DREDGED MATERIAL RESEARCH PROGRAM

TECHNICAL REPORT D-77-20

AQUATIC DISPOSAL FIELD INVESTIGATIONS GALVESTON, TEXAS, OFFSHORE DISPOSAL SITE

EVALUATIVE SUMMARY

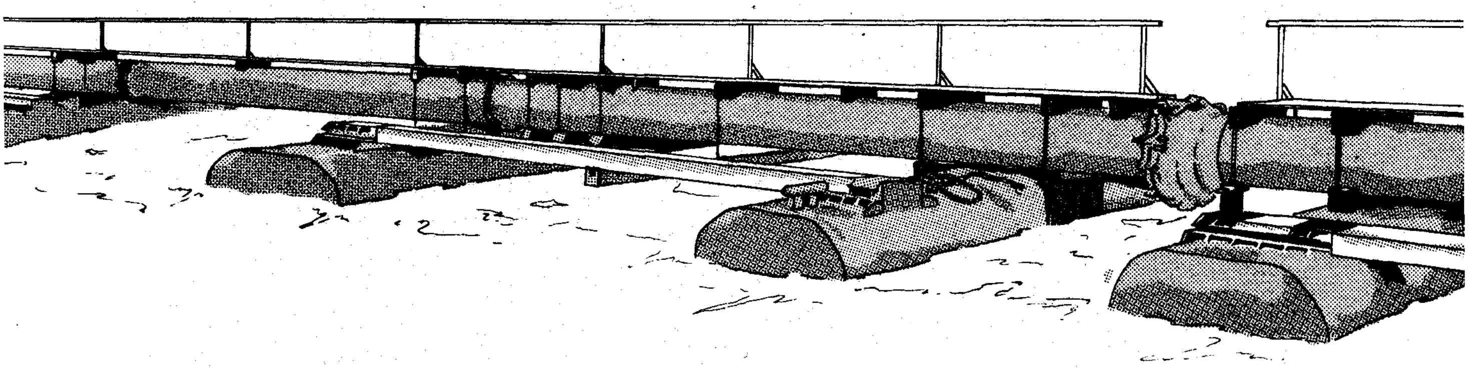
by

Thomas D. Wright, David B. Mathis, James M. Brannon

Environmental Laboratory
U. S. Army Engineer Waterways Experiment Station
P. O. Box 631, Vicksburg, Miss. 39180

May 1978
Final Report

Approved For Public Release; Distribution Unlimited



Prepared for Office, Chief of Engineers, U. S. Army
Washington, D. C. 20314

Under DMRP Work Unit No. 1A09

AQUATIC DISPOSAL FIELD INVESTIGATIONS,
GALVESTON, TEXAS, OFFSHORE DISPOSAL SITE

Appendix A: Investigation of the Hydraulic Regime and Physical Nature of Sedimentation

Appendix B: Investigation of Water-Quality Parameters and Physicochemical Parameters

Appendix C: Investigation of the Effects of Dredging and Dredged Material Disposal on Offshore Biota

DEPARTMENT OF THE ARMY
WATERWAYS EXPERIMENT STATION, CORPS OF ENGINEERS
P. O. BOX 631
VICKSBURG, MISSISSIPPI 39180

IN REPLY REFER TO: WESYV

15 July 1978

SUBJECT: Transmittal of Technical Report D-77-20

TO: All Report Recipients

1. The technical report transmitted herewith contains a summary of the results of several research efforts (work units) undertaken as part of Task 1A, Aquatic Disposal Field Investigations, of the Corps of Engineers' Dredged Material Research Program (DMRP). Task 1A was part of the Environmental Impacts and Criteria Development Project (EICDP), which had as a general objective the evaluation of the effects of open-water disposal on biota and on water quality at selected disposal areas. This report is a summary of the physical, chemical, and biological studies that were conducted at the Galveston, Texas, disposal site. This research site was one of five studied under the DMRP in various geographical regions of the United States.

2. This report, Aquatic Disposal Field Investigations, Galveston, Texas, Offshore Disposal Site; Evaluative Summary, presents an overview of three research efforts conducted at the Galveston site. Three contractor-prepared reports (Appendices A-C) describe these research efforts. The titles of the appendices are listed on the inside front cover of this report. Appendix C was reproduced on microfiche and is inclosed in an envelope inside the back cover. This report provides additional results, interpretations, and conclusions not found in the appendices and, in addition, provides a comprehensive summary and synthesis of the entire study.

3. The purpose of the Galveston study was to determine the physical, chemical, and biological effects of open-water disposal of dredged material in the Gulf of Mexico adjacent to the entrance to Galveston Bay. This study involved the detailed monitoring of disposal of small amounts of highly contaminated material dredged from the Texas City Turning Basin as well as clean sand and sandy silt from the Galveston Bay Channel.

4. Disposal events and the short-term impacts of the disposal of dredged material and the subsequent recolonization of the affected sites were evaluated at three dump sites within the main site. The material deposited in the shallow parts of the disposal site experienced a rather

rapid rate of erosion and dispersal while the material in the deeper parts tended to remain in place. The chemical impact of disposal on water-quality and sedimentological parameters was minimal. Biological impacts also appeared to be of marginal significance. Changes in the abundance and types of organisms in the disposal areas could not be distinguished from changes in reference areas.

5. Conclusions based on the data presented indicate that while effects of disposal were indicated in the benthic communities and in the sediments, these effects generally were transient in nature. In addition, there was no indication of accelerated uptake of contaminants by organisms as a direct result of disposal.

6. Results of this research will be useful on a regional basis for evaluating the possible environmental impacts of open-water disposal in shallow Gulf of Mexico environments. This information will be helpful in planning future dredging and disposal projects involving open-water disposal so as to minimize adverse environmental effects.

John Cannon
JOHN L. CANNON
Colonel, Corps of Engineers
Commander and Director

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER Technical Report D-77-20	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) AQUATIC DISPOSAL FIELD INVESTIGATIONS, GALVESTON, TEXAS, OFFSHORE DISPOSAL SITE; Evaluative Summary		5. TYPE OF REPORT & PERIOD COVERED Final report 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Thomas D. Wright David B. Mathis James M. Brannon		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS U. S. Army Engineer Waterways Experiment Station Environmental Laboratory P. O. Box 631, Vicksburg, Miss. 39180		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS DMRP Work Unit No. 1A09
11. CONTROLLING OFFICE NAME AND ADDRESS Office, Chief of Engineers, U. S. Army Washington, D. C. 20314		12. REPORT DATE May 1978 13. NUMBER OF PAGES 89
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

Appendices A and B to this report were reproduced separately (see list of appendices on inside of front cover). Appendix C was reproduced on microfiche and is enclosed in an envelope inside the back cover.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Aquatic environment	Galveston Offshore Dredged Material Disposal Site
Dredged material	Pollutants
Dredged material disposal	Sediment
Environmental effects	Waste disposal sites
Field investigations	Water quality

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

An investigation of the physical (sedimentological), chemical, and biological impacts of dredged material disposal was conducted in 1975 and 1976 at an authorized disposal site offshore from Galveston, Tex. A hopper dredge was used for dredging and disposal, and most of the dredged material consisted of clean sand and sandy silt from the Galveston Bay Channel. A small amount of contaminated material from the Texas City Turning Basin was also placed in the disposal site.

(Continued)

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

20. ABSTRACT (Continued)

Three areas within the site were employed for disposal. Two reference areas, also within the site, were chosen to provide a basis for distinguishing natural changes from those which might result from disposal. The disposal and reference areas were selected on the basis of information obtained from a predisposal pilot study.

The physical (sedimentological) effort consisted of the installation of equipment to determine current direction and magnitude, overflights to assess turbidity, sediment grain-size analyses, bathymetric surveys for the rate of disposal mound erosion, and sediment tracers (labelled sediment) to describe the direction of sediment transport.

The chemical studies were oriented toward the determination of changes in the water column during dredged material disposal and in the sediments after disposal. Although a number of variables were evaluated, primary emphasis was placed upon heavy metals, nutrients, and changes in dissolved oxygen.

The primary thrust of the biological investigations centered upon the impact that disposal of dredged material might have upon communities of bottom-dwelling organisms (benthic macroinvertebrates). Samples were taken to determine the numbers and kinds of organisms present in disposal and reference areas before and after disposal.

The results indicated that the authorized disposal site was appropriate for the disposal of material from the areas that were dredged. Sediment movement after disposal was away from the dredged areas; disposition would not occur in navigation channels. As expected, material deposited in the shallow parts of the disposal site had a rather rapid rate of erosion and dispersal, while that placed in the deeper areas tended to remain in place throughout the study period.

The chemical impact of disposal on water quality and sedimentological parameters was minimal. Although some changes were observed, these could best be described as having little, if any, significance and were difficult to separate from natural variation in the reference areas.

Biological impacts also appeared to be of marginal significance. Changes in the abundance and types of organisms in disposal areas could not be distinguished from changes in reference areas. There appeared to be very large seasonal (natural) changes in organism abundance, and these changes coincided with the disposal of dredged material.

THE CONTENTS OF THIS REPORT ARE NOT TO BE USED FOR ADVERTISING, PUBLICATION, OR PROMOTIONAL PURPOSES. CITATION OF TRADE NAMES DOES NOT CONSTITUTE AN OFFICIAL ENDORSEMENT OR APPROVAL OF THE USE OF SUCH COMMERCIAL PRODUCTS.

SUMMARY

To investigate the environmental impact of open-water disposal, five field sites were chosen for Aquatic Disposal Field Investigations (ADFI). One of these was located offshore from Galveston, Tex. Field work at Galveston was initiated in the spring of 1975 and continued until early summer of 1976. The first phase consisted of a pilot study for the selection of suitable disposal and reference areas within the authorized disposal site. This was followed by the collection of predisposal physical, chemical, and biological data from disposal and reference areas during the summer of 1975. The majority of disposal took place in the fall of 1975, and the remainder of the investigation concerned postdisposal changes in physical variables, chemistry, and the biota.

The experimental design of the Galveston ADFI was such that a number of questions concerning disposal were to be answered. The major ones are given below:

Physical characteristics:

- a. What is the current regime and how can currents affect the redistribution of disposed material?
- b. Does disposed material remain in situ and, if so, for how long?
- c. Does disposal result in short- and/or long-term changes in the sediment in the disposal area?

Chemical characteristics:

- a. Does disposal cause short- and/or long-term changes in the quality of water and sediment?
- b. If there are water quality changes, are these of such a magnitude or do they involve substances that will affect organisms in the sediment or in the water column?

Biological characteristics:

- a. Are there changes in the number, kind, and biomass of bottom-dwelling organisms as a result of disposal, and, if so, what is the time frame and pattern of recovery?
- b. Are the organisms which inhabit the water column affected during disposal or by the release of substances from dredged material after disposal?

It was anticipated that sampling would be done in such a manner as to allow the relation of physical and chemical effects with each other and to also relate them, perhaps in a cause-and-effect manner, to biological effects. This was not possible because the various physical, chemical, and biological samples were generally taken at different times and places. This factor, in itself, made it difficult to detect and evaluate changes which may have taken place as a result of disposal.

In general, the Galveston ADFI reached a series of negative conclusions. That is, one cannot effectively demonstate the absolute lack of an effect; one may demonstate (with some degree of statistical confidence) that an effect of significance did occur. When an anticipated effect is not found, the causal factors may include inappropriate sampling techniques, high variability of results (commonly resulting from an inadequate sample size), or errors in data collection and analysis.

It was found that currents (and perhaps wave action) were adequate to erode material from the most shallow disposal area. There was some evidence of erosion at an intermediate depth, and there appeared to be little erosion in the deepest area. Quantitative estimates of erosion are suspect because of doubt as to the amount of material deposited, position location error, and the sporadic nature and inaccuracy of bathymetric surveys. Likewise, variability in sediment collection and analyses was such that conclusions regarding changes in sediment composition are highly tentative. It did appear that the movement of disposed material was away from the dredging area and the material would not likely be redeposited in the navigation channel.

With the exception of manganese and ammonium, none of the chemical variables examined exhibited an appreciable change in the water column. Some increases were observed in manganese and ammonium, but these were of such small temporal and spatial magnitudes as to be of little significance to organisms in the water column. There was a reduction in dissolved oxygen during several disposal operations, but this appeared to be quite transient and of low magnitude. There was essentially no change in sediment chemistry as a result of disposal of dredged material.

Most of the biological data were of such a nature that no conclusions regarding the effects of dredged material disposal could be drawn. The most reliable body of information concerned the bottom-dwelling organisms (benthic macroninvertebrates). Detailed analyses of the response of these organisms to disposal indicated that there was little overall effect when sampling error and natural variability were taken into account. In the few instances where a change in abundance or species composition was observed, the overall ecological impact could not be estimated. This represents a clear deficiency in the current state of knowledge concerning many of these organisms because there is no way of knowing what ultimate impact that small changes in species composition or abundance may have upon the biotic community as a whole.

Again, it should be emphasized that the general lack of demonstrable effects does not imply that there were none. It merely indicates that, within the constraints and confines of the available data and the analyses which were applied to them, none were found.

An overall conclusion of the Galveston ADFI is that the authorized disposal site appears to be appropriate for the disposal of dredged material from the areas that were dredged. Physical, chemical, and biological impacts appeared to be quite minimal within the disposal site. Current philosophy is such that, by definition, effects and impacts of a fairly severe nature are expected and tolerated within an authorized disposal site. Since there appeared to be no such severe effects or impacts within the disposal site, it is unlikely that any occurred outside the site. Thus, there would seem to be little reason to modify current disposal techniques or to conduct additional investigations concerning impacts beyond the limits of the site.

PREFACE

This report presents a summary of the results of a comprehensive investigation of open-water disposal of dredged material offshore of Galveston, Tex. The investigation was conducted during the period March 1975-June 1976, as part of the Dredged Material Research Program (DMRP), Environmental Impacts and Criteria Development Project (EICDP), under Work Unit No. 1A09. The DMRP was sponsored by the Office, Chief of Engineers, U. S. Army, and was managed by the Environmental Laboratory (EL) of the U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Miss.

This report was prepared by Dr. Thomas D. Wright, Mr. David B. Mathis, and Mr. James M. Brannon under the general supervision of Dr. John Harrison, Chief of EL, and Dr. Roger T. Saucier, Special Assistant for Dredged Material Research. Dr. Robert M. Engler was Project Manager. Site Managers were Mr. Mathis, Environmental Monitoring and Assessment Branch (EMAB) (January 1975-August 1976), and Dr. Wright, EMAB (September 1976-August 1977). Mr. Stephen P. Cobb, EMAB, was site coordinator. Dr. Peter J. Shuba, Ecosystem Research and Simulation Division, and Mr. Barry W. Holliday, EICDP, made significant contributions in analysis and interpretation of the physical and biological data.

COL D. S. McCoy, CE, of the Galveston District, was the Contracting Officer. Mr. Dolan Dunn, Galveston District, provided liaison with the District, coordinated various activities, and provided information concerning dredging schedules and other logistic and administrative matters.

Directors of WES during the investigation were COL G. H. Hilt, CE, and COL J. L. Cannon, CE. Mr. F. R. Brown was Technical Director.

CONTENTS

NOTE: Appendices A and B to this report were reproduced separately (see list of appendices on inside of front cover). Appendix C was reproduced on microfiche and is included in an envelope inside the back cover.

LIST OF TABLES

LIST OF FIGURES

AQUATIC DISPOSAL FIELD INVESTIGATIONS
GALVESTON, TEXAS, OFFSHORE DISPOSAL SITE
EVALUATIVE SUMMARY

PART I: INTRODUCTION

Background

1. The Dredged Material Research Program (DMRP) was initiated in 1973 as a four-phase, 5-year comprehensive program authorized under the River and Harbor Act of 1970 (PL 91-611, Section 123). The primary objective of the program is to investigate the environmental impact of dredging and dredged material disposal operations and to develop technically sound, environmentally compatible, and economically feasible dredging and disposal alternatives, including the use of dredged material as a manageable resource.[1]

2. An important component of the DMRP is Task 1A, the Aquatic Disposal Field Investigations (ADFI) of the effects of dredged material disposal on the biota and water quality within designated open-water disposal sites. This research task is part of the Environmental Impacts and Criteria Development Project which is being conducted at freshwater, estuarine, and marine sites, one of which is offshore from Galveston, Tex., in the Gulf of Mexico.

3. Site selection was by an interdisciplinary study team from the U. S. Army Engineer Waterways Experiment Station. The team surveyed 22 sites in the Gulf region which had received significant use as dredged material disposal sites.[2] Each of these sites was evaluated in terms of its suitability for study purposes. Criteria used for evaluation included availability of background information, ecological data, availability of logistic support for a comprehensive field investigation, and availability of characteristics (as defined by the regional survey) that represent the major types of open-water disposal activities within the Gulf region. The representative parameters included physical and chemical characteristics of dredged material disposed at the site, type(s) of substrate the material is disposed upon, annual volume of material

disposed, frequency of disposal, and water depth at the disposal site. Based on this evaluation and the scheduled maintenance dredging, the Galveston offshore disposal site was selected as an ADFI site.

4. Offshore disposal in the Gulf region annually accounts for about 15 percent (by volume) of all federally sponsored open-water dredged material disposal within the United States. Table 1 compares annual disposal of dredged material at Galveston with that for the Gulf region.

Table 1

Dredged Material Disposal at Galveston, Tex., and in the Gulf Region

	Dredged Material Discharged, 10^6 m^3	
Year	Gulf Region	Galveston
1965	25.8	0.9
1966	22.9	1.8
1967	32.2	1.2
1968	32.5	2.2
1969	25.8	1.1
1970	31.5	1.8
1971	28.4	1.4
1972	NA	2.4
1973	NA	1.4
1974	NA	0.9
1975	NA	1.3

NOTE: NA denotes not available.

5. Much of the material dredged in the Gulf region consists of sandy sediments deposited in harbor entrances and channels by littoral processes, although some results from riverine sources. Designated offshore disposal sites in the Gulf are normally situated adjacent to their associated navigation channel and within the 15-m depth contour. Most of the dredged material is classified as "nonpolluted" and hence is deposited offshore.

Purpose and Objectives

6. The Galveston ADFI had three principal objectives:

   a. To evaluate the impact of disposal upon the aquatic biological community.

   b. To determine the chemical impact of disposal on the water column and sediment.

   c. To ascertain the movement and eventual fate of dredged material deposited at the offshore disposal site.

These broad objectives formed the basis for a variety of biological, chemical, and physical studies. The general research plan is described in Becker et al.[3] Specific objectives are described below.

Physical studies

7. Specific objectives of the physical studies were:

   a. To determine the bathymetric, sedimentological, and subbottom characteristics of the dredged material disposal site prior to the initiation of disposal activities.

   b. To determine the characteristics of the hydraulic regime including the critical erosion velocities necessary to suspend and transport sediments, current velocities and direction, and amounts of suspended matter in the water column.

   c. To determine the natural changes in sediment composition with time.

   d. To determine if the dredged material mounds were being eroded with time and, if so, where the material was being transported.

   e. To monitor disposal activities to determine the length of time required for the reestablishment of ambient conditions.

Chemical studies

8. Specific objectives of the chemical studies were:

   a. To determine the concentrations of nutrients, heavy metals, and other chemical parameters in sediments and perform water quality studies of appropriate parameters of the disposal site prior to disposal operations.

b. To determine the dissolved and particulate materials that are released into the water from dredged material and the temporal and spatial extent to which these released materials remain above ambient levels during and immediately after disposal.

c. To determine if the disposal of dredged material would alter the chemical composition of sediment in the disposal site and, if so, how long such alteration would persist.

Biological studies

9. Specific objectives of the biological studies were:

a. To determine the spatial and temporal distributions of the biological assemblages within the disposal site prior to disposal operations.

b. To determine if changes occur in the composition and abundance of benthic and demersal assemblages after dredged material disposal, with particular emphasis on the rate of colonization of dredged material mounds by benthic organisms.

c. To determine if changes occur in the composition, abundance, and distribution of plankton as a result of disposal operations.

Experimental Design

10. A cursory review of available literature and discussions with researchers knowledgeable of past investigations of the Galveston study area indicated a gross deficiency of background data; hence, a pilot survey was conducted prior to disposal. The primary objectives of the survey were:

a. To determine the location of previous disposal deposits within the disposal site.

b. To determine spatial variability of selected environmental variables for the selection of experimental disposal areas and reference areas.

11. The designated disposal site was divided into twenty-eight 0.8-km-square grid squares for sampling purposes. From subbottom profiles, bathymetry, sediment samples, and other evidence from the pilot survey, it was found that most previous disposal had been inshore of the designated disposal site.

12. Following the pilot survey, five sampling areas were established within the disposal site. Three of these were designated as experimental areas for the disposal of dredged material; the other two were designated as reference areas for comparative purposes. Within each area, five stations were to be sampled for biological, chemical, and physical parameters. Predisposal, disposal, and postdisposal measurements were taken. Additional details of the experimental design are given in Part IV of this report.

Chronology of Events

13. The Galveston ADFI spanned 4 years (Table 2). The project did not always proceed on schedule because of circumstances which were often beyond the control of the participants. These delays and malfunctions prevented the complete attainment of some project objectives.

Table 2

Chronology of Significant Events Associated with the Galveston ADFI

Date	Event
Dec 1974	Site selection completed.
Jan 1974	Mr. David B. Mathis appointed site manager.
Mar 1975	Contract No. DACW64-75-C-0069 awarded to College of Geosciences, Texas A&M Research Foundation, for "An Investigation of the Hydraulic Regime and Physical Nature of Sedimentation at the Offshore Disposal Site, Galveston, Texas," Drs. Arnold H. Bouma and George L. Huebner, co-principal investigators.
Mar 1975	Contract No. DACW64-75-C-0070 awarded to Moody College of Marine Sciences and Maritime Resources, Texas A&M University, for "An Investigation of the Biota at a Dredged Material Disposal Site," Dr. Donald E. Harper, principal investigator.

(Continued)

Table 2 (Continued)

Date	Event
Mar 1975	Contract No. DACW64-75-C-0071 awarded to The Center for Environmental Studies, The University of Texas at Dallas, for "An Investigation of Water Quality Parameters and Physicochemical Parameters at the Offshore Disposal Site, Galveston, Texas," Dr. G. Fred Lee, principal investigator.
Mar-Apr 1975	Pilot survey completed.
May 1975	Predisposal data obtained at disposal area 2.
May 1975	Disposal terminated at disposal area 2 with no disposal data obtained; postdisposal data obtained.
Jun-Aug 1975	Postdisposal data obtained at disposal area 2; predisposal data at others.
Aug-Sep 1975	Disposal data obtained.
Sep-Dec 1975	Postdisposal data obtained.
Dec 1975	Final report for Contract No. DACW64-75-C-0070 required and received.
Jan 1976	Final report for Contract No. DACW64-75-C-0069 required and received.
Jan-May 1976	Postdisposal data obtained.
Feb 1976	Final reports for Contract Nos. DACW64-75-C-0069 and DACW64-75-C-0070 determined to be inadequate and relegated as internal working documents.
Feb 1976	Contract No. DACW64-76-C-0038 awarded to Texas A&M University, for "An Investigation of Sediment Transport Phenomena and Biological Recolonization at Three Experimental Dredged Material Disposal Sites Offshore from Galveston, Texas," Dr. Donald E. Harper, principal investigator.
Feb-Mar 1976	Unscheduled disposal of dredged material at disposal area 2.
Mar 1976	Final report for Contract No. DACW64-75-C-0071 required.

(Continued)

Table 2 (Concluded)

Date	Event
Apr 1976	Draft report for Contract No. DACW64-75-C-0071 received.
May 1976	Biological field work completed.
Jun 1976	Draft report for Contract No. DACW64-75-C-0071 returned to contractor following review; all field work completed with final bathymetry survey.
Sep 1976	Dr. Thomas D. Wright appointed site manager.
Nov 1976	Final reports for Contract No. DACW64-76-C-0038 required.
Dec 1976-Mar 1977	Review and return of various sections of second draft report for Contract No. DACW64-75-C-0071 as each is received.
May 1977	Draft reports for Contract Nos. DACW64-75-C-0071 and DACW64-76-C-0038 received for editorial review; returned following review.
Jun 1977	Final report for physcial aspects of Contract No. DACW64-76-C-0038 received; draft report for biological aspects returned to contractor following review.
Aug 1977	Final reports for Contract Nos. DACW64-75-C-0071 and biological aspects of DACW64-76-C-0038 received.

PART II: SITE-SPECIFIC LITERATURE

14. There are few comprehensive reports on the Galveston area of use for an ADFI. Among these are the environmental impact statements[4,5] prepared by the U. S. Army Engineer District, Galveston, for maintenance dredging of the channel to Port Bolivar and of Galveston Harbor and Entrance Channel. Copeland and Fruh[6] conducted extensive ecological studies on Galveston Bay which included portions of the Galveston Entrance Channel.

15. The remainder of the literature is generally quite specific with regard to subject. Appropriate references to this literature are given in Appendices A-C.

PART III: DESCRIPTION OF STUDY AREA

Regional Setting

16. Galveston, Tex., is located on Galveston Island, a part of a chain of geologically recent barrier islands that skirt the greater part of the northwestern Gulf of Mexico (Figure 1). The island, which has a northeast-southwesterly trend, is about 48 km long and tapers from an eastern width of about 4 km to a blunt point at the western end. West Bay, which borders most of the landward side of the island, is continuous with Galveston Bay, Trinity Bay, and East Bay, the other bodies of water that constitute the Galveston Bay system. Two jetties, north and south, project into the Gulf in an easterly direction from Bolivar Peninsula and Galveston Island, respectively.

17. There are three legs of the Galveston Bay Channel from which dredged material is removed and deposited offshore: the entrance channel, the outer bar channel, and the inner bar channel (Figure 2). The entrance channel is 7.8 km long, 240 m wide, and has a controlling depth of 12.6 m below mean low water (MLW). The outer bar channel is 1.4 km long, 240 m wide, and has a controlling depth of 12.6 m below MLW. The inner bar channel is 4.4 km long, 240 m wide, and has a controlling depth of 12 m below MLW. The inner and outer bar channels lie entirely within the jetties. Most of the entrance channel is unprotected.

18. The climate of the Galveston area is subtropical, with short mild winters and long hot summers. Summer conditions extend from May through September, with highest temperatures in July and August. Winter conditions occur from December through February. Seasonal air temperature averages are: winter, 13°C; spring, 20.5°C; summer, 28.5°C, and fall, 22°C. The mean annual temperature is approximately 21°C.

19. The trend of the average monthly water temperature is a smooth almost bell-shaped curve. Between November and March, the temperature is usually less than 20°C. In July and August, it is usually above 30°C.

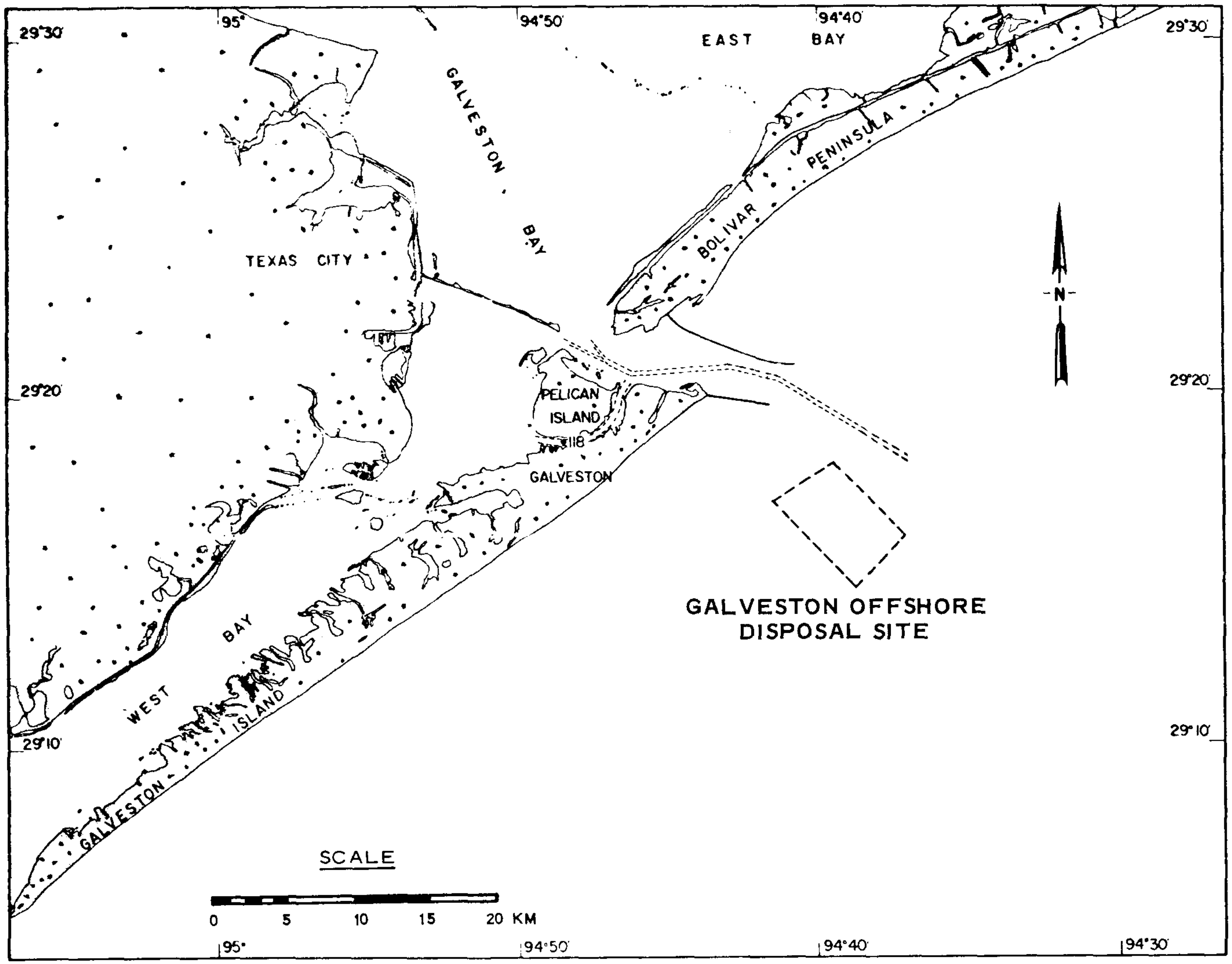


Figure 1. Map of study area

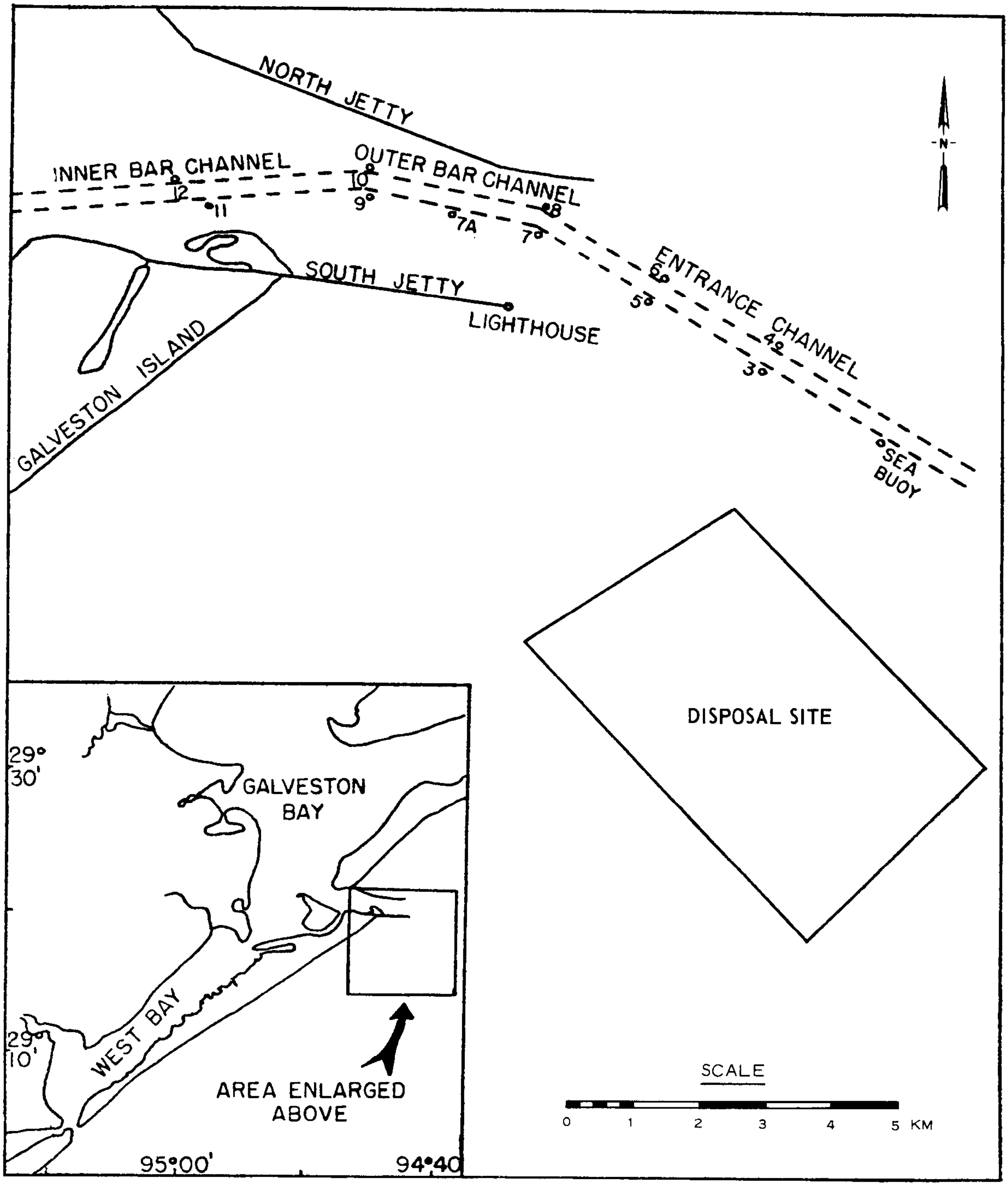


Figure 2. Details of Galveston Bay Channel segment from which material deposited in offshore disposal site is dredged

Comparison of the average water temperatures for the periods 1922 through 1949 and 1950 through 1975 indicates that the average water temperature has gradually decreased. For the past 10 years, the average annual water temperature has fluctuated around 22°C. There is rarely any significant thermal stratification in the offshore waters.

20. The predominantly maritime climate is frequently modified by continental air masses from mid-September to mid-April. Winds during spring and summer are generally from the southeast; during the fall and winter, strong southeasterly winds occur before winter fronts and northerly winds after. Average wind speeds range from 14.5 kph in August to 19.3 kph in April.

21. The average monthly Galveston Bay Channel salinity decreases from January to a low in May. The May low is followed by a rapid increase to an August high, followed by a decreasing trend through December. The average salinity ranges from 20.5 ppt in May to 28.5 ppt in August. Disposal site salinity is highly variable and at any time and place is partially a function of water column depth, since the Galveston Bay waters tend to overlie the more dense, saline Gulf of Mexico waters. The primary determinant of salinity, however, is the mixture of higher salinity Gulf of Mexico open waters with lower salinity Galveston Bay waters and with nearshore Gulf waters that are generally more saline than Galveston Bay waters.

22. The tidal amplitude of the Northwest Gulf is very small, averaging only about 30 to 45 cm between high and low tides. The diurnal tides of the area are of the mixed type, with one low and one high during each 24-hour period of maximum range and two highs and two lows during each 24-hour period of minimum range. Abnormal tidal action is the result of strong wind action, the principal instances of which are: (a) strong, persistent east, southeast, or southerly winds blowing across the Gulf for several days, and (b) strong, persistent north to northwesterly winds after the passage of a vigorous cold front. In the first case, tides may be as much as a metre above normal, while, in the second case, they may be as much as a metre below normal.

23. Currents are determined by the interactions of tides, wind, and freshwater discharge. During flood tide, currents flow into the bay; during ebb tide, they flow out of the bay. There is a long shore current flowing northeast to southwest. Often there are differences in current magnitude and direction for surface, intermediate, and deep waters.

24. Severe climatic events sometimes occur which have an impact on organisms in the Galveston Bay area. One of these events is the passage of a cold front. An especially severe cold front following a period of mild temperature can cause extensive mortalities among the fish and invertebrates. Such severe cold spells occur every few years. Survival during these cold spells depends not on how low the temperature falls but on the temperature prior to the front. If there is a drastic change in temperature, there is usually extensive mortality.

25. Tropical storms and hurricanes have a severe impact on Galveston Bay. On the average, the Galveston area experiences a tropical storm every 4 years, a hurricane every 5 years, and an extreme hurricane every 19 years.

26. The intense wave action associated with hurricanes is an important agent in reworking sediments. Water piled up on the bay by winds rushes back to the sea when wind pressure decreases, causing scouring of existing channels, opening of new channels, and transport of large quantities of sediment into the Gulf. Rain may cause flash floods which decrease the salinity, causing mass mortalities among organisms in the bay.

27. During very high freshwater discharge, Galveston Bay and part of the nearshore Gulf waters can be rendered essentially fresh. The minimum salinity recorded in the Galveston Bay Channel was 0.4 ppt in 1960. Very low salinities can cause drastic changes in the benthic populations and migration of nektonic forms into more saline waters. During periods of low freshwater discharge, saline water invades much of the Galveston Bay system. Salinities in the 20- to 25-ppt range were recently recorded in Trinity Bay and upper Galveston Bay. When

this occurs, high-salinity fauna and flora fill ecological niches vacated by less tolerant biota.

28. Because of nearby Houston and Texas City, Galveston Bay is a heavily utilized port area. Its economic importance stems from its proximity to major population centers in Texas which depend on the bay for transportation of goods, waste disposal, cooling water, recreation, and aesthetic appeal. The Galveston Bay estuarine system is lined with industrial and domestic waste outfalls, urban and agricultural areas, bayous, rivers, and tidal flats in addition to several small shallow embayments. Municipal and industrial effluents and land runoff introduce a substantial amount of material to the bay, some of which is incorporated into the estuarine sediments.

29. The multitude of industrial plants located on the Houston Ship Channel and around Texas City are major potential sources of heavy metals, organics, and other contaminants to the bay. Among these industries are pulp and paper mills; caustic and vinyl chloride plants; metallurgical, electroplating, and other metal production and processing plants; oil refineries; and paint, rubber, fertilizer, and other types of petrochemical plants. Pesticide contamination arises from agricultural and residential use as well as the several pesticide-producing plants located within the bay system.

30. Commercially important invertebrates in the bay include white and brown shrimp, blue crab, and oysters, with all but the latter common at the disposal site. In fact, Galveston Bay constitutes the largest commercial fishery for shrimp and oysters in Texas estuaries. The most important commercial and sport finfish are sand and spotted seatrout, red and black drum, sheepshead, flounder, and croaker. These species occur in the bay and at the disposal site. Because of the close proximity of large population centers, recreational fishing pressure is heavy.

Disposal Site Description

31. The disposal site is located approximately 4.3 km offshore from Galveston. The site is nearly a rectangle 5.6 by 3.2 km (Figure 3). The long axis of the site is oriented northwest-southeast, perpendicular to the coastal trend. It is bounded by parallels $29^{\circ}18.0'$ N and $29^{\circ}14.4'$ N on the north and south corners, respectively, and by parallels $94^{\circ}37.1'$ W and $94^{\circ}41.5'$ W longitude on the east and west corners, respectively. There are no markers delineating the periphery of the site.

32. Depths range from about 10.0 m along the northwestern boundary to about 15.5 m along the southeastern boundary, with the depth contours parallel to the short northeast-southwest axis of the site (Figure 3). There are several mounds northwest of the site which are thought to have resulted from previous disposal.

Dredging Activities

33. Maintenance dredging of the Galveston Bay Channel has been accomplished in recent years by the U. S. Army Corps of Engineers hopper dredge McFARLAND, with a single-load capacity of 2294 m^3. Maintenance dredging involves removal of accumulated sediment from the channel bottom. Dredging is done by lowering a hydraulic suction arm to the bed of the channel while the dredge is under way. Sediment is sucked into the arm and pumped into onboard hopper bins. As the hoppers fill, excess water is vented over the side. The dredged material is transported offshore to the designated disposal site and released by opening the hopper doors while the vessel is under way. The entire hopper load is usually released in a few minutes.

34. From less than 1 million to over 2 million cubic metres of dredged material has been disposed of annually during the past several decades. Prior to 1975, the dredged material was distributed among three disposal sites. One of these was at approximately the same location as the offshore disposal site shown in Figure 3. The other two

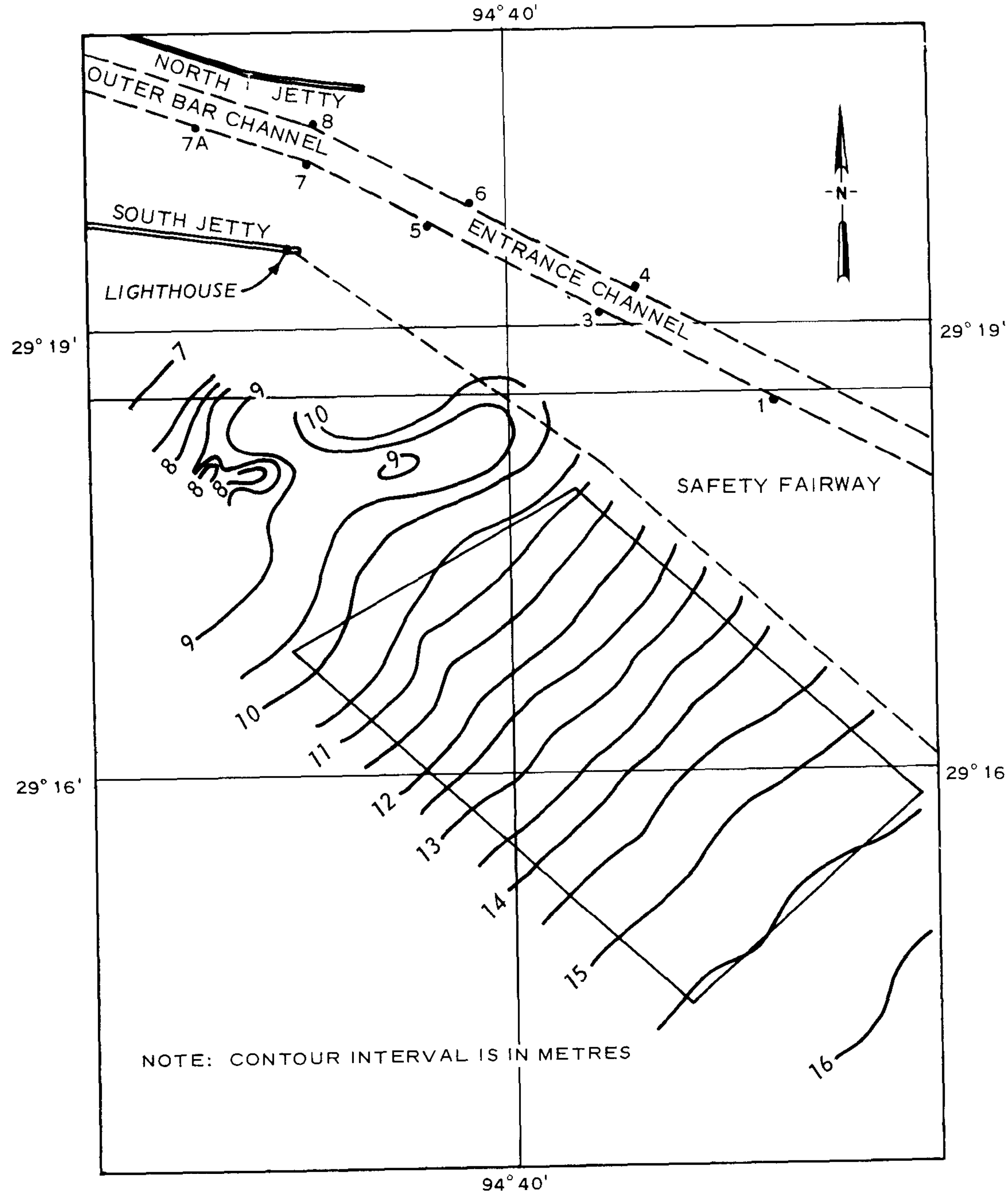


Figure 3. Bathymetry of the disposal site prior to disposal operations (March 1975)

were located adjacent to the entrance channel between buoys 3-4 and 7-8. Other than during the ADFI, no data are available on the amount of sediment disposed of at the currently designated disposal site. It is thought to have been minimal because of the longer distances involved in the transport of the sediments from the channel to the disposal site. After 1973, all dredged material from the entrance channel was supposed to be placed in the designated disposal site.

35. The bathymetry of the disposal site demonstrates little or no evidence of previous dredged material disposal. The previously noted mounds are outside of the designated disposal site. Since approximately 1.4 million cubic metres per year has been disposed of in this general area for the past several years, the lack of evidence of its presence would indicate that there is rapid dispersion of the dredged material after disposal or that most disposal occurred outside the designated site.

36. The amount of material dredged from the entrance channel in recent years has been somewhat variable. Estimated amounts and the disposal locations are given in Table 3.

Table 3

Estimated Amounts of Material Dredged from the Galveston Bay Channel and Disposed of In or Near the Disposal Site

Date	Material Dredged (m^3)	Disposal Area
1-13 Oct 1973	111,300	Unknown. Possibly sampling area 2
23 Jan-20 May 1974	796,000	Unknown. Possibly sampling area 2
18 Jul-24 Sep 1974	1,301,600	Unknown. Possibly sampling area 2
7-13 May 1975	88,100	Sampling area 2
24 Aug-24 Sep 1975	223,900	Sampling area 2
24 Aug-24 Sep 1975	73,100	Sampling area 12
24 Aug-24 Sep 1975	197,600	Sampling area 14
9-10 Oct 1975	2,300*	Sampling area 2-A
18 Feb-3 Mar 1976	211,200	Sampling area 2

* This material was dredged from the Texas City Turning Basin.

PART IV: METHODS AND MATERIALS

37. The Galveston ADFI consisted of a pilot study and predisposal, disposal, and postdisposal phases. These divisions were not, however, entirely consistent, and distinctions between them in the contractor-prepared reports (Appendices A-C) are not always made. In general, all work done prior to 7 May 1975 is considered to be part of the pilot study, though it was also predisposal. Disposal began at area 2 on 8 May and was terminated after the disposal of 88,100 m^3 of material. Hence, data obtained from area 2 after that time are postdisposal rather than predisposal.

38. Sample collection and analysis procedures used during the pilot study were not always comparable to those used in later phases of the investigation. For example, different sieve sizes were employed to concentrate macrobenthic organisms in the pilot than in the other three phases; a pump was employed for phytoplankton sampling during the pilot study, but a sampling bottle (Van Dorn) was used in later phases; and three different devices were used to collect sediment for physical analyses during the pilot study and predisposal phase. Hence, it is not always appropriate to combine data from the pilot study and the predisposal phase.

39. The overall experimental design was quite straightforward. In or near the disposal site, four sampling areas were selected to evaluate the effects of the disposal of several types of sediment. Two reference areas were chosen to provide comparative data. It had initially been planned to use the centers of areas 2, 12, and 14 (from the pilot study) as the primary disposal areas and the centers of areas 15 and 27 as reference areas. Five sampling stations were located in the vicinity of the disposal and reference areas (except area 2-A). Buoys were positioned at the disposal areas prior to the August-September disposal operations. The locations of the buoys and sampling stations in the disposal and reference areas are given in Figure 4 and the characteristics of the areas are listed in Table 4.

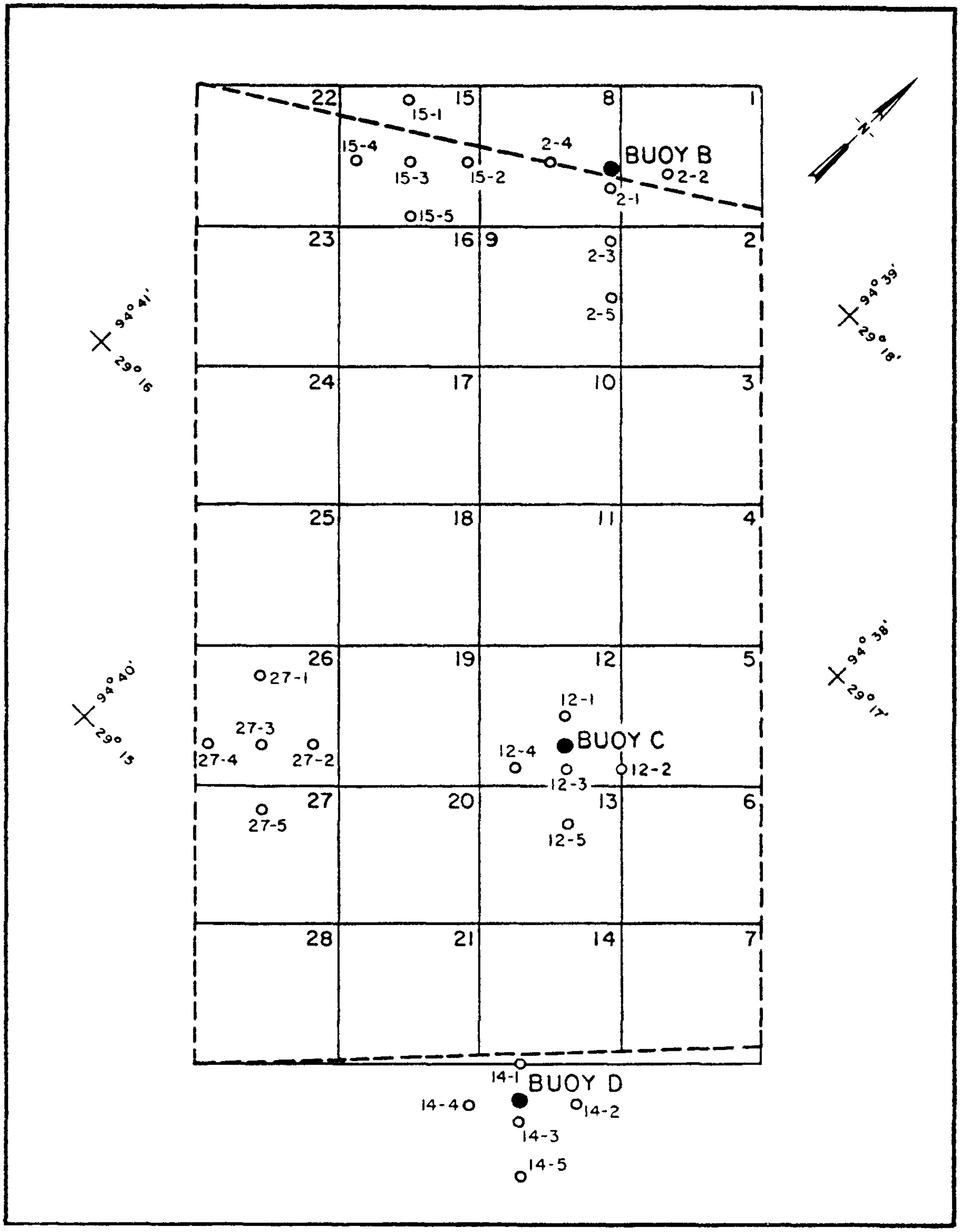


Figure 4. Locations of buoys and sampling stations in the disposal and reference areas

Table 4

Characteristics of the

Disposal and Reference Areas

Designation* No.	Designation* Type Area	Bottom Type	Depth	Disposal Frequency	Disposal Material
2	Disposal	Silty sand over silty clay	Within wave action	Often	Uncontaminated sand, silt, and clay
2A	Disposal	Silty sand over silty clay	Within wave action	Once	Contaminated silt and clay
15	Reference	Silty sand over silty clay	Within wave action	NA**	None
12	Disposal	Silty clay	Below wave action	Once	Uncontaminated sand
14	Disposal	Silty clay	Below wave action	Once	Uncontaminated sand and clay
27	Reference	Silty clay	Below wave action	NA	None

* Locations of disposal and reference areas are shown in Figure 4.

** Not applicable.

40. Replicate predisposal and postdisposal physical, chemical, and biological samples were to be concurrently obtained from each of the stations. Water quality studies were to be performed during disposal. In addition, numerous other tasks (such as current measurements, bathymetry surveys, sediment movement measurements, etc.) to determine the effects of disposal were planned.

41. Because of the number of different contractors and a general lack of coordination, only a very limited amount of concomitant data were collected. Other than in a few isolated instances, the concomitant data consists of benthic macroinvertebrate and grain-size data for January, April, and May 1976. The remainder of the data were generally taken at different places, different times, or both. Descriptions of actual sampling stations for physical, chemical, and biological variables are given in the Appendixes.

42. It was initially planned to use a precision electronic navigation system for position location when sampling. The distance offshore of the disposal and reference stations, together with commonly prevailing atmospheric conditions (haze, etc.), required some such system so that samples could be taken at or as near the same position as possible during each sampling period.

43. The system was functional only for two bathymetric surveys and the pilot physical studies. During the remainder of the investigation, the three buoys at the disposal areas served as reference points, for three stations with samples being taken adjacent to the buoys. Dead reckoning was used to locate the other 22 stations. No estimates of the variability or accuracy of this method are available, but it is not thought to be especially precise. Hence, other than when the electronic navigation system was operable, samples were taken in a general area rather than at a precise location.

44. Several contractors were involved in the physical and chemical aspects of the Galveston ADFI. The field and laboratory methods used by the first physical contractor are given by the second physical contractor in Appendix A. Field and laboratory chemical methods used by the first contractor are given in Appendix B. Those chemical methods

used by the second contractor are not reported because initial handling of the samples and subsequent analyses invalidated the results. Biological field and laboratory methods are given in Appendix C.

45. Physical, chemical, and biological field and laboratory procedures are given in Table 5. For detailed information on procedures the appropriate Appendices should be consulted, since, for example, sediments were collected with three different devices by various contractors and all three were sometimes utilized during a given sampling period. Likewise, samples were often subsampled by assorted techniques to provide material for analyses other than that for which the sample was primarily collected.

Table 5

Field and Laboratory Methods Used in the Collection and Analysis of Physical, Chemical, and Biological Data

Variable	Procedure
	Physical Study Variables
	Field Procedures
Bathymetry	200-kHz side-scan sonar, fathometer
Currents	Bendix Q-15 meter, Braincon Savonius meter
Remote sensing of turbidity	Aerial photography with Eastman-Kodak Ektachrome infrared film
Sediment collecting	136-kg gravity corer, Van Veen grab, 3/4-size Reineck spade corer
Sediment tracing	Sand grains coated with fluorescent dye
Subbottom profiles	3.5-kHz high-resolution system
Suspended sediment	Pump
	Laboratory Procedures
Carbonate	Sheibler volumetric technique
Clay mineralogy	X-ray diffraction
Critical erosion velocity, shear stress, transport mode	Flume

(Continued)

Table 5 (Continued)

Variable	Procedure
	Laboratory Procedures (Continued)
Grain size	Sieve and pipette
Heavy metals	Bromoform separation and optical analysis
Organic matter	Weight loss after combustion (600°C for 2 hours)
	Chemical Study Variables
	Field Procedures (Water)
Conductivity	6-D Hydrolab Surveyor
Dissolved oxygen	6-D Hydrolab Surveyor
Light transmission	Transmissometer
pH	6-D Hydrolab Surveyor
Sample collection	Van Dorn sampler, submersible pump
Temperature	6-D Hydrolab Surveyor
Turbidity	Secchi disk
	Field Procedures (Sediment)
Sediment collection	Ponar grab, Peterson grab, 3/4-size Reineck spade corer
	Laboratory Procedures (Water)
Ammonium	Specific ion electrode
As, Cd, Cr, Cu, Fe, Hg, Mn, Ni, Pb, Zn	Atomic absorption spectrophotometry
Carbon	Organic carbon analyzer
Nitrate	Brucine method
Oil and grease	Solvent extraction (EPA)
Organic nitrogen	Subtraction of ammonium from Kjeldahl nitrogen
Pesticides and PCB's	Electron capture gas chromatography
Phosphorous	Ascorbic acid method
Turbidity	Hach turbidimeter

(Continued)

Table 5 (Continued)

Variable	Procedure
Laboratory Procedures (Sediment)	
Ammonium	Specific ion electrode
As, Ce, Cr, Cu, Fe, Hg, Mn, Ni, Pb, Zn	Atomic absorption spectrophotometry
Carbon	Organic carbon analyzer
Cation exchange capacity	Ammonia saturation
Interstitial water collection	Centrifugation
Moisture content	Weight loss after drying (60°C for 24 hours)
Oil and grease	Solvent extraction (EPA)
Organic nitrogen	Subtraction of ammonium from Kjeldahl nitrogen
Oxygen demand test	Membrane electrode
Particle size	Hydrometer method
Pesticides and PCB's	Electron capture gas chromatography
pH	pH meter
Phosphorus	Ascorbic acid method
Redox potential	Platinum electrode
Sulfide	Iodometric titration
Laboratory Procedures (Organisms)	
As, Cd, Cr, Cu, Fe, Mn, Ni, Pb, Zn	Atomic absorption spectrophotometry
Pesticides and PCB's	Electron capture gas chromatography
Biological Study Variables	
Field Procedures	
Macrobenthos	Van Veen grab, spade corer
Meiobenthos	Subsampled with 4.9-cm-diam tube from macrobenthos
Nekton	Otter trawl
Phytoplankton	Pump, Van Dorn sampler
Zooplankton	Plankton net

(Continued)

Table 5 (Concluded)

Variable	Procedure
	Laboratory Procedures
Macrobenthos	1.0-mm or 0.5-mm sieve
Meiobenthos	0.5-mm sieve followed by 0.062-μm sieve
Nekton	Wet weight biomass, length in 1-, 5-, or 10-cm increments
Phytoplankton	Fluorometric with acetone extraction
Zooplankton	Displacement volume

PART V: RESULTS AND DISCUSSION

Physical Studies

Bathymetry

46. The predisposal bathymetric surveys of the Galveston disposal site revealed a featureless, gently sloping bottom, except in the northernmost section. This had a topographic high believed to be dredged material. After disposal, additional bathymetric surveys at disposal areas 2, 12, and 14 indicated that definite mounds of dredged material had formed. Because of variable navigation techniques, only crude estimates of the mound volume at each area could be made (see Appendix A). Moreover, inadequate documentation on the hopper dredge log sheets of which area was used for each disposal operation precluded accurate determination of actual volumes disposed of at each area. However, using daily records and assuming specific travel times to each area, the following estimates were made of volumes of dredged material disposed of at each area prior to October 1975:

Disposal Area	Estimated Volume m^3	Measured Volume m^3	Percent Accounted for
2	223,900	137,664	61
12	73,075	69,468	95
14	197,640	163,200	83

By June 1976, the estimated in-place dredged material volumes were 64,900, 61,170, and 163,200 m^3 at areas 2, 12, and 14, respectively. Thus, the mound at area 12 was reduced by approximately 8,300 m^3, and there was a substantial loss of volume of area 2 considering that an additional 211,200 m^3 of material was disposed of at area 2 in late winter of 1976.

47. From comparisons of mound configurations with time, a qualitative indication of the degree of erosion at each area was made. Area 2 experienced the most pronounced erosion and had mounds of low relief. The area 12 mound was circular, with 0.3 m of relief and an approximate diameter of 400 m. The area 14 mound probably experienced little

redistribution of material because of the continued presence of a steep, pointed mound with a relief of approximately 2.4 m. Some of the changes in all of the areas may have resulted from compaction and dewatering of the dredged material.

Sediment distribution

48. Evaluation of sediment samples taken during the pilot study and the predisposal period within the disposal site indicated a highly variable distribution of sandy silts and sand. Few results pertaining to predisposal sediment distribution in the disposal site can be considered useful for any evaluation of potential changes after disposal because of the few sampling stations within the site. However, some rather broad generalizations can be made from the postdisposal sediment data from the individual disposal areas.

49. The variability of sand, silt, and clay percentages between replicate samples was so great that comparisons between stations are almost impossible (see Table 4, Appendix A). This variability is indicative of dredged material deposits but was also observed for the two reference areas. Relative changes in carbonate content after disposal from samples taken on the dredged material mounds indicated a general decrease in concentration, except at area 12 where a substantial increase was observed. All of the carbonate concentrations of samples from the mounds were substantially higher than those found at the reference stations and most of the stations off of the dredged material mounds. The extremely high carbonate values at area 12 suggest a low-energy winnowing of fine material with little bed-load transport. This conclusion is substantiated by the small volume reduction (about 8300 m^3) and the general decrease in average grain size to the west. The sediments at area 14 experienced little change in mean grain size during the postdisposal period.

Circulation and transport

50. As stated previously, the diurnal tides of the Galveston area are of the mixed type, with one low and one high per 24-hour period of maximum range and two highs and two lows per 24-hour period of minimum range. These two tides can be designated as tropical tides and

equatorial tides, respectively. The water level variation coincident with this cycling of tides generates the largest exchange of water between the bays and the Gulf and has a direct effect on current velocities within the disposal site.

51. The wind can cause noticeable fluctuations in the primary tidal oscillations and, consequently, may modify the circulation of the nearshore Gulf waters. Prolonged southeasterly winds can effectively "set up" the water level along the coast and within the bays, dampen the tidal forces, and force the nearshore shelf waters into a nearly unidirectional alongshore flow toward the southwest. Maximum current velocities of 90 cm/sec were measured within the disposal site during a period of prolonged southeasterly winds. Local shrimpers and fishermen indicated that a southwest-trending coastal current is generally present for most of the year offshore from Galveston. Annual sea surface data and synoptic meteorological observations indicate that the winds are predominently from the southeast for most of the year.

52. The disposal site thus experiences tidally-induced flows which tend to be rotary at the surface and primarily northeast-southwest near the bottom. Superimposed on this current, semipermanent southwest-flowing nearshelf currents and wave-induced bottom oscillatory currents may develop a flow regime with velocities in excess of 90 cm/sec in the near-bottom waters which can effectively cause erosion, resuspension, and transport of dredged material. Analysis of near-bottom current measurements indicates that median velocities at area 2 were approximately 28 cm/sec and at area 14 were about 20 cm/sec; both areas experienced velocities greater than 70 cm/sec at 1 m above the bed.

53. These data and other observations indicate that the Galveston disposal site experiences an energy gradient dependent upon depth and proximity to shore. This is evident from the net changes in mound configuration and sediment distribution at disposal areas 2, 12, and 14. Area 2 was predominantly an erosion zone with high median velocities, pronounced reductions in mound volume, and high-velocity tidal currents and wave-induced oscillatory currents. Sand tracer studies at area 2 indicated an effective southwesterly transport of the dyed materials,

with substantial reworking of the sediments. Area 12 had a more stratified flow distribution, with a net southwesterly drift and a slightly reduced median velocity. Erosion and transport of fine sand and silt could occur in area 12 but not to the extent of that in area 2. The high postdisposal carbonate concentrations suggest that winnowing was effectively removing the fine-grained fraction of dredged material. Area 14 (in deeper water) probably experienced little change in volume during the period between September 1975 and June 1976. The mound experienced generally lower velocity currents which did not change its configuration. Grain-size data suggest an increase in the finer fractions; this implies that depositional velocities were prevalent at the site.

54. Thus, the Galveston disposal site can be categorized into two energy-related disposal sites. The shallow, nearshore, high-energy portion could be used for nonpolluted entrance channel material which would be effectively reworked and transported out of the site by natural processes. This would help to maintain the natural southwest-trending alongshore movement of nearshore sands which become trapped in the entrance channel system. This portion of the disposal site would naturally have a capacity for large volumes of uncontaminated dredged material.

55. The offshore lower-energy portion of the disposal site would be more suitable for fine-grained, contaminated dredged material which should remain in situ. A potentially effective management technique to assure the stability of fine-grained dredged material is use of the cohesive high-density Beaumont clay, found in the outer bar portion of the channel, as a capping material for the contaminated mounds. Although the Galveston disposal site has not been investigated for an extended period of time to assure the stability of dredged materal in the outer portion, the available data indicate that these assumptions are valid for disposal.

Chemical Studies (Water Column)

Short-term effects

56. During this discussion of short-term water quality alterations, two situations which could potentially result in harm to aquatic organisms will be considered. One of these is the worst-case situation; a planktonic or nektonic organism moves with or remains within the turbid plume until the plume disperses. The other case involves non-motile organisms that the plume passes or nektonic organisms which may swim through the turbid plume and thus receive a short-term exposure.

57. The evaluation of the worst-case situation (movement with the turbid plume) was difficult because of the sampling procedure used. The sampling vessel was anchored, and soluble constituents associated with the turbid plume were sampled as the turbid plume passed under the boat. This did not permit estimation of the rate of dilution of contaminants released from the dredged material. To obtain this information, multiple sampling stations at varying distances from the point of disposal would have been required.

58. Optical properties. The data collected during the disposal operation indicated that a well-defined distribution of suspended material occurred in the water column immediately after the disposal of dredged sediments. In general, the surface and middepth plumes were short-lived, lasting 2 to 15 minutes at any one location near the disposal area. The bottom plume was often more turbid than either the surface or the middepth plume and lasted from 10 minutes to well over 1 hour. The persistance of the bottom plume may have been caused by bottom currents which dislodged previously deposited sediments to create a plume which traveled along the bottom. Surveys conducted some 12 hours after cessation of disposal indicated that the bottom plume was relatively short-lived.

59. Overflights indicated that the turbid surface plume generally persisted for 1 hour or less. Even for organisms moving with the plume, such short-term exposure should not result in harm to the organisms. Peddicord et al.[7] have reported that, in general, aquatic organisms are

insensitive to concentrations of suspended solids greater than those normally associated with disposal operations. Many aquatic organisms are adversely affected only by concentrations in the grams per litre range and greater and, even then, only when these levels persist for several days or weeks.

60. Dissolved oxygen. Decreased concentrations of dissolved oxygen were noted in all but four of the disposal operations. Only once during the disposal operations did the dissolved oxygen concentration fall below the 5.0-mg/ℓ lower limit proposed by the U. S. Environmental Protection Agency (EPA).[8] This level of dissolved oxygen is considered to be the minimum concentration required by many aquatic organisms. During Texas City disposal number 2, ambient dissolved oxygen concentrations in the bottom waters were such that a dissolved oxygen decrease of 1.5 mg/ℓ during disposal reduced dissolved oxygen concentrations to slightly over 4 mg/ℓ. This dissolved oxygen depletion was of short duration (minutes), and it is doubtful that the depletion would have had a significant effect on pelagic organisms passing through or moving with the plume.

61. Heavy metals. During the disposal operations, elevated concentrations of some heavy metals were observed in the water column. However, as with other toxicants, it is important to consider the available concentration and exposure time. The aqueous environmental chemistry of many heavy metals is such that, with few exceptions, the predominant forms present in natural waters are in a relatively unavailable and nontoxic state. This is especially true for sediments where binding of the heavy metals to the sediment would generally be expected to greatly reduce mobility and possibly eliminate any toxicity toward most aquatic species.

62. Manganese concentrations increased in the water column during seven of the nine monitored disposal operations. This development agrees with results found by Lee et al.[9] with elutriate tests on Galveston Bay Channel and Texas City Turning Basin sediments where manganese was the only heavy metal that exhibited the potential for release of significant amounts. The magnitude of manganese release

varied between disposal operations and seemed to be independent of other variables. Galveston Bay Channel disposal 5 showed the greatest release, as moderately elevated manganese concentrations (105 to 190 mg/ℓ) persisted in bottom waters for at least 35 minutes after disposal. When one considers the 35-minute period of time a nonmotile organism could be in contact with concentrations of manganese above the ambient exposure level (100 μg/ℓ, EPA[8]) for protection of consumers of marine mollusks, it seems unlikely that the release of manganese would have a detrimental effect on water quality. No criteria are available for manganese in marine waters other than the exposure level for marine mollusks. However, tolerance values reported for freshwater aquatic life range from 1.5 mg/ℓ to 100 mg/ℓ.[8] The slightly elevated manganese concentrations found in the water following the disposal of dredged materials do not appear to pose any problems to marine organisms.

63. Increases in concentrations of nickel, cadmium, and mercury were noted in the water column following the disposal of dredged material during a few disposal operations. The magnitude of the release was minor, however, and did not exceed the safe chronic exposure levels recommended by the EPA[8] for cadmium and mercury. (No numerical criteria are available for nickel.) Release into the water column was small (usually less than 10 μg/ℓ) and would therefore not have an adverse effect on water quality at the disposal site.

64. Nitrogen compounds. The primary concern over nitrogen compounds in dredged sediments is related to the amount of ammonia* released to the water column during disposal. Of the various nitrogenous compounds present in dredged sediments, ammonia represents the greatest potential hazard to aquatic life.[10]

65. The magnitude of ammonium-N release from the contaminated Texas City sediments into the water column was greater than the release of ammonium-N into the water column during the disposal of Galveston

---

* For the purposes of their study this form as nitrogen was measured as ammonium (NH_4^+)-N, and the more toxic ammonia (NH_3)-N was calculated from the concentration of NH_4^+-N at a given pH.

Bay Channel sediments. This was expected because of the much higher interstitial water ammonium-N concentrations in Texas City sediments than in Galveston Bay Channel sediments.

66. Under the temperature, pH, and salinity conditions found in the water, un-ionized ammonia concentrations exceeded the EPA[8] criteria of 0.02 mg/ℓ only during Texas City disposal 2. Calculations of un-ionized ammonia concentrations from ammonium-N concentrations by the method of Thurston et al.[11] were made assuming a pH of 8, salinity of 25 ppt, and temperature of 22°C in the disposal site bottom water. Using these criteria, the un-ionized ammonia concentration reached 0.06 mg/ℓ when ammonium-N concentrations were at a maximum of 1.86 mg/ℓ. These high concentrations of un-ionized ammonia persisted for less than 2 minutes before declining to levels of 0.025 mg/ℓ or less. Un-ionized ammonia concentrations in bottom waters exceeded the safe chronic exposure level for approximately 12 minutes. It is doubtful that such a short exposure to moderately elevated un-ionized ammonia concentrations would result in harm to nonmotile organisms exposed for the entire 12 minutes or to organisms swimming through the plume.

67. It must be remembered that the safe chronic exposure criteria[8] specify concentrations of water constituents which will provide for the protection and propagation of fish and other aquatic life and for recreation in and on the water. Concentrations considerably greater than the chronic exposure criteria can be allowed for short periods of time without having a significant adverse effect on water quality. The exposure criterion used for un-ionized ammonia or any other parameter must exceed the critical concentration time of exposure relationship for an organism of interest in the water column before any harm to the organism will occur.

68. An example of the importance of the concentration time of exposure relationship was demonstrated by Mattice and Zittle[12] in a literature review on the impact of chlorine on aquatic organisms. They determined that, for marine organisms of the types they tested, the acute safe level of chlorine for a 1-minute exposure was approximately 0.15 mg/ℓ. For 10 minutes of exposure, the safe level for acute toxicity

was approximately 0.06 mg/ℓ, while, for 100 minutes of exposure, the safe level was approximately 0.03 mg/ℓ. They also reported that a chronic safe level for chlorine was about 0.02 mg/ℓ.

69. The importance of these results is that a doubling of the safe acute toxicity level is achieved when the exposure time is reduced from 100 to 10 minutes. Decreasing the duration of exposure from 100 to 10 minutes increases the acute toxicity threshold from approximately 0.04 mg/ℓ to 0.2 mg/ℓ chlorine.[12]

70. It is impossible to reach any conclusions regarding the fate of organisms moving with the plume because of the unknown rate of dilution of the plume. Water in the plume will, however, mix with water containing lower ammonium-N concentrations. It was determined in the physical studies that bottom currents tend to mix the plume with water masses of lower ammonium-N concentrations. In a shallow-water area such as the disposal site, turbulent diffusion is sufficient for rapid mixing of water column constituents. Ammonium-N concentrations in the turbid plume would, therefore, be expected to decrease rapidly.

71. Bioassay studies[9] were conducted to determine the toxicity of sediments disposed of in the Galveston disposal site. Elutriates of sediment from the Galveston Bay Channel and Texas City Turning Basin were evaluated for toxicity to Paleomonetes pugio (grass shrimp) in a 96-hour bioassay. Little toxicity was demonstrated by the dredged material from either the Galveston Bay Channel or the Texas City Turning Basin.

72. Increased concentrations of organic-N were found in the turbid plumes. This development was expected since organic-N in natural water systems occurs primarily in a particulate form. No water quality significance can be attached to a certain concentration of organic-N in natural waters. It is very unlikely that the organic-N associated with the turbid plume would cause any water quality problems as a result of its conversion to ammonia. In the study area, the conversion of organic nitrogen to ammonia would be slow (weeks or months). Thus, any ammonia would be dispersed in Gulf waters so that it would not adversely affect aquatic life. In addition, the ammonia-N would rapidly convert

to nitrate-N.

73. Nitrate-N is not normally present in anaerobic bottom sediments. Under the reducing conditions that prevail in the Texas City and Galveston sediments, any nitrate-N present in the interstitial waters should be rapidly denitrified. During several disposal operations, the nitrate concentration increased. This result might have been due to a positive interference in the nitrate analyses of iron, manganese, or other materials. However, if the observed nitrate increase was real, there should have been no adverse effect on water quality.

74. Phosphorus compounds. Phosphorus is of concern in dredged material disposal primarily because, in phosphorus-limited waters, certain forms of this element can stimulate the growth of aquatic plants. The seagrasses and benthic algae of the Gulf of Mexico serve as valuable food sources and habitats for fishes and invertebrates. However, massive amounts of algae occur seasonally at shallow depths in the Gulf and may become nuisances.[13]

75. Data from nine disposal operations indicated that the direction and degree of change in soluble orthophosphate concentrations during disposal were unrelated to either the disposal area or the sediment source in question. The general trend was for concentrations of soluble orthophosphate-P to increase and rapidly return to ambient levels. Where these increases occurred, they ranged from 2- to 55-fold and appeared to be quite localized. Frequently, however, no increase was found in the surface waters. The increases in soluble orthophosphate-P were such that no stimulation of photosynthetic activity would be expected because of the compensation depth.

76. Texas City sediments released less orthophosphate-P than did Galveston Bay Channel sediments. In some cases, Texas City sediments appeared to remove orthophosphate-P from the water column by sorption and/or precipitation. This may have been related to the higher ambient orthophosphate-P concentrations in disposal site waters prior to disposal of Texas City sediments. The Texas City sediments may also have contained more soluble ferrous iron than Galveston Bay Channel sediments. This would result in the increased removal of orthophosphate-P by ferric

hydroxide formation during disposal of Texas City sediments.[14]

Long-term effects

77. Optical properties. No evaluation of the long-term effect of dredged material disposal on optical properties could be conducted because of inadequate data. However, the ambient turbidity was generally so great that the disposal of dredged material would be very unlikely to alter water quality.

78. Dissolved oxygen. There were no observed long-term effects on dissolved oxygen concentrations in the disposal site water column. Results of the postdisposal surveys indicated that dissolved oxygen concentrations in the water column immediately above the disposal site were essentially the same as predisposal and reference area concentrations.

79. Heavy metals. The results indicated that disposal of dredged material caused no long-term release of heavy metals to the disposal site water column.

80. Nitrogen compounds. Only ammonium-N concentrations were evaluated in postdisposal water samples. Ammonium-N concentrations were not greater than 0.05 mg/ℓ and were comparable to predisposal levels.

81. Phosphorus compounds. Postdisposal orthophosphate-P concentrations in the water column were generally 2.5 to 22 times greater than those observed before and during disposal. Similar increases were observed in the reference areas which indicates that these increases reflect normal variation.

82. There are several reasons why changes in soluble orthophosphate concentrations resulting from dredged material disposal probably have little ecological significance. First, it has been shown by Ryther and Dunstan[15] and Copeland and Fruh[6] that nitrogen limits algal growth in the coastal marine environment and in Galveston Bay waters. Copeland and Fruh[6] further state that growth of aquatic plants in Galveston Bay is most likely limited by the presence of toxic substances rather than by a lack of nutrients.

83. As shown by the predisposal data, soluble orthophosphate-P

concentrations were generally 0.01 mg P/ℓ or higher, whereas inorganic-N (NH_3-N + NO_3^--N) concentrations were usually well below 0.3 mg N/ℓ. Concentrations of 0.01 mg P/ℓ and 0.3 mg N/ℓ are usually regarded as the critical limiting factor for algal growth.[6,16,17] In addition, the ratios (available N:available P) were generally less than 10:1 (atomic ratio), indicating that nitrogen would likely become limiting before phosphorus. Nitrogen concentrations in 7 May samples were above the 0.3-mg N/ℓ level, while soluble orthophosphate-P concentrations remained in the same range as found on other sampling dates. In most of these cases, the N:P ratio was still below 10:1 (atomic ratio). Several samples collected at the disposal site on 17 April showed N:P ratios as great as 39:1 (atomic ratio), indicating the possibility of phosphorus limitation before nitrogen limitation if other conditions favored algal growth. Subsequently, eutrophic conditions did not exist as a result of disposal.

Chemical Studies (Sediments)

84. The sampling program was conducted in such a manner that only long-term alteration of sediment properties by dredged material disposal could be evaluated. Also, with the exception of ammonium-N analyses, only total analyses (bulk sediment analyses) were conducted on the disposal site sediments. Therefore, no evaluation of possible changes in the mobile forms of contaminants other than ammonium-N could be made.

85. It is assumed that the data are representative of the general properties in an area at the time of sampling. However, it is known that natural sediments in areas such as that near the Galveston Bay Channel tend to be highly variable in composition and are influenced by storms and ship traffic. It is also likely that the characteristics of the sediments changed during the course of the study due to factors other than dredged material disposal. This conclusion is reinforced by significant differences in predisposal and postdisposal trace metal and sulfide concentrations in the reference areas.

86. There was no increase in concentrations of trace metals or nitrogen compounds in disposal site sediments where dredged material

disposal had occurred. Total mercury concentrations increased in reference area 27 (compared to predisposal concentrations) although there was no dredged material disposal in this reference area. A decrease in trace metal concentration was noted following disposal.

87. Decreased trace metal concentrations in sediments where disposal occurred may have been due to transport of finer sediment particles and associated trace metals out of the disposal areas by currents. This is supported by the presence of lower concentrations of trace metals in sediment mounds created by disposal than in sediments immediately adjacent to the mounds.

88. It can be concluded that disposal operations at the Galveston disposal site resulted in no major changes in the concentrations of chemical parameters measured in this study. In addition, no major changes in pH, Eh, or percent solids were noted in disposal site sediments.

Biological Studies

Phytoplankton

89. Phytoplankton samples for pigment analysis (chlorophyll-a and phaeophytin) were collected with an on-deck pumping system during the pilot study. The resulting samples contained numerous ruptured cells which the contractor attributed to the effect of suspended particulate matter as the cells passed through the pump impeller. Thus, phytoplankton data from the pilot study were not analyzed.

90. Samples for pigment analysis were obtained with a Van Dorn sampler during the experimental study. The resulting data indicated a trend towards a decrease in total pigment concentration for the first four sampling periods and a slight increase during the last sampling period. However, samples were collected only once per month for 5 months, and only two replicates were collected (in some cases no replicates) at each sampling time. In addition, there was only one sampling station within the dredged material disposal site.

91. Phytoplankton samples were collected during and after the

disposal of dredged material on 9 September 1975 and 9 October 1975. Two replicates were taken at the surface and near the bottom before and after disposal. The concentration of pigments was slightly lower after disposal on both dates. Samples were also collected at intervals following a second disposal operation on 9 October. The postdisposal concentration of pigments was lower than the predisposal concentration at 30 minutes and higher than that at 50 minutes in the surface samples. Only one sample was collected for each sampling interval during the postdisposal period.

92. The lack of sufficient sampling periods and replicates precluded any statistical analysis between sampling intervals. It is concluded that the phytoplankton data were insufficient to make any determinations on the impact of disposal of dredged material on phytoplankton communities.

Zooplankton

93. Replicate oblique plankton tows were obtained from one inshore station and from one offshore station during the pilot study. During the experimental study, replicate samples were obtained (on a monthly basis between 25 July and 24 November 1975) from a station within the disposal site and from a station within the entrance channel. Additionally, 24 samples were obtained from the National Marine Fisheries Service (NMFS) Archive collection for further analysis of temporal abundance of meroplankton populations and for a more detailed evaluation of reproductive patterns of the offshore macroinvertebrates and nekton. These samples were collected by the NMFS during the period 1 January 1963 to 31 December 1965 from an established sampling station in close proximity to the disposal site.

94. Pilot data were collected on 14 May 1975. Copepods comprised 82 percent of the total number of individuals at the inshore station and 90 percent at the offshore station. The Chaethognatha accounted for 11 percent of the holoplankton at the inshore station and 5.5 percent of the holoplankton at the offshore station. The meroplankton component accounted for only 3 to 5 percent of the total population.

95. During the experimental study, copepods comprised 36, 47, 84, and 70 percent of the total number of holoplankton individuals in the four reported samples. Three of the samples contained members of the Chaethognatha which, when added to the Copepoda, accounted for 85 to 97 percent of the holoplankton. The other sample contained 60 percent cladocerans. Hence, copepods, cladocerans, and/or Chaethognatha accounted for 85 to 98 percent of the holoplankton collected during the experimental study.

96. The total numbers of meroplankton were virtually unchanged throughout the experimental study period. Mollusk larvae were abundant in most collections. Crustacean larvae were most abundant in September and October.

97. Twenty-two of the 24 samples obtained from the NMFS Archive collection were dominated by members of the Copepoda; these comprised 54 to 99.9 percent of the total number of individuals of the holoplankton. Urochordates were the second most abundant group of animals in many of the samples and, together with the copepods, accounted for most of the animals present.

98. The larval forms of benthic invertebrates comprised most of the meroplankton (fish eggs and larvae were included in this category but were always a minor component). Barnacle nauplii and cypris larvae were abundant in some spring samples. However, because there were few hard substrates in the disposal site on which to settle, they were of minor importance in repopulating disrupted bottoms. The three important groups in the meroplankton were the young of polychaete worms, mollusks (principally snails and clams), and crustaceans (mostly various types of crabs and shrimp), which live on or burrow into the bottom. Polychaete larvae were most abundant in the spring of 1963 and 1965 and in the summer of 1964. The larval mollusk populations peaked in the summer of 1963, the spring and fall of 1964, and the spring of 1965. Mollusk larvae were present in large numbers compared to other meroplanktonic forms. Crustacean larvae were generally most abundant between May and October.

99. In general, the holoplanktonic species composition of samples collected during the present study was similar to that of the NMFS samples obtained during 1963-1965. Even the order of abundance among the more common species was quite similar between the two time periods. Because of the taxonomic difficulties involved in positive identification of meroplanktonic organisms below the phylum or class level, no definitive information was obtained on macroinvertebrate and nekton population reproductive patterns.

Meiobenthos

100. Meiobenthic samples were not collected during the pilot study. For reasons discussed in Appendix C, meiobenthic samples were collected only in July, September, and December 1975. These were subsamples of the macrobenthic samples. There were insufficient meiobenthic data to provide comparisons of trends between any of the sampled areas. The contractor did not present any data in Appendix C or attempt to draw any conclusions from the meiobenthic data because, in addition to the small number of samples, the variability between replicates was large.

Finfish and nektonic invertebrates

101. From a series of otter trawls during the pilot study, it was found that two species, the drum, Micropogon undulatus, and a portunid crab, Callinectes similis, were widespread and abundant throughout the study area. Other species, the anchovy, Anchoa mitchilli, cutlass fish, Trichiurus lepturus, sea robin, Prinotus rubio, brown shrimp, Penaeus aztecus, and short squid, Loliguncula brevis, were also widespread, though less abundant.

102. Of the remaining species, 10 were used to divide the study area into nearshore and offshore station groups which corresponded roughly to the macrobenthic invertebrate station groups. The inshore station group was characterized by the shrimp, Xiphopeneus kroyeri, blue crab, Callinectes sapidus, star drum, Stellifer lanceolatus, sea trout, Cynoscion arenarius, banded croaker, Larimus fasciatus, and spot, Leiostomus xanthurus.

103. The offshore station group was characterized by the tongue fish, Symphurus civitatus, white shrimp, Penaeus setiferus, and mantis

shrimp, Squilla empusa. The remaining species were either irregularly distributed or uncommon.

104. A number of trawl samples were also obtained during the post-disposal period. The benthic invertebrate numbers decreased with the onset of fall and remained low during the remainder of the study. No particular pattern was evident for the nektonic invertebrates. The numbers present varied erratically between disposal and reference areas and between stations within each area. Other than a somewhat general decrease in the fall, the finfish followed much the same general trend as the nektonic invertebrates; i.e., there was no consistent pattern of change.

105. Statistical analyses of trawl samples indicated that there were no significant differences within or between disposal and reference areas with regard to benthic macroinvertebrates, nektonic invertebrates, finfish, or total biomass.

106. During September 1975, comparative trawls were made in clear water and adjacent turbid water created by disposal. It was found that three species of fish (croaker, star drum, and sea catfish) and the sea bob were more abundant in turbid-water trawls. Likewise, a much greater biomass was obtained in the turbid water.

Stomach analyses

107. Stomach analyses were conducted on almost 6000 fish. Of these, 26 percent had empty stomachs and 40 percent had full stomachs. The condition of the other stomachs was not given by the contractor (Appendix C). As would be expected, most of the food items consisted of the more abundant animals in the general area.

Benthic macroinvertebrates (pilot study)

108. Two replicate samples were taken from each of the 28 grid squares of the disposal site (Figure 4) between 15 April and 3 May 1975. A hemichordate (Balanoglossus sp.) was the most abundant organism and accounted for 60 percent of the total organisms; it occurred at 15 of the 28 stations but was primarily found in the deeper (offshore) portion of the disposal site. Its abundance was more than an order of magnitude greater than the second most abundant animal, a phoronoid (Phoronis architecta).

109. Numerical analyses of the macrobenthic invertebrate data indicated that there were two major assemblages at the disposal site. The first of these was the inshore group. It was characterized by few, if any, Balanoglossus sp., high numbers of polychaete worms, and lesser dominants among nemerteans, crustaceans, and mollusks. It is of interest that the more uncommon organisms were frequently found in this group. The second assemblage was an offshore group which was dominated by Balanoglossus sp., with polychaete worms as the second most abundant organisms. Several other assemblage groups were tentatively identified, but their relationship with the two major groups was not clear.

110. Principal components analysis was used to determine which, if any, abiotic variables were primarily responsible for determining the relationship of the biotic assemblages. This approach indicated that sediment grain size was the most important factor.

111. Ten replicates were taken at three of the stations to ascertain how many samples were needed to obtain a reasonable estimate of the number of species present at a given location. It was found that at station 6 (sandy mud bottom) more than 10 samples would be required; at station 17 (sand bottom) 8 samples; and at station 21 (soft clay bottom) 6 or 7 samples (Figure 5).

112. The pilot study results can not be used in the determination of impacts on the macroinvertebrates resulting from the disposal of dredged material because: (a) the sieve size was different, (b) the samples were collected over a rather long time span, and (c) position location was extremely poor. Hence, it will not be further considered. Of more interest are the macrobenthic invertebrate results obtained during the experimental phase of the investigation. Most of the biological effort was concentrated on these organisms since it was felt that they would be the most likely to exhibit any effects resulting from disposal.

Benthic macroinvertebrates (experimental study--results)

113. The raw results of the macrobenthic samples are given in Appendix E' of Appendix C. By and large, the contractor's approach to the portrayal of results and subsequent analyses was limited to an

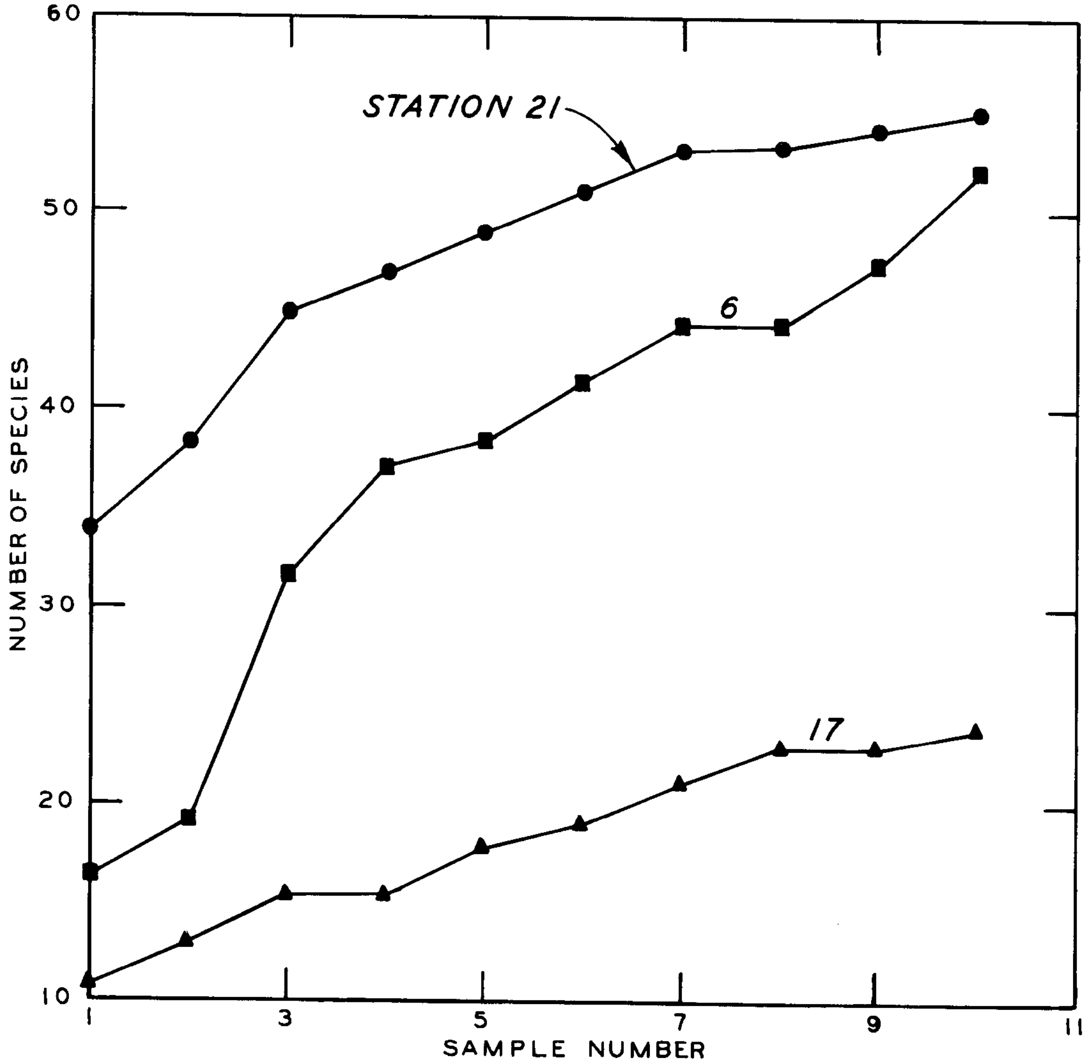


Figure 5. Plots of macroinvertebrate samples taken at three grid square stations during the pilot survey to determine the number of sample replicates required for estimating the number of species present

examination of the total number of individuals and total number of species at various areas and stations through time and to numerical analyses. Because this approach did not lead to defensible conclusions concerning the impact of dredged material disposal upon benthic macroinvertebrates, additional analyses were conducted.

114. These analyses involved 19 organisms. Selection of each was based on several factors including temporal and spatial distribution, numerical abundance, and dominance in the community. Table 6 is a summary of these characteristics for the selected organisms.

115. Magelona sp. was the most abundant organism in the study area (see Table 6). It was among the top fifteen taxa in 143 of 150 samples (25 stations sampled 6 times) and was the dominant organism in 58. The most poorly represented organisms of the 19 selected for detailed study were Spiophanes bombyx and Vitrinella helicoides. A rather distinct division was observed between these organisms and the remaining organisms found during the study period. The remaining organisms tended to be represented by few individuals, were rarely dominant, and did not occur with any regularity in the various areas. It is felt that the 19 selected organisms were the principal components of the benthic communities and, hence, probably of the greatest ecological significance.

116. The first estimation of change which may have resulted from dredged material disposal consisted of determining the direction of change in abundance (increase, decrease, no change) between July and September for each of the 19 species at the disposal and reference areas. The results of this analysis are given in Table 7. It was found that 68 percent of the species decreased in abundance at both the disposal and the reference areas. Thus, no acute impact could be demonstrated.

117. Changes in relative numerical abundance or dominance within benthic assemblages may also have resulted from dredged material disposal. Spearman's rank correlation procedure[18] was employed to evaluate such changes by using estimates of relative abundance of each of the 19 selected organisms at the stations thought most likely to be severely impacted by disposal. The buoyed stations (2-1, 12-3, and 14-3; see

Table 6

Characteristics of the 19 Organisms Selected for Detailed Analysis

Organism	Occurrence by Replicate*	Occurrence by Station Among 19 Most Dominant Taxa**	Occurrence by Station as Dominant Taxon†	No. of Organisms per m^2 Mean	No. of Organisms per m^2 Standard Deviation	Total Number of Organisms
Ampelisca abdita	171	60	1	17.6	41.6	7916
Balanoglossus sp.	111	41	11	45.1	232.0	20288
Cerebratulus lacteus	282	115	1	32.9	57.2	14794
Diopatra cuprea	302	111	5	35.0	53.1	15754
Glycera americana	111	32	0	8.5	21.9	3834
Glycinde solitaria	181	52	0	15.4	30.4	6944
Lumbrinereis impatiens	345	130	8	50.9	59.2	22912
Magelona spp.	395	143	58	154.6	172.5	69560
Mediomastus californiensis	251	98	14	78.6	177.9	35369
Nemertean, yellow-banded	202	66	0	16.1	25.3	7260
Nereis sp.	272	106	6	33.1	49.6	14906
Nereis succinea	113	39	1	12.4	34.7	5575
Ninoe nigripes	162	56	0	11.5	20.6	5184
Nuculana concentrica	162	59	1	18.2	41.7	8208
Prionospio pinnata	303	107	22	118.1	239.7	53240
Sigambra tentaculata	174	57	0	14.3	25.7	6416
Sigambra wassi	175	64	1	17.1	37.4	7678
Spiophanes bombyx	61	18	2	22.5	175.8	10132
Vitrinella helicoides	66	24	2	5.6	22.2	2512

Note: The total number of replicates was 450 (3 replicates per station × 5 stations per area × 5 areas × 6 sampling intervals = 450); the total number of station samples was 150 (5 stations per area × 5 areas × 6 sampling intervals = 150).

*The number of times that the organism was found among the 450 replicates.

**The number of times that the organism was found among the most dominant 19 taxa in the 150 station samples.

†The number of times that the organism was dominant in the 150 station samples.

Table 7

Direction of Change in Abundance of the 19 Selected Organisms Between July and September 1975

	Percent Change			
	Not Present	No Change	Increase	Decrease
Disposal areas 2, 12, and 14 (N = 57)*	18	2	12	68
Reference areas 15 and 27 (N = 38)*	18	5	9	68

Note: Both significant ($\alpha \leq 0.05$) and nonsignificant changes are included.

* N is the number of replicates for the disposal areas, 19 organisms × 3 areas = 57; for the reference areas, 19 organisms × 2 areas = 38.

Figure 4) in the disposal areas were used, and stations 15-3 and 27-3 from the reference areas were included for comparative purposes. Relative numerical abundance was estimated for each of the 19 organisms from each station for each sampling period by summing over replicates. The resulting estimates were then ranked in descending order, and coefficients of association were computed between sampling intervals at each station and between each disposal station and its assumed reference for each sampling interval. For the latter analyses, station 15-3 was assumed to be the reference for disposal station 2-1, and station 27-3 was assumed to be the reference for disposal stations 12-3 and 14-3. The results of these analyses are presented in Table 8. This analysis, however, does not evaluate direction of change or temporal extent of change for each of the selected organisms.

118. Hence, Duncan's multiple-range test[19] was employed to determine significant changes in the abundance of each selected organism through time and between areas and stations. The results of these analyses are given in Table 9 and, for reader convenience, in summary form in Table 10.

119. Significant changes were found to occur for all 19 organisms. These changes were randomly distributed over all stations. At disposal station 2-1, 37 percent of the possible* changes took place; at reference station 15-3, 47 percent of the possible changes were observed. The reference station (27-3) for stations 12-3 and 14-3 exhibited 32 percent of the possible change, while the disposal stations (12-3 and 14-3) showed 63 and 58 percent, respectively. This suggests that there was more change at the reference station (15-3) for disposal station 2-1 than there was at the disposal station itself. Conversely, disposal stations 12-3 and 14-3 had a greater degree of change than did their reference station (27-3).

120. However, these changes do not take into account the direction or magnitude of change. They merely indicate that a significant change

---

* The maximum change at a station would occur if significant changes were observed in all 19 organisms throughout the study.

Table 8

Results of Correlation Analyses Between Selected Stations and Sampling Intervals Using Estimates of Relative Numerical Abundance of the 19 Selected Organisms

A. Comparisons between predisposal abundance and each postdisposal sampling period at reference stations.

1. Station 15-3:

	Sep	Dec	Jan	Apr	May
Spearman R	0.885	0.780	0.598	0.623	0.390
Level of significance	0.0001	0.001	0.001	0.004	0.10

2. Station 27-3:

	Sep	Dec	Jan	Apr	May
Spearman R	0.447	0.632	0.397	0.408	0.499
Level of significance	0.05	0.005	0.09	0.08	0.03

B. Comparisons of abundance over time at each disposal area buoyed station.

1. Station 2-1: Comparisons between July 1975* data and remaining sampling intervals:

	Sep	Dec	Jan	Apr	May
Spearman R	0.377	0.664	0.641	0.624	0.400
Level of significance	0.11	0.003	0.003	0.004	0.09

2. Station 12-3: Comparisons between predisposal data and each postdisposal sampling interval:

	Sep	Dec	Jan	Apr	May
Spearman R	-0.058	0.175	-0.165	-0.335	0.089
Level of significance	0.82	0.50	0.50	0.16	0.72

3. Station 14-3: Comparisons between predisposal data and each postdisposal sampling interval:

	Sep	Dec	Jan	Apr	May
Spearman R	0.517	0.370	0.225	0.080	0.082
Level of significance	0.03	0.20	0.36	0.75	0.74

(Continued)

* Corresponds to predisposal sampling interval at disposal area buoyed stations 12-3 and 14-3.

Table 8 (Concluded)

C. Comparisons of abundance between each disposal area buoyed station and its assumed reference station for each sampling interval.

1. Station 2-1 versus Station 15-3:

	Jul	Sep	Dec	Jan	Apr	May
Spearman R	0.614	0.639	0.838	0.497	0.606	0.381
Level of significance	0.01	0.005	0.001	0.05	0.01	0.20

2. Station 12-3 versus Station 27-3:

	Jul	Sep	Dec	Jan	Apr	May
Spearman R	0.612	0.267	0.555	0.251	-0.053	0.285
Level of significance	0.01	0.50	0.02	0.50	0.80	0.50

3. Station 14-3 versus Station 27-3:

	Jul	Sep	Dec	Jan	Apr	May
Spearman R	0.601	0.408	0.247	0.253	0.184	0.251
Level of significance	0.01	0.10	0.50	0.50	0.50	0.50

Table 9

Results of Duncan's Multiple-Range Test ($\alpha \leq 0.05$) for Selected Organisms; Analysis of Stations over Time

Organism	Station	Number of Organisms per m^2					
		Jul	Sep	Dec	Jan	Apr	May
Ampelisca abdita							
	12-3	27*	0	0	20*	48	21*
	14-3	59*	0	107	27	11	53*
	15-3	5	0	0	5	0	53
Balanoglossus sp.							
	12-3	59	0	0	0	0	32*
	14-3	5	0	101*	277	5	69*
Cerebratulus lacteus							
	15-3	5	0	11	32*	0	80
Diopatra cuprea							
	12-3	32	11	11	3	0	11
	14-3	53	0	16	0	5	0
Glycera americana							
	12-3	11*	5*	0	3*	32	11*
	15-3	0	0	5	0	5	69
Glycinde solitaria							
	2-1	0	16*	0	0	0	32
	12-3	32	0	0	0	0	16*
	14-3	32	0	0	0	0	27

(Continued)

Note: Only those stations with significant changes in abundance are included.
Numbers which are underlined are significantly different from those which are not underlined.
Numbers marked with an asterisk (*) are not significantly different from the extremes.

Table 9 (Continued)

Organism	Station	Number of Organisms per m^2					
		Jul	Sep	Dec	Jan	Apr	May
Lumbrinereis impatiens							
	2-1	0	16*	0	0	0	32
	12-3	32	0	0	0	0	16*
	14-3	32	0	0	0	16*	27
Magelona spp.							
	2-1	0	21	5	0	5	0
	14-3	160*	5	64*	144*	128*	224
	15-3	5	16*	48*	16*	21*	69
Mediomastus californiensis							
	2-1	27	11	347	0	16	112
	14-3	80	5	32*	48*	5	0
	15-3	107	37	677	107	315*	176
	27-3	75	5	11	5	11	0
Nemertean, yellow-banded							
	14-3	5	0	0	11	0	43
	27-3	11	0	0	0	0	0
Nereis sp.							
	2-1	155	5	64*	5	32*	37*
	12-3	11	16	80*	57*	91	53*
	15-3	5	5	21*	64*	75	5
Nereis succinea							
	2-1	5	48	117	11	0	5
	12-3	11	0	0	0	0	144
	15-3	11	0	59	0	0	16
Ninoe nigripes							
	12-3	21	0	0	0	0	0

(Continued)

Table 9 (Concluded)

Organism	Station	Number of Organisms per m^2 Jul	Sep	Dec	Jan	Apr	May
Nuculana concentrica							
	14-3	219*	0	0	0	5	37
	27-3	48*	5*	69	16*	5*	0
Prionospio pinnata							
	12-3	21	16	32*	13	75	16
	14-3	128	5	48*	21	11	75*
	15-3	288	208	715	128	192	11
	27-3	122	0	11	0	5	21
Sigambra tentaculata							
	14-3	69	0	16*	11	0	5
	15-3	16	21	80	0	11	5
	27-3	85	0	21	11	0	21
Sigambra wassi							
	12-3	64	0	0	10*	5*	37*
Spiophanes bombyx							
	2-1	5	0	0	37	21	144
	12-3	0	0	0	220	2064	16
Vitrinella helicoides							
	27-3	21*	0	32*	0	0	0

Table 10

Summary of Significant Station-Over-Time Changes in Abundance of Selected Organisms

Organism	Station	Change by Date
Ampelisca abdita		
	12-3	Apr > Sep and Dec
	14-3	Dec > Sep
	15-3	May > all other dates
Balanoglossus sp.		
	12-3	Jul > Sep, Dec, Jan, and Apr
	14-3	Jan > Jul, Sep, and Apr
Cerebratulus lacteus		
	15-3	May > Jul, Sep, Dec, and Apr
Diopatra cuprea		
	12-3	Jul > all other dates
	14-3	Jul > all other dates
Glycera americana		
	12-3	Apr > Dec
	15-3	May > all other dates
Glycinde solitaria		
	2-1	May > Jul, Dec, Jan, and Apr
	12-3	Jul > Sep, Dec, Jan, and Apr
	14-3	Jul and May > Sep, Dec, and Jan
Lumbrinereis impatiens		
	2-1	Sep > all other dates
	14-3	May > Sep
	15-3	May > Jul

(Continued)

Note: Only significant ($\alpha \leq 0.05$) changes are included here. For actual numbers of organisms per square metre, see Table 9.

Table 10 (Continued)

Organism	Station	Change by Date
Magelona spp.		
	2-1	Dec > all other dates
	14-3	Jul > all other dates
Mediomastus californiensis		
	2-1	Dec > all other dates
	14-3	Jul > Sep, Apr, and May
	15-3	Dec > Jul, Jan, Sep, and May
	27-3	Jul > all other dates
Nemertean, yellow-banded		
	14-3	May > all other dates
	27-3	Jul > all other dates
Nereis sp.		
	2-1	Jul > Sep and Jan
	12-1	Apr > Jul and Sep
	15-3	Apr > Jul, Sep, and May
Nereis succinea		
	2-1	Dec > all other dates
	12-3	May > all other dates
	15-3	Dec > all other dates
Ninoe nigripes		
	12-3	Jul > all other dates
Nuculana concentrica		
	14-3	Jul > all other dates
	27-3	May > Dec
Prinospio pinnata		
	12-3	Apr > Jul, Sep, Jan, and May
	14-3	Jul > Sep, Jan, and Apr
	15-3	Dec > all other dates
	27-3	Jul > all other dates

(Continued)

Table 10 (Concluded)

Organism	Station	Change by Date
Sigambra tentaculata		
	14-3	Jul > Sep, Jan, Apr, and May
	15-3	Dec > all other dates
	27-3	Jul > all other dates
Sigambra wassi		
	12-3	Jul > Sep and Dec
Spiophanes bombyx		
	2-1	May > all other dates
	12-3	Apr > all other dates
Vitrinella helicoides		
	27-3	Dec > Sep, Jan, Apr, and May

in abundance was noted for a particular organism during two or more sampling periods within the time frame of the study. As an example, it was found (Table 9) that Ampelisca abdita was more abundant in April 1976 at station 12-3 than in September 1975 or December 1975; it was more abundant in December 1975 at station 14-3 than in September 1975; finally, it was more abundant at station 15-3 in May 1976 than at any other time at that station. There were no significant changes in its abundance at stations 2-1 (in a disposal area) or 27-3 (in a reference area).

121. To facilitate comparisons of this nature, Table 10 was prepared. It consists of significant changes and the direction of change. It should be kept in mind that, for a given organism, five stations were evaluated (2-1, 12-3, 14-3, 15-3, and 27-3). Six sampling periods were included, and a significantly different abundance could have been noted in each. Alternately, there might not have been any differences between the six. Significant differences occurred as a result of presence/absence phenomena in many cases, and this probably has little ecological significance. An example is provided by Ninoe nigripes (Table 9): 21 animals/m^2 were recorded in July 1975. This was a significant difference from the other sampling periods because no organisms were observed at that station at other times. Thus, sampling error and/or seasonal variation was probably responsible for the observed difference rather than the disposal of dredged material.

122. Duncan's multiple-range test was also employed to determine differences between areas and sampling times. Areas and dates were initially compared for the entire study period. When significant area/date interactions were observed, an areas-within-dates and dates-within-areas comparison was utilized. The results of these analyses are given in Table 11.

123. Differences among all comparisons were not common. As with the impacted station comparisons, Table 11 portrays significant differences. There seems to be no consistent pattern which can be related to dredged material disposal.

Table 11

Results of Duncan's Multiple-Range Test ($\alpha \leq 0.05$) for Selected Organisms;

Analysis of Areas-Within-Dates and Dates-Within-Areas

		Number of Organisms per m^2												
		Areas-Within-Dates					Dates-Within-Areas							
Organism	Date	Area 2	Area 12	Area 14	Area 15	Area 27	Area	Jul	Sep	Dec	Jan	Apr	May
Ampelisca abdita	All	7	18	42	10	10							
Cerebratulus lacteus							All	37*	26	46	23	22	41*
Diopatra cuprea							All	67	33	37	30*	30*	12
Glycera americana	May	43	28	23	51	5	2	6	2	1	3	23	43
							12	2	2	2	1	16*	28
							14	4	1	1	3	10*	23
							15	2	1	1	0	10	51
Glycinde solitaria	Apr	27*	11	12	39	8	2	11	11	5	10	27	85
	May	85	28	18	34	23	12	22*	2*	0	3*	14*	28
Lumbrinereis impatiens	All	35	57	89	30	44	All	44*	28	51	52	53	79
Magelona spp.	Jul	153*	58	47	288	106	2	152*	22	199	385	28	85*
	Dec	189	9	19	278	10	15	288	50	276	65	70	330
Mediomastus californiensis	All	145	27	18	180	22	All	130	24	103	100	27	88*

(Continued)

Note: Only those areas and dates with significant changes in abundance are included.
Numbers with no underline, a single underline, or double underline are significantly different.
Numbers marked with an asterisk (*) are not significantly different.

Table 11 (Continued)

Organism	Date	Area 2	Area 12	Area 14	Area 15	Area 27	Area	Jul	Sep	Dec	Jan	Apr	May
		Number of Organisms per m^2											
		Areas-Within-Dates					Dates-Within-Areas						
Nemertean, yellow-banded	Jul	23*	28	10	22*	8	2	23	9	16	51	22	50
	Dec	16*	7*	16*	22	3	12	28	7	7	9	15*	26
	Jan	51	9	6	11	1	14	10	5	16	6	0	32
	Apr	22	15*	0	25	1	14	22*	7	22*	11*	25*	50
	May	50	26*	32*	47*	1							
Nereis sp.	All	34*	46	17	53	17							
Nereis succinea	All	13*	15*	15*	18	1							
Ninoe nigripes	Jul	2	16	51	2	4*	14	51	18	17	27	25	15
	Sep	7*	21	18*	10*	1							
	Jan	3	18*	27	2	9*							
	Apr	1	20*	25	8*	12*							
	May	2*	12*	15	0	7*							
Nuculana concentrica	Jul	4	39	118	0	48	12	39	18*	36*	21*	10*	1
	Dec	13	36*	32*	16	53	14	118	25	32	15	3	19
							27	48*	17*	52	28*	5	1
Prionospio pinnata	Jul	179	63	61	458	124	2	179*	44	442	322*	165*	205*
	Dec	442	32	36	440	13	15	458	118*	440	283*	219*	43

(Continued)

Table 11 (Concluded)

Organism	Date	Area 2	Area 12	Area 14	Area 15	Area 27	Area	Jul	Sep	Dec	Jan	Apr	May
		Number of Organisms per m^2											
		Areas-Within-Dates					Dates-Within-Areas						
Prionospio pinnata (Cont'd)	Jan	322	71	12	283	3							
	Apr	165*	26	19	219	5							
Sigambra tentaculata	Jul	4	9	30	25*	74	2	4	0	7	16*	3	30
	Dec	7	15	6	45	17	14	30	10	6	3	3	5
	May	30	13*	5	9	22*	15	25	7	45	13	17	9
							27	74	2	17	12	16	22
Vitrinella helicoides	Dec	2	0	4*	20	48	15	0	0	20	0	0	1
	Jan	1	6*	0	6*	22	27	11*	11*	48	22	0	0

124. Areas-within-dates and dates-within-areas differences occurred for many of the organisms. A summary of significant differences and the direction of change is given in Table 12. As with the overall changes, there is little commonality in the observed differences.

Benthic macroinvertebrates (experimental study--discussion)

125. There were a number of approaches which were followed in attempting to evaluate the impact of dredged material disposal upon aquatic organisms. As noted in the results section above, little useful data were obtained except for benthic macroinvertebrates. Several hypotheses were developed, and it is important to understand the rationale behind each and the limitation that each has.

126. First, disposal may have an immediate effect on the community. This may be reflected in increases or decreases in the number of organisms and/or changes in community composition. Such changes can be evaluated only if there are baseline (predisposal) data available. In addition, reference areas are also required so that changes at a disposal area can be distinguished from those caused by natural events rather than disposal.

127. In this investigation, there were no baseline data for area 2. Moreover, disposal in this area took place on three separate occasions, so this area, at best, represents a chronically impacted area. It is assumed that area 15 was a suitable reference area for area 2.

128. Predisposal data are available for areas 12 and 14, and area 27 was assumed to be a reference area for these two disposal areas. An examination of the grain-size data for area 27 indicates that this assumption may not be correct because the substrate at area 27 was quite different from that at areas 12 and 14.

129. There may also be a delayed effect from disposal. It is assumed that such an effect would be demonstrated by differences in the number and type of organisms between the disposal and reference areas weeks (perhaps months) after disposal. If the reference area is not comparable to the disposal area, there is no basis for evaluating delayed or long-term effects.

Table 12

Summary of Significant Areas-Within-Dates and Dates-Within-Areas Changes in Abundance of Selected Organisms

Organism	Areas-Within-Dates		Dates-Within-Areas	
	Date	Change in Areas	Area	Change in Dates
Ampelisca abdita	All	14 > all other areas		
Cerebratulus lacteus			All	Dec > Sep, Jan, and Apr
Diopatra cuprea			All	Jul > Sep and Dec > May
Glycera americana	May	2 and 15 > 12 and 14 > 27	2	May > Apr > Jul, Sep, Dec, and Jan
			12	May > Jul, Sep, Dec, and Jan
			14	May > Jul, Sep, Dec, and Jan
			15	May > Jul, Sep, Dec, and Jan
Glycinde solitaria	Apr	15 > 12, 14, and 27	2	May > all other dates
	May	2 > all other areas	12	May > Dec
Lumbrinereis impatiens	All	14 > all other areas	All	May > Sep > Dec, Jan, and Apr
Magelona spp.	Jul	15 > 12, 14, and 27	2	Jan > Dec > Sep and Apr
	Dec	2 and 15 > 12, 14, and 27	15	Jul, Dec, and May > Sep, Jan, and Apr
	Jan	2 > all other areas		
Mediomastus californiensis	All	2 and 15 > 12, 14, and 27	All	Jul, Dec, and Jan > Sep and Apr
Nemertean, yellow-banded	Jul	12 > 14 and 27	2	Jan and May > all other dates
	Dec	15 > 27	12	Jul and May > Sep, Dec, and Jan
	Jan	2 > all other areas	14	May > all other dates
	Apr	2 and 15 > 14 and 27	15	May > Sep
	May	2 > 27		

(Continued)

Note: Only significant ($\alpha \leq 0.05$) changes are included here. For actual numbers of organisms per square metre, see Table 11.

Table 12 (Concluded)

Organism	Areas-Within-Dates: Date	Areas-Within-Dates: Change in Areas	Dates-Within-Areas: Area	Dates-Within-Areas: Change in Dates
Nereis sp.	All	12 and 15 > 14 and 27		
Nereis succinea	All	15 > 27		
Ninoe nigripes	Jul	14 > 12 > 2 and 15	14	Jul > all other dates
	Sep	12 > 27		
	Jan	27 > 2 and 15		
	Apr	14 > 2		
	May	14 > 15		
Nuculana concentrica	Jul	14 > 12 > 27 > 2 and 15	12	Jul > May
	Dec	27 > 2 and 15	14	Jul > all other dates
			27	Dec > Apr and May
Prionospio pinnata	Jul	15 > all other areas	2	Dec > Sep
	Dec	2 and 15 > 12, 14, and 27	15	Jul and Dec > May
	Jan	2 and 15 > 12, 14, and 27		
	Apr	15 > 12, 14, and 27		
Sigambra tentaculata	Jul	27 > 14 > 2 and 12	2	May > Jul, Sep, Dec, and Apr
	Dec	15 > all other areas	14	Jul > all other dates
	May	2 > 14 and 15	15	Dec > all other dates
			27	Jul > all other dates
Vitrinella helicoides	Dec	27 > 15 > 2 and 12	15	Dec > all other dates
	Jan	27 > 2 and 14	27	Jan > Dec > Apr and May

130. Several other requirements must be met if a realistic evaluation of disposal impacts is to be made. The most important of these is an assurance that samples which have been impacted by disposal can be separated from those which have not. It was not possible to utilize physical or chemical measurements in such a way as to be able to characterize a sample; this led to three hypotheses and each required a slightly different treatment of the data.

131. The biological investigator attempted (through visual observations) to characterize each station with regard to the presence or absence of dredged material. This appears not to be a valid procedure because it is subjective and apparently resulted in dredged material appearing and disappearing in a sporadic fashion at various stations through time. As an example, some samples were described as having dredged material prior to disposal, but, in area 14, the initial post-disposal samples appeared not to contain dredged material. Table 13 presents a summary of the presence or absence of dredged material at areas 2, 12, and 14 as determined by visual examination.

132. Disposal was concentrated in the vicinity of a buoy in each disposal area. Hence, station 2-1 should have had dredged material present for all sampling intervals as should stations 12-3 and 14-3 from September through May. This was not the case, however, since no dredged material was evident at station 14-3 in the immediate postdisposal period or at any station in area 2 in December and May.

133. These irregularities can be partially explained by the inability of the contractor to return to a given station (other than the three with buoys). Navigation was by dead reckoning, and a fathometer was not used to determine bottom irregularities which may have represented dredged material.

134. A cursory attempt was made to compare stations with dredged material within an area to those which did not exhibit dredged material. In essence, this established reference and disposal stations within a disposal area. This comparison led to no conclusions concerning disposal because of the erratic temporal and spatial distribution of stations having dredged material.

Table 13

Presence and Absence of Dredged Material in Areas 2, 12, and 14

Station	Jul	Sep	Dec	Jan	Apr	May
2-1	+	+	-	+	+	-
2-2	-	-	-	-	+	-
2-3	-	-	-	-	-	-
2-4	-	-	-	-	-	-
2-5	+	+	-	+	+	-
12-1	+	-	-	+	-	-
12-2	-	-	-	+	-	-
12-3	-	+	+	+	+	+
12-4	-	-	-	-	-	-
12-5	-	+	-	-	-	+
14-1	-	-	-	+	-	+
14-2	-	-	-	+	-	-
14-3	-	-	+	+	+	+
14-4	-	-	-	-	+	-
14-5	-	-	-	-	+	-

Note: Plus (+) sign denotes presence; minus (-) sign denotes absence. Determination was made by visual examination (Appendix C).

135. Since the visual determination approach was rejected as invalid, several other hypotheses were proposed. The first of these assumed that immediate impact would be demonstrated by differential population changes between the disposal areas and the reference areas. Upon investigation, it was found that the reference and disposal area populations behaved in an essentially identical fashion. The 68 percent decrease in the 19 selected organisms observed in the disposal areas was matched by a 68 percent decrease in the reference areas. This probably represents a seasonal decline and can in no way be attributed to the disposal of dredged material.

136. The second hypothesis assumed that disposal would result in changes in dominance through time. Correlation analysis was employed to test for general trends in relative numerical dominance of the 19 selected organisms between predisposal and postdisposal conditions at each disposal station. The resulting trends were then analyzed in terms of general trends found to occur (between predisposal and postdisposal sampling intervals) at each reference station and between each disposal station and its assumed reference station for each sampling interval.

137. An initial analysis of reference station data (Table 8) indicated a significant ($\alpha \leq 0.10$) positive association in relative numerical abundance of the 19 organisms over time for both reference stations. Thus, based on these results, although temporal changes in abundance may have occurred for one or more of the selected organisms over one or more sampling intervals, there were no apparent major shifts in relative numerical abundance at either reference station during the study.

138. The remaining analyses involved tests of association between predisposal and postdisposal data obtained at each disposal station, and between each disposal station and its assumed reference station for each sampling interval. A discussion of these results is presented below.

139. Station 2-1. During the pilot study, this station was identified as being previously impacted by dredged material. The degree of impact was not known, and no background data were available to

determine baseline or predisposal conditions at the station.

140. The station was established as representative of an area subjected to frequent dredged material disposal. Although a variety of dredged sediments, ranging from silts and clays to sands and shell hash, were deposited at the station, sediment analyses indicated a predominant sand and shell hash substrate each time samples were obtained.

141. Comparisons between sampling intervals at this station indicated a high degree of positive association in the dominance of the 19 selected organisms over time. This trend was similarly observed at both established reference stations over time. Additionally, there was a high degree of positive association between this station and its assumed reference station (15-3) for each sampling period.

142. Based on these analyses, it appears that, although untested temporal changes in abundance may have occurred for one or more of the 19 selected organisms over one or more sampling intervals, there were no apparent major shifts in relative numerical abundance at this station during the study period. This trend was apparently maintained even though the station received substantial quantities of dredged material on three separate occasions.

143. Station 12-3. Predisposal sediment samples obtained from this station were characterized as predominantly silts and clays. Postdisposal sediment analyses indicated a shift to a predominantly sand and shell hash substrate for each time interval when samples were obtained (Appendix C).

144. Analyses of trends at this station over time indicated a general lack of association between predisposal data and data obtained for each of the five postdisposal sampling intervals. Of additional interest was the fact that three of the five postdisposal sampling intervals showed a negative association when compared to predisposal conditions.

145. Station 12-3 was then compared to its assumed reference station (27-3) for each sampling interval. Significant ($\alpha \leq 0.10$) positive associations were found between the two stations for the predisposal (July) samples and again for the December (postdisposal) samples.

However, the remainder of the postdisposal comparisons indicated a general lack of association between the two stations.

146. Overall trends in these analyses indicate that a shift in relative numerical abundance of the 19 selected organisms may have occurred at this station after dredged material disposal.

147. Station 14-3. Predisposal sediment samples obtained at this station were characterized as predominantly silts and clays. Postdisposal sediment analyses indicated a substantial increase in shell hash and Beaumont clay (Appendix C).

148. An analysis of trends in dominance at this station indicated a general lack of association between predisposal conditions and all postdisposal sampling intervals except for the immediate postdisposal period (September). This sampling period exhibited a significant positive association with predisposal conditions.

149. Comparisons of association between this station and its assumed reference station (27-3) exhibited similar trends. Both the predisposal and immediate postdisposal sample comparisons exhibited a high degree of positive association; however, the remainder of postdisposal comparisons indicated a general lack of association between the two stations.

150. Overall trends in these analyses indicate that a shift in dominance may have occurred at this station after dredged material disposal. The apparent anomaly for the immediate postdisposal period was probably due to error in station location at station 14-3 for this sampling period. This assumption is supported by the contractor's statement (Appendix C) that dredged sediments were visibly evident at this station in all postdisposal samples except during the immediate postdisposal period.

151. The results of these analyses indicated that shifts in dominance of the 19 selected organisms may have occurred at stations 12-3 and 14-3 after dredged material disposal.

152. The remaining hypotheses involved the use of Duncan's multiple-range test to examine the response of individual species to disposal. Disposal was thought to be greatest near the buoyed stations;

stations 2-1, 12-3, and 14-3 were compared to 15-3 and 27-3 (the latter are designated as reference stations). Alternately, it was hypothesized that all stations in a disposal area were impacted, and the disposal areas were compared to the reference areas. An interpretation of these analyses is given below on an organism-by-organism basis. Only significant differences are considered.

153. It should be kept in mind that disposal occurred at area 2 in May and September 1975 and February 1976. Therefore, samples taken in July, September, and March are considered to be immediate postdisposal. At areas 12 and 14, only the September samples are immediate postdisposal.

154. Ampelisca abdita. At station 12-3, the April abundance was greater than that for September and December, while, at station 14-3, the December abundance was greater than the September. Throughout the study period, its abundance at area 14 was greater than at the other areas. At station 15-3, it was most abundant in May. The lack of agreement between the time of maximum abundance at stations 12-3 and 14-3 and the fact that it was more abundant in area 14 than in any other area suggests that disposal did not have an impact on this organism.

155. Balanoglossus sp. The only significant changes in the abundance of this animal occurred at stations 12-3 and 14-3. At the former, it was more abundant in July than in September, December, January, and April, while, at the latter in January, its abundance was greater than in July, September, and April. Again, this suggests that no impact occurred because the abundance patterns at the two areas are quite different.

156. Cerebratulus lacteus. At station 15-3 the abundance in May was greater than that in July, September, December, and April. When all areas were compared, it was found that its abundance in December was greater than in September, January, and April. Although it is possible that the abundance pattern observed at station 15-3 but not at station 2-1 resulted from periodic disposal at the latter station, the lack of any differences at station 27-3 makes this effect unlikely. Although the overall comparison indicates a peak of abundance in December, changes in abundance were not great enough to result in significant differences other than at station 15-3.

157. _Diopatra cuprea._ The abundance of this animal was greater in July at stations 12-3 and 14-3 than during the other months. Although this might suggest that disposal reduced the population and that recovery did not occur, it is observed that overall July abundance was greater than September and December; the latter months had significantly greater populations than May. This indicates that _Diopatra cuprea_ is quite seasonal, with a population peak in late summer and a decline throughout fall, winter, and spring.

158. _Glycera americana._ Stations 12-3 and 15-3 exhibited a peak of abundance in April and May, respectively. However, at station 12-3, the abundance in April was different only from December, while, at station 15-3, the abundance in May was greater than for the other five sampling periods. When areas-within-dates were compared, it was found that in May the abundance in areas 2 and 15 was greater than that in areas 12 and 14. The latter two, in turn, had a greater abundance than area 27. This suggests that this animal was not impacted at area 2, because its abundance is comparable with that at area 15, and that area 27 does not adequately serve as a reference area.

159. When dates-within-areas were compared, a very strong pattern of seasonality appeared, with no changes occurring in the populations at areas 2, 12, 14, and 15 until late sping when a definite increase occurred. It is concluded that _Glycera americana_ was not impacted by the disposal of dredged material.

160. _Glycinde solitaria._ This animal appears to have been influenced by the disposal of dredged material. A peak of abundance was noted at station 14-3 in July and May and at station 12-3 in July. At station 2-1, the May abundance was different than that seen in July, December, January, and April. A similar pattern is seen for April and May. Areas 2 (May) and 15 (April) had greater populations that the other areas. Likewise, in the dates-within-areas comparisons, population peaks were observed at areas 2 and 12 in May.

161. These abundance patterns are interpreted as evidence that continued disposal reduced the population at station 2-1 and, in general, throughout area 2, with some recovery occurring in late spring.

Similarly, the animal was virtually eliminated from stations 12-3 and 14-3 after disposal but recovered in late spring at both stations. There is a small possibility that seasonality was responsible, but this seems unlikely as there was no evidence for it at either of the reference areas.

162. Lumbrinereis impatiens. This organism was not abundant at station 2-1 in September and at stations 15-3 and 14-3 in May. Overall, its abundance was greatest in area 14 and there was a peak in May and a low in September when all areas were considered. The lack of consistency in abundance at disposal stations versus reference stations and at disposal areas versus reference areas indicates that disposal did not appreciably change the abundance of this organism.

163. Magelona spp. This group of organisms was the most abundant and dominant in the study area. As such, it may be considered as a "weed" species; i.e., one which can tolerate a wide variety of conditions and habitats. Significant changes in abundance were noted at stations 2-1 and 14-3, with a peak being present in December and July, respectively. When all stations were considered, July and December exhibited abundances greater than the other sampling periods. When areas-within-dates were compared, the abundance in area 15 was greater than in areas 12, 14, and 27 in July; in areas 2 and 15, than in areas 12, 14, and 27 in December; and in area 2, than in areas 12, 14, 15 and 27 in January. For dates-within-areas, the abundance at area 2 was greatest in January. This, in turn, was different from December, and December was greater than September and April. In area 15, the abundance in July, December, and May was greater than in September, January and April.

164. It can be seen that this group of organisms was most common in areas 2 and 15 and that a bimodal pattern of peak abundance (summer and winter) occurred at both areas. This suggests that they were not particularly sensitive to dredged material disposal. It is conceivable that individual species within the genus were affected by disposal, but, if this did occur, it is obscured by the treatment of some unknown number of species (each of which may have had a different response) as a collective entity.

166. Mediomastus californiensis. Significant differences in the abundance of this organism were observed at stations 2-1 and 15-3. With the exception of April at station 15-3, a peak occurred in December at each station. A July peak was observed at stations 14-3 and 27-3. The similarity in abundance patterns between the disposal and reference stations suggests that disposal had little, if any, impact at the primary disposal stations.

166. When areas-within-dates were considered, it was found that the abundances at areas 2 and 15 were comparable over the entire study period. For dates-within-areas, a population low was observed to occur at all stations in September and April. As with Magelona spp., this bimodality appears to be independent of any influence from dredged material disposal.

167. Nemertean, yellow-banded. Stations 14-3 and 27-3 had a peak of abundance of this organism in May and June, respectively. During the entire period, it was present at these stations only in June and December. Great variation was seen when areas-within-dates comparisons were made. In July, it was most abundant at area 12; in December, at area 15; in January, at area 12; in April, at areas 2 and 15; and in May, at area 2. It was rarely observed at area 27, and, in July, December, January, April, and May, its abundance at area 27 was significantly lower than that at most of the other areas. In the dates-within-areas comparisons, January and May abundances were different from the other sampling period at area 2; July and May, at area 12; and July, at area 14. In area 15, May was different only from September.

168. These differences in abundance at various times and in various areas are impossible to reconcile with disposal activity. Reference area 15 behaved much the same as disposal area 2, while reference area 27 appeared to be an unsuitable habitat for this animal. If disposal had any impact at all, it cannot be ascertained from the available data.

169. Nereis sp. At station 2-1 this animal reached a peak of abundance in July (immediate postdisposal), while its peak of abundance at stations 12-3 and 15-3 occurred in April. Throughout the study

period, it was more abundant in areas 12 and 15 than in 14 or 27. There is no evidence for an effect of disposal because of the changes in the disposal areas relative to the reference areas.

170. Nereis succinea. A peak of abundance was observed at stations 2-1 and 15-3 in December and at 12-3 in May. At other times, it was quite rare at these stations and in area 27. In the areas-within-dates comparison, areas 15 and 27 were different throughout the study period, with this organism being most abundant at area 15 and least abundant at area 27. The other areas exhibited intermediate abundances. Because of the similarity of abundance at stations 2-1 and 15-3 and the lack of any change at area 14 or station 14-3, it is concluded that disposal of dredged material did not affect N. succinea.

171. Ninoe nigripes. The only significant change at any of the stations occurred at 12-3 in July; the animal was absent from 12-3 during the remainder of the study. In comparison of areas-within-dates, it was most abundant at area 14 in July, January, and May and at area 12 in September. Throughout the study period, it was most abundant in area 14 in July.

172. The animal appears to have had a definite affinity with area 14 and, to a lesser extent, area 12 since it was more abundant there than elsewhere. This relationship is further supported by the general coincidence of peaks of abundance at these two areas. If this is an impact of disposal, an increase, rather than a decrease, was the observed response; however, it should be kept in mind that the organism disappeared at station 12-3 after disposal.

173. Nuculana concentrica. As with Ninoe nigripes, this animal exhibited significant changes in abundance primarily in areas 12, 14, and 27. It was most abundant at 14-3 in July and at 27 in December. It was virtually absent from the former station after July. This may represent an impact of disposal although no changes were observed at station 2-1 or 12-3. The abundance at area 14 was significantly greater than at the other areas in July and was significantly lower at areas 2 and 15. In December, area 27 had a greater population than areas 2 and 15. In dates-within-areas comparisons, a peak of abundance occurred at areas 12 and 14 in July and at area 27 in December.

174. Although the peak of abundance occurred at areas 12 and 14 in July and at area 27 in December, it is possible that disposal adversely affected this organism in areas 12 and 14. However, there is evidence of a seasonal effect in that the animals were least abundant in April and May at both disposal areas and the reference area. This seasonal effect may also have been responsible for the observed distributional patterns.

175. Prionospio pinnata. A population peak for this organism was observed at station 12-3 in April, at 14-3 and 27-3 in July, and at 15-3 in December. In the comparison of areas-within-dates, the greatest abundance was at area 15 in July, at areas 2 and 15 in December and January, and at area 15 in April. The only significant changes in the comparison of dates-within-areas were the abundance peak at area 2 in December and the two peaks (July and December) at area 15.

176. As areas 2 and 15 behaved in almost precisely the same manner, there is no evidence for an effect of disposal at area 2. The abundance patterns at areas 12 and 14 were different from that at area 27; however, there was so much difference between areas 12 and 14 that it is difficult to tell whether or not there may have been an impact from disposal.

177. Sigambra tentaculata. This organism exhibited a peak of abundance at stations 14-3 and 27-3 in July and at 15-3 in December. No differences were observed at stations 2-1 or 12-3. It was most abundant in area 2 in May, area 15 in December, area 14 in July, and area 27 in July. It does not appear to have been affected by disposal at area 14 but may have been at area 2 since the peak of abundance at area 2 took place in May rather than in December as at the reference area (area 15).

178. Sigambra wassi. The only change in abundance shown by this animal was a population peak at station 12-3 in July. There were no other changes or interactions between the various stations, areas, and dates. There is no evidence of an impact of disposal.

179. Spiophanes bombyx. Only two differences were observed in the abundance of this organism. There was a population peak at station

2-1 in May and at 12-3 in April. This may reflect an effect of disposal. If so, the effect appears to have been a change of conditions which operated to make the animal uncommonly abundant at these two stations in late spring.

180. Vitrinella helicoides. Changes in abundance for this organism primarily took place at station 27-3 and in area 27 and, to a lesser degree, in area 15. A mid-winter peak of abundance was observed in December at station 27-3 and in December and January in area 27. A peak was also noted at area 15 in December.

181. This indicates that disposal may have had an impact on this animal because the population peaks common to both reference areas did not take place in the disposal areas. It should be noted that the organism was not very common in any of the areas, and this fact increases the probability of significant differences occurring as a result of sampling error.

Summary

182. In general, the Galveston ADFI failed to demonstrate any major impacts associated with disposal. This finding should not be taken as an indication that none occurred. Rather, it is a reflection of the available data, their interpretation, and the validity of a number of assumptions. There are no means to test the assumptions, and, if they are incorrect, the interpretation is probably incorrect.

183. The extreme variability of the numbers of organisms present indicates that a large number of samples are required in order to adequately compare stations and areas. In some instances for the number of samples required for the standard error to equal 20 percent of the mean, over 1000 samples would have had to be taken. Thus, variability not compensated for by an adequate sample size may have obscured some impacts and indicated changes when none occurred.

184. The fact that almost all of the organisms selected for detailed analyses underwent essentially identical changes in abundance when the predisposal values were compared to the immediate postdisposal

values indicates that there was no immediate impact of disposal. There is some evidence (in a few instances) for an impact at some later point in time. It is difficult, however, to separate such a delayed impact from changes which occurred as a result of natural seasonal abundance. Both reference areas were downdrift from the disposal areas, and area 27 had a substrate unlike that of disposal areas 12 and 14.

185. Analyses are further complicated by the matter of position location. In attempting to compare physical characteristics of the substrate (such as grain size) or organisms at the same station through time, gross inconsistencies were noted even in the reference areas. This may result from large variations in substrate over a short distance or from position error. It is quite possible that both factors were responsible.

186. There is no way to be sure whether or not a given sample contained dredged material. This led to the two major assumptions necessary to analyze the data. It is more reasonable to assume that buoyed stations (2-1, 12-3, and 14-3) always had dredged material present after disposal (although this was not confirmed by visual examination of the sediment) than to assume that all five stations within a disposal area were equally impacted. Hence, if these assumptions are grossly incorrect, no definitive statement can be made concerning the impact of dredged material disposal upon benthic communities.

PART VI: CONCLUSIONS

Physical Studies

187. Disposal of dredged material resulted in the formation of distinct mounds at the disposal site. These mounds were gradually eroded, with the most rapid change occurring in shallow water (area 2) and the slowest change in deep water (area 14).

188. Transport of dredged material appeared to be predominantly to the southwest and thus away from the Galveston Bay Channel.

189. It was not possible to distinguish dredged material from natural sediments, except when occasional lumps of Beaumont clay were present. There was limited evidence that some sorting was occurring, primarily consisting of the removal of the finer fraction.

Chemical Studies

190. Disposal operations at the disposal site resulted in no apparent major alterations in the total concentrations of sediment chemical parameters measured during this investigation.

191. Disposal of dredged material at the disposal site exerted no apparent long-term effects on heavy metals, nutrient, or dissolved oxygen concentrations in the disposal area waters.

192. During disposal operations, no Fe, Cu, As, Cd, Ni, Hg, Pb, or Zn water column concentrations were found that would pose any potential hazard for marine life.

193. Manganese concentrations increased in the disposal site water column during seven of the nine disposal operations monitored. The magnitude (less than 200 g/ℓ) and duration (less than 35 minutes) increases were such that no harm would result to aquatic organisms.

194. Ammonium-N concentrations reached levels where un-ionized ammonia concentrations could have potentially harmed aquatic organisms in the disposal site water column only during the second Texas City disposal operation. However, the ammonium-N concentrations increased

only in bottom waters and exceeded chronic water quality criteria at the sampling point for only 12 minutes. Exposure to moderate concentrations of un-ionized ammonia (0.025 to 0.06 mg/ℓ) greater than the chronic exposure level of 0.02 mg/ℓ for such a short period of time should not pose any problems for nonmotile organisms that the plume passes over or for nektonic organisms that might swim through the plume.

Biological Studies

195. Studies of phytoplankton, zooplankton, nekton, fish stomachs, meiobenthos, and macrobenthic biomass did not yield any information which could be used in assessing the impact of dredged material on aquatic communities.

196. Detailed analysis of dominant macrobenthic invertebrate species indicated that there appeared to be little, if any, impact of dredged material disposal upon these organisms. The validity of this conclusion rests upon a number of assumptions which were required in order to be able to analyze the macrobenthic data.

197. There was a pronounced seasonal decline in macrobenthic invertebrates in late summer. Disposal at that time appears to be preferable to other times in that adverse effects would probably be less than when populations are high.

REFERENCES

1. Boyd, M. B., et al., "Disposal of Dredge Spoil; Problem Identification and Assessment and Research Program Development," Technical Report H-72-8, Nov 1972, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

2. Mathis, D. B., et al., "Collection and Assessment of Data on Open-Water Disposal Sites," Internal Working Document D-76-3, May 1976, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

3. Becker, Paul R., et al., "General Research Plan for the Field Investigations of Coastal Dredged Material Disposal Areas," Miscellaneous Paper D-75-13, Apr 1975, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

4. U. S. Army Engineer District, Galveston, CE, "Maintenance Dredging, Galveston Channel to Port Bolivar, Texas; Final Environmental Statement," Oct 1974, Galveston, Tex.

5. U. S. Army Engineer District, Galveston, CE, "Maintenance Dredging, Galveston Harbor and Channel, Texas; Final Environmental Statement," 1975, Galveston, Tex.

6. Copeland, B. J. and Fruh, E. G., "Ecological Studies of Galveston Bay, 1969," Final Report on Contract IAC (68-69)-408, Feb 1970, Texas Water Quality Board, Austin, Tex.

7. Peddicord, R. K., et al., "Effects of Suspended Solids on San Francisco Bay Organisms, Physical Impact Study; Appendix G: Dredge Disposal Study, San Francisco Bay and Estuary," Jul 1975, U. S. Army Engineer District, San Francisco, CE, San Francisco, Calif.

8. U. S. Environmental Protection Agency, "Quality Criteria for Water," USEPA 440/9-76-023, 1976, Washington, D. C.

9. Lee, G. F., et al., "The Technical Development of Criteria for Dredged Material Disposal," Technical Report (in preparation), 1977, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

10. Lee, G. F., et al., "Research Study for the Development of Dredged Material Disposal Criteria," Contract Report D-75-4, Nov 1975, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

11. Thurston, R. V., et al., "Aqueous Ammonia Equilibrium Calculations," Fisheries Bioassay Laboratory Technical Report No. 74-1, 1974, Montana State University, Bozeman, Mont.

12. Mattice, J. S. and Zittel, H. E., "Site-Specific Evaluation of Power Plant Chlorination," Journal of Water Pollution Control Federations, Vol 48, No. 10, Oct 1976, pp 2284-2308.

13. El-Sayed, S. Z., et al., "Serial Atlas of the Marine Environment," Folio 22, 1972, American Geographical Society, New York.

14. Lee, G. F., "Role of Hydrous Metal Oxides in the Transport of Heavy Metals in the Environment," Progress in Water Technology, Vol 17, 1975, pp 137-147.

15. Ryther, J. H. and Dunstan, W. M., "Nitrogen, Phosphorus, and Eutrophication in the Coastal Marine Environment," Science, Vol 171, 1971, pp 1008-1013.

16. Vollenweider, R. A., "Scientific Fundamentals of the Eutrophication of Lakes and Flowing Waters with Particular Reference to Nitrogen and Phosphorus as Factors in Eutrophication," Technical Report DAS/CSI/68, 1968, Paris.

17. Sawyer, C. N., "Fertilization of Lakes by Agricultural and Urban Drainage," Journal of the New England Water Works Association, Vol 61, 1947, pp 109-127.

18. Spearman, C., "The Proof and Measurement of Association Between Two Things," American Journal of Psysiology, Vol 15, 1904, pp 72-107.

19. Duncan, D. B., "Multiple Range and Multiple F Tests," Biometrics, Vol 11, 1955, pp 1-42.

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Wright, Thomas D
Aquatic disposal field investigations, Galveston, Texas, offshore disposal site; evaluative summary / by Thomas D. Wright, David B. Mathis, James M. Brannon. Vicksburg, Miss. : U. S. Waterways Experiment Station ; Springfield, Va. : available from National Technical Information Service, 1978.
89 p. : ill. ; 27 cm. (Technical report - U. S. Army Engineer Waterways Experiment Station ; D-77-20)
Prepared for Office, Chief of Engineers, U. S. Army, Washington, D. C., under DMRP Work Unit No. 1A09.
Appendices A-B published separately.
Appendix C on microfiche in pocket.
References: p. 88-89.
1. Aquatic environment. 2. Dredged material. 3. Dredged material disposal. 4. Environmental effects. 5. Field investigations. 6. Galveston Offshore Dredged Material Disposal Site. 7. Pollutants. 8. Sediment. 9. Waste disposal sites. 10. Water quality. I. Mathis, David B., joint author. II. Brannon, James M., joint author. III. United States. Army. Corps of Engineers. IV. Series: United States. Waterways Experiment Station, Vicksburg, Miss. Technical report ; D-77-20.
TA7.W34 no.D-77-20