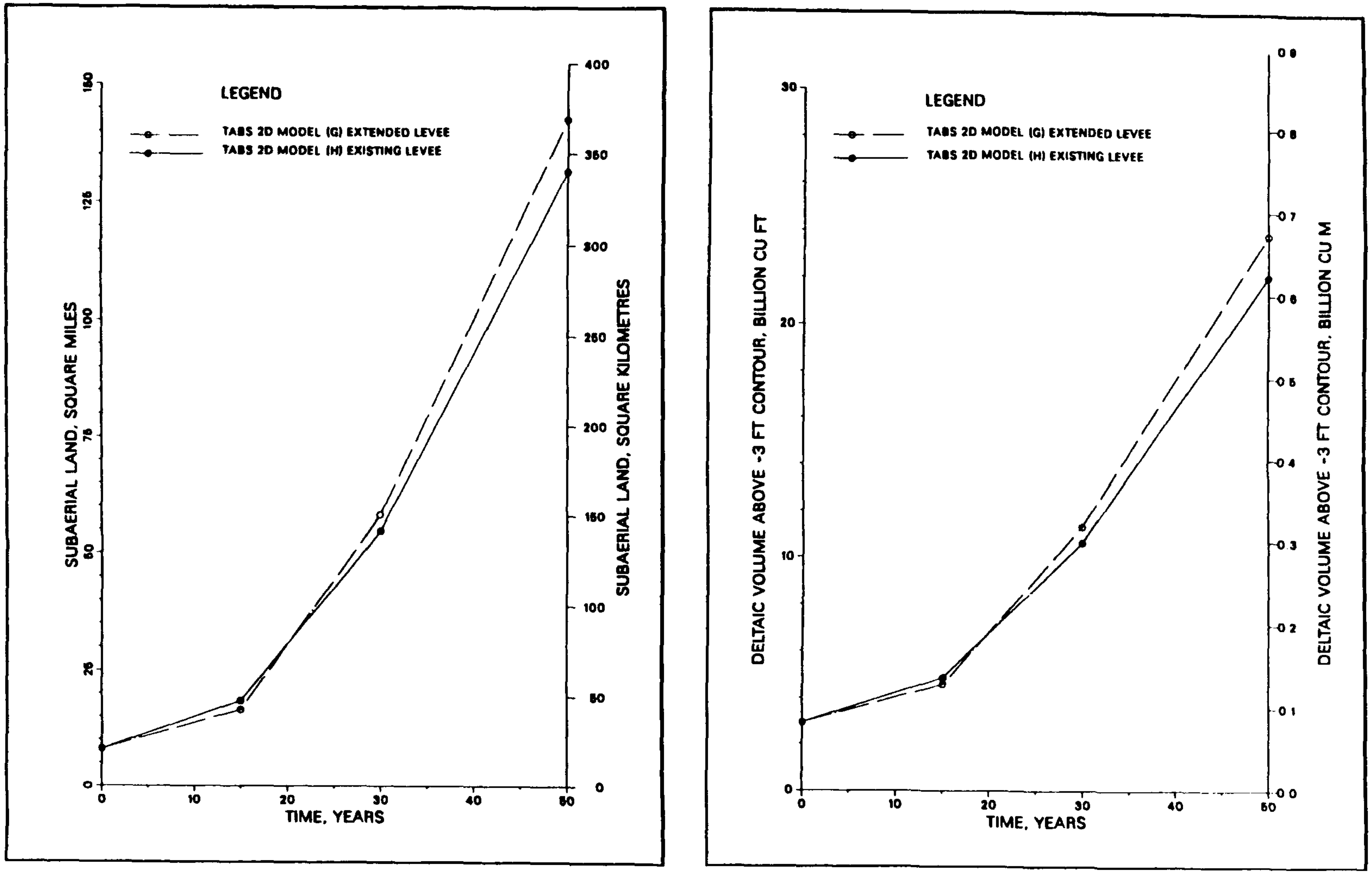


Figure 21. TABS-2D subaerial land predictions for simulations including degree disposal placement (long-term extrapolation window)



a. Subaerial land area

b. Delta volume

Figure 22. TABS-2D modeling delta growth predictions for Plans G and H (long-term extrapolation window)

incorporated the effect of delta growth on circulation and salinity within the bay and the adjacent Terrebonne Marshes, and it employed the spatially varying subsidence rates determined from the regression work mentioned in paragraphs 8 through 14. The limitations of the fully two-dimensional modeling technique were as follows: discretization issues associated with time and space, the unsteady influence of physical processes that were not explicitly simulated (processes which have a dynamic nature less than the 1-hr time step), and the forward-stepping linear projection of sedimentation rates starting from the beginning of an extrapolation period (10-20 years).

PART III: COMPARATIVE RESULTS AND DISCUSSION

39. The results from each of the methods used within the study are now discussed as a group for each of the significant processes of interest. Furthermore, some additional analysis is presented to clarify the 50-year projections.

Apparent Subsidence

40. In this context, subsidence is the relative lowering of the land surface with respect to sea level, which is the sum of sea level change and land elevation change. The methods used to predict delta growth within Atchafalaya Bay considered the subsidence rate to vary between 0.0 and 1.6 cm/year. Basically there were four approaches: (a) do not consider subsidence (analytical study), (b) assume that the historical projections inherently contain the proper subsidence rate (extrapolation/regression and generic analysis), (c) use the analysis of historical tide-gage data at Eugene Island in Atchafalaya Bay from 1940-1970 which suggested a rate of 1.3 cm/year (quasi-two-dimensional model), and (d) use the multiple station regression analysis which produced a spatial distribution of subsidence (TABS two-dimensional model). Because of the known variation of subsidence from open-gulf waters landward, it is believed that the spatial distribution used in the extrapolation, generic analysis, and TABS two-dimensional modeling is the most appropriate representation. For a complete discussion of subsidence predictions refer to Report 11, Appendix A, of this series (Donnell, Letter, and Teeter 1991).

Delta Evolution

41. Delta growth (over the short term and long term) can be measured in a variety of ways, and comparisons between the several predictions must be made carefully to ensure true comparability. For the purposes of this report, subaerial land is defined as the new (post 1969) area at or above 0.0 ft NGVD, delta extent is the area at or above the -3.0 ft NGVD contour, and delta volume is the mass of sediment at or above the -6.0 ft NGVD contour.

42. The differences in delta growth predictions between techniques when

hydrological variables are carefully controlled were comparable to the variation for a single technique associated with hydrological uncertainities. Thus delta growth projections should be made with the TABS modeling approach with careful hydrologic inputs.

Subaerial land

43. Table 4 presents the comparisons of the best estimates of the various methods which all used the verification window (smallest) described previously in Figure 4 and did not consider dredge disposal. The predictions for subaerial land at year 50 ranged from a low of 45 square miles (quasi-2D modeling with 1.0 cm/year subsidence) to a high of 105 square miles (analytical treatment with no subsidence).

44. The variation in results obtained from the various prediction methods is significant (47-107 percent) relative to the average. Considering that the total Atchafalaya Bay covers approximately 200 square miles, the mean value of 77 square miles obtained by simple averaging suggests that 38 percent of the bay will be subaerial by the year 2030 (if there is no dredge disposal placement).

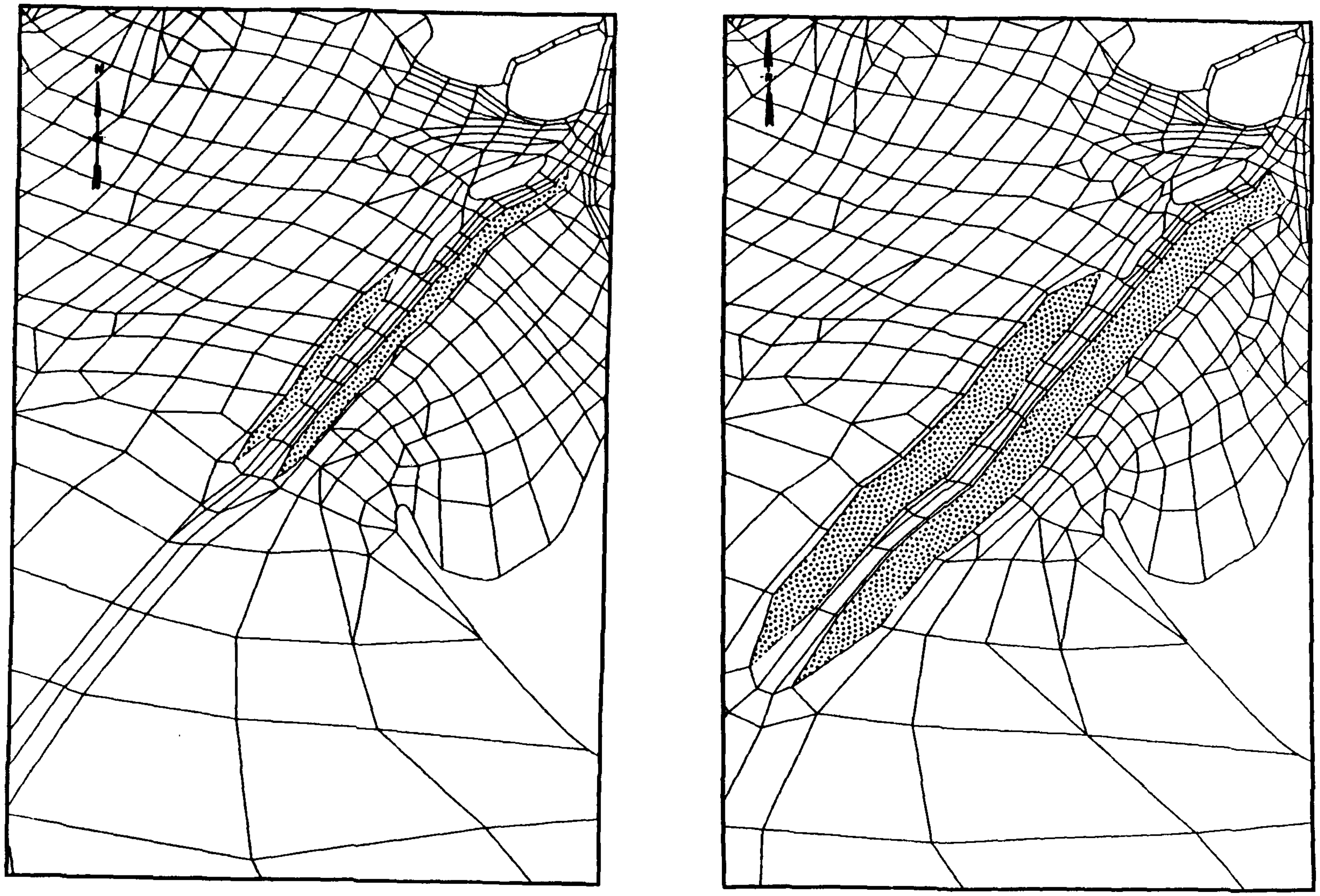
45. However, the TABS two-dimensional modeling technique permitted dredge disposal placement of all deposits within the LAR navigation channel. The dredged disposal was placed alongside the channel in a designated zone which was enlarged as needed during the 50-year simulation (Figure 23). Table 5 compares some of the alternatives tested with the two-dimensional modeling technique (for the small window shown in Figure 4). Note that dredge

Table 4

Projections of Total Subaerial Land, Square Miles

Source	Year-10 1990	Year-15 1995	Year-20 2000	Year-30 2010	Year-40 2020	Year-50 2030
Analytical method*	21	31	42	63	84	105
Extrapolation	19	28	36	55	73	87
Generic analysis	30	39	46	61	73	80
Quasi-2D modeling	22	28	34	39	47	45
TABS-2D modeling (X)	9	10	13	19	49	79
Average	20	27	34	47	65	79
Variation	105%	107%	97%	93%	57%	76%

* This method did not contain subsidence.



a. Years 0-15

b. Years 30-50

Figure 23. TABS-2D modeling dredge disposal placement locations

Table 5

Two-Dimensional Modeling Predictions

Plan	Levee Reach	Channel Maint	Disposal Placement	Project WLO	Subaerial Land Square Miles* Year-15 1995	Year-30 2010	Year-50 2030
X	0	Yes	No	Yes	10	19	79
Y	2	Yes	No	Yes	10	17	56
G	2	Yes	Yes	Yes	15	54	118
H	0	Yes	Yes	Yes	17	51	107
F	0	Yes	Yes	No	17	51	92
C	0	No	No	No	-	-	61

* Within verification window (Figure 4).

disposal placement alongside the channel (Plans D, E, F, G and H) significantly revised the subaerial size of the delta and the comparative impact of the levee extension.

46. Figure 24 compares results from each of the delta subaerial prediction methods within the verification window (Figure 4). Note that the analytical method, which did not consider subsidence, is the highest prediction.

47. The data of Figure 24 contain a variety of differences between the techniques which may exaggerate the scatter. In an effort to clarify the overall study prediction, the most appropriate ("best") prediction for each technical approach was selected (Figure 25) and a regression analysis performed on these predictions along with the available field data. The regression analysis assumed a Gaussian distribution function in time, which gave a maximum delta area (Figure 26) of 89 square miles at year 55 (2035). Figure 26 also includes the range of predicted values for the best estimates and the range of predictions for all of the sensitivity runs from all of the techniques. The inner bounds represent the influence of the technical approach and the outer bounds are more indicative of the full range of environmental uncertainty associated with meteorological influences, subsidence, and deviations of the flows from the 50-year hydrograph. The range of delta sizes for year 50 was 45 to 118 square miles for the "best" estimates from each technique and was 32 to 152 square miles for all techniques.

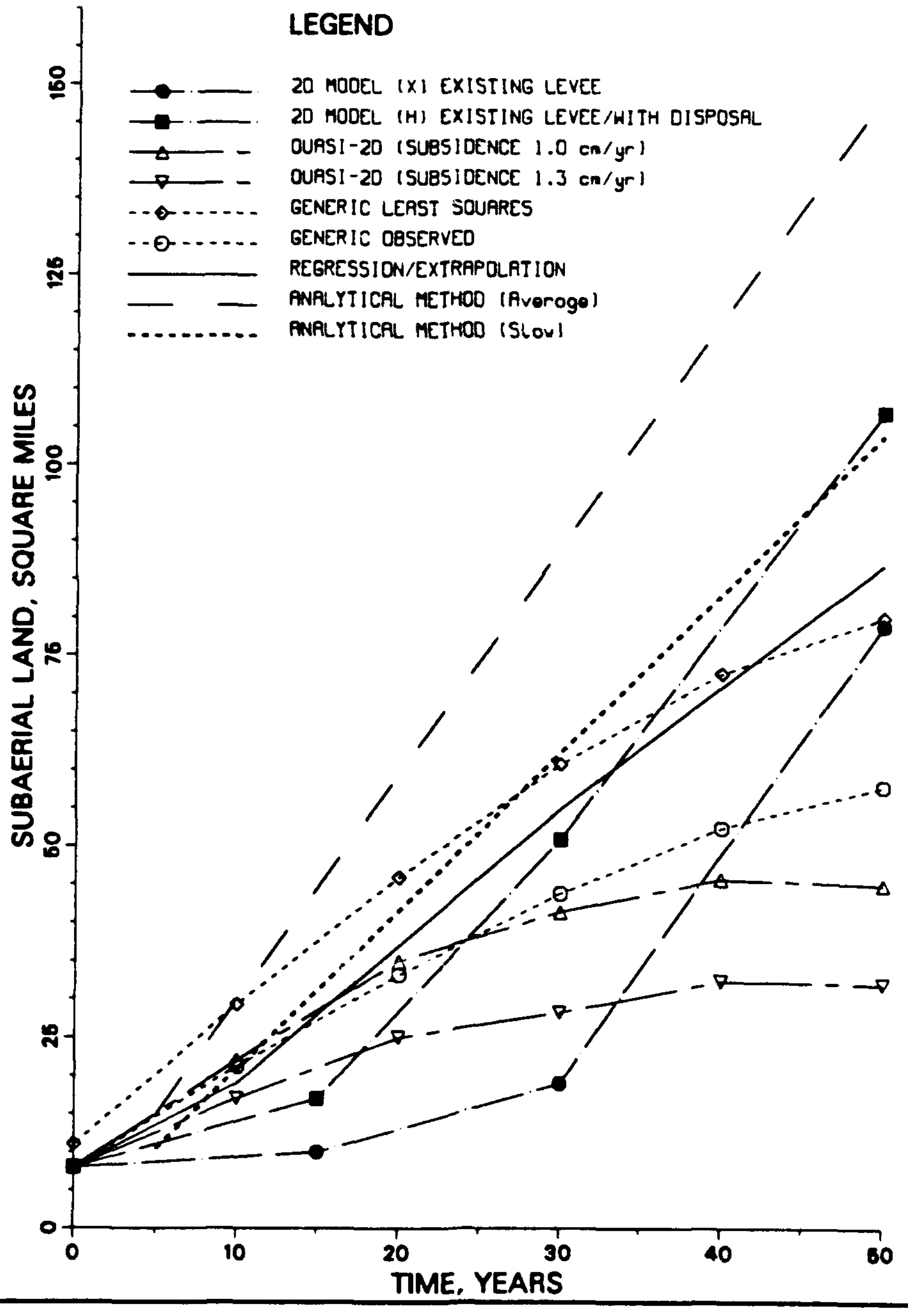


Figure 24. Comparison of subaerial delta prediction methods

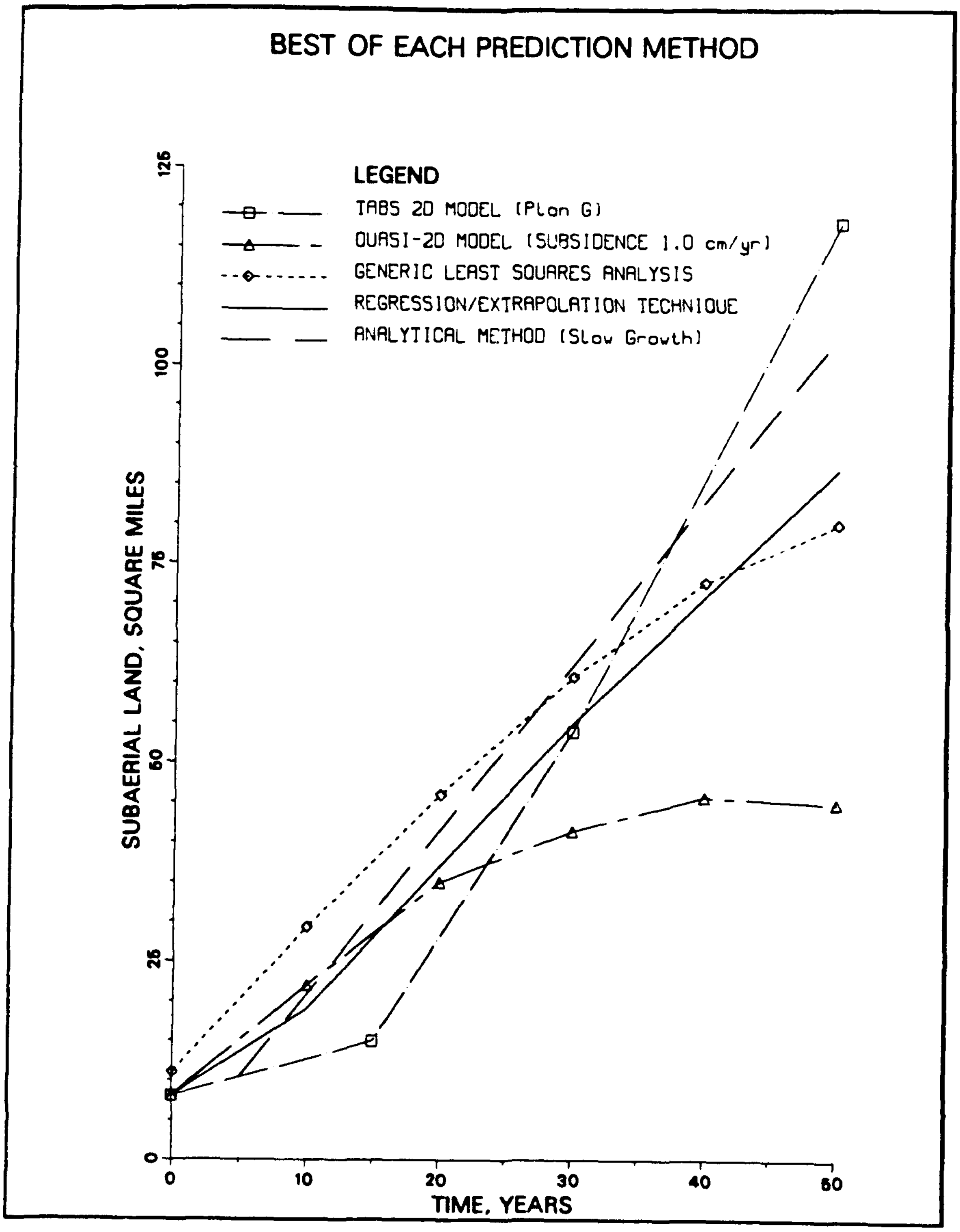


Figure 25. Most appropriate ("best") prediction of subaerial land from each method

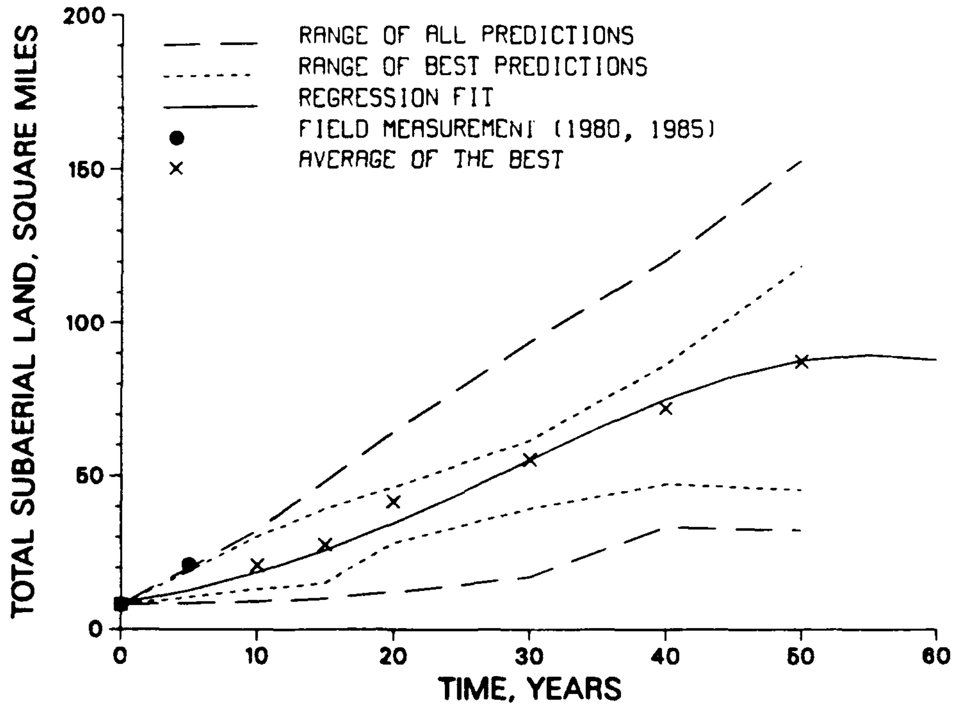


Figure 26. Regression analysis results of subaerial delta prediction methods

Volume of the delta

48. The 50-year TABS two-dimensional delta volume and subaerial extent are summarized in Table 6 for most of the plans tested (Table 3). These are all associated with the verification window (Figure 4). Plans X, Y, and C all had smaller deltas than any of the other plans primarily because dredged material was not placed adjacent to the channel and was removed from the system. Plan C had no channel maintenance at all and represents the delta evolution with no further activities of man in the system.

49. Table 7 provides a comparison of the predicted volume of the delta evolution for the alternatives which incorporated dredged material placement. The sediment volumes presented were calculated based upon the larger long-term extrapolation window, as shown in Figure 4. Figure 21 compared the subaerial land for these alternatives.

50. Table 8 summarizes and compares the delta volume prediction from each method using the smaller verification window (Figure 4). For the purposes of this comparison, delta volume is considered to be the volume of sediment demarcated by the −3 ft contour. All of the techniques are very close in

Table 6

Summary of Delta Evolution for TABS Production Runs Year 50

Plan	Volume of Sediment, cubic km* Above elevation, ft, plane -6	-3	0	Subaerial Area* sq km	sq mi
X	1.045	0.410	0.095	204	79
Y	0.912	0.319	0.052	145	56
C	0.924	0.340	0.057	159	61
D	1.141	0.499	0.127	279	108
E	1.246	0.522	0.141	306	118
F	1.064	0.444	0.099	237	92
G	1.253	0.554	0.141	306	118
H	1.138	0.498	0.126	278	107

* Within the verification window (see Figure 4).

Table 7

TABS Two-Dimensional Production Runs with Dredge Disposal

Predicted Volume of Sediment, cubic kilometers

Above the Given Elevation Plane

Plan/Year	Volume of Sediment, cu km* Above elevation, ft, plane -6	-3	0	Subaerial Aeral* (sq km)	(sq mi)
D - 0	0.363	0.083	0.007	18	8
D - 15	0.523	0.138	0.016	48	18
D - 30	0.847	0.299	0.059	141	55
D - 50	1.464	0.634	0.158	346	134
E - 15	0.509	0.130	0.013	43	16
E - 30	0.881	0.319	0.062	151	58
E - 50	1.566	0.683	0.171	374	144
F - 30	0.850	0.293	0.055	137	53
F - 50	1.350	0.548	0.119	283	109
G - 50	1.540	0.673	0.169	369	143
H - 50	1.436	0.622	0.156	340	131

* Within long-term extrapolation window.

Table 8

Predicted Delta Volumes (above -3 ft contour) for Year 50

Method	Billions of Cu Ft	Cubic Kilometers
Extrapolation/Regression	18	0.509
Generic Analysis	25	0.708
Quasi-2D Modeling	21	0.594
Analytical Study+	28	0.792
TABS-2D Modeling (Plan X)	15	0.410
TABS-2D Modeling (Plan H)*	18	0.498
Average	21	0.594

+ Indicates that effects of subsidence were not included.
* Indicates that the method included dredged material placement.

volume predictions, with a 48-percent variation of extremes from the mean.

Extent of the delta

51. Figure 27 compares the land distribution at year 50 for the five methods discussed previously. The 'coast-line' shown in these figures correlates to the 0.0 ft NGVD 1969 configuration and the subaerial land for year 50 (2030) represents 0.0 ft NGVD at the time of the prediction. The generic analysis method and the TABS two-dimensional prediction (Plan H with dredge disposal placement) each predict subaerial land beyond Pt au Fer. The generic analysis did not require that the WLO navigation channel be maintained, as evidenced by the solid land mass at the WLO coastline.

52. Figure 28 presents the predicted delta extent as defined as the area within the -3 ft NGVD elevation contour. The two modeling approaches both have zones within the bay itself deeper than 3 ft in response to hydraulic forces. The extrapolation technique and an earlier projection by Garrett, Hawxhurst, and Miller (1969) did not involve any accounting for water rerouting to the gulf.

53. The delta extent predictions for each of the techniques were consolidated by overlaying each of the year 50 subaerial maps and applying Boolean set logic to compile an intersection map. Zones were delineated as the intersections of the predicted subaerial deltas from each technique. Then an evaluation of the factors of importance to the deltaic process and simulation was

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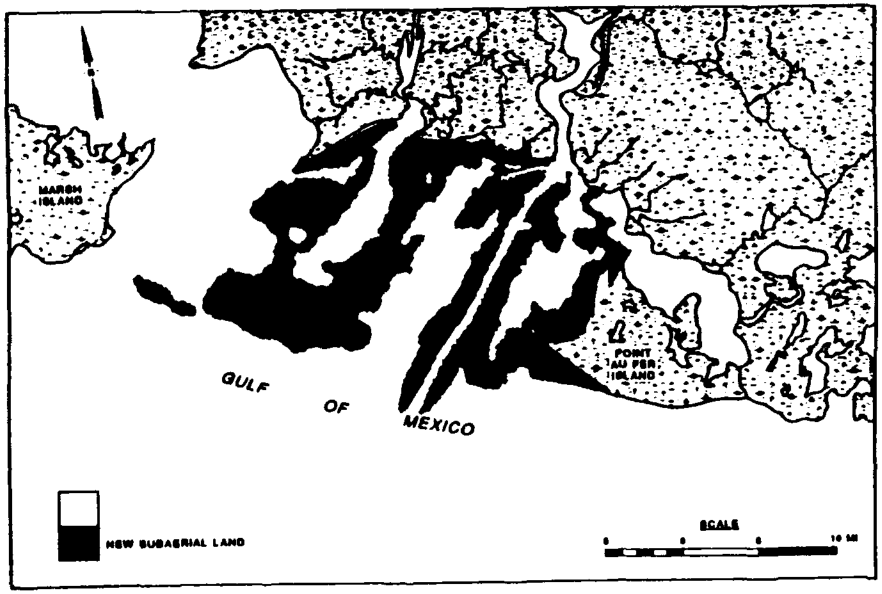
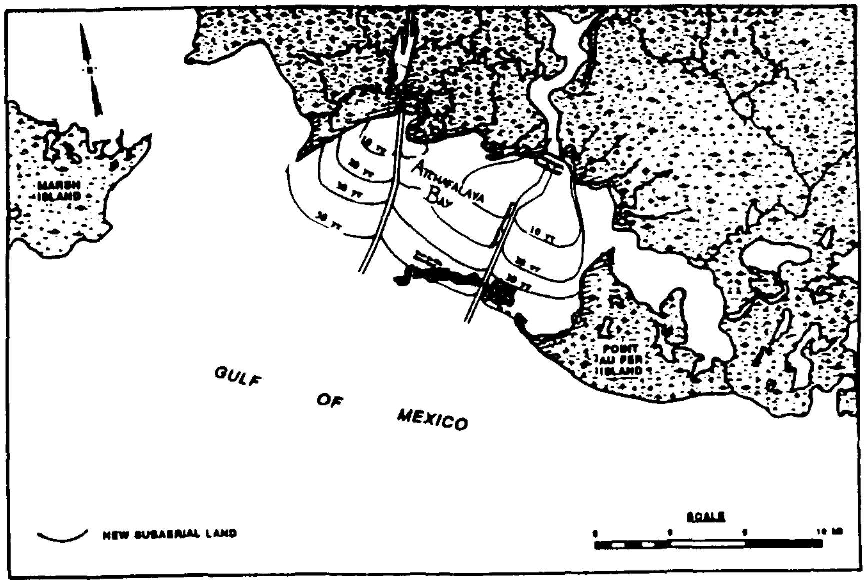
52. Figure 28 presents the predicted delta extent as defined as the area within the -3 ft NGVD elevation contour. The two modeling approaches both have zones within the bay itself deeper than 3 ft in response to hydraulic forces. The extrapolation technique and an earlier projection by Garrett, Hawxhurst, and Miller (1969) did not involve any accounting for water rerouting to the gulf.

53. The delta extent predictions for each of the techniques were consolidated by overlaying each of the year 50 subaerial maps and applying Boolean set logic to compile an intersection map. Zones were delineated as the intersections of the predicted subaerial deltas from each technique. Then an evaluation of the factors of importance to the deltaic process and simulation was

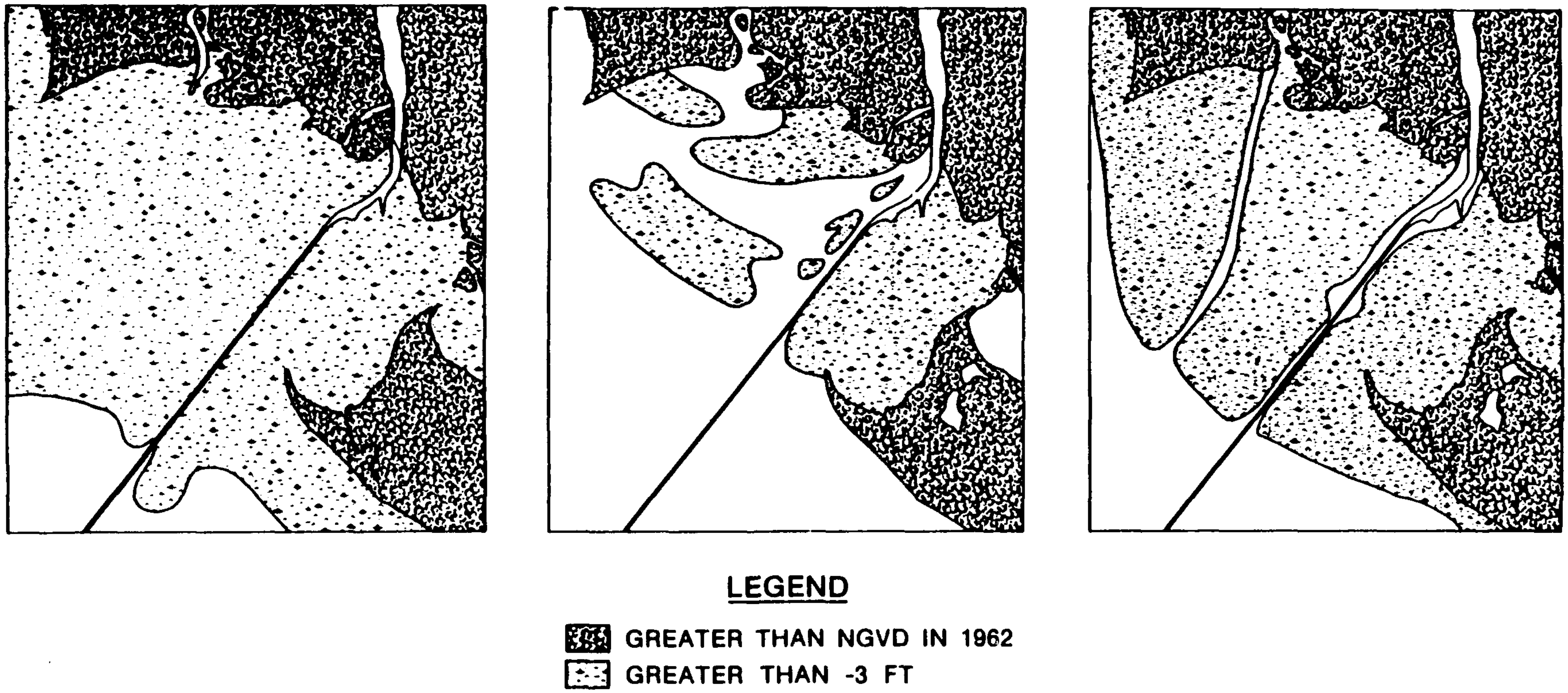


d. TABS two-dimensional modeling



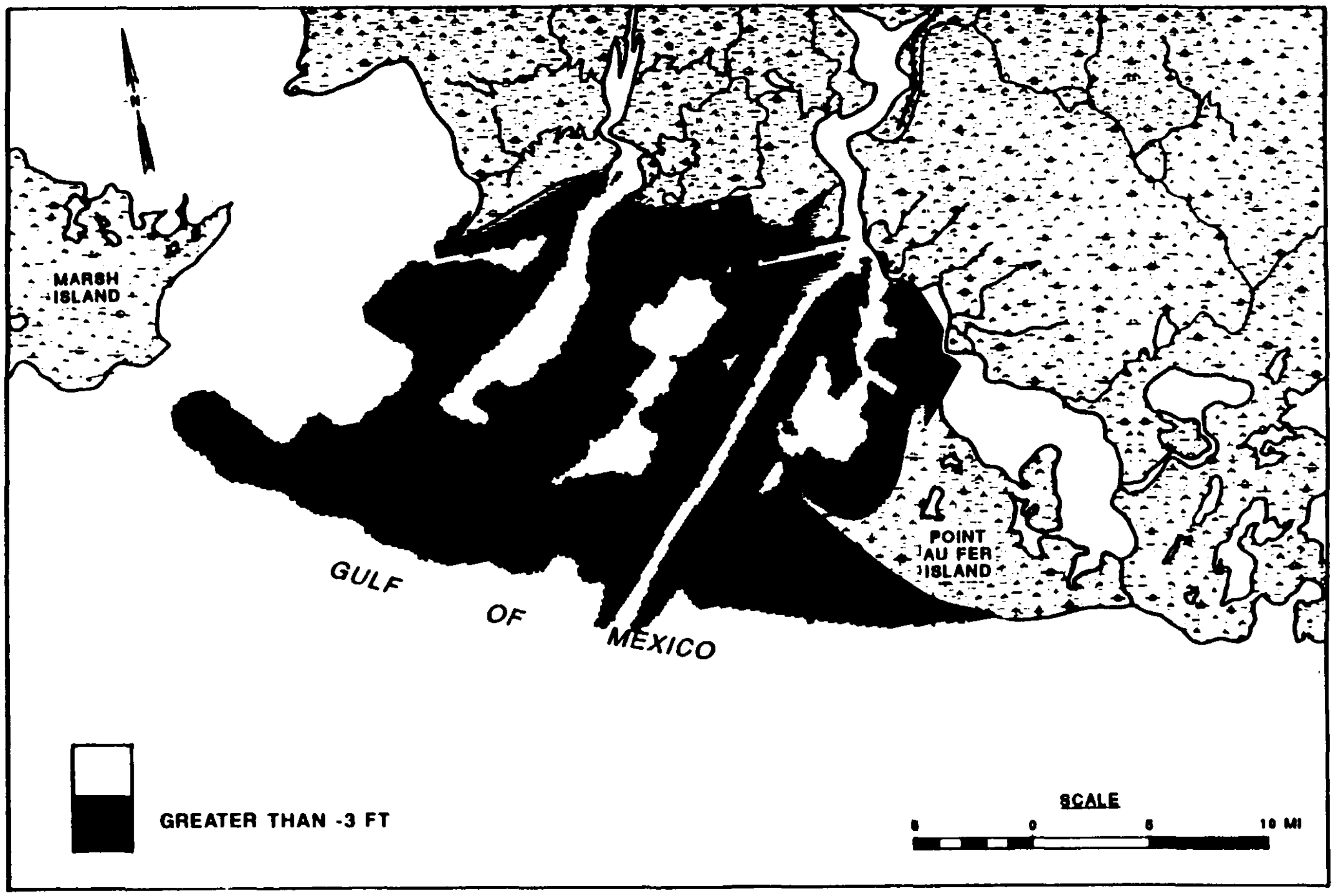
e. Analytical technique

Figure 27. (Concluded)



a. Extrapolation b. Quasi-two-dimensional modeling c. Garrett 1969)

Figure 28. Delta extent at 50 years (Continued)



d. TABS two-dimensional modeling

Figure 28. (Concluded)

made to assign relative probabilities to those zones. The evaluation of these factors is presented in Table 9. The TABS modeling received the highest total weight and the analytical technique received the lowest total weight. Development of weights is subjective but reflects the authors' best judgments based on thorough understanding of the methods and their limitations.

54. In the development of a prediction probability, the dimensionless weights from Table 9 were summed for each of the techniques that had predicted subaerial development in the zone. The maximum sum of technique weights would be 2.34, which arose when every technique predicted subaerial in that zone. Therefore, the subaerial probabilities were further nondimensionalized by this value, resulting in a maximum prediction probability of 1.0 in that case.

55. These zonal prediction probabilities for subaerial delta are presented in Figure 29. These values represent the probability associated with the predictions. That is, a value of 1.0 implies that all of the techniques have predicted subaerial delta at that location. It should not be inferred that this modeling effort is giving a probability of 1.0 to there being a subaerial delta at that location. The system processes are too random for any method to precisely predict configuration 50 years in the future.

56. It is interesting to note that the greatest spatial variability in the probabilities occurs in the upper portion of the Lower Atchafalaya Bay Delta. This is a reflection of the higher energy levels in that zone associated with the river inflow and possibly, in part, related to the greater resolution and attention paid by each technical approach to that area. In addition, this figure provides some visual reinforcement of the level of complexity of the deltaic system with regard to the subaerial delta.

57. The LMN Engineering Division acquired photography of the prototype deltas for Dec 1990 (photo 1), which would be comparable to year 10 in terms of the analysis presented in this series of reports. Analysis of the photograph to define subaerial area was ongoing at the time of publication of this report. However, it is evident from the photograph that the Wax Lake outlet delta is evolving more rapidly than projected. This may be due to the fact that the control structure was not in operation until 1988.

Life cycle of the delta

58. Only a few of the delta growth techniques predicted a life cycle of the delta (i.e., a period after which size actually declines). The generic analysis method predicted a maximum delta growth to occur at an average of

Table 9

Development of Prediction Probabilities for Delta Extent

Factor of Importance	Maximum Weight	Predictive Technique: Extrapolatory Regression	Generic Analysis	Analytical Technique	Quasi-2D	TABS-2D	
Time discretization							
Real-time sequencing	10	5	0	0	10	0	
Extreme events	5	5	5	0	3	0	
Consistent probabilities	10	10	0	0	10	4	
Spatial discretization							
Two-dimensional	10	10	10	5	3	10	
Area covered	5	3	5	2	2	5	
Realistic geometry	10	5	5	0	2	10	
Dredged material placement	10	3	0	0	0	10	
Hydrodynamic processes							
Meteorological inputs	10	5	5	0	0	0	
Rerouting of water	10	0	3	3	5	10	
Solves governing equations	10	0	0	10	10	10	
Sediment processes							
Multiple grain sizes	10	10	10	0	10	2	
Solves transport equations	10	0	0	10	10	10	
Dependent on sediment supply	10	10	0	0	10	10	
Other							
Verification rigor	10	5	3	0	8	10	
Man-induced impacts	10	0	0	0	7	10	
Total	140	71	46	30	90	101	
Dimensionless weight	1.4	0.51	0.33	0.21	0.64	0.72	
Dimensionless probability component		0.21	0.14	0.09	0.27	0.29	Total 1.0

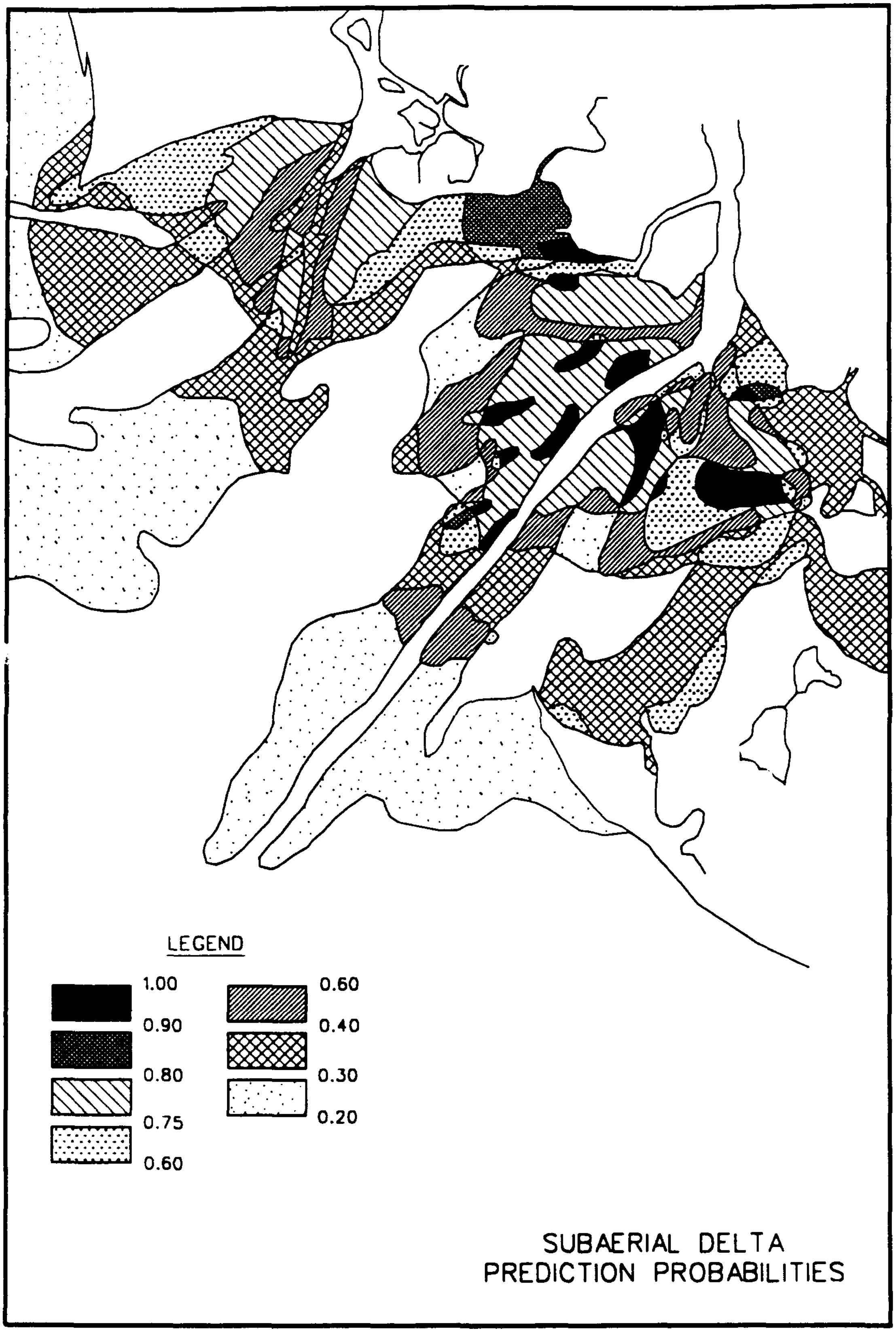


Figure 29. Subaerial delta prediction probabilities

66 years and the growth/decay life cycle to be complete after 116 years. The quasi-2D modeling predicted a subaerial maximum growth to occur at year 40 and suggested that the complete growth/decay life cycle would end sometime beyond 50 years.

59. The TABS-2D modeling method did not show a peak in the delta growth during the 50-year simulation. However, there is an inflection in the derivative of the slope of the growth curve at year 50, based on a sensitivity run which projected the delta growth beyond year 50. This does indicate that the model technique would simulate the growth/decay cycle if the model were run for a longer period than 50 years. If it is assumed that the growth/decay cycle is symmetric in time, then it can also be inferred from the TABS modeling that the total period of the cycle is in excess of 100 years.

60. The model results for delta subaerial extent were fit to a Gaussian distribution in two different manners. In the analysis of the TABS model results alone, an analytical Gaussian function was fit to the TABS model results explicitly. This analysis estimated a peak in the delta growth at about 81 years. The Gaussian analysis described earlier in paragraph 44 involved all of the technical approaches and a regression was performed to fit the analytical curve through the growth predictions. This analysis resulted in an estimated peak in delta growth after 55 years.

Impacts of Delta Growth on the System

61. Only the quasi-2D and TABS-2D modeling techniques were capable of estimating impacts of delta growth, e.g. backwater flooding, changes in salinity, and Terrebonne Marsh circulation and sedimentation changes resulting from extensive delta growth within Atchafalaya Bay.

Water levels

62. The quasi-2D work predicted LAR and WLO water-surface profiles for flood events and did not address salinity intrusion or impacts in the areas east of the Avoca Island Levee. The quasi-2D results of water-surface profiles for LAR and WLO were computed for the 1973, 1975, and 58AEN flood events, respectively, at year 0 and 50.

63. The TABS-2D modeling results examined the impacts of delta growth on: flood stages, circulation, salinity intrusion, sedimentation rates within Terrebonne Marshes, and LAR navigation channel maintenance. For a detailed

analysis of these impacts, refer to Report 12 of this series, according to Donnell and Letter (1992).

64. Figures 30 and 31 compare water-surface elevations between the quasi-2D and TABS-2D modeling results for the LAR and the WLO at the coastline for years 0 and 50. Table 10 presents the results. Not all points were readily available.

65. The comparison between the TABS and the quasi-2D results with regard to year 0 elevations is very consistent for the Lower Atchafalaya River coastline but shows considerable disparity at the Wax Lake Outlet coastline. This may be associated with the relative schematization of the Wax Lake Outlet marshes adjacent to the outlet channel. The differences between the two modeling techniques at year 50 are directly the result of the differences in the extent of subaerial delta between the two methods; 107 square miles for the TABS results and 32 square miles for the quasi-2D results.

66. The general impact of the delta evolution is to raise the flood stages throughout the system. Increases in stages may be as much as 6 ft near the mouths of the Atchafalaya River and Wax Lake Outlet.

On circulation

67. The circulation patterns within the system were modeled only by the TABS-2D effort and those results will be given in Report 12 of this series (Donnell and Letter 1992). The circulation will be altered to divert more flow through Fourleague Bay at all discharges. This diversion will be in response to the increasing backwater at the upper end of Atchafalaya Bay in response to the reduced hydraulic efficiency of the bay. The degree of flow through the Terrebonne Marshes will increase as well, due to the increased stages and greater inundation.

On salinity intrusion

68. Salinity impacts were studied only by the TABS-2D effort and details can be found in Report 12 of this series. As a result of the delta evolution over the 50 year period, salinities will be reduced in Terrebonne Marshes by as much as 1 ppt. No significant change in salinities was observed in the western bays or Atchafalaya Bay.

On sedimentation rates
in Terrebonne Marshes

69. As the delta evolves, the sedimentation rates within the Terrebonne Marshes will increase on an average of about 3 cm/year by year 50 relative to

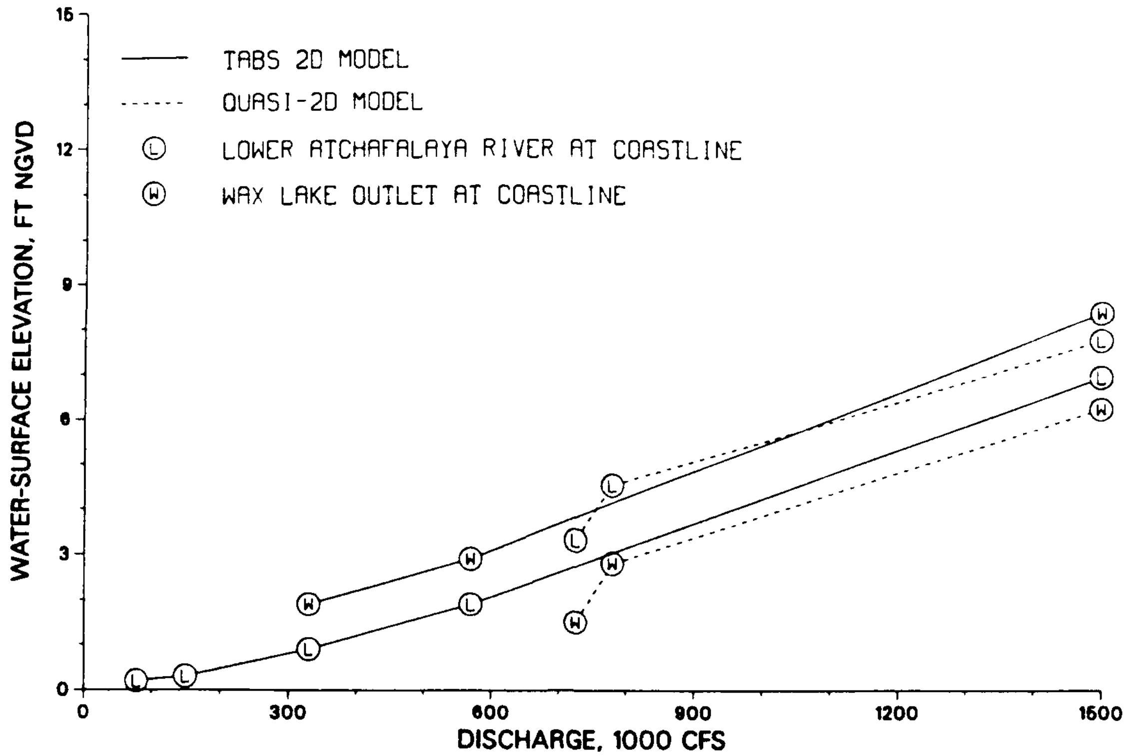


Figure 30. Water-surface elevation comparisons for year 0

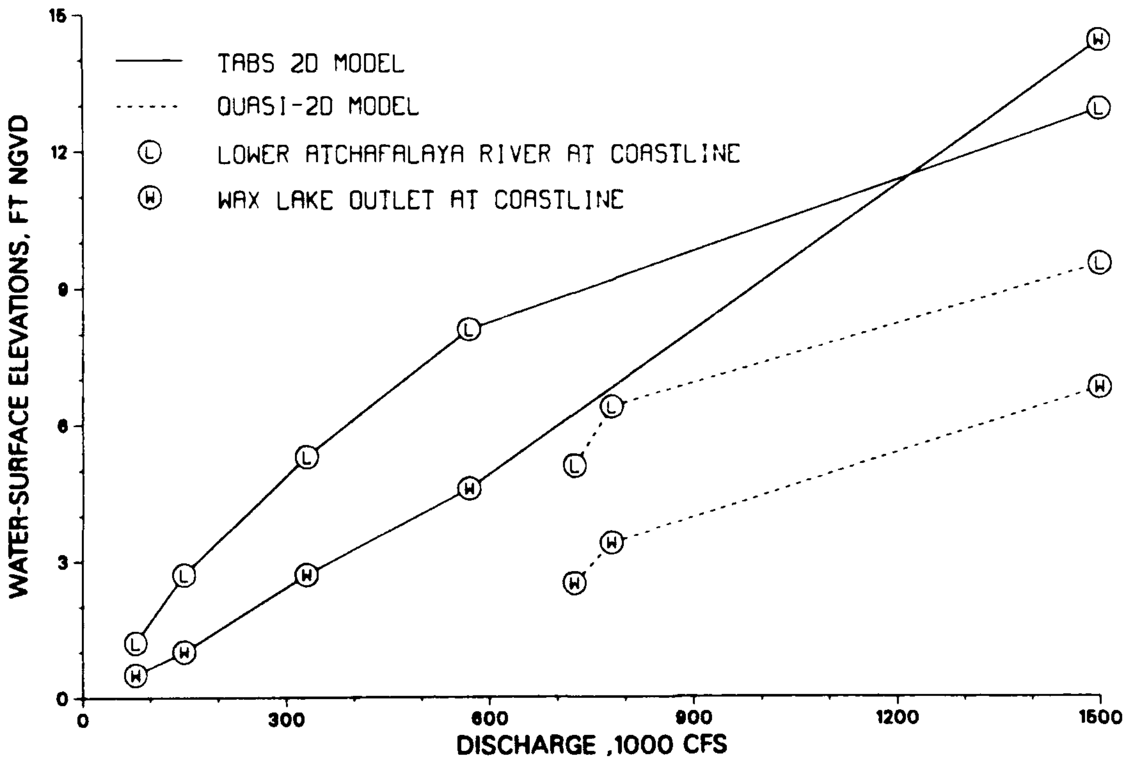


Figure 31. Water-surface elevation comparisons for year 50

Table 10

Water-Surface Elevations (ft NGVD) for the Atchafalaya Coastline

Simmesport Discharge (cfs)	YEAR 0				YEAR 50			
	Quasi-2D		TABS-2D		Quasi-2D		TABS-2D	
	WLO	LAR	WLO	LAR	WLO	LAR	WLO	LAR
78,000	-	-	-	0.2	-	-	0.5	1.2
150,000	-	-	-	0.3	-	-	1.0	2.7
330,000	-	-	1.9	0.9	-	-	2.7	5.3
570,000	-	-	2.9	1.9	-	-	4.6	8.1
725,000	1.5	3.3	-	-	2.5	5.1	-	-
780,000	2.8	4.5	-	-	3.4	6.4	-	-
1,500,000*	6.2	7.7	8.3	6.9	6.8	9.5	14.4	12.9

* Indicates that the gulf level was 5 ft above mean gulf.
\- Indicates that the data were not accessible.

year 0 sedimentation rates (Donnell and Letter 1992).

On navigation channel maintenance

70. Dredging requirements may be reduced in the short term, but should increase for the long term to as much as three times present requirements. Report 12 of this series (Donnell and Letter 1992) gives details. Requirements will peak around year 30, then they will begin to diminish.

Impacts of Alternatives

71. The only technical approach applied in the overall study that evaluated the impacts of alternatives under the control of man was the TABS-2D modeling effort. The details of the impacts will be presented in Report 12 of this series (Donnell and Letter 1992), and no attempt is made here to present model results relative to those impacts. However, the general findings of that study are summarized herein.

Effects on Avoca Island Levee extension

72. This facet of the study has lead to the optimized length of the proposed Avoca Island levee extension with attendant construction cost avoidance over the original design in excess of $180,000,000.

73. On delta evolution. The extended levee results in about 8 percent more subaerial land than the existing levee by year 50. This is apparently the result of the levee extension delivering more sediment to the bay at the expense of Terrebonne Marshes as is evidenced by the reduced deposition rates in the marshes for the extended levee.

74. On flood stages. The primary effect of the levee extension is to provide flood protection to the communities east of the existing levee. With no action (Plan C) for the 570,000 cfs, the flood stages in the vicinity of Amelia, LA, will rise by almost 4 ft by year 50 with the existing levee. Extending the levee reduces that increase down to about 2 ft. For the project flood, there is a comparable level of relative protection (2 ft) with the levee extension.

75. On circulation. The response of the circulation patterns to the levee extension is very subtle and is only clearly noticeable in the vicinity of the levee itself. The overall flow patterns do not appear to be dramatically impacted.

76. On salinity intrusion. There was very little impact on salinities associated with the levee extension. There is a slight freshening of Atchafalaya Bay and increasing of salinity in Terrebonne Marshes, but by only an insignificant amount (less than 1 ppt) relative to the existing levee tests.

77. On sedimentation in Terrebonne Marshes. The general trend of sedimentation in response to the levee extension at year 0 is a reduction in rates associated with reduced supply from around the tip of the levee. This trend is repeated at year 50, but with the center of the system experiencing some localized increase in deposition. However, these impacts are to reduce the general level of the increase in deposition associated with the evolving delta.

78. On navigation channel maintenance. For the year 0 to 15 conditions, the impact of the levee extension on navigation channel maintenance was not significant. There could be a slight reduction in requirements (10 percent) due to the additional flow supplied to the bay. However, by year 50 the extended levee may result in a 5- to 10-percent increase in maintenance requirements relative to the existing levee at year 50.

Effect of Wax Lake Outlet flow control

79. The WLO flow control project would consist of a weir and low-level

levee constructed upstream of the Wax Lake Outlet. The purpose of the project is to maintain the approximate existing distribution of outlet flows.

80. On delta evolution. The loss of flow control on Wax Lake Outlet results in a significant reduction (18 percent) in the extent of delta by year 50. In addition, the developing delta will have a greater degree of channelization in the western end of Atchafalaya Bay compared to the eastern end of the bay.

81. On flood stages. The shift in flow split also results in a shifting of the flood stages, with increased water levels (by 0.4 ft) at WLO coastline and decreased levels on the eastern end of the bay and throughout the Terrebonne Marshes.

82. On circulation. The circulation patterns for year 50 were noticeably altered to favor the WLO side of the bay to carry greater flow, with increased channelization in the evolving delta as a result.

83. On salinity intrusion. The salinity conditions at year 50 for the lower flow rate have been increased in Terrebonne marshes with Plan F and reduced in Atchafalaya Bay and adjacent waters.

84. On sedimentation in Terrebonne Marshes. The sedimentation rates for year 50 in the Terrebonne Marshes have been generally reduced with the Plan F loss of flow and sediment supply from the LAR to the eastern portion of the system.

85. On navigation channel maintenance. The estimated channel maintenance with the loss of flow control (Plan F) is 10 percent lower than estimated for the controlled flow condition (Plan D) for year 30 and is 30 percent lower by year 50, as a result of the reduced sediment supply from the LAR.

Effect of dredged material placement

86. Dredge material disposal zones were symmetrically positioned on either side of the LAR navigation channel Figure 19.

87. On delta evolution. The placement of dredged material adjacent to the navigation channel resulted in a dramatic increase in the extent of delta evolution. The area of subaerial land increased by approximately 40 percent with the placement. However, the elimination of all dredging activity could result in a 20-percent reduction in the delta area.

PART IV: CONCLUSIONS

88. The overall study approach for the delta evolution in Atchafalaya Bay has resulted in the following conclusions concerning technical approach and study objectives.

- a. The technical approaches used have been demonstrated to be appropriate by comparisons to field observations for the appropriate processes.
- b. There were differences between delta evolution predictions among the several techniques due to different assumptions and limitations.
- c. The differences in delta growth predictions between techniques when hydrological variables are carefully controlled were comparable to the variation for a single technique associated with hydrological uncertainties. Thus, delta growth projections should be made with the TABS modeling approach with careful control of hydrologic inputs.
- d. The modeling tools developed are capable of predicting both the short-term and long-term delta evolution.
- e. The study approach has provided tools which can be used to investigate alternative actions of man.
- f. The study has led to the optimization of the length of the proposed Avoca Island Levee extension with attendant construction cost avoidance over the original design in excess of $180,000,000.

89. Future improvements in the technical approach may be realized by more closely integrating the techniques developed in the plan implementation as defined in Report 1 of this series (McAnally, Heltzel, and Donnell 1991). Examples are:

- a. Using the TABS modeling results to develop the regression model for the extrapolation of the delta in time as an integral part of the TABS delta evolution projection.
- b. Using the generic delta analysis to assist in the specification of marsh porosity parameters which can now be incorporated into the delta simulations (version 4.2 of RMA-2).
- c. Running more 2-D real-time computations of delta growth with marsh porosity included and incorporating a wider range of tidal forcing.

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Photo 1. Prototype delta evolution for Dec. 1990.
Photography provided by University of Wisconsin
working under government contract

APPENDIX A: NOTATION

FCP	WLO flow control project
HAD-1	Quasi-2D sediment movement model
HEC	Hydrologic Engineering Center
LAR	Lower Atchafalaya River
MBM	Mississippi Basin Physical Model
MCM	Multiple Channel Model
MSL	Mean sea level
NGVD	National geodetic vertical datum of 1929
NOAA-NOS	National Oceanic and Atmospheric Administration-National Ocean Survey
R	Regression coefficient
SOCHMJ	Simulated Open Channel Hydraulics in Multiple Junction
SPSS	Statistical Package for Social Sciences
TABS	Numerical Modeling System
USAED	US Army Engineer District
USAEWES	US Army Engineer Waterways Experiment Station
WLO	Wax Lake Outlet
2D	Two-dimensional