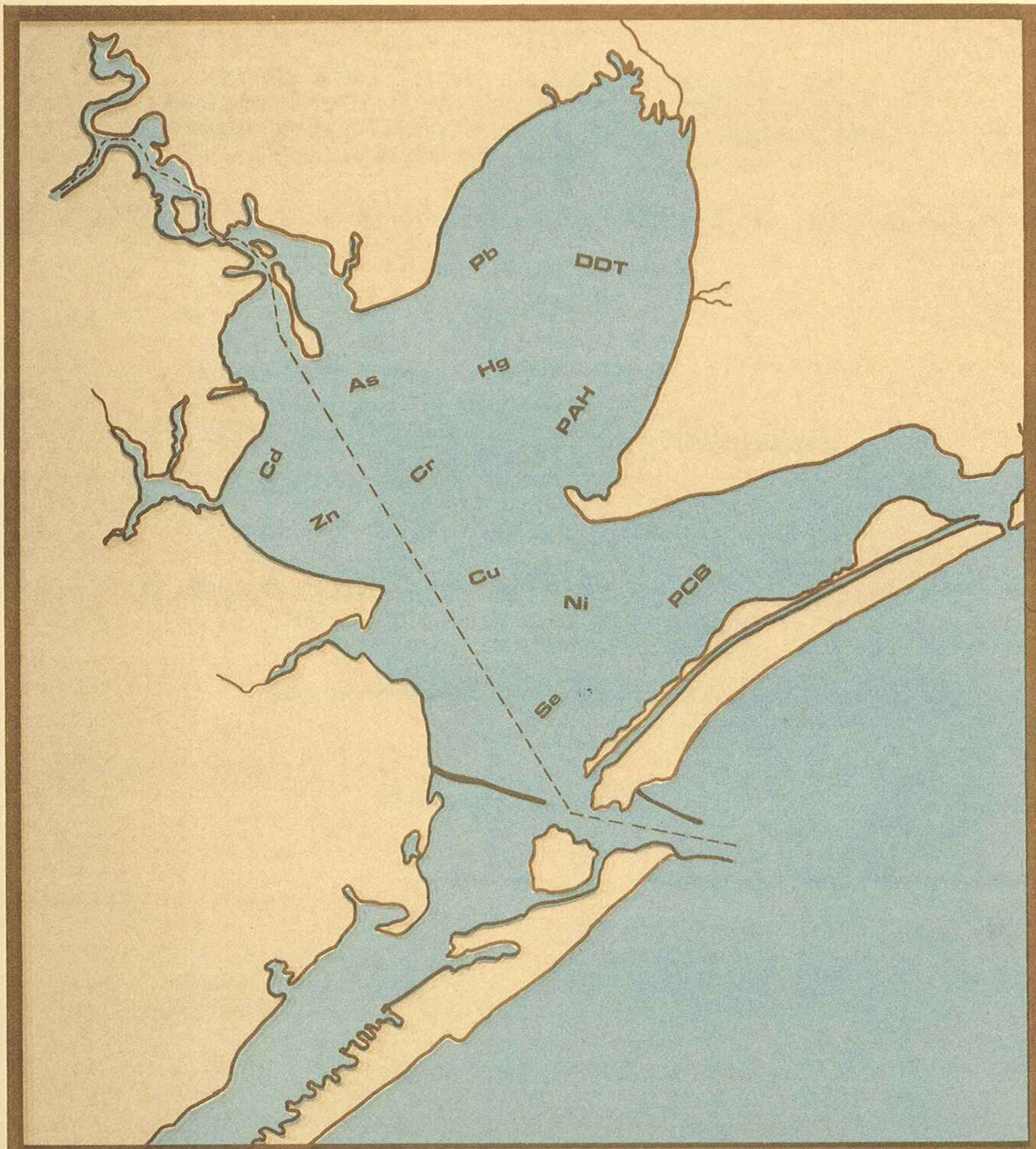
6-7-89

# CONTAMINANT ASSESSMENT OF MAINTENANCE DREDGED MATERIAL FROM THE HOUSTON SHIP CHANNEL GALVESTON BAY, TEXAS




U.S. FISH AND WILDLIFE SERVICE

MARCH, 1989

# CONTAMINANT ASSESSMENT OF MAINTENANCE DREDGED MATERIAL FROM THE HOUSTON SHIP CHANNEL GALVESTON BAY, TEXAS

by

BRIAN W. CAIN, Ph.D.
ENVIRONMENTAL CONTAMINANT SPECIALIST

U.S. FISH AND WILDLIFE SERVICE
ECOLOGICAL SERVICES
17629 EL CAMINO REAL
SUITE 211
HOUSTON, TEXAS 77058

MARCH, 1989

## PREFACE

Maintenance dredging of coastal waterways is a continuing process regulated by the U.S. Army Corps of Engineers. In Texas the Galveston District is responsible for issuing permits to dredge after they have been reviewed by several state and federal agencies. The potential to alter coastal estuaries and a concern over environmental contaminants impacting the biota are two issues associated with maintenance dredging that evoke public response.

This study was designed to determine if maintenance material in the Houston Ship Channel is contaminated, and if the sediment bound contaminants have a pathway to the Galveston Bay biota. The study idea was generated jointly by the Galveston District of the Corps of Engineers and the Clear Lake Ecological Services Field Office of the U.S. Fish and Wildlife Service. Questions raised during review of our environmental impact assessment associated with a proposal to widen and deepen the Houston Ship Channel prompted the study. Funding was provided by the Construction-Operations Division of the Corps of Engineers, and the field work was provided by the U.S. Fish and Wildlife Service. Chemical analyses during this study were provided by contact laboratories to the Corps of Engineers, that were quality control tested by the U.S. Environmental Protection Agency before the contracts were awarded.

TABLE OF CONTENTS

Page

Preface....ii

List of Tables....iv

List of Figures....v

Acknowledgements....vi

Abstract....1

Introduction....2

Methods....6

Results and Discussion....9

Assessment of Routine Maintenance Data....9

1. Oil and Grease....11
2. Heavy Metals....11
   a. Arsenic....12
   b. Copper....12
   c. Zinc....13

Assessment of Field Test Data....14

A. Unconfined Disposal Area....16

   1. Heavy Metals....16
      a. Arsenic....18
      b. Chromium....18
      c. Copper....19
      d. Lead....19
      e. Nickel....21
      f. Zinc....21

   2. Polycyclic Aromatic Hydrocarbons....22

B. Confined Disposal Areas....23

   1. Heavy Metals....25
   2. Polycyclic Aromatic Hydrocarbons....25

C. Benthic Evaluations....26

D. Vegetation Evaluation....28

Summary and Recommendations....29

Conclusions....32

Literature....33

## LIST OF TABLES


Table | Page

1. Contaminants analyzed in maintenance sediments from the Houston Ship Channel by the contact laboratories for the Galveston District of the Corps of Engineers....................................7

2. Selected contaminants detected in maintenance sediments from the Houston Ship Channel between Redfish Reef and Morgans Point.............10

3. Contaminants analyzed in maintenance dredged material by the contract laboratories for this study...................................15

4. Oil and grease in sediments from the Atkinson Island disposal area and adjacent bay bottom............................................17

5. Contaminants detected in maintenance dredged material from the Houston Ship Channel and placed in an unconfined upland disposal area..................................................................20

6. Contaminants detected in maintenance dredged material from the Houston Ship Channel and placed in a confined disposal area.............24

7. Contaminants detected in blue crabs collected at the Morgans Point control site and placed for three days at the Alexander Island confined disposal area discharge point................................27

LIST OF FIGURES

Figure Page

1. Galveston Bay and the Houston Ship Channel........................3

2. Confined disposal area on Alexander Island (A), unconfined disposal area on Atkinson Island (B), and control site off Morgans Point, Texas (C)..............................................4

# ACKNOWLEDGEMENTS

This assessment was made possible because of the work and support given by several individuals in both the U.S. Army Corps of Engineers, Galveston District, and the U.S. Fish and Wildlife Service, Clear Lake Field Office. Denise Baker, Denise Smith, Carlos Mendoza, Dave Frederick, and Dawn Whitehead contributed to the collection of samples. Fred Werner, Allan Mueller and Dave Hankla provided several ideas, reviewed the drafts, and offered support during the entire study.

Rick Medina, Casey Cutler, Ray Proctor and Bob Bass from the Galveston District were very helpful with ideas and the logistics associated with sample analysis and data retrieval. George Rochen and Bill Wooley were instrumental in providing the funding for their project. The manuscript was typed several times by Pam Justice and Vanessa Jensen.

ABSTRACT

Sediment samples were collected by the U.S. Army Corps of Engineers from the Houston Ship Channel before maintenance dredging in 1976, 1983, and 1986. These samples were analyzed for heavy metals, organochlorine pesticides, oil and grease, and some polycyclic aromatic hydrocarbons (PAH). Residue data indicate some contaminants were at levels that may produce adverse impacts on Galveston Bay biota if the contaminants migrate from the sediment during dredging or other disturbances of the material. Arsenic, copper, and zinc were hundreds of times higher in the sediment than their corresponding water quality criteria established by the U.S. Environmental Protection Agency (EPA) to protect saltwater aquatic life. Kinetics of these metals in reduced sediment during disturbances allows toxic forms of each metal to be mobilized into the Galveston Bay water columns at levels that exceed chronic toxicity values for estuarine species. These metals continuously dissolve and precipitate in unending cycles as water temperature, salinity, alkalinity, pH, and dissolved oxygen change.

Sediment samples for this assessment were collected during 1987-88, from both unconfined disposal and confined disposal areas along the Houston Ship Channel, as well as a control site, for analysis of heavy metals and 27 different PAH compounds. Blue crabs (Callinectes sapidus) were collected from the control site and placed in the discharge area of the confined disposal area to monitor if PAH contaminants migrate from the area during runoff events. Arsenic, chromium, copper, lead, nickel, and zinc were higher in the maintenance dredged material than from sediment at the control site. Arsenic, chromium, copper, and zinc were at levels that were hundreds of times higher than their corresponding water quality criteria established by the U.S. EPA to protect saltwater aquatic life. Contaminated sediment from both the unconfined disposal and confined disposal areas migrated into Galveston Bay. Resuspension of these fugitive sediment particles into the water column occurs with wave action, boating activity, and trawling, creating a continuous chronic exposure scenario to the aquatic life in Galveston Bay. Sediment bound contaminants are desorbed and resorbed during this continuous resuspension process as the physical parameters (i.e., pH, salinity,

oxygenation, etc.) of the water column change. Contamination of blue crabs was documented in a five-day in situ bioassay.

## INTRODUCTION

The Houston Ship Channel is a 51 mile long navigation channel dredged across Galveston Bay from the Gulf of Mexico to near the center of Houston, Texas (Figure 1). Confined portions of the channel were dredged through the San Jacinto River delta up to the river's junction with Buffalo Bayou, and then up the bayou to form the Port of Houston and the turning basin. Several large petrochemical complexes line the Houston Ship Channel from Morgans Point up to the turning basin.

Shipping lanes dredged in shallow bays and estuaries, such as Galveston Bay, require maintenance dredging to remove restrictive shoaling that accumulates in the channels. Shoaling occurs as a result of channel wall sluffing, movement of bay bottom sediments by currents, and settling of sediments transported by rivers and bayous. Removal of this restrictive shoaling in commercial shipping lanes is a responsibility of the U.S. Army Corps of Engineers.

Large amounts of sediments are transported into the Houston Ship Channel from urban runoff and the San Jacinto River. These sediments are composed of fine silt and clay particles along with some sand size material. These sediments are hydraulically dredged from the ship channel and placed on upland sites, sites confined in open water, or into the open bay at designated disposal areas (Figure 2). Small silt and clay particles, because of their large surface area to volume ratio, will either absorb or adsorb the nonsoluble organic chemicals that are discharged into the bay system. Nearly 400 toxic and hazardous waste discharge and disposal sites are located in the Houston-Baytown area within the Buffalo Bayou and San Jacinto River drainages (Dames and Moore, Inc. 1982).

Silt and clay particles that contribute to restrictive shoaling in the Houston Ship Channel are exposed to over 400 hazardous chemicals (Dames and Moore, Inc. 1982) such as heavy metals, chlorinated styrenes and phenols, and petroleum hydrocarbons. These silt and clay particles become contaminated with nonsoluble

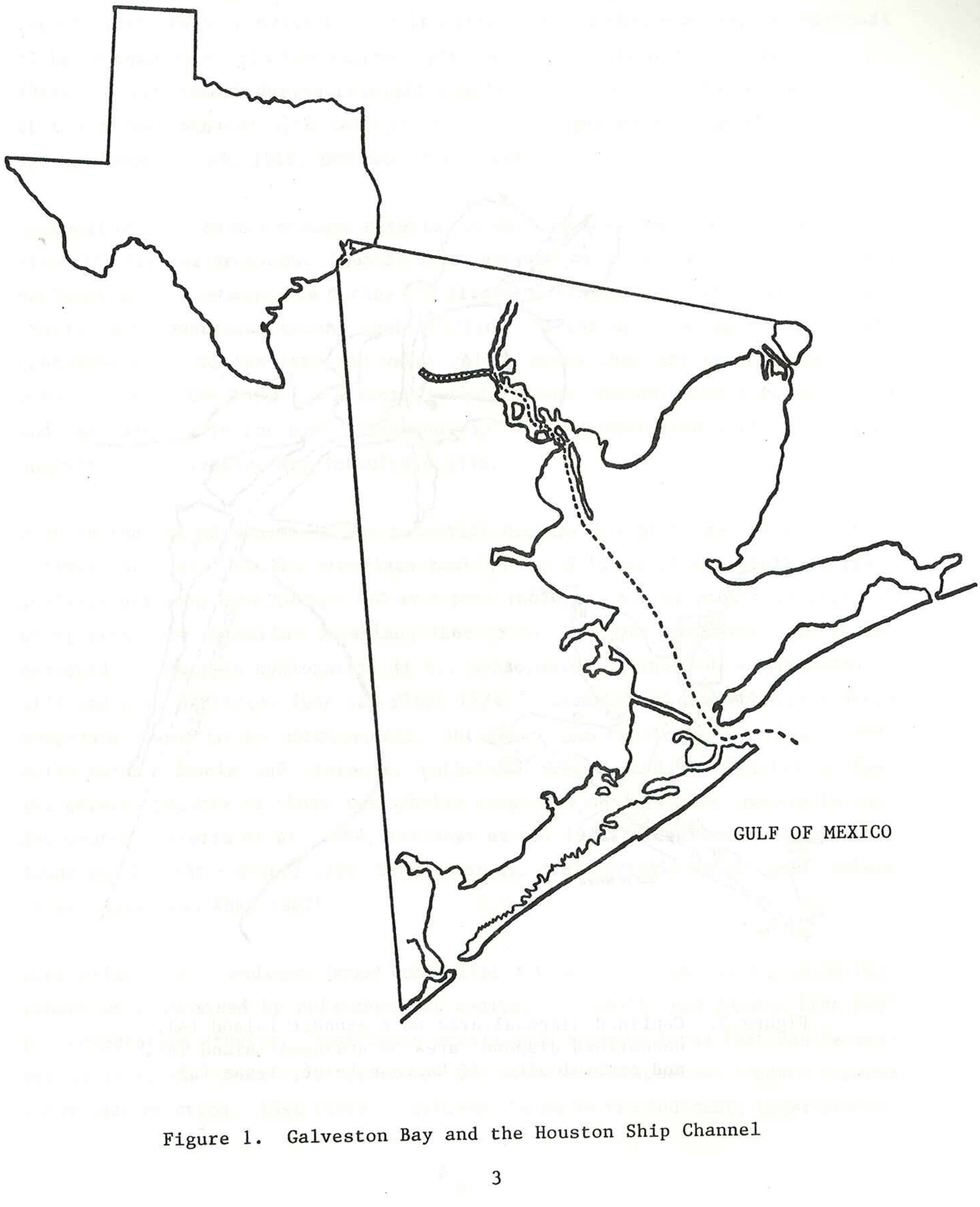



Figure 1. Galveston Bay and the Houston Ship Channel

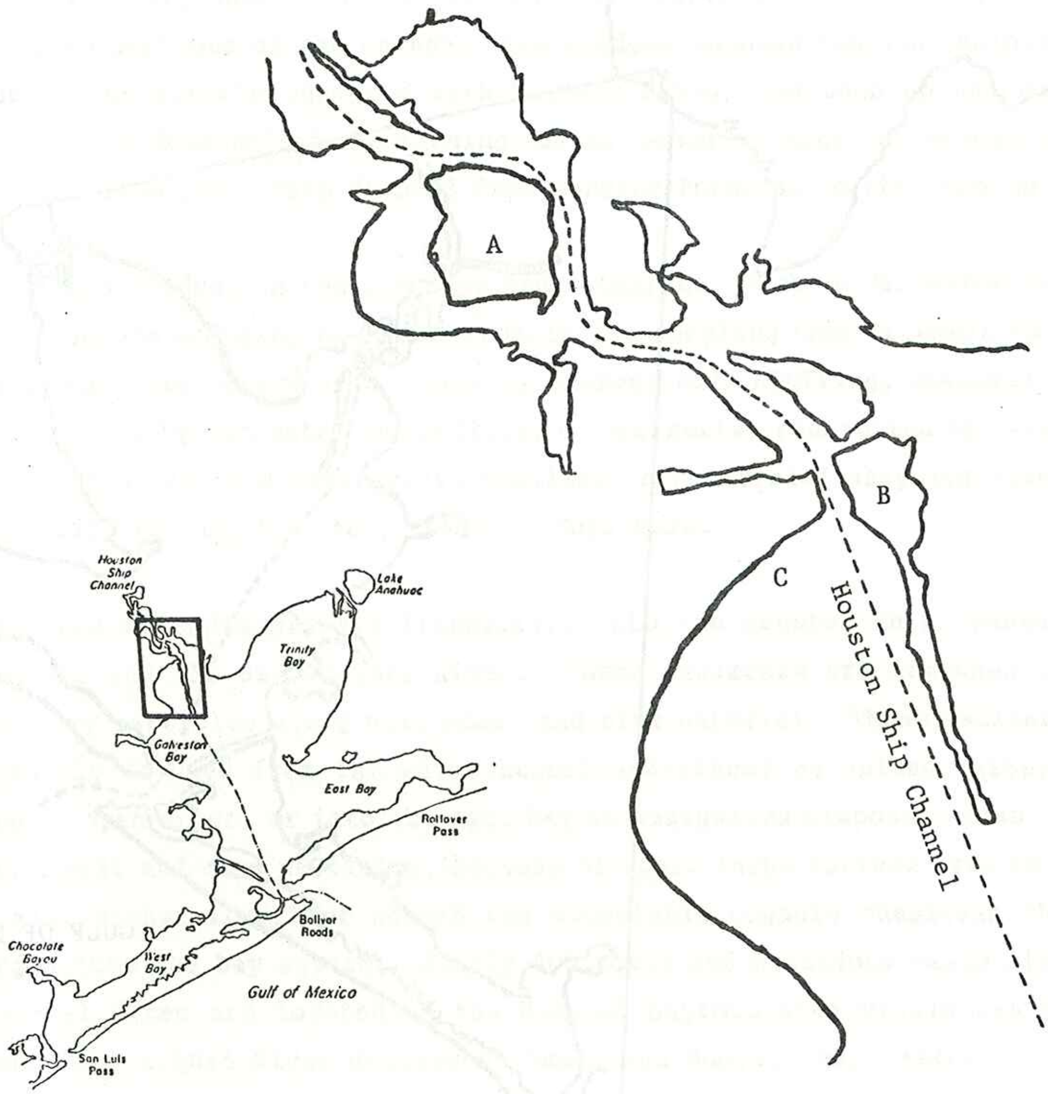



Figure 2. Confined disposal area on Alexander Island (A), unconfined disposal area on Atkinson Island (B), and control site off Morgans Point, Texas (C).

organic chemicals and settle into deep channels in estuaries. Dissolved salt in the estuarine water results in a "salting-out" effect that enhances the movement of these compounds into the sediment portion of the environment (Pereira et al. 1988). Urban runoff during rainfall events also carries large sediment loads that are contaminated with polycyclic aromatic hydrocarbons (PAH) to coastal waters (Brown et al. 1985, Hoffman et al. 1984).

Disposal of maintenance dredged material in shallow bays and estuaries is associated with several problems. Aquatic biota are exposed to increased turbidity and sediment-bound contaminants during and after the dredging operation (King et al. 1986). Wind generated waves, boat traffic, and shrimp trawling resuspend the contaminated particles into the water column where they may be transported to other parts of the bay. In a similar disturbance, oyster reefs were smothered and made unsuitable for spat attachment up to 5,900 feet from a shell dredging operation in Galveston Bay (Benefield 1976).

Past evaluation of sediments for potential contaminant problems relied on bulk sediment analysis and the elutriate test (Lee and Plumb 1974). Bulk sediment analysis has long been recognized as a poor indicator of the bioavailability of heavy metals to estuarine organisms (Lee 1976), and the elutriate test is not designed to evaluate hydrophobic (i.e., nonsoluble) organic compounds bound to silt and clay particles (Lee and Plumb 1974). Examples of hydrophobic organic compounds known to be carcinogenic, mutagenic, or teratogenic include PAH, chlorinated phenols and styrenes, phthalate esters, and halogenated arenes. The adverse impacts of these hydrophobic compounds on estuarine species is well documented (Pereira et al. 1988, Fletcher et al. 1981, Kiceniuck and Khan 1983, Johns and Gutjahr - Gobell 1988, Widdows et al. 1981, Stickle et al. 1985, Nelson et al. 1987, and Khan 1987).

Bioavailability of sediment bound contaminants is a chronic exposure problem that cannot be determined by bulk-chemical analysis or short term (i.e., five day) bioaccumulation studies. Most heavy metals have soluble forms that can be precipitated to the sediment layer if the pH, dissolved oxygen, or organic ligands favor that reaction. When these conditions change in the sediment, these precipitates are chemically changed, and the heavy metal is again soluble. Sediment ladened with heavy metals, that are insoluble in a reduced state, will release these contaminants as the sediment becomes oxidized during resuspension, drying and cracking, or during benthic organism burrowing. Benthic organisms will ingest these contaminated particles and incorporate the contaminant into their body tissue and transfer then to higher trophic levels. Because these transfers are slow, and the rate is temperature or pH dependent, short term bioassays or elutriate water testing are not accurate procedures to assess the environmental impact of sediment bound contamination.

The U.S. Army Corps of Engineers (1987) states that since there are no sediment criteria for these organic contaminants, there is no expected significant impact on coastal water quality by unconfined disposal of dredged materials. However, impacts to the estuarine ecosystem do occur. Estuarine aquatic organisms ingest these compounds as they filter the resuspended particles, or as they eat smaller food chain organisms (plankton) that have absorbed the contaminated sediment. Contamination of fish-eating birds along the Houston Ship Channel by several non-soluble organic chemicals has recently been documented (King et al. 1987).

This study was designed to determine the level of contaminants present in maintenance material dredged from the Houston Ship Channel, and if these contaminants impact biota in Galveston Bay. This assessment considered possible exposure to contaminants from both confined and unconfined disposal areas.

## METHODS

Routine sediment analysis data from the Corps of Engineers were analyzed to determine levels of contaminants in the bottom sediment of the Houston Ship Channel. Each maintenance dredging project is preceded by sediment analysis for a limited number of contaminants (Table 1). Levels reported in these data were evaluated for possible impacts on the Galveston Bay biota by using published literature.

Table 1. Contaminants analyzed in maintenance sediments from the Houston Ship Channel by contract laboratories for the Galveston District of the Corps of Engineers.

| Contaminants | 1976 | 1983 | 1986 |
|---|---|---|---|
| Total solids | + | | |
| Total volatile solids | + | | |
| Total Kjeldahl nitrogen | + | + | |
| Ammonia nitrogen | | + | |
| Oil and grease | + | + | + |
| Chemical oxygen demand | + | | |
| Arsenic | + | + | + |
| Cadmium | + | + | + |
| Chromium | + | + | |
| Copper | + | + | + |
| Lead | + | + | + |
| Mercury | + | + | + |
| Nickel | + | + | + |
| Zinc | + | + | + |
| Total PCB's | | + | + |
| Aldrin | | + | + |
| Chlordane | | + | + |
| 4, 4'-DDD | | + | |
| 4, 4'-DDE | | + | + |
| 4, 4'-DDT | | + | + |
| Dieldrin | | + | + |
| Heptachlor | | + | + |
| Lindane | | + | + |
| Toxaphene | | + | + |
| Total PAH | | | + |

Two sites were selected for field tests to evaluate the existence and possible release of heavy metals and petroleum hydrocarbons from maintenance dredged material along the Houston Ship Channel. One site was a confined disposal area (Alexander Island) with a single point-source discharge structure (Figure 2). The second site was an unconfined upland area on Atkinson Island that allowed the dredged material to flow across the back of the island (east side) forming a sediment fan in Galveston Bay. A control area was selected along the Morgans Point beach area where contamination of sediments and fauna is unlikely. Each of the two experimental sites had maintenance material deposited on them during the year prior to the study.

In tests at the unconfined area on Atkinson Island, impacts of maintenance material on growth of Spartina alterniflora were evaluated by sprigging at one-meter intervals in the sediment fan on the back side of the Island. Sprigs were removed from a growing stand of Spartina next to the sediment fan during April, and transplanted between the low water edge and 10 meters up the sloping fan. Each sprig was placed in a six inch hole in the sediment and the removed sediment plug replaced and pressed against the sprig. The number of culms (stalks) were counted and each sprig used was required to have at least three roots. The re-planted sprigs were not fertilized or protected from wave action. At monthly intervals for two months (May, June) the number of sprigs remaining and the number of culms were counted to evaluate the revegetation. Revegetation of the stand, from which the sprigs were removed, was visually monitored as a reference for the health of the Spartina in the area.

A density study of clams present in the sediment fan and at a control site on Atkinson Island was performed by counting vent holes on the surface during low tides. A one-meter square frame was dropped 10 times on the exposed mud at both the control site and the sediment fan during the tides. The average number of vent holes per square meter was calculated for each site.

For confined area studies, several benthic aquatic organisms were targeted for contaminant analyses including blue crabs (Callinectes sapidus), polychaete worms, and burrowing clams. Only blue crabs, however, were collected in amounts sufficient to yield enough tissue for chemical analysis. Crabs were collected with live traps from the Morgans Point control area and placed in holding cages for five days in the water receiving discharge from the confined disposal area. Soft tissue (i.e., viscera, gills) were removed from the crabs, chilled, and sent to the analytical laboratory for contaminant assessment.

Sediment samples were collected for analysis from the Morgans Point control area, the sediment fan at Atkinson Island, and the bay bottom at the discharge point from Alexander Island. Sediment samples were also collected from dried areas at both the confined and unconfined disposal sites. A petite ponar sampler was used to collect the top four inches of sediment from the bay bottom. A steel spade was used to obtain a four-inch diameter core from the top eight inches of sediment from the dried part of the two disposal areas. A one liter glass bottle was filled from the extracted sediment plug and chilled with ice until delivered to the analytical laboratory.

Crab tissue and sediment samples were analyzed for heavy metals and PAH by a contract laboratory. The analytical techniques followed established procedures that are quality controlled through the EPA. These documents are available for review at the Galveston District of the U.S. Army Corps of Engineers.

## RESULTS AND DISCUSSIONS

### Assessment of Routine Maintenance Data

Contaminant analyses of material dredged from the Houston Ship Channel between 1976 and 1986 included several chemical parameters (Table 1). The analyses, however, were performed by different laboratories, and the list of chemicals changed, making data comparisons difficult. In order to evaluate these data, only four parameters (Table 2) were used from the sediment samples taken between Morgans Point and Redfish Reef. These four parameters were consistently detected in the samples, and at levels high enough to mask variation that may have been introduced by inter-laboratory techniques.

Table 2. Selected contaminants detected in maintenance sediments from the Houston Ship Channel between Redfish Reef and Morgans Point.

| Station[a] | Contaminant Parameters (ppm) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Oil and Grease | | | Arsenic | | | Copper | | | Zinc | | |
| | 1976 | 1983 | 1986 | 1976 | 1983 | 1986 | 1976 | 1983 | 1986 | 1976 | 1983 | 1986 |
| H-MR-1 | 700 | 926 | ND[b] | 5.7 | 5.8 | 3.1 | 19.0 | 13.0 | 13.3 | 110.0 | 76.3 | 45.9 |
| H-MR-2 | 870 | 464 | --- | 6.5 | 6.2 | --- | 17.0 | 12.9 | ---- | 74.0 | 71.3 | ---- |
| H-MR-3 | 670 | 783 | 188 | 5.7 | 3.9 | 5.4 | 16.0 | 7.9 | 10.6 | 66.0 | 30.0 | 26.0 |
| H-MR-4 | 830 | 532 | --- | 4.3 | 4.4 | --- | 14.0 | 12.8 | ---- | 55.0 | 56.0 | ---- |
| H-MR-5 | 760 | 417 | 243 | 6.6 | 5.0 | 2.9 | 18.0 | 12.8 | 17.8 | 60.0 | 74.4 | 49.4 |
| H-MR-6 | 670 | 245 | --- | 6.3 | 5.4 | 3.2 | 16.0 | 12.9 | 12.2 | 57.0 | 67.1 | 49.3 |
| H-MR-7 | 710 | 701 | --- | 6.0 | 5.2 | --- | 16.0 | 14.2 | ---- | 58.0 | 66.0 | ---- |
| H-MR-8 | 920 | 182 | 128 | 8.5 | 4.4 | 5.8 | 19.0 | 9.8 | 24.8 | 67.0 | 73.4 | 30.4 |
| H-MR-9 | 560 | 529 | --- | 6.5 | 6.7 | 4.4 | 16.0 | 13.2 | 12.7 | 70.0 | 78.3 | 57.9 |
| H-MR-10 | 640 | 886 | --- | 5.6 | 5.1 | 7.5 | 12.0 | 9.5 | 12.4 | 80.0 | 53.0 | 41.5 |
| H-MR-11 | 600 | 715 | 105 | 6.0 | 7.0 | 3.3 | 11.0 | 11.3 | 10.0 | 60.0 | 57.2 | 43.2 |
| H-MR-12 | 920 | 686 | --- | 6.0 | 7.0 | 3.3 | 16.0 | 7.5 | 8.7 | 76.0 | 47.5 | 43.0 |
| H-MR-13 | 690 | 624 | 195 | 6.0 | 5.7 | 3.5 | 12.0 | 12.0 | 6.2 | 65.0 | 77.5 | 41.8 |
| H-MR-14 | 730 | 294 | 127 | 7.5 | --- | 18.0 | 12.0 | ---- | 8.8 | 60.0 | 55.0 | 27.8 |
| H-MR-15 | 810 | --- | --- | 7.5 | --- | 9.1 | 12.0 | ---- | 5.4 | 60.0 | 36.7 | ---- |
| H-MR-16 | 340 | 310 | 111 | 3.5 | 3.5 | 9.9 | 7.0 | ND | 11.8 | 48.0 | 38.2 | 22.5 |
| $\overline{X}$ | 716 | 553 | 84 | 6.1 | 5.2 | 6.5 | 14.7 | 10.7 | 11.7 | 66.6 | 61.4 | 39.6 |

a Stations were located at about one mile intervals from Morgans Point (H-MR-1) to Redfish Reef (H-MR-16).
b ND means not detected; -- means not analyzed.

1. Oil and Grease - The average oil and grease concentration appears to have decreased from 716 parts per million (ppm) to 84 ppm between 1976 and 1986 (Table 2) in this section of the Houston Ship Channel. This reduction, however, is probably a result of the shorter maintenance dredging interval between 1983 and 1986. The sediments had only three years to accumulate contaminants as opposed to seven years in the 1976-1983 interval. The oil and grease parameter includes several types of compounds such as hydrocarbons, fatty acids, soaps, fats, waxes, and oils (Engineering-Science Inc. 1977). Industrial waste chemicals such as PAH, phthalate esters, and phenols are not quantitatively measured by the oil and grease parameter. These industrial contaminants are, however, known to produce adverse effects on aquatic organisms at very low concentrations (Eisler 1987, Neff 1979), but their detection require specific analytical techniques. Most sediment analyses for oil and grease do not include separate determinations for PAH residues, therefore, contaminant assessment of PAH is done by inference.

Thirty-two sediment samples collected during this assessment were analyzed for oil and grease as well as for total PAH residues. The average oil and grease concentration was 440 ppm and the average total PAH concentration was 1.6 ppm, which is 0.3 percent. A 1.6 ppm residue value is equivalent to a 1,600 parts per billion (ppb) level which is approximately five times the water quality criteria of 300 ppb needed to protect saltwater aquatic life (EPA 1980a). Most PAH compounds strongly sorb to fine silt and clay particles and are not dissolved into the water. They nevertheless impact aquatic organisms that filter and ingest suspended particles and other planktonic food items that have been contaminated by sorption of PAH compounds to their surface.

2. Heavy Metals - Several heavy metals were detected in the maintenance sediment dredged from the Houston Ship Channel including arsenic, chromium, copper, lead, nickel, and zinc. Cadmium and mercury residues did not consistently appear at or above the detection levels. Chromium, lead, and nickel were present in most sediment samples but at levels not expected to pose a severe environmental threat because of their kinetics in estuarine water. Arsenic, copper, and zinc were used in this contaminant assessment (Table 2) because these elements are toxic to estuarine aquatic organisms at levels detected in the sediment (Eisler 1967,

1988a, Ahsanullah and Arnott 1978, Arnott and Ahsanullah 1979, U.S. EPA 1980b, 1980c).

a. Arsenic - Arsenic residues in the maintenance material were similar for the three years sampled and averaged 6.0 ppm (Table 2). Although there are no sediment criteria for arsenic, acute toxicity to saltwater aquatic life occurs at 508 ppb (0.5 ppm) for recoverable trivalent inorganic arsenic (U.S. EPA 1980b). Trivalent arsenic compounds are more toxic, more soluble, and more mobile than pentavalent arsenic compounds, and in anaerobic soils, which would typify maintenance sediments, the trivalent forms are the major soluble species (Eisler 1988a, U.S. EPA 1980b). Soluble arsenic varies between one-eighth and one-fourth of the total arsenic in soils (Eisler 1988a). If soluble trivalent arsenic is one-eighth to one-fourth of the total arsenic in the Houston Ship Channel sediment (averaging 6,000 ppb), then residues of trivalent arsenic between 750 ppb and 1,500 ppb would be expected to contaminate the Galveston Bay water. Both of these values exceed the 508 ppb acute toxicity level of arsenic to saltwater aquatic organisms (U.S. EPA 1980b). Several studies of arsenic impacts on estuarine species reviewed by Eisler (1988a), indicate that mortality of copepods occur at 100 ppb, and the American oyster (Crassostrea virginica) bioconcentrated arsenic 350 times the ambient water concentration of 5 ppb.

Organoarsenals present in the sediments exert toxic effects by initial metabolism to the trivalent arsenoxide forms, and then reacts with sulfhydryl groups of proteins and enzymes which then inhibits oxidative degradation of carbohydrates. This decreases the cellular adenosine triphosphate (ATP) formation which reduces cellular energy production (Eisler 1988a). The reduced ATP results in less energy available to develop eggs or withstand short term demanding environmental stresses, both of which require increased energy reserves.

b. Copper - Copper residues in the maintenance dredged material appeared to decrease from 1976 to 1983, and as the samples were taken farther down the channel toward Redfish Reef (Table 2). The average copper residue for all samples evaluated was 12.4 ppm. Copper generally appears as the divalent cupric ion in both free and complex forms in water, and is an essential nutrient at low concentrations, but is very toxic at slightly elevated levels (U.S. EPA 1980c). A concentration of 1 to 10 ppb is normally present in marine environments, but polluted coastal water along Texas had levels up to 49 ppm (Steele 1983). Copper is used as an aquatic algicide, and in antifouling paints on vessels because of its toxicity to barnacles, clams, and other sedentary invertebrates.

Analytical techniques for total recoverable copper measure the cupric forms that are directly toxic to aquatic life such as the free ion and the hydroxides, carbonates, and phosphates. The criterion to protect saltwater aquatic life for total recoverable copper is 4.0 ppb and should never exceed 23 ppb at any time (U.S. EPA 1980c). This latter value is only 0.2 percent of the average concentration of 12.4 ppm (12,400 ppb) detected in sediments from the Houston Ship Channel.

In a long-term experiment, clams (Protothaca staminea) exposed to sediment with 4.4 ppm copper residues had up to 25 percent mortality (Phelps et al. 1985). This is one-third of the residue levels detected in the maintenance material considered in this assessment. Copper toxicity is temperature dependent as demonstrated by a study showing copper to be 100 times more toxic to the soft-shelled clam (Mya arenaria) at 22°C than 4°C (U.S. EPA 1980c). Most juvenile stages of fish and invertebrates are more sensitive than adult stages (U.S. EPA 1980c). Four fish and 18 saltwater invertebrate species exposed for a short time to copper indicate that sensitivity varies between 28 ppb to 600 ppb (U.S. EPA 1980c). This latter value is only 4.8 percent of the copper residue detected in the maintenance dredged material from the Houston Ship Channel. If the material releases one - twentieth of this copper to the water, this exceeds the 600 ppb high side of the sensitivity range.

c. Zinc - Zinc residues in maintenance dredged material decreased from an average level of 66.6 ppm to 39.6 ppm between 1976 and 1986 (Table 2), with most of the decline occurring between 1983 and 1986. Zinc is usually partitioned into sediments by sorption when the pH of water is above 7, however, zinc is desorbed from sediments as salinity increases (U.S. EPA 1980d). Zinc is a required trace element in the metabolism of most organisms, but all forms are potentially toxic if they can be sorbed or bound at higher levels by biological tissues.

Forms of zinc that are found in water are measured by the total recoverable zinc procedure, and are the forms that are toxic to aquatic life, or can be converted to the toxic forms under natural conditions (U.S. EPA 1980d). The criterion to protect saltwater aquatic life for zinc is 58 ppb as a 24 hour average and should not exceed 170 ppb at any time (U.S. EPA 1980d). The latter value is 0.4 percent of the average zinc residue for 1986 (Table 2), the lowest average reported for the three dredging operations. Arnott and Ahsanullah (1979) reported the LC50 value of zinc to the marine copepod _Scutellidium_ sp. to be 1.09 ppm, and to crab larvae the LC50 value was 1.23 ppm (Ahsanullah and Arnott 1978). Reduction in growth of larvae of three oyster species was caused by zinc concentrations of 20, 50, and 100 ppb (Watling 1982) which increased the time larvae remained pelagic. Mortality of copepods and crab larvae, and reduction in growth of oyster larvae, are adverse impacts on estuarine productivity induced by zinc contamination.

The information presented above demonstrates that maintenance dredged material taken from the Houston Ship Channel between Morgans Point and Redfish Reef during 1976, 1983, and 1986 is contaminated with oil and grease, arsenic, copper, and zinc at levels that would cause mortality to larval stages of crabs, clams, oysters, and fish. This occurs when the dredged material is deposited and allowed to flow uncontrolled into the bay. This potential to contaminate Galveston Bay was the reason for the following field studies to assess impacts in more detail.

## Assessment of Field Test Data

Assessment of routine sediment data for adverse impacts on fish and wildlife resources demonstrated a need for field assessments that included an expanded list of chemicals. For example, the oil and grease parameters that are routinely included in a contaminant assessment do not provide a full evaluation of the potential contamination of aquatic organisms by PAH compounds. This field study considered an expanded list of contaminants (Table 3), and lower levels of detection, which makes a better assessment possible. The following discussion

Table 3. Contaminants analyzed in maintenance dredged material by the contract laboratories for this study.

| Contaminants | Detection Level |
|---|---|
| **Routine Parameters** | |
| Arsenic | 1.0 mg/kg |
| Cadmium | 0.1 mg/kg |
| Chromium | 1.0 mg/kg |
| Copper | 1.0 mg/kg |
| Lead | 1.0 mg/kg |
| Mercury | 0.1 mg/kg |
| Nickel | 1.0 mg/kg |
| Selenium | 0.5 mg/kg |
| Zinc | 1.0 mg/kg |
| p,p' - DDT | 0.2 mg/kg |
| Chlordane | 0.2 mg/kg |
| Toxaphene | 5.0 mg/kg |
| Total PCB's | 5.0 mg/kg |
| Oil and Grease | 5.0 mg/kg |
| Naphthalene | 50.0 mg/kg |
| Acenaphthene | 50.0 mg/kg |
| Fluoranthene | 10.0 mg/kg |
| Benzo(a) pyrene | 10.0 mg/kg |
| Total PAH | 0.2 mg/kg |
| **Supplemental Parameters** | |
| Bis(2-Ethylhexyl) phthalate | 50.0 ug/kg |
| Total chlorinated phenols | 20.0 ug/kg |
| Total methylnaphthalenes | 50.0 ug/kg |
| Total ethylnaphthalenes | 50.0 ug/kg |
| Total propylnaphthalenes | 50.0 ug/kg |
| Acenaphthylene | 50.0 ug/kg |
| Fluorene | 10.0 ug/kg |
| Total methylfluorenes | 50.0 ug/kg |
| Total ethylfluorenes | 50.0 ug/kg |
| Total propylfluorenes | 50.0 ug/kg |
| Phenanthrene | 20.0 ug/kg |
| Anthracene | 20.0 ug/kg |
| Total methylphenanthrenes | 120.0 ug/kg |
| Total ethylphenanthrenes | 120.0 ug/kg |
| Total propylphenanthrenes | 120.0 ug/kg |
| Pyrene | 10.0 ug/kg |
| Total methylpyrenes | 50.0 ug/kg |
| Total ethylpyrenes | 50.0 ug/kg |
| Total propylpyrenes | 50.0 ug/kg |
| Chrysene | 10.0 ug/kg |
| Benzo(b+k)fluoranthene | 2.0 ug/kg |
| Benzo(ghi)fluoranthene | 2.0 ug/kg |
| Perylene | 2.0 ug/kg |
| Total dibenzanthracenes | 2.0 ug/kg |
| Benzo(ghi)perylene | 2.0 ug/kg |
| Octachlorinated styrenes | 50.0 ug/kg |

addresses contaminated sediment that was placed on the upland site at Atkinson Island and allowed to flow back into the bay system, and sediments that were discharged into the confined disposal area at Alexander Island.

A. <u>Unconfined Disposal Area</u> - Maintenance dredged material from the Morgans Point to Redfish Reef section of the Houston Ship Channel was intended to be placed on Atkinson Island in a leveed area. The levee, however, collapsed and the material flowed out into the bay. This fugitive sediment from the disposal area formed a large mud fan in Galveston Bay and covered the bay bottom at least 300 yards from the shore of Atkinson Island. This fluid mud is constantly re-suspended into the water column by wave action and boat traffic. Most contaminants of concern are not water soluble but are sorbed to the fine sediment particles that are resuspended into the water column.

Analysis of this fluid mud from Atkinson Island in 1985 revealed high contamination by oil and grease (Table 4). There was no corresponding analysis for PAH residue, so the PAH concentrations in Table 4 are estimates, using the 0.3 percent value calculated from the 32 samples previously discussed. The average PAH level of 2.0 ppm (2,000 ppb) is nearly seven times the EPA criterion for water of 300 ppb (U. S. EPA 1980a). The significance of these data is that organisms that filter sediment may be exposed to PAH residues nearly seven times higher than the dissolved level that is toxic to aquatic life.

Maintenance dredging of this section was again accomplished in 1986. Sediment taken from the Atkinson Island disposal area in 1987 was analyzed for the contaminants listed in Table 3, as were samples from the control area (Morgans Point). Contaminants detected in these samples are presented in Table 5 and discussed below.

1. <u>Heavy Metals</u> - Samples from the Atkinson Island disposal area had elevated levels of arsenic, chromium, copper, lead, and zinc compared to samples from the control area. The average residue level of each metal, as well as the maximum residue for all metals but nickel, was higher in the maintenance sediment (Table 5) than in sediment from the control site.

Table 4. Oil and grease in sediments from the Atkinson Island disposal area and adjacent bay bottom.[a]

| Sample site | Oil and Grease (ppm) | PAH at 0.3%[b] (ppm) |
|---|---|---|
| Atkinson Island disposal area | 980 | |
| Atkinson Island disposal area | 460 | |
| Atkinson Island disposal area | 820 | |
| Atkinson Island disposal area | 430 | |
| Atkinson Island disposal area | 640 | |
| | $\bar{x}$=666 | 2.0 |
| Mud flat formed after breach in levee | 790 | 2.4 |
| Bay bottom 100 yards from mud flat | 750 | |
| Bay bottom 100 yards from mud flat | 810 | |
| | $\bar{x}$=780 | 2.3 |
| Bay bottom 200 yards from mud flat | 640 | |
| Bay bottom 200 yards from mud flat | 830 | |
| | $\bar{x}$=735 | 2.2 |
| Bay bottom 300 yards from mud flat | 830 | |
| Bay bottom 300 yards from mud flat | 200 | |
| | $\bar{x}$=515 | 1.5 |
| Average of all samples | | 2.0 |

[a] All samples collected in 1985.
[b] PAH parameter was 0.3% of the oil and grease parameter derived from 32 samples taken during the 1987 analysis.

a. Arsenic - Arsenic residues from the disposal site averaged 3.8 ppm which was almost three times higher than in sediment taken from the control site. The 3.8 ppm residue level is seven times higher than the acute toxicity value for water (0.5 ppm) established to protect saltwater aquatic life (U.S. EPA 1980b). Arsenic in the sediment is methylated in aquatic systems by fungi, bacteria, and algae (Baker et al. 1983) and becomes very soluble in this state. Salinity is known to increase the toxicity of soluble arsenic to an estuarine amphipod (*Corophium volutator*) and a bivalve (*Macoma balthica*) (Bryant et al. 1985.). Arsenic residue levels in the maintenance dredged material are high enough to be a serious environmental contaminant. Since oxidation of arsenite (most toxic form) to arsenate (less toxic form) occurs in strongly alkaline or acidic conditions (U.S. EPA 1980b), open bay disposal of maintenance dredged material should be avoided because any transformation will be highly toxic in saline water.

Disposal on upland sites will still allow the arsenic to be mobilized during rainfall events and subsequent runoff. Confined disposal areas, however, if allowed to dry, will favor formation of arsenate which is less toxic and will form insoluble precipitates with calcium, sulfur, aluminum, and barium (U.S. EPA 1980b).

b. Chromium - Chromium residue averaged 8.5 ppm in the maintenance material deposited on Atkinson Island (Table 5) which was nearly two times the average level detected at the control site. In aquatic environments chromium is virtually always found in the hexavalent (+6) or trivalent (+3) states (U.S. EPA 1980e). Hexavalent chromium is very soluble in natural waters and exists in solution as a component of an anion (e.g. $CrO_3$), precluding its precipitation from alkaline solutions. To protect saltwater aquatic life the total recoverable hexavalent chromium criterion is 0.018 ppm as a 24 hour average and should not exceed 1.26 ppm at any time (U.S. EPA 1980e). The 8.5 ppm average chromium level detected in the maintenance material is nearly seven times the 1.26 ppm criterion or 470 times the 24 hour average criterion of 0.018 ppm.

Chromium residues in maintenance dredged material from the Houston Ship Channel are at levels that could severely contaminate the Galveston Bay benthic environment in areas where the material is allowed to flow out of a confined area. Kinetics of chromium in confined disposal areas as the sediment dries is not understood at the present time. The strong oxidizing power of hexavalent chromium explains its toxic properties, and its mutagenic and carcinogenic activity (U.S. EPA 1980e). Chromium salts are used in metal finishing industries, catalytic manufacturing, pigments, fungicides, and wood preservatives which may explain the elevated levels in the ship channel sediment.

c. Copper - Copper residue was also higher from Atkinson Island samples than samples from the control site (Table 5). The average residue level of 5.5 ppm was over twice the average of 2.6 ppm for the control site sediment. To protect saltwater aquatic life total recoverable copper should not exceed 23 ppb (0.02 ppm) at any time (U.S. EPA 1980c). In a long-term experiment, clams exposed to sediment with 4.4 ppm copper had up to 25 percent mortality (Phelps et al. 1985). Dredging of copper-contaminated reduced sediment, and allowing the mud particles (fine silts and clay) to flow into Galveston Bay, increases the mobility of cupric ions as the material is aerated by resuspension into the water column. The resuspension of the particles by wave action into the water column is a long-term chronic exposure scenario to the aquatic organisms in Galveston Bay.

d. Lead - Lead was the fourth heavy metal that had a higher average residue level (8.7 ppm) in maintenance sediment placed on Atkinson Island compared with the control sediment (Table 5). All authorities agree that lead is neither essential nor beneficial to living organisms, and is toxic in most of its chemical forms (Eisler 1988b). In nature lead occurs mainly as the divalent (2+) form, and several lead salts are soluble in water. Lead entering natural waters is precipitated to sediments as carbonates or hydroxides, but may be released as pH decreases (Eisler 1988b).

Available data for total recoverable lead indicate that acute and chronic toxicity to saltwater aquatic life occurs at 0.668 ppm and 0.025 ppm, respectively (U.S. EPA 1980f). Several invertebrate and algae species accumulate lead. Bioconcentration factors range from 17 for the hard clam to 2,570 for the mussel (U.S. EPA 1980f). Lead modifies the function and structure of kidneys,

Table 5. Contaminants detected in maintenance dredged material from the Houston Ship Channel and placed in an unconfined upland disposal area.

| | Control (Morgans Point) Range | $\bar{X}$ | Atkinson Island Range | $\bar{X}$ |
|---|---|---|---|---|
| **Metals** | 5 samples (ppm) | | 15 samples (ppm) | |
| Arsenic | ND[a] - 4.9 | 1.3 | ND - 11.7 | 3.8 |
| Chromium | ND - 6.8 | 4.4 | ND - 10.1 | 8.5 |
| Copper | ND - 3.4 | 2.6 | ND - 8.7 | 5.5 |
| Lead | 4.1 - 6.5 | 5.2 | 3.9 - 11.6 | 8.7 |
| Nickel | 4.0 - 9.9 | 4.7 | ND - 9.1 | 5.7 |
| Zinc | 13.0 - 19.0 | 17.6 | 17.0 - 38.0 | 26.6 |
| **PAH's** | 4 samples (ppb) | | 8 samples (ppb) | |
| Fluoranthene | ND - 3.5 | 1.5 | ND - 14.8 | 2.7 |
| Benzo(a)pyrene | ND - 7.1 | 1.8 | ND - 1.3 | 0.2 |
| Pyrene | ND - 23.0 | 8.1 | 2.3 - 10.3 | 4.5 |
| Chrysene | ND - 25.9 | 6.3 | ND - 6.2 | 0.8 |
| Benzo(ghi)fluoranthene | ND - 5.1 | 1.3 | ND - 10.7 | 1.3 |
| Fluorene | ND | | ND - 2.0 | 0.3 |
| Phenanthrene | ND | | ND - 18.7 | 1.9 |
| Anthracene | ND | | ND - 2.7 | 0.3 |
| Total methylphenanthrene | ND | | ND - 124.0 | 15.5 |
| Total ethylphenanthrenes | ND | | ND - 57.2 | 6.1 |
| Perylene | ND | | ND - 20.6 | 3.0 |
| Total of PAH Means | | 19.0 | | 36.6 |

a ND = not detected

bones, the central nervous system, and the blood formation system, resulting in adverse biochemical, histopathological, neurophysiological, and reproductive effects (Eisler 1988b).

Lead is not desorbed from sediment in alkaline conditions, but the lower the pH of water and the lower the concentration of dissolved salts the greater the solubility of lead (U.S. EPA 1980f). These characteristics should prevent lead from leaving disposal area sediments except by transport of contaminated silt and clay particles. At levels detected in the maintenance dredged material, lead does not pose a severe environmental threat to biota of Galveston Bay because it is not likely to desorb from the sediment. Filter feeding organisms such as oysters may however remove lead from the sediment particles.

e. <u>Nickel</u> - Residues of nickel were not different in the maintenance dredged material placed on Atkinson Island as compared to the control area (Table 5). Nickel was not detected at levels that would pose an environmental problem from maintenance dredging.

f. <u>Zinc</u> - Zinc residues were higher from samples taken on Atkinson Island than those from the control site (Table 5). Zinc is a required trace element in the metabolism of most organisms, however, all forms of zinc are potentially toxic if they can be sorbed or bound by biological tissue. Total recoverable zinc in samples does measure the forms of zinc toxic to aquatic life. To protect saltwater aquatic life, zinc should not exceed 0.058 ppm as a 24 hour average or exceed 0.17 ppm at any time (U.S. EPA 1980d). The average sediment concentration of zinc from the maintenance dredged material was 26.6 ppm (Table 5) which is 156 times the 0.17 ppm that should not be exceeded at any time in water. Zinc generally partitions into the sediment by sorption onto hydrous iron and manganese oxides, clay minerals, and organic material. Zinc is desorbed from sediment as the salinity increases in brackish and saline water (U.S. EPA 1980d), which would allow an increase to potentially toxic levels in Galveston Bay water.

The toxic heavy metals considered in this assessment of maintenance dredged material from the Houston Ship Channel, between Morgans Point and Redfish Reef, are present at levels that will adversely affect aquatic biota in Galveston Bay. These toxic heavy metals (i.e., arsenic, chromium, copper, and zinc) will sorb to fine silt and clay particles and will migrate from an open bay disposal area as wave action resuspends the particles, or during runoff events from upland unconfined areas. Resuspended sediments will carry these sorbed metals into the water column at levels that will cause reduced growth, mortality, and adverse biochemical changes in aquatic biota that filter or ingest suspended particles. Reduced survival of eggs and larval stages of fish and shellfish is a likely but undocumented result.

2. Polycyclic Aromatic Hydrocarbons - PAH compounds were detected in sediment samples from the maintenance dredged material placed on Atkinson Island as well as samples from the control area (Table 5). Eleven specific PAH compounds were detected from the dredged sediment with a total mean residue level of 37 ppb (0.037 ppm), and five PAH compounds were detected in the control sediment with a total mean residue level of 19 ppb (0.019 ppm). Acute toxicity to saltwater aquatic species occurs at 300 ppb but would occur at a lower concentration to species more sensitive than those tested (U.S. EPA 1980a). Chronic toxicity values are much lower than acute toxicity values, ranging from 10 to 50 percent of the 24 hour LC50 value, thus would range from 30 ppb to 150 ppb.

Assessment of PAH contamination to estuarine aquatic life is important because these compounds are among the most potent carcinogens known, and affect nearly every species and tissue studied (Eisler 1987). Substitution of methyl, ethyl, or propyl groups on certain locations of benzene rings in a PAH enhances the uptake of those compounds by animal tissue. Methylation of PAH compounds in the sediment by bacteria would enhance their uptake and provide the pathway into aquatic organisms.

Two and three ring PAH compounds are more volatile than four, five, or six ring compounds. The acute toxicity of PAH compounds to aquatic life is caused by the more soluble lower molecular weight PAH compounds with two or three benzene rings (i.e. naphthalene, fluorene, or anthracene). Higher molecular weight PAH compounds with four to six benzene rings (i.e. chrysene, benzo(a)pyrene, or benzo(b)fluoranthrene) are not acutely toxic, however, all the carcinogenic PAH compounds are the higher molecular weight compounds (Eisler 1987).

PAH compounds, especially those of higher molecular weight, are hydrophobic and strongly sorb to fine silt and clay particles. Transport of these contaminants to the water surface microlayer during disturbance of sediments is well documented (Word et al. 1987). Fish and aquatic invertebrate eggs float in this microlayer and are exposed to toxic concentrations of these contaminants. Contaminated sediment was transported from the unconfined disposal area on Atkinson Island (King et al. 1986), and continues as a result of rainfall runoff (see Table 4), allowing these contaminated particles to enter the surface microlayer.

Sediment samples taken from Atkinson Island were collected after the sediment bed had dried and cracked exposing the material to thermal and oxygenation processes. Both volatilization and biogradation of PAH compounds were likely responsible for a lower detection of PAH compounds than expected based on the estimate described in the preceding section, i.e., extrapolation from oil and grease parameters reported in Table 4. To more accurately assess the environmental impact of PAH-contaminated maintenance material, sediment samples should be collected before the surface dries.

B. <u>Confined Disposal Area</u> - Confined disposal of maintenance dredged material from the Houston Ship Channel is the method used to reduce impacts on Galveston Bay biota from contaminated sediments. Eight sediment samples taken from inside the confined disposal area at Alexander Island near the discharge weir were heavily contaminated (Table 6) relative to the control sediment (Table 5). Palermo and Thackston (1988) state that, "the quality of effluent from confined disposal areas is strongly dependent on the concentration of total suspended solids in the effluent". These authors also indicate that, under field conditions, wind and advective flow generates turbulence in confined disposal areas that inhibits sedimentation. This then increases the suspended solids concentration in the effluent.

Table 6. Contaminants detected in maintenance dredged material from the Houston Ship Channel and placed in a confined disposal area.

| Contaminant | Inside the Disposal Area (8 samples) | | Below the Discharge Area (3 samples) | |
|---|---|---|---|---|
| | Range | $\overline{X}$ | Range | $\overline{X}$ |
| **Metals (ppm)** | | | | |
| Arsenic | 1.1 - 3.7 | 2.1 | 1.4 - 2.2 | 1.8 |
| Chromium | 7.1 - 25.3 | 16.6 | 7.5 - 16.7 | 11.4 |
| Copper | 8.2 - 11.6 | 10.0 | 6.3 - 8.2 | 7.0 |
| Lead | 12.6 - 19.1 | 16.2 | 10.7 - 12.9 | 12.2 |
| Nickel | 4.6 - 11.5 | 9.3 | 6.1 - 10.7 | 8.1 |
| Zinc | 30.0 - 53.1 | 40.3 | 27.6 - 50.9 | 38.1 |
| **Organics (ppm)** | | | | |
| Oil and Grease | 340 -1235.0 | 700.0 | 324.0 - 760.0 | 488.0 |
| Total PAH's[a] | 0.6 - 19.3 | 4.9 | 0.2 - 2.8 | 1.5 |
| **PAH's[b] (ppb)** | | | | |
| Fluoranthrene | ND[c] - 125.0 | 34.5 | ND - 15.1 | 27.8 |
| Benzo(a)pyrene | ND - 68.2 | 23.9 | ND - 54.9 | 38.0 |
| Pyrene | ND - 269.0 | 165.6 | 69.0 - 178.0 | 119.3 |
| Chrysene | ND - 300.0 | 127.3 | 26.0 - 188.0 | 133.3 |
| Perylene | ND - 19.5 | 12.4 | 1.6 - 41.6 | 21.7 |
| Benzo(ghi)perylene | ND - 16.2 | 5.5 | ND - 17.5 | 11.0 |
| Benzo(ghi)fluoranthene | ND - 118.0 | 28.6 | 1.7 - 29.0 | 17.3 |
| Total dibenzanthracenes | ND - 37.7 | 5.7 | ND - 6.9 | 3.8 |
| Total ethylpyrenes | ND - 687.0 | 116.4 | ND - 54.2 | 18.6 |
| Total propylpyrenes | ND - 387.0 | 58.6 | ND - 64.5 | 18.6 |
| Total methylpyrenes | ND - 314.0 | 73.2 | ND | |
| Phenanthrenes | ND - 38.2 | 7.5 | ND | |
| Anthracene | ND - 13.2 | 3.2 | ND | |
| Benzo (b&k) fluoranthrene | ND - 48.0 | 16.6 | ND | |
| Total propylnaphthalenes | ND - 7.8 | 0.9 | ND | |
| Total buthylnaphthalenes | ND - 37.6 | 4.7 | ND | |
| Total methylphenanthrenes | ND - 174.0 | 21.7 | ND | |
| Total ethylphenanthrenes | ND - 621.0 | 180.1 | ND | |
| Total of PAH means | | 886.4 | | 416.0 |

[a] Fluoranthrene equivalents as described by Riggin and Strup 1984.

[b] Twenty-seven specific polycyclic aromatic hydrocarbons determined by laboratory analytical techniques (i.e., gas chromatography and mass spectrometry).

[c] ND = not detected

1. <u>Heavy Metals</u> - The average concentrations of chromium, copper, lead, nickel, and zinc were higher inside the confined area than the contaminant levels from either the control area or the unconfined disposal area. Residues of these five heavy metals were also higher in the sediment collected outside the confined area in the receiving water (Table 6) than in the control sediments. It appears that the Alexander Island confined disposal area does not prevent the migration of some toxic compounds into the San Jacinto delta. Toxicity levels and potential impacts of the heavy metals present in this confined sediment were discussed earlier in this paper. Since these residues were higher, the impact to organisms in the discharge area are expected to be more severe.

2. <u>Polycyclic Aromatic Hydrocarbons</u> - PAH compounds were detected at elevated levels (4.9 ppm) in sediments within the confined disposal area, as well as in sediments from the bay bottom at the discharge point (Table 6). PAH levels were 0.7 percent of the oil and grease parameter within the confined area and 0.3 percent outside the disposal area at the discharge. This reduction probably reflects the mixing of the suspended sediment over a wide area in the receiving water with its sediment load, as well as volatilization of the two and three ringed compounds.

The average residue of 18 individually detected PAH compounds totaled 886 ppb in the sediment from within the confined area (Table 6). This is 46 times the background concentration of 19 ppb detected in sediment samples from the control site (Table 5). There was also three times the number of specific PAH compounds. Acute toxicity to saltwater aquatic life occurs at 300 ppb (U.S. EPA 1980a). Sediment from the bay bottom at the discharge point had a total mean concentration of 416 ppb which is 22 times the value detected from control sediment. Serious contamination of the bay bottom by PAH compounds migrating out of the confined disposal area occurred during this study. The extent of the contamination was not measured nor was the impact on most biota surveyed. Mahoney and Noyes (1982) clearly demonstrated that significant mortality and weight loss in oysters was due to sediment contamination of PAH residues as low as 500 ppb. Word et al. (1987) and Hardy et al. (1987) also demonstrated that disturbance of PAH-contaminated sediment releases these compounds to the water surface microlayer and is toxic to developing sea urchin larvae, sole and trout eggs, and caused chromosomal aberrations in developing sole larvae. The fact that no studies have been done on PAH levels affecting Galveston Bay biota should not lend support to a notion that no effects are occurring.

C. Benthic Evaluations - Blue crabs collected from the control site and placed for a five day bioaccumulation study at the discharge pipe from Alexander Island died on the third day. Analysis of these crabs indicate that heavy metals did not accumulate in their tissue above that detected in the control crabs (Table 7). Arsenic, chromium, lead, and nickel were not present in the blue crabs at detection levels. Of interest is that cadmium was detected in all crab samples but was not reported above detection levels in any sediment sample. Unfortunately the cadmium detection level for these samples is 0.1 ppm (Table 3) which may be too high to evaluate cadmium as a pollutant in Galveston Bay sediment. The criteria to protect saltwater aquatic life from cadmium is 0.004 ppm as a 24-hour average, and the concentration should not exceed 0.059 ppm at any time (U.S. EPA 1980g).

Two PAH compounds (pyrene and chrysene) were detected in the crabs collected at the control site, as well as in the samples placed in the receiving water at the confined disposal area. The total residue of these two compounds was 19.4 ppb in the control crabs and increased to 41.5 ppb in the crabs left at the discharge area (Table 7). All of the experimental crabs were dead of unknown causes before the holding cages were retrieved on the third day of the five day study period.

Suspended sediment from the discharging water from the confined disposal area was measured 50 meters from the discharge pipe by the Texas Water Commission and equalled 327 mg/l (ppm). Beyond the discharge plume the suspended sediment concentration was only 90 mg/l. Oil and grease measured in the discharging water totaled 185 ppm which translates to 5.5 ppm PAH residues (185 x 0.3). This is equivalent to 5,500 ppb which is 18 times higher than the EPA water quality criterion of 300 ppb to protect saltwater aquatic life. Marine organisms are known to accumulate the more hydrophobic contaminants such as anthracene and hexachlorobenzene as suspended sediment concentration increases (Landrum and Scavia 1983, Ekelund et al. 1987). Contaminated sediment from the Alexander Island con-

Table 7. Contaminants detected in blue crabs collected at the Morgans Point control site and placed for three days at the Alexander Island confined disposal area discharge point.

| Contaminants | Control site (one sample) | Confined disposal discharge point (six samples) Range | $\bar{X}$ |
|---|---|---|---|
| Metals (ppm) | | | |
| Cadmium | 0.4 | 0.2 - 0.3 | 0.2 |
| Copper | 15.5 | 15.5 - 26.6 | 16.6 |
| Zinc | 42.8 | 26.4 - 30.8 | 28.8 |
| PAHs (ppb) | | | |
| Pyrene | 9.2 | ND[a] - 48.4 | 34.1 |
| Chrysene | 10.2 | ND - 27.6 | 7.4 |
| Total | 19.4 | | 41.5 |

[a]ND = not detected

fined disposal area is mobilized during runoff events and seriously contaminates the receiving water. Mortality of benthic organisms is assured, and mortality of eggs and juvenile stages that float at the surface in the nutrient rich boundary layer (Word et al. 1987, Hardy et al. 1987) would also occur.

At Atkinson Island an assessment of benthic populations in the fugitive mud was made by counting the number of vents on the surface at low tide. Vents in the mud are indications of clams burrowed into the sediment. Density of vents from 10 square-meter samples averaged 54 per square meter along the shoreline of Atkinson Island not impacted by the fugitive mud from the disposal site. There were no vents in the 10 square-meter samples from the fugitive mud one year after the material escaped from the disposal site even though there was ample time for recolonization. Results discussed above on the chemical analysis of this sediment indicate both heavy metals and polycyclic aromatic hydrocarbons were present at residue levels associated with clam mortality.

D. Vegetation Evaluation - One hundred *Spartina alterniflora* sprigs, each with at least three roots, were transplanted from a vigorous stand into the fugitive mud fan at the same elevation in April 1987. The *Spartina* sprigs had an average of 1.2 culms per plant. In June 1987 the transplanted sprigs had declined to 49 plants with an average of 1.6 culms per plant. All the plants transplanted in the fugitive mud were washed away before the July site visit.

The stand of *Spartina* next to the transplanted area which was used as the sprig source was vigorous and resisting wave action in July. It appears that the transplanted *Spartina* could not generate enough rhizome growth to help stabilize the plants. *Spartina alterniflora* was successfully transplanted in an uncontained dredge material disposal site in Chocolate Bay, Texas (Webb 1985). This small effort suggests that a more intense research project to determine if contaminated maintenance material restricts *Spartina* growth, is an important information need in assessing open water disposal in coastal waters.

## SUMMARY AND RECOMMENDATIONS

More than 400 hazardous chemicals such as PAH, chlorinated styrenes, phenols, and phthlates are discharged in the Galveston Bay drainage basin (Dames and Moore, Inc. 1982). Maintenance material dredged from the Houston Ship Channel in Galveston Bay is routinely evaluated by the Corps for contaminants such as heavy metals, organochlorine pesticides, and conventional pollutants (i.e., Kjeldahl nitrogen and suspended solids) before each dredging cycle. These contaminant assessments rely on water quality criteria for pollutants and the elutriate test to predict contaminant impacts on estuarine biota. The weakness in this assessment technique is its failure to recognize that biota are constantly exposed to the contaminated suspended sediment particles. Published literature is replete with data that shows contaminated particles suspended in water increase contamination of filter feeding biota (Ekelund et al. 1987, Fletcher et al. 1981, Landrum and Scavia 1983, and Pereira et al. 1988), and increases the toxicity to eggs and larvae from contamination of the water surface boundary layer (Hardy et al. 1987, Word et al. 1987).

Maintenance sediment is routinely removed from the Morgans Point to Redfish Reef section of the Houston Ship Channel and placed on Atkinson Island, as occurred in 1976, 1983, and 1986. The disposal site was once leveed, however, one side of the levee failed and the dredged material flowed into Galveston Bay. A large sediment fan formed along the shoreline and the finer sediment particles covered the bay bottom at least 300 meters from the shoreline. Contaminant analysis of this dredged material was used to assess the impact of this maintenance material on the biota of Galveston Bay (King et al. 1986), and to develop this investigation for a more comprehensive assessment.

The oil and grease parameter used to evaluate maintenance material by the Corps of Engineers was high in both the 1976 and 1983 dredging cycle. The reduction in this parameter for the 1986 data was, perhaps, more a reflection of the shorter interval between maintenance (3 years vs. 7 years) than an indication of less contamination. Some compounds in the oil and grease parameter are hydrophobic and strongly sorb to fine silt and clay particles. Since maintenance material in this section of the Houston Ship Channel has a high fraction of silt and clay, the shorter dredging cycle probably reduced this fraction and its associated contaminants relative to the 1976-1983 period.

Petroleum hydrocarbons, especially the PAH compounds, are a small fraction of the oil and grease parameter. Thirty-two sediment samples collected during this investigation had an average oil and grease residue of 440 ppm. Specific analysis for total PAH compounds in these samples had an average concentration of 1.6 ppm. This is only 0.3 percent of the oil and grease parameter but it is three times higher than the water quality criterion of 0.3 ppm to protect salt-water aquatic life (U.S. EPA 1980a).

Other contaminants evaluated in this assessment such as arsenic, chromium, copper, lead, nickel, and zinc were all present at elevated levels in the maintenance sediment. Sediment concentrations of these metals were many times higher than their respective water quality criteria. Nickel and lead were the only heavy metals that were present at levels that pose no threat to biota of Galveston Bay. Mobility and availability of the other toxic metals depends upon salinity, pH, oxidative state of the sediment, and sediment transport into the water column. Toxic forms of each of these metals are continually released to the water column and scavenged from the water column as temperature, salinity, and oxygen levels change as a result of currents and wave action.

Fugitive sediments from either unconfined disposal on upland sites or from confined disposal sites is a pathway for contaminants sorbed to fine silt and clay particles to reenter the bay water and contaminate benthic organisms. Suspended sediments in the discharge from the confined disposal site at Alexander Island exceeded 300 ppm during the <u>in situ</u> accumulation study using blue crabs. The total concentration of two PAH compounds (pyrene and chrysene) increased from 19.0 ppb to an average of 41.5 ppb in the three samples of five crabs each within a three day period. These data illustrate that confined disposal of contaminated maintenance dredged material is a point source of contamination because of high suspended sediment in the effluent.

To insure that maintenance dredging of the Houston Ship Channel does not continue to contaminate the Galveston Bay biota, the following recommendations are presented.

1. Maintenance dredged material with greater than 100 ppm oil and grease residues be considered as too contaminated for release into Galveston Bay because at 0.3 percent PAH compounds these contaminants will exceed 300 ppb, the criterion to protect saltwater aquatic life.

2. Contaminated sediment from maintenance dredging of the Houston Ship Channel be confined in containment areas.

3. Containment areas be operated in such a manner that the return flow of effluent not exceed a suspended sediment concentration criterion of 100 mg/l during dredging operations or rainfall runoff events.

4. Contractors for dredging of the Houston Ship Channel post a performance bond that will insure the reconfinement of all fugitive sediment from any levee failure or suspended sediment criterion violation.

5. A comprehensive study of the effects of contaminated maintenance dredged material on the growth of <u>Spartina alterniflora</u> be conducted.

6. Evaluation of maintenance dredging for environmental affects include an <u>in situ</u> bioassay using clams, oysters, or crabs, before dredging contracts are advertised.

7. Contaminant assessment of maintenance dredging include the supplemental list of PAH compounds presented in this study.

## CONCLUSIONS

**Maintenance dredged material from the Morgans Point to Redfish Reef section of the Houston Ship Channel is contaminated with heavy metals and petroleum waste such as PAH compounds. Contaminated maintenance material will migrate from both unconfined and confined disposal areas as fine suspended silt and clay particles. Sediment bound contaminants are available to Galveston Bay biota at chronic toxicity levels during resuspension of these fine sediment particles into the water column. Benthic organisms such as crabs accumulate contaminants from effluents discharged from confined disposal areas that are heavily laden with suspended sediment. Maintenance dredging, as currently done, will continue to present a toxic hazard to Galveston Bay aquatic life.**

## LITERATURE


Ahsanullah, M. and G.H. Arnott. 1978. Acute toxicity of copper, cadmium, and zinc to larvae of the crab Paragrapsus quadridentatus (H. Milne Edwards), and implications for water quality criteria. Aust. J. Mar. Freshwater Res., 29:1-8.

Arnott, G.H. and M. Ahsanullah. 1979. Acute toxicity of copper, cadmium and zinc to three species of marine copepod. Aust. J. Mar. Freshwater Res., 30:63-71.

Baker, M.D., W.E. Inniss, C.I. Mayfield, P.T.S. Wong, and Y.R. Chou. 1983. Effects of pH on the methylation of mercury and arsenic by sediment microorganisms. Environ. Tech. Lett., 4:89-100.

Benefield, R.L. 1976. Shell dredging sedimentations in Galveston and San Antonio Bays, 1964-69. Texas Parks and Wildl. Dept., Tech. Ser. No. 19. 34 pp.

Brown, R.C., R.H. Pierce, and S.A. Rice. 1985. Hydrocarbon contamination in sediments from urban stormwater runoff. Mar. Pollut. Bull., 16:236-240.

Bryant, V., D. Newberry, D. McLusky, and R. Campbell. 1985. Effects of temperature and salinity on the toxicity of arsenic to three estuarine invertebrates (Corophium volutator, Macoma balthica, Tubifex costatus). Mar. Ecol. Prog. Ser., 24:129-137.

Dames and Moore, Inc. 1982. Inventory of toxic and hazardous waste disposal and discharge sites in the New Orleans and Houston areas: user's guide. Biological Services Program, FWS/OBS-82/64, Wash. D.C. 111 pp.

Eisler, R. 1967. Acute toxicity of zinc to the killfish, Fundulus heteroclitus. Chesapeake Sci., 8:262-264.

-----. 1987. Polycyclic aromatic hydrocarbon hazards to fish, wildlife, and invertebrates: a synoptic review. U.S. Fish and Wildl. Serv. Biol. Rept. 85(1.11). 81 pp.

-----. 1988a. Arsenic hazards to fish, wildlife, and invertebrates: a synoptic review. U.S. Fish and Wildl. Serv. Biol. Rept. 85(1.12). 92 pp.

-----. 1988b. Lead hazards to fish, wildlife and invertebrates: a synoptic review. U.S. Fish and Wildl. Ser. Biol. Rept. 85 (1.14). 134 pp.

Ekelund, R., A. Granmo, M. Berggren, L. Renberg, and C. Wahlberg. 1987. Influence of suspended solids on bioavailability of hexachlorobenzene and lindane to the deposit-feeding marine bivalve, Abra nita (Muller). Bull. Environ. Contam. Toxicol., 38: 500-508.

Engineering - Science, Inc. 1977. An evaluation of oil and grease contamination associated with dredged material containment areas. Tech. Rept. D-77-25. U.S. Army Engineers Waterways Experiment Station, Vicksburg, MS. 147 pp.

Fletcher, G.L., J.W. Kiceniuk, and U.P. Williams. 1981. Effects of oiled sediments on mortality, feeding and growth of winter flounder (Pseudopleuronectes americanus). Mar. Ecol. Prog. Ser., 4:91-96.

Hardy, J., S. Kiesser, L. Antrim, A. Stubin, R. Kocan and J. Strand. 1987. The sea-surface microlayer of Puget Sound: part 1. toxic effects on fish eggs and larvae. Mar. Environ. Res., 23:227-249.

Hoffman, E.J., G.L. Mills, J.S. Latimer, and J.G. Quinn. 1984. Urban runoff as a source of polycyclic aromatic hydrocarbons to coastal waters. Environ. Sci. & Tech., 18:580-587.

Johns, D.M. and R. Gutjahr-Gobell. 1988. Bioenergetic effects of Black Rock Harbor dredged material on the polychaete Nephtys incisa: a field verification. Tech. Rept. D-88-3. U.S. Army Engineers Waterways Experiment Station, Vicksburg, MS. 121 pp.

Khan, R.A. 1987. Effects of chronic exposure to petroleum hydrocarbons on two species of marine fish infected with a hemoprotozoan, Trypanosoma murmanensis. Can. J. Zool., 65:2703-2709.

Kiceniuck, J.W. and R.A. Khan. 1983. Toxicology of chronic crude oil exposure: sublethal effects on aquatic organisms. Aquat. Toxicol., 13:425-436.

King, B.D. III, B.W. Cain, F.T. Werner, and N.E. Sears. 1986. Fish and wildlife coordination act report Galveston Bay area navigation study, Galveston, Harris and Chambers Counties, Texas. U.S. Fish and Wildlife Service, Clear Lake Ecological Services Field Office, Houston, TX. 123 pp.

King, K.A., C.J. Stafford, B.W. Cain, A.J. Mueller, and H.D. Hall. 1987. Industrial, agricultural, and petroleum contaminants in cormorants wintering near the Houston Ship Channel, Texas, USA. Colonial Waterbirds, 10:93-99.

Landrum, P.F. and D. Scavia. 1983. Influence of sediment on an anthracene uptake, depuration and biotransformation by the amphipod Hyalella azetca. Can. J. Fish Aquat. Sci., 40:298-305.

Lee, G.F. 1976. Dredged material research problems and progress. Environ. Sci. Tech. 10: 334-338.

Lee, G.F. and R.H. Plumb. 1974. Literature review on research study for the development of dredged material disposal criteria. Contract Rept. D-74-1, U.S. Army Engineers Waterways Experiment Station, Vicksburg, MS. 145 pp.

Mahoney, B.M.S. and G.S. Noyes. 1982. Effects of petroleum on feeding and mortality of the American oyster. Arch. Environ. Contam. Toxicol., 11:527-531.

Neff, J.M. 1979. Polycyclic aromatic hydrocarbons in the aquatic environment. Applied Science Publ. Ltd., London. 262 pp.

Nelson, W.G., D.K. Phelps, W.B. Galloway, P.F. Rogerson, and R.J. Pruell. 1987. Effects of Black Rock Harbor dredged material on the scope for growth of the blue mussel Mytilus edulis, after laboratory and field exposures. Tech. Rept. D-87-7, U.S. Army Engineers Waterways Experiment Station, Vicksburg, MS. 118 pp.

Palmero, M.R. and E.L. Thackston. 1988. Refinement of column settling test procedures for estimating the quality of effluent from confined dredged material disposal area. Tech. Rept., D-88-9. U.S. Army Corps of Engineers, Waterways Experiment Station, Vicksburg, MS. 42 pp.

Pereira, W.E., C.E. Rostad, C.T. Chlou, T.I. Brinton, L.B. Barber II, D.K. Demcheck, and C.R. Demas. 1988. Contamination of estuarine water, biota, and sediment by halogenated organic compounds: a field study: Environ. Sci. Technol., 22:772-778.

Phelps, H.L., W.H. Pearson, and J.T. Hardy. 1985. Clam burrowing behavior and mortality related to sediment copper. Mar. Pollut. Bull., 16:309-313.

Riggin, R.M. and P.E. Strup. 1984. Screening methods for PAH priority pollutants in wastewater. EPA-600/4-84-007. National Technical Information Service, #PB 84-132992, Springfield, VA. 87 pp.

Steele, C.W. 1983. Effects of exposure to sublethal copper on the locomotor behavior of the sea catfish, Arius felis. Aquatic Toxicol., 4:83-93.

Stickle, W.B., S.D. Rice, C. Villars, and W. Metcalf. 1985. Bioenergetics and survival of the marine mussel, Mytilus edulis, during long-term exposure to the water soluble fraction of Cook Inlet crude oil. pp. 427-446 In: Marine pollution and physiology: recent advances. F.J. Vernberg, F.P. Thurberg, A. Calabrese, and W.B. Verberg (eds). Univ. South Carolina Press, Columbia, S.C.

U.S. Army Corps of Engineers. 1987. Final feasibility report and environmental impact statement Galveston Bay area navigation study. Four Volumes. Galveston District, Texas.

U.S. Environmental Protection Agency. 1980a. Ambient water quality criteria for polynuclear aromatic hydrocarbons. EPA 440/5-80-069. National Tech. Info. Ser. PB 81-17806., Springfield, VA. 192 pp.

-----. 1980b. Ambient water quality criteria for arsenic. EPA 440/5-80-021. Natl. Tech. Info. Serv. PB81-117327, Springfield, VA. 205 pp.

-----. 1980c. Ambient water quality criteria for copper. EPA 440/5-80-036. Natl. Tech. Info. Serv. PB81-117475, Springfield, VA. 163 pp.

-----. 1980d. Ambient water quality criteria for zinc. EPA 440/5-80-079. Natl. Tech. Info. Serv. PB81-117897, Springfield, VA. 157 pp.

-----. 1980e. Ambient water quality criteria for chromium EPA 440/5-80-035. Natl. Tech. Info. Serv. PB 81-117467. Springfield, VA 85 pp.

-----. 1980f. Ambient water quality criteria for lead. EPA 440/5-80-057. Natl. Tech. Info. Serv. Springfield, VA. 151 pp.

-----. 1980g. Ambient water quality criteria for cadmium. EPA 440/5-80-025. Natl. Tech. Info. Serv., PB81-117368, Springfield, VA. 183 pp.

Watling, H.R. 1982. Comparative study of the effects of zinc, cadmium and copper on the larval growth of three oyster species. Bull. Environ. Contam. Toxicol., 28:195-201.

Webb, J. 1985. Monitoring of transplanted marsh at Chocolate Bay, Texas. Rept. Submitted to Corps of Engineers, Galveston District, Cont. No. DACW64-85-M-0490, Galveston, TX. 16 pp.

Widdows, J., D.K. Phelps, and W.B. Galloway. 1981. Measurement of physiological conditions on mussels transplanted along a pollution gradient in Narragansett Bay. Mar. Environ. Res. 4:181-194.

Word, J.Q., J.T. Hardy, E.A. Crecelius, and S.L. Kiesser. 1987. A laboratory study of the accumulation and toxicity of contaminants at the sea surface from sediments proposed for dredging. Mar. Environ. Res. 23:325-338.

United States Department of the Interior
Fish and Wildlife Service
DIVISION OF ECOLOGICAL SERVICES
17629 EL CAMINO REAL, SUITE 211
HOUSTON, TEXAS 77058

TAKE PRIDE IN AMERICA

October 3, 1989

To Recipients of the Report: Contaminant Assessment of Maintenance Dredged Material from the Houston Ship Channel, Galveston Bay, Texas.

The Corps of Engineers reviewed the report and provided this office with their comments. Enclosed with this letter is an errata sheet correcting some minor errors in the report, corrected copies of Tables 2,3 and 7, and our comments that address the concerns expressed by the Corps of Engineers. The author regrets any problems the errors may have caused.

ERRATA

| | |
|---|---|
| Page 10 | Table 2. New table attached. |
| Page 15 | Table 3. New table attached. |
| Page 26 | Line 21. 41.5 ppb change to 22.0 ppb |
| Page 26 | Line 33. Restatement. Oil and grease measured in the discharging water totaled 185 ppm which translates to 0.555 ppm PAH residues (185 x .003). This is equivalent to 555 ppb which is 1.85 times higher than..... . |
| Page 27 | Table 7. New table attached. |

Table 2. Selected contaminants detected in maintenance sediments from the Houston Ship Channel between Redfish Reef and Morgans Point.

| | Contaminant Parameters (ppm) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Oil and Grease | | | Arsenic | | | Copper | | | Zinc | | |
| Station[a] | 1976 | 1983 | 1986 | 1976 | 1983 | 1986 | 1976 | 1983 | 1986 | 1976 | 1983 | 1986 |
| H-MR-1 | 700 | 926 | ND[b] | 5.7 | 5.8 | 3.1 | 19.0 | 13.0 | 13.3 | 110.0 | 76.3 | 45.9 |
| H-MR-2 | 870 | 464 | --- | 6.5 | 6.2 | --- | 17.0 | 12.9 | ---- | 74.0 | 71.3 | ---- |
| H-MR-3 | 670 | 783 | 188 | 5.7 | 3.9 | 5.4 | 16.0 | 7.9 | 10.6 | 66.0 | 30.0 | 26.0 |
| H-MR-4 | 830 | 532 | --- | 4.3 | 4.4 | --- | 14.0 | 12.8 | ---- | 55.0 | 56.0 | ---- |
| H-MR-5 | 760 | 417 | 243 | 6.6 | 5.0 | 2.9 | 18.0 | 12.8 | 17.8 | 60.0 | 74.4 | 49.4 |
| H-MR-6 | 670 | 245 | ND | 6.3 | 5.4 | 3.2 | 16.0 | 12.9 | 12.2 | 57.0 | 67.1 | 49.3 |
| H-MR-7 | 710 | 701 | --- | 6.0 | 5.2 | --- | 16.0 | 14.2 | ---- | 58.0 | 66.0 | ---- |
| H-MR-8 | 920 | 182 | 128 | 8.5 | 4.4 | 5.8 | 19.0 | 9.8 | 24.8 | 67.0 | 73.4 | 30.4 |
| H-MR-9 | 560 | 529 | ND | 6.5 | 6.7 | 4.4 | 16.0 | 13.2 | 12.7 | 70.0 | 78.3 | 57.9 |
| H-MR-10 | 640 | 886 | ND | 5.6 | 5.1 | 7.5 | 12.0 | 9.5 | 12.4 | 80.0 | 53.0 | 41.5 |
| H-MR-11 | 600 | 715 | 105 | 6.0 | 7.0 | 3.3 | 11.0 | 11.3 | 10.0 | 60.0 | 57.2 | 43.2 |
| H-MR-12 | 920 | 686 | ND | 6.0 | 4.6 | 8.2 | 16.0 | 7.5 | 8.7 | 76.0 | 47.5 | 43.0 |
| H-MR-13 | 690 | 624 | 195 | 6.0 | 5.7 | 3.5 | 12.0 | 12.0 | 6.2 | 65.0 | 77.5 | 41.8 |
| H-MR-14 | 730 | 294 | 127 | 7.5 | 4.9 | 18.0 | 12.0 | 8.0 | 6.8 | 60.0 | 55.0 | 27.8 |
| H-MR-15 | 810 | --- | ND | 7.5 | --- | 9.1 | 12.0 | ---- | 5.4 | 60.0 | ---- | 36.7 |
| H-MR-16 | 340 | 310 | 111 | 3.5 | 3.5 | 9.9 | 7.0 | ND | 11.8 | 48.0 | 38.2 | 22.5 |
| X | 714 | 553 | 84 | 6.1 | 4.6 | 6.4 | 14.7 | 10.5 | 11.7 | 66.6 | 61.3 | 39.6 |

[a] Stations were located at about one mile intervals from Morgans Point (H-MR-1) to Redfish Reef (H-MR-16).

[b] ND means not detected; -- means not analyzed.

Table 3. Contaminants analyzed in maintenance dredged material by the contract laboratories for this study.

| Contaminants | Detection Level |
|---|---|
| Routine Parameters | |
| Arsenic | 1.0 mg/kg |
| Cadmium | 0.1 mg/kg |
| Chromium | 1.0 mg/kg |
| Copper | 1.0 mg/kg |
| Lead | 1.0 mg/kg |
| Mercury | 0.1 mg/kg |
| Nickel | 1.0 mg/kg |
| Selenium | 0.5 mg/kg |
| Zinc | 1.0 mg/kg |
| p,p' - DDT | 0.2 mg/kg |
| Chlordane | 0.2 mg/kg |
| Toxaphene | 5.0 mg/kg |
| Total PCB's | 5.0 mg/kg |
| Oil and Grease | 5.0 mg/kg |
| Naphthalene | 50.0 ug/kg |
| Acenaphthene | 50.0 ug/kg |
| Fluoranthene | 10.0 ug/kg |
| Benzo(a) pyrene | 10.0 ug/kg |
| Total PAH | 0.2 mg/kg |
| Supplemental Parameters | |
| Bis(2-Ethylhexyl) phthalate | 50.0 ug/kg |
| Total chlorinated phenols | 20.0 ug/kg |
| Total methylnaphthalenes | 50.0 ug/kg |
| Total ethylnaphthalenes | 50.0 ug/kg |
| Total propylnaphthalenes | 50.0 ug/kg |
| Acenaphthylene | 50.0 ug/kg |
| Fluorene | 10.0 ug/kg |
| Total methylfluorenes | 50.0 ug/kg |
| Total ethylfluorenes | 50.0 ug/kg |
| Total propylfluorenes | 50.0 ug/kg |
| Phenanthrene | 20.0 ug/kg |
| Anthracene | 20.0 ug/kg |
| Total methylphenanthrenes | 120.0 ug/kg |
| Total ethylphenanthrenes | 120.0 ug/kg |
| Total propylphenanthrenes | 120.0 ug/kg |
| Pyrene | 10.0 ug/kg |
| Total methylpyrenes | 50.0 ug/kg |
| Total ethylpyrenes | 50.0 ug/kg |
| Total propylpyrenes | 50.0 ug/kg |
| Chrysene | 10.0 ug/kg |
| Benzo(b+k)fluoranthene | 2.0 ug/kg |
| Benzo(ghi)fluoranthene | 2.0 ug/kg |
| Perylene | 2.0 ug/kg |
| Total dibenzanthracenes | 2.0 ug/kg |
| Benzo(ghi)perylene | 2.0 ug/kg |
| Octachlorinated styrenes | 50.0 ug/kg |

Table 7. Contaminants detected in blue crabs collected at the Morgans Point control site and placed for three days at the Alexander Island confined disposal area discharge point.

| Contaminants | Control site (one sample) | Confined disposal discharge point (six samples) | |
|---|---|---|---|
| | | Range | X |
| Metals (ppm) | | | |
| Cadmium | 0.4 | 0.2 - 0.3 | 0.2 |
| Copper | 15.5 | 15.5 - 26.6 | 16.6 |
| Zinc | 42.8 | 26.4 - 30.8 | 28.8 |
| PAHs (ppb) | | (three samples) | |
| Pyrene | 9.2 | ND[a] - 43.9 | 14.6 |
| Chrysene | 10.2 | ND - 27.6 | 7.4 |
| Total | 19.4 | | 22.0 |

[a]ND = not detected

## FISH AND WILDLIFE SERVICE RESPONSE TO CORPS OF ENGINEERS COMMENTS

1. Comparison of sediment values to water quality criteria.

Response: We do not believe it is correct to say, "That no such criteria exist demonstrates that the scientific community is as yet unable to relate ecological effects to concentrations in sediments or vice-versa." The scientific literature throughout the 1980's published by researchers at Research Triangle Park, Gulf Breeze Laboratory, Puget Sound, and many foreign countries, is abundant with information relating the occurrence of tumors in fish, decreased benthic diversity, and many other adverse biological effects to sediments contaminated with heavy metals and polycyclic aromatic hydrocarbons. The fact that there are no sediment criteria or standards is not a result of a lack of scientific information.

Contaminated dredged material has been a concern for at least 20 years, and this concern no doubt contributed to the formation of the Dredged Material Research Program and the Field Verification Program. This concern speaks boldly for careful handling of the dredged material and the need to develop sediment quality criteria. The fact that there are no such criteria does not, in our opinion, relieve the Corps of Engineers (COE) of its obligations to protect the public and public resources from the adverse impacts caused by inappropriate handling of contaminated sediments.

Our presentation of the potential for sediment bound heavy metals to be released after maintenance dredging disposal requires clarification. Our intent was to identify the heavy metal concentrations that could become soluble due to physicochemical changes induced by shallow water disposal. We compared these to water quality criteria as a point of reference. It was not implied that the concentrations in the entire water column would be the same as the concentration in the sediment. The contaminant concentration would be lower in the water column due to dilution, and because only a portion of the contaminant in the sediment is in a soluble form at any particular time. The sediment is a reservoir for these contaminants. Neither the Corps of Engineers nor the Fish and Wildlife Service can at this time predict the water concentration of a contaminant, once the sediment has been dredged and disposed into the shallow water of Galveston Bay. Thus the Corps of Engineers should not imply that data from the limited elutriate test indicates no in situ biological effects of a contaminant in the sediment.

2. Discrepancies in data.

Response: We regret the typographical errors found by your staff in Tables 2 and 3 and will correct them in an errata sheet to be sent to all recipients of the report. However, it is important to note that these errors do not have a bearing on the conclusions and recommendations. Other errors have been discovered and will be noted in the errata sheet.

## SPECIFIC COMMENTS AND RESPONSES

7. Report States: "Kinetics of these metals in reduced sediment during disturbances allows toxic forms of each metal to be mobilized into the Galveston Bay water column at levels that exceed chronic toxicity values for estuarine species."

   COE Comment: "Whether these reactions are occurring is speculative as no data are presented relative to them in the report. Even if they were to occur, and this can be determined through the elutriate test, they can only be evaluated in light of mixing occurring at the site. Elutriate data do not show this mobilization to be widespread. The ambient water levels included with the sediment data are high in many instances, indicating levels may be exceeded even in the absence of maintenance dredging. This paragraph should be revised in light of all of the available data, not just selected data."

   FWS Response: The elutriate test, as it is applied, is an inappropriate assessment technique that was designed to test solubility of contaminants from dredged material to be disposed in the ocean during the dumping process. It is not applicable to disposal of maintenance material disposed into a shallow bay. Material disposed in a shallow bay gets long-term disturbance (not 1/2 hour of mixing) by wave action, boat traffic, etc., and is exposed to changes in salinity and other parameters (pH, dissolved oxygen, temperature etc.) that allow both solubility and reprecipitation of contaminants onto sediment particles. The elutriate test, as well as the 10-day bioassay test, as currently performed are inappropriate assessment tools to predict contaminant impacts on the biota in a shallow bay.

   The fact that the ambient water levels are high in many instances supports the FWS assessment that there is solubility of contaminants occurring, and perhaps is a result of sediment being resuspended by boat traffic in the ship channel. If this is correct, maintenance material deposited into the shallow waters of Galveston Bay may be a more serious problem than the COE has recognized to date.

9. Report States: "Resuspension of these fugitive sediment particles into the water column occurs with wave action, boating activity, and trawling, creating a continuous chronic exposure scenario to the aquatic life in Galveston Bay."

   COE Comment: "This is speculative as no data are presented to support the statement. Further, the statement needs to be put in the proper perspective. For example, it has been estimated that shrimp trawling in Corpus Christi Bay suspends 16-131 times more sediment than maintenance dredging. Contaminants and sediments are not generated within the channel; they originate elsewhere and, in order to accumulate in the channel, must be suspended and transported. Therefore, organisms are exposed to the sediment long before their subsequent deposition and removal from the navigation channel."

FWS response: Your comments are correct and support the assessment that sediments are resuspended by trawling. The issue is that once contaminated sediments are removed from the channel and deposited in the bay, they are resuspended into the water column and thus increase the exposure above the ambient level mentioned in the COE comment.

10. Report States: "Small silt and clay particles, because of their large surface area to volume ratio, will either absorb or adsorb the nonsoluble organic chemicals that are discharged into the bay system."

COE Comment: "Because the contaminants are absorbed or adsorbed to the silt and clay particles, they are probably not bioavailable."

FWS Response: Several published reports indicate that a solution of pH 1.1 dissolved 100% of all metals from sediments. The pH of stomach acids from fish and wildlife species vary in the 2.0 to 3.0 range. If contaminated silts and clay particles are ingested by aquatic organisms (filter feeders and those that eat filter feeders) the acid (pH) content of their digestive systems is strong enough to release sediment bound contaminants, not necessarily 100%, but at a level not yet known. The COE, in our opinion should not state, "they are probably not bioavailable" without scientific studies or literature citations that support that position.

12. Report States: "These silt and clay particles become contaminated with nonsoluble organic chemicals and settle into deep channels in estuaries."

COE Comment: "The nonsoluble organic chemicals settle in all parts of the bay, not just in the deep channels."

FWS Response: Silt and clay particles are suspended in turbulent water and tend to settle in quiet water. Deep channels are a sediment trap because they offer less turbulent water than the surrounding shallow water. If sediments did not accumulate in the deep channels there would be no need to perform maintenance dredging. It follows then, if these silt and clay particle are contaminated, the deep channels will accumulate larger amounts of these contaminants than the shallow parts of the bay. Maintenance dredging then places sediments back into the bay during disposal and results in increasing the exposure of biota to those contaminants.

16. Report States: "Bioavailability of sediment bound contaminants is a chronic exposure problem that cannot be determined by bulk-chemical analysis or short term (i.e., five day) bioaccumulation studies."

COE Comment: "There are no chronic bioassay tests which are suitable for regulatory evaluation of dredged material. Current practice for benthic marine acute toxicity bioassays or bioaccumulation potential is a 10 day exposure period, not 5 days. In addition, this statement would appear to conflict with the 5 day crab study that was attempted."

FWS Response: That there are no chronic bioassay tests which are suitable for regulatory evaluation of dredged material does not, in our opinion, release the COE from its obligation to see that its activities do not degrade the Galveston Bay estuary. There is a wealth of published literature on techniques for in situ bioassays using clams or oysters that, we believe, should be routinely done before, during, and after maintenance dredging in Galveston Bay. The 10-day, in-laboratory, bioassays currently paid for by the COE are an inappropriate assessment technique and those data should not be extrapolated to speculate on impacts to Galveston Bay biota. We believe that a five day crab study in situ would yield better data than a 10-day bioassay performed in the laboratory, as currently done. The COE has excellent biologists on its staff that could design, perform, and interpret results from in situ studies.

17. Report States: "Benthic organisms will ingest these contaminated particles and incorporate the contaminant into their body tissue and transfer them to higher trophic levels.

COE Comment: "Numerous studies have documented that trophic transfer in aquatic ecosystems is uncommon (see for example, "Potential for Biomagnification of Contaminants within Marine and Freshwater Food Webs", Technical Report D-84-7, USAE, WES). 10 day bioassays and elutriate testing are within the scope of current regulatory guidance."

FWS Response: Numerous studies have demonstrated that biomagnification, not trophic transfer or bioaccumulation, in aquatic ecosystems is uncommon. Aquatic ecosystems do not stratify in a similar manner as terrestrial ecosystems because aquatic ecosystems are more food webs than trophic levels, thus biomagnification is not the issue. Table 9 in the Technical Report D-84-7 shows that silver was up to 40 times higher in clams than in the sediment, cadmium was up to 60 times higher in a dogwhelk than the sediment, and copper was up to 5 times higher in a clam species than in the sediment. This is bioaccumulation at a serious level. The author of the Technical Report concludes (without any data), "As the biological availability of contaminants from sediments should be similar regardless of whether or not these sediments have been dredged and placed in an open water disposal site, it is unlikely that the open water disposal of contaminated dredged material will cause any widespread ecological perturbations due to biomagnification." This statement is pure speculation and is written in such a manner that it masks the potential for serious impact by bioaccumuluation due to contaminated maintenance material discharged in shallow estuaries.

22. COE Comment: "Page 10, Table 2 - the 1980 data should be included in this table. In addition, in verifying the data numerous typogra-

phical errors were found in the table. A corrected table is enclosed. These values should also be put in the proper perspective. For example, the earth's crustal abundance for these parameters is as follows: arsenic - 5 ppm., copper - 70 ppm, and zinc - 80 ppm."

FWS Response: The COE 1980 data came from 8 sample sites out of the 16 sampled in 1976, 1983 and 1986. The numerous typographical errors noted in Table 2, once corrected, did not change the meaning, interpretation, or importance of the findings. Stating that the earth's crustal abundance for any metal is relative to sediment loading in estuaries, when looking at the "proper perspective", is irrelevant. Using published material such as the 1985 report by the Bureau of Economic Geology titled, "Submerged Lands of Texas, Galveston-Houston area: Sediments, Geochemistry, Benthic Macoinvertebrates, and Associated Wetlands", indicates the channel sediment is highly contaminated relative to bay wide samples.

24. Report States: "Thirty-two sediment samples collected during this assessment were analyzed for oil and grease as well as for total PAH residues."

COE Comment: "Page 11, Line 15 - It is unclear where these 32 samples came from and if they are included in the report. They appear to be 1987 samples but it is not possible to account for all of them in the report or with the data we have. It is also not clear whether the samples are all dredged material, all control areas, or a combination. Since specific PAH's were analyzed in the report it is questionable why the PAH inference is necessary."

FWS Response: The 32 samples were all of the sediment samples collected during this assessment in which both "oil and grease" and "total PAH" parameters were measured. In order to evaluate the oil and grease parameter in sediment samples one must know if there are problem chemicals masked by the "oil and grease" parameter. Simply knowing the "oil and grease" value is of little use. The COE has historically responded to FWS assessments that there is no constant relationship between oil and grease and PAHs. We agree. However, that does not preclude establishing the relationship in maintenance dredged material from Galveston Bay, so that an environmentally sensitive assessment of those important pollutants can be made. The COE is correct in saying that specific PAH's were analyzed. However only a minor portion of more than 200 specific PAH compounds and their metabolites are considered in the analytical techniques. This is the reason why the sum of the specific compounds never equals the <u>total</u> PAH value. The COE must also recognize that the recovery rate for PAHs in spiked samples is less than 100 percent so that the reported values, from sediment analysis, should theoretically be multiplied by some factor greater than 1.0. The FWS report did not do this: it could be said that our assessment was based on less than 100 percent of the actual contaminants in the samples.

43. Report States: "Maintenance dredged material with greater than 100 ppm oil and grease residues be considered as too contaminated for

release into Galveston Bay because at 0.3 percent PAH compounds these contaminants will exceed 300 ppb, the criterion to protect saltwater aquatic life."

COE Comment: "This recommendation is untenable because it presumes that there is a constant relationship between oil and grease and PAH's. There is no such relationship, nor is there any relationship between PAH's in sediment and water quality criteria."

FWS Response: The report stated (page 11 Line 15-17) that "32 samples collected during the assessment had an average of 440 ppm oil and grease residues and the total PAH compound value average 1.6 ppm which is 0.3 percent." That was the mathematical constant developed from the average of 32 samples. That information should alert the COE that there are problems with their previous assessments of impacts on Galveston Bay biota from maintenance dredged material disposal. The fact that there is no clear relationship between PAHs in sediment and water quality criteria does not mean that sediment bound PAHs do not get suspended into the water column and do not get ingested by estuarine biota. Our position is that they are probably ingested, and they are resuspended into the water column, and perhaps more importantly, the surface microlayer.

44. Report States: "Contaminated sediment from maintenance dredging of the Houston Ship Channel be confined in containment areas."

COE Comment: "There is no such thing as uncontaminated sediment. Under the report's assumptions, the control areas would qualify as contaminated as well. Does the report advocate confining all of the bay bottoms in Galveston Bay?"

FWS Response: The issue here, of course, is the contaminated sediment handled by the COE in the maintenance operation. The COE has long recognized that maintenance material is generally more contaminated than new work material (see the many reports generated by the Dredged Material Research Program). The report advocates confining maintenance dredged material so that the mobilization and resuspension of this material no longer increases contamination or aggrevates contaminant problems in wider areas of the bay. This should improve the quality of the bay bottom so that a less contaminated control area can be identified.

46. Report States: "Contractors for dredging of the Houston Ship Channel post a performance bond that will insure the reconfinement of all fugitive sediment from any levee failure or suspended sediment criterion violation.

COE Comment: "This recommendation is outside the scope of the report. It also is based on an erroneous assumption of the disposal operation (see General Comment 4). Since the areas are used by many different contractors for both public and private uses, it is questionable whether this recommendation is legal or enforceable."

FWS Response: This recommendation addresses the heart of the problem; i.e. contaminated maintenance dredged material reentering the bay. There was indeed levee failure on Atkinson Island. For dredging funded by the COE any restriction written in a dredging contract should be legal and enforceable.

47. Report States: "A comprehensive study of the effects of contaminated maintenance dredged material on the growth of Spartina alterniflora be conducted."

COE Comment: "This is outside the scope of our environmental requirements. Many studies have already been performed to evaluate this potential."

FWS Response: We believe the COE has an environmental responsibility that may be outside of their environmental requirements. Most studies previously performed have all been associated with establishing Spartina marshes with noncontaminated maintenance material, or looking at heavy metal uptake by Spartina. We are aware of no studies that concern impact on growth of Spartina using contaminated sediment from maintenance dredging in the Galveston Bay area.

48. Report States: "Evaluation of maintenance dredging for environmental affects include an in situ bioassay using clams, oysters, or crabs, before dredging contracts are advertised" and, "Contaminant assessment of maintenance dredging include the supplemental list of PAH compounds presented in this study."

COE Comment: "These types of evaluations have already been performed and discussed in other documents (GBANS) and have found no significant effects."

FWS Response: Evaluations performed and discussed in other documents do not address the concerns raised in the report. Those evaluations considered very few contaminants or were not performed in Galveston Bay or any habitat that would be a suitable substitute. The data discussed in GBANS was generated from a one-time small effort with an inadequate assessment. The GBANS discussion, of the 1987 data collected by the COE, is in our opinion, replete with inaccuracies. The discussion in GBANS continuously referred to data from elutriate tests, bioassay, and bioaccumulation studies performed on new work material to evaluate maintenance material. The 1987 data on PAH concentrations actually supports the ideas presented in the FWS report, but was dismissed by the COE as, "no significant effects."