ENVIRONMENTAL MANAGEMENT OF A SHIP CHANNEL-HARBOR COMPLEX

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ABSTRACT

This study discusses the environmental management of a typical ship channel-harbor complex located along the Texas Gulf Coast. The best current available literature was utilized along with a number of previous studies completed at Texas A&M University. This information was supplemented by a field study of the Port of Corpus Christi Inner Harbor and the Port of Brownsville Fishing Harbor, along with a non-point source pollution study of the Port of Brownsville watershed. The study explains the most important pollution sources, discusses their impact upon the waterways, outlines their priorities, provides a general solution for each, and presents a suggested plan of action. The long-range environmental implications of the various activities are discussed so that management entities may make competent decisions in future planning that are conducive to an active industrial climate and a healthy environment.

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CHAPTER I

INTRODUCTION

The increased demand on water transportation, rapid industrial growth, and expanded harbor facilities combined with more stringent environmental regulations has created a need to intensify environmental management techniques. As industrial waste treatment methods are improved, many of the environmental problems once thought to be insignificant need to be re-evaluated. The pollution problems that will be considered in this study are dredged materials disposal; waste, bilge, and ballast water from ships; tank and barge washings; rural and urban runoff; domestic sewage discharges; water withdrawals and returns; industrial wastes; oil spills; floating debris; seafood processing wastes; and hazardous materials spills. In view of the environmental progress that has been made on some of the problems, others that were previously obscure may now be studied.

Management entities responsible for ship channel-harbor complexes need a broader understanding of these problems so that competent decisions can be made. The major environmental decision that the management personnel will be confronted with are:

1. What should be the navigation district's level of involvement in waste treatment?

2. What should be the scope of future expansion involving dredged material disposal?

3. Is it the navigation district's responsibility to provide a collection system for wastes from vessels?

4. Should the navigation district be responsible for contingency plans for oil and hazardous materials spills?

There are numerous references presently available on the study of water pollution from various sources emptying into harbors. However, there is limited data dealing with the ship channel-harbor complex as a complete system. This project considers the available data and supplements it with new data gained from field studies involving two ship channel-harbor complexes along with visits to eight of the major facilities on the Texas Gulf Coast.

Objectives

This study will describe the many sources of pollution, their relationship to the overall problem, their importance in present and long-range planning, their solutions, and their priorities.

The objectives of this project are:

1. To identify, describe, and classify the many sources of water pollution in ship channel-harbor complexes,

2. To assess the magnitude and the impact of the various sources of water pollution within these complexes, and

3. To discuss the solutions to the environmental problems in a ship channel-harbor complex, their priorities, and a suggested plan of action.

Narrative

Chapter II provides a literature review of research concerning ports as a whole, and specific water pollution problems within them. This review includes recent studies published by federal and state organizations as well as independent authors.

Chapter III is a collection of studies and data that are relevant to field studies completed during this project. This previous research is included to provide the reader with background information with which the collected field data may be compared. Original research completed during this project includes interviews with various regulatory agencies and port authorities, water quality studies of the Port of Corpus Christi Inner Harbor and the Port of Brownsville Fishing Harbor, and a non-point source study of the Port of Brownsville watershed.

Chapter IV combines the information presented in Chapter II and Chapter III and proposes a priority list of water pollution problems followed by a discussion of the alternative solutions to the problems. The remainder of the chapter is dedicated to discussing a proposed plan of action for the purpose of providing guidance to entities faced with the mentioned problems.

Chapter V summarizes the previous chapters and lists the conclusions of this study. This chapter also makes recommendations concerning the application of the conclusions.

CHAPTER II

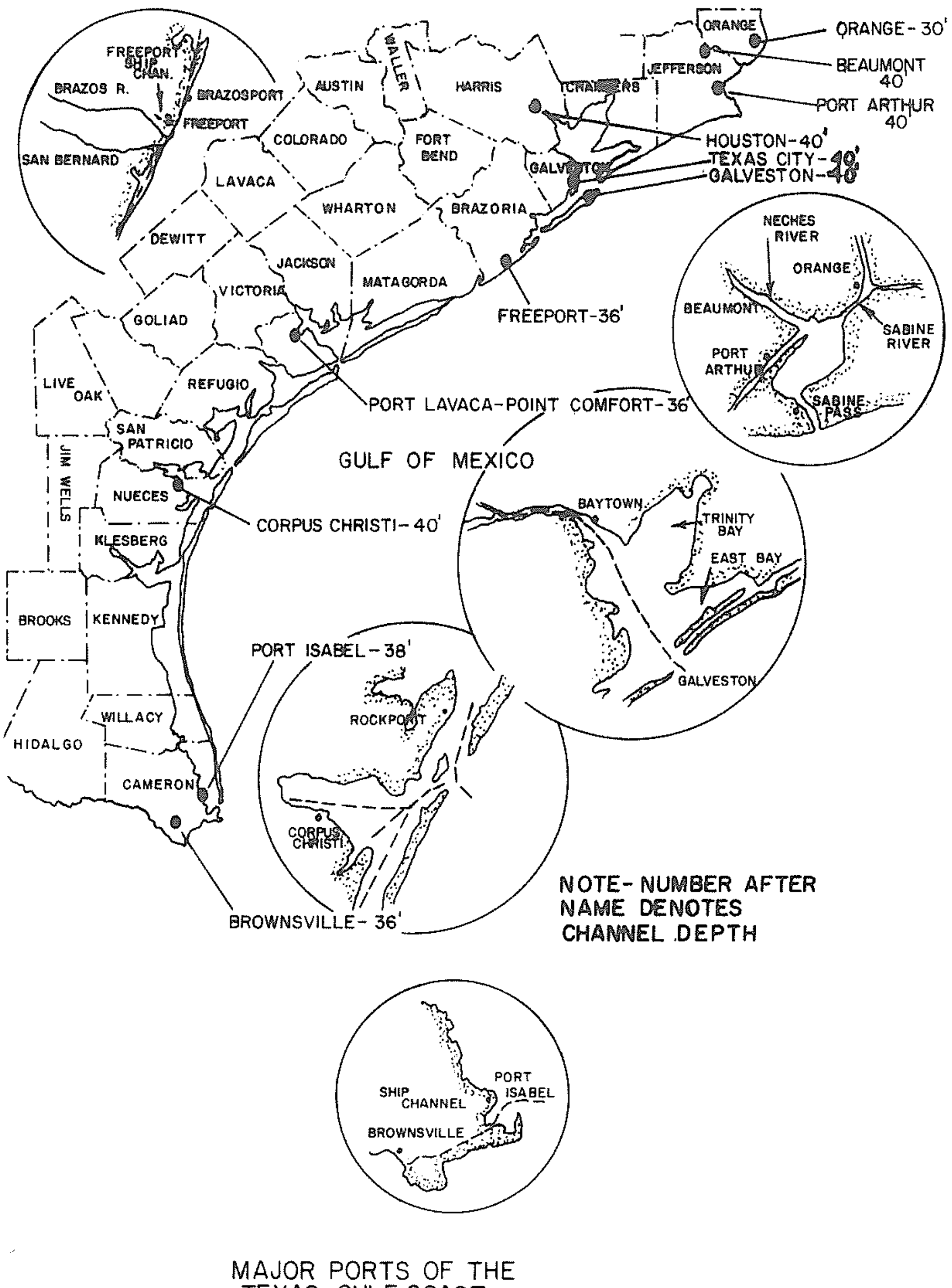
THE SHIP CHANNEL-HARBOR COMPLEX AND THE RELATED WATER QUALITY PROBLEMS

Introduction

Quinn (1) defined a harbor as a water area partially enclosed and so protected from storms as to provide safe and suitable accommodation for vessels seeking refuge, supplies, refueling, repairs, or the transfer of cargo. Bird (2) defined a port as a facility where cargo is loaded or discharged. Quinn added the thought that a port consists of piers or wharves, warehouses, and overland transportation terminals. According to Bird, the words 'port' and 'harbor' have become interchangeable and will be used interchangeably in this report. The term 'ship channel' will refer to the waterway providing vessels access to a port or harbor.

General Statistics and Description

The 14 major deep-water ports in Texas according to Hann (3) are shown in Figure 1. Some are considerably more significant than others; both environmentally and economically. All of the ports required dredging. Parts of some ports are entirely man-made while other ports may have natural channels that were deepened. The ship channel-harbor complexes considered in this research ranged from 30 to 40 feet deep and varied in length from just a few miles up to 50 miles. These systems are connected by a 426-mile intracoastal waterway with a design depth of 12 feet.



MAJOR PORTS OF THE
TEXAS GULF COAST
FIGURE I

Cargo and Industries Served

According to Miloy, et al. (4), water transportation is responsible for nearly 75 percent of all the goods shipped from the state. Also, they reported that 45 percent of our nation's urban population resides in coastal counties. Bradley (5) reported the relationship between dry and liquid cargoes handled shown in Table 1. It is obvious that the role of the port is to serve everyone. Water transportation brings in raw materials, fuel, and manufactured goods to supply industry over a wide geographic area. In turn, the industries are directly or indirectly responsible for the livelihood of a large portion of the citizens of Texas.

The Port Authority

The port authorities in Texas, often called navigation districts, are governmental bodies created to manage publicly owned ship channel-harbor complexes. According to Etter and Graham (6), such organizations are authorized by Article III, Section 52 and Article XVI, Section 59 of the Texas Constitution. They also stated that all deep-water ports in Texas are administered by navigation districts except the Texas City Terminal. The Texas City Terminal Railway Company is privately owned. The Navigation Districts' responsibilities are to engage in projects involving conservation, reclamation, and support of the State's waterways for navigational purposes. They are also concerned with port development and operation.

The navigation districts of Texas must obey all state and federal environmental laws just like privately owned companies. These

TABLE 1

Types of Cargo Handled by the Major Texas Ports

Port	Dry Cargoes (Grain, Cotton, Sulphur)	Liquid Cargoes (Petroleum & Chemical Products)
Orange	38%	62%
Beaumont	9%	91%
Port Arthur	9%	91%
Sabine Pass	6%	94%
Houston	37%	63%
Texas City	2%	98%
Galveston	95%	5%
Freeport	24%	76%
Corpus Christi	31%	69%
Port Isabel	13%	87%
Brownsville	12%	88%

Source: Bradley (5)

entities have the power to seek federal improvements to waterways, and must provide areas for the disposal of removed dredged material. Two sources of funding available to districts are revenues from its services and long-term tax or revenue bonds. A district seldom can support capital expansion and improvement without long-term debt.

The ports of Texas provide a varied array of services for their users. These services require a great number of skilled employees and a diverse technical and management staff.

Characteristics of a Ship Channel

Hann (7), in his 1975 report concerning the Texas Gulf Coast, discussed port and inner harbor complexes and their characteristics. He mentioned how they were often protected by barrier islands and had only very small inflows from overland runoff. He pointed out that this, combined with the one-to two-foot tides, caused very long flushing times. The limited tidal mixing and freshwater inflow created a condition vulnerable to pollutant buildups. Hann also listed environmental modifications affecting Texas estuaries. The modifications were: (1) ship channels, (2) upstream water resource development, (3) water withdrawals and returns, (4) drainage of marshlands, (5) urbanization, (6) sand, gravel, and shell dredging, and (7) dikes, jetties, and other structures.

The Quality, Quantity, and Frequency of Discharge of the Various Sources of Water Pollution

A knowledge of the sources of water pollution is necessary before solutions can be found. It is not the intention of this report to imply that all of the pollution sources named are the cause of a problem. It has, however, been determined that the listed sources have the potential for contributing to a problem.

Dredging

Dredging is the mechanical alteration of a body of water by the removal of materials from it. There are basically two types of materials: (1) sedimentation and (2) natural or virgin material. In this report, the removal of sedimentation is referred to as maintenance dredging, while the removal of natural materials is referred to as new dredging.

New Dredging. New dredging causes a turbidity problem immediately around and for some distance out from the dredging activity. According to Ketchum (8), increased turbidity can smother bottom organisms and cause oxygen depletion. However, he added that these effects are of such small extent and short duration that they are generally considered insignificant.

Materials from new dredging are usually disposed of in open water. According to Ketchum, extensive quantities of disposal may alter the bottom or bank configuration, subsequently altering flow conditions. This may cause sedimentation in the dredged channel or it may alter the biological habitat of the body of water. Ketchum also related an incident where dredged material was disposed of in the Laguna Madre, south of Corpus Christi. It covered the grass beds and blue green algal mats of the shallow flats, eliminating the dominant benthic producers. It also caused a decrease of depth and circulation, resulting in the loss of many plankton and fish species.

Cases often occur where it is advantageous to place the dredged materials in marshes along the coast. Ketchum reported that this practice destroys the habitat for many birds and mammals.

Slotta and Williamson (9) agreed that dredged materials can be detrimental to the environment, but the positive results of dredging can offset the disadvantages. They mentioned that channels not only provide good navigation, but often they provide improved circulation within an estuary. This can increase the available food for shellfish and fish. Also, it can cause dilution and flushing of man-made wastes that are frequently discharged into estuaries.

Maintenance Dredging. In maintenance dredging, the sediment is quite often too polluted to dispose of in open water. Research done by Bassi and Basco (10) revealed that in open water dredged materials can be a semi-mobile mass. This would spread contaminants around the estuary, as well as causing oxygen depletion by any oxygen-demanding organics present. This was verified by Holmes (11) in his study of the migration and redistribution of heavy metals in an estuary.

Therefore, the Corps of Engineers must issue a permit before any dredging can begin. The permit will state how the dredged materials may be disposed of. If specific criteria are exceeded, open-water dredged materials disposal may not be used. Slotta and Williamson (9) reproduced what they call the EPA "Basic Seven", which is shown in Table 2. In addition to the criteria in Table 2, the information in Table 3 must also be supplied to the EPA so that the approximate environmental impact can be assessed.

TABLE 2

EPA Guidelines for Dredged Materials

Parameter	Percentage (dry wt. basis)
Total Volatile Solids (TVS)	6.0
Chemical Oxygen Demand (COD)	5.0
Total Kjeldahl Nitrogen (TKN)	0.10
Oil-Grease	0.15
Mercury	0.0001/1 ppm
Lead	0.005/50 ppm
Zinc	0.005/50 ppm

Source: Slotta and Williamson (9)

TABLE 3

Environmental Impact Information Required by the EPA to Obtain a Permit to Dredge

1. Volume of dredged material.
2. Existing and potential quality and use of water in the disposal area.
3. Other conditions at the disposal site, such as depth and currents.
4. Time of year of disposal (in relation to fish migration and spawning, etc.).
5. Method of disposal and alternatives.
6. Physical, chemical, and biological characteristics.
7. Likely recurrence and total number of disposal requests in the receiving water area.
8. Predicted long-and short-term effects on receiving water quality.

Source: Slotta and Williamson (9)

If the criteria for dredged materials are exceeded, the Corps of Engineers may not permit the dredging, or they may require that the materials be disposed of on land within a diked area. Naturally, the diked area has to be chosen in a location with the least environmental impact. The land area must be large enough to hold the required dredged material and to accomplish the desired amount of solids settling. The availability and the cost of this land area can be a tremendous problem to a navigation district. In waterway expansion projects involving estuaries, where the sediment is contaminated, the cost of disposal area or right-of-way may be prohibitive.

Hann (12) found that the decay rate of undesirable materials in sediment in the Houston Ship Channel was negligible. He predicted no improvement in the outlook for future dredging projects unless better methods of handling the dredged materials are devised. Hann also said that the primary source of pollutants composing the sediments warrant more attention.

In his study of natural background levels of heavy metals in the Texas Gulf Coast, Slowey (13) found that the EPA criteria for zinc concentrations in dredged materials may be too stringent. He found that in the upper Gulf Coast, natural zinc levels often exceeded the 50 ppm allowed.

Waste from Ships

The waters of ship channel-harbor complexes are the recipients of two basic wastes from ships. These wastes are sanitary sewage along with miscellaneous solids and wash water from loading.

Sanitary Sewage. According to Robins (14), sanitary sewage when discharged has harmful effects such as (1) virus and bacteria harmful to people directly or through marine life; (2) excessive oxygen demands; (3) upset of aquatic environment by blockage of sunlight with suspended solids or by the deposition of sludge layers on the bottom; and (4) the aesthetic insult created by floating sewage solids.

Sewage varies depending on whether the system employs a flush water reuse system or not. According to Robins (14), most of the wastes are highly concentrated, deeply colored, and sometimes contain deodorizing chemicals. He found samples from boats to have up to 3400 milligrams per liter suspended solids, a BOD_5 of 3500 milligrams per liter, and a coliform count of up to 10^{10} MPN per 100 milliliters. Robins (14) added that as of June 1972 the Coast Guard, acting under authority of the EPA, must certify sanitation devices aboard vessels.

Solid Wastes. Weinheimer and Hooper (15) mentioned that even though laws prohibit it, solid wastes generated in loading and unloading operations are still discharged freely into water. They say that bulk-loading facilities are designed for capacity, not cleanliness. They also say that often the material is allowed to blow across the water or is washed into the water by rainfall. The primary commodities (5) handled are alumina, bauxite, coal, wheat, iron ore, and phosphate rock.

Ship Bilge Water

Section 311 of Public Law 92-500 stated that it is illegal to discharge oil or hazardous materials upon the navigable waters of the

United States in harmful quantities. The aforementioned law obviously prohibits the pumping of bilges in ports.

According to Hooper and Myrick (16), the bilge of a vessel is a collection point that receives effluent from on-deck drains, wash water, leakage from tanks, spillage, seawater leakage, condensate, and engine leaks. This sump must be periodically pumped out to lighten the vessel. The frequency of the required discharge depends usually on the condition of the vessel's hull, mechanical equipment, and tanks.

Hooper and Myrick observed that the more common contents of bilge water are oil and grease, pathogenic organisms, cargo leakage, chemical cleaning compounds, and nutrients. They also stated that most commercial ocean-going vessels only use oil-water separators to clean bilge discharges.

Ship Ballast Water

Ship ballast water is seawater pumped aboard in the port of destination as the cargo is unloaded. It provides the ship with greater stability while at berth, insures adequate propeller immersion, and lowers the center of gravity for improved seaworthiness. Hooper and Myrick (16) reported that tanks used for ballast water are often used alternately for fuel oil or cargo oil, especially on tanker type vessels.

Hooper and Myrick (16) categorized the pollutants in the ballast water discharged as usually containing oil, suspended solids, and pollutants from the waterways where the ballast water was pumped aboard. Ketchum (8) reported that unless a tanker has an oil-water separator tank, the oil or clingage pumped overboard can amount to 0.3 to 0.4 percent of the cargo. Hooper and Myrick (16) reported that most wellmanaged hydrocarbon loading terminals have receiving facilities for ballast water.

Ship Tank and Barge Washings

Hooper and Myrick (16) referred to the effluent produced from the washing of tanks as tank-cleaning slops. They also said that the slops contained oil, oily sludge, and chemical tank-cleaning compounds. Hooper and Myrick discovered that most tankers are now disposing of tank-cleaning slops through shoreside facilities.

Ball, et al. (17) discovered in their research that tank washings are now usually disposed of through shoreside facilities or at sea. Ball also stated that many terminals follow load-on-top procedures, where ballast or tank washings are drawn off the bottom and pumped to treatment facilities.

Ball (17) found that there were ten major commercial barge cleaning companies along the Texas Gulf Coast, as well as refineries and petrochemical plants that clean their own barges. He stated that crude oil and diesel fuel barges were the type most frequently cleaned. However, some of the barges contained asphalt and chemicals such as benzene.

Ball's field research revealed that between 10,000 and 150,000 gallons of wastewater are generated from each barge cleaning. He found that in 1974 only four of the companies had in operation what he called "semi-permanent" disposal systems. Some of the barge-cleaning companies had their wastewater hauled away by vacuum trucks. One company used an evaporation pond, which, if not properly designed, could be over-topped by rainfall, or could leak, allowing wastewater to possibly pollute nearby bodies of water. Ball reported that one company utilized sprayers to increase evaporation, but that most of the wastewater was removed by some other unknown means. He reported that other barge-cleaning facilities were separating the oil and water, and treating the effluent before returning it to the channel. Some plants yielded good effluents, while others did not. Several of the plants were either in the process of upgrading facilities or were planning to expand.

Non-Point Source Pollution

Drainage from pastures, farmlands, urban and industrial areas, forests, irrigation tail water, decaying vegetation,and wastes from range livestock and wild animals is considered non-point source pollution and has largely been overlooked in the past. It has been considered natural, uncontrollable, and insignificant. However, in the study of ship channel-harbor complexes, the area drained through the channel is significant. Non-point source pollution is more difficult to quantify and qualify than the more typical point source pollution that may be traced to one particular discharge.

Rural Runoff. One study of virgin lands which had been transformed into farmland indicated a marked decrease in organic matter due to cultivation (18). It was found that organic nitrogen in the organic matter was transformed into inorganic nitrogen that could readily be leached away as a nitrate (19). Romkens and Nelson (20) found a direct relationship between the addition of phosphorus fertilizer and soluble orthophosphate concentrations in runoff. Typical values for nitrogen and phosphorus loss in surface runoff, as listed by the EPA (21), are given in Table 4. However, in Nebraska, Muir,

TABLE 4
General Quality of Surface Runoff From Rural Non-Point Discharges

Item	Benson (23)	McCarl (24)	Weidner, et al. (25)
Land Use	Farmland	Farmland	Research plots and apple orchard
BOD, mg/l	5-30	3-15	3-8.4
BOD, lb/acre/yr	-	6-9	3.7-120
COD, mg/l	50-360	70-780	40-68
COD, lb/acre/yr	-	246	27.8-1300
Solids, mg/l	90-5000 SS	180-6000 SS	500-575 TS
Solids, lb/acre/yr	-	2040 SS	185-13,200 TS
Total Phosphorus, mg/l	0.26-2.4 Soluble P	0.04-60	0.42-0.98
Total phosphorus, lb/acre/yr	-	0.07	0.36-9.0
Org. N + NH_3, mg/l	1.3-20.3	2.8-17	-
Total nitrogen mg/l	-	12.9-33.2	4.9-9.0
Total nitrogen lb/acre/yr	-	8.4	0.8-237

et al. (22) reported that the nitrogen content of rain water (2 PPM) is a larger contributor of nitrogen to streams than overland runoff. The same study indicated that human and livestock concentrations are linearly related to nitrogen and phosphorus levels in runoff. White and Williamson (26) found a relationship between fertilization and nutrient losses.

Klausener,et al. (27) found that the total yearly nitrogen in runoff did not exceed the amount in rainfall. However, during the fall, nitrogen concentrations in rainfall were exceeded by runoff from highly fertilized crops, poor management, and improper tillage practices. Studies by Thomas and Crutchfield (28) in Kentucky, revealed a relationship between phosphorus concentrations and land use. They also concluded that neither nitrate nor phosphorus concentrations had increased during the past 50 years.

Weidner, et al. (25) studied six watersheds in Ohio and found that with improved cultivation practices in a wheat farming operation, the phosphate losses could be reduced from 27.7 lb/ac to 1.1 lb/ac. He found no significant phosphate loss from pasture land.

Willrich and Smith (29) found that phosphorus concentrations of streams in unfertilized forested lands was 0.007 mg/liter, whereas for fertilized agricultural watersheds, it ranged from 0.03 mg/liter to 0.11 mg/liter.

Weibel,et al. (3) studied the runoff from a 27-acre urban area and found that it yielded 730 lb/acre/yr suspended solids, 22 percent of which were volatile, 33 lb/acre/yr BOD, and 240 lb/acre/yr COD.

Weidner,et al. (25) studied two 1.5 acre watersheds and a 5-acre apple orchard in Ohio, and found that the BOD ranged from 3.7 - 120 lb/acre/yr and the COD losses ranged from 27.8 to 1300 lb/acre/yr.

McCarl (24) and Bragonn and Miller (31) concluded that 50 percent or more in sediment reduction could be realized by implementing soil conservation measures on agricultural lands.

Researchers have found that agricultural chemicals are an important factor in the quality of surface waters. If the chemicals are loosely held by the soil, they can be dissolved into the runoff. If they are tightly held by soil particles, the chemicals may get into streams (21) as sediment. Field data concerning concentrations of pesticides in streams is important if the waters studied drain predominately agricultural areas. Toxaphene and Benzene Hexachloride were found in the water supply for a town in Alabama that was supplied from a 400-square-mile cotton-growing watershed. DDT was also used on the cotton, but has a strong affinity for organic matter in soil and was not dissolved by the runoff (32).

Urban Runoff. Van Sickle (33) reported that larger volumes of runoff and higher stream channel velocities are the common result of urbanization. He claimed that the unnatural runoff rates cause scour and erosion and consequently increase the suspended solids carried to the receiving bodies of water. Van Sickle also found that the decreased travel time in the channels provided less time for the natural purification processes in the streams to reduce the pollutant load. Hence, he concluded that the BOD and pollutant load from urban areas, which eventually reaches the receiving bodies of water, is much greater than the natural pollutant loads received when the land area was in its original state.

Van Sickle reported the data in Table 5 from a Federal Water Pollution Control Administration study of a 27-acre tract of urbanized Cincinnati, Ohio. These data (Table 5) showed that the average suspended solids concentration was a little greater than that of raw sewage. They showed the COD of storm water to be much less than raw sewage, but much greater than treated sewage. According to Van Sickle, the upper range of all parameters mentioned and the tremendous quantity of runoff involved revealed their critical significance in relation to water quality problems.

Van Sickle added that in urban areas, rainwater cannot be considered a pure resource. He said that the concentration of impurities removed from the air by rainwater can be of considerable significance.

Van Sickle utilized the data from Table 5 and computed the projected pollution loads shown in Table 6. In Table 6, he compared the BOD and suspended solids concentrations of treated sewage to urban runoff. Van Sickle assumed, for the sake of comparison, two types of treated sewage. The first type was effluent from a plant employing the secondary treatment processes most commonly found today. The second type was a plant using a tertiary treatment process. Tertiary treatment processes are more advanced and provided the purity of effluent that will surely be necessary in the future. According to projections for the Galveston Bay area this data showed that the BOD loading from surface runoff will be close to double the BOD loading from treated domestic sewage. Van Sickle concludes that, if the Cincinnati data is even approximately representative of runoff quality in the Galveston Bay area, then an "already serious" sanitary sewage and

TABLE 5
Summary of Storm Water Runoff Quality Data

Constituent	Cincinnati Study			Sewage Effluent		
	Rain-Water	Storm Runoff Avg.	Storm Runoff Range	Raw	90% Removal	95% Removal
Suspended Solids, ppm	13.0	227.0	5-1200	200	20.0	10.0
COD, ppm	16.0	111.0	20-610	350	35.0	17.5
BOD, ppm	-	17.0	1-173	200	20.0	10.0
Total N, ppm	1.27	3.1	0.3-7.5	40	4.0	2.0
Inorganic N, ppm	0.69	1.0	0.1-3.4	30	3.0	1.5
Total PO_4, ppm	0.24	1.1	0.02-7.3	10	1.0	0.5

Source: Van Sickle (33)

TABLE 6

Projections of Pollution Load From the Urban Runoff and Treated Sewage for the Galveston Bay Area

Year	Population	Sewage Load Pounds X 10^3 BOD and Suspended Solids		Urban Area	Urban Runoff Load Pounds X 10^3	
		Primary Treatment	Tertiary Treatment	Square Miles	Suspended Solids	BOD
1950	950,900	4,850	2,400	373	136,000	10,100
1960	1,423,500	7,300	3,650	548	200,000	14,800
1967	1,805,000	9,270	4,600	682	249,000	18,400
1970	1,985,500	10,100	5,050	730	267,000	19,700
1980	2,698,000	13,800	6,800	965	353,000	26,100
1990	3,595,800	18,300	9,150	1,250	458,000	33,700
2000	4,712,000	24,000	12,000	1,600	585,000	43,200

Source - Van Sickle (33)

industrial waste problem which exists now will be further complicated by urban runoff in the future.

Colston (34) did a study in 1972 in Durham, North Carolina for the purpose of characterizing urban land runoff. The results of his study are shown in Table 7. His findings showed that the organic concentration in urban runoff is approximately one-half that for raw sewage and that the concentrations of heavy metals and solids were two to fifty times greater. He also found that during the wetter periods of 1972, the COD of the urban runoff was four and one-half times that of raw sewage, while the suspended solids concentrations were approximately one hundred times that of raw sewage.

Colston specifically stated that urban land runoff was a significant non-point source of pollution. He also suggested that perhaps storm-water quality guidelines will be implemented in the future.

McElroy, et al. (35) completed an analysis of non-point source pollution in the Missouri Basin Region in January of 1975. They basically concurred with the findings of the before-mentioned authors. They said that sediment is the most important non-point source pollutant because it is a carrier of nutrients, pesticides, metals, organics, bacteria, and other contaminants.

Shaheen (36) studied the non-point source pollution contribution from urban roadways. He determined that less than five percent of the traffic-related roadway deposits came directly from motor vehicles. These deposits included grease and n-paraffins from lubricants, antifreeze and hydraulic fluid; lead from fuel; lead oxide from tires;

TABLE 7
Characteristics of Urban Land Runoff in Durham, North Carolina

Pollutant	Mean, ppm	Range (ppm) Low	High
COD	170.00	20.00	1042.00
TOC	42.00	5.50	384.00
Total Solids	1440.00	194.00	8620.00
Volatile Solids	205.00	33.00	1170.00
Total Suspended Solids	1223.00	27.00	7340.00
Volatile Suspended Solids	122.00	5.00	970.00
Kjeldahl Nitrogen as N	0.96	0.10	11.60
Total Phosphorus as P	0.82	0.20	16.00
Fecal Coliform(#/m)	230.00	1.00	2000.00
Aluminum	16.00	6.00	25.70
Calcium	4.80	1.10	31.00
Cobalt	0.16	0.04	0.47
Chromium	0.23	0.06	0.47
Copper	0.15	0.04	0.50
Iron	12.00	1.30	58.70
Lead	0.46	0.10	2.86
Magnesium	10.00	3.60	24.00
Manganese	0.67	0.12	3.20
Nickel	0.15	0.09	0.29
Zinc	0.36	0.09	4.60
Alkalinity	56.00	24.00	124.00

Source: Colston (34)

zinc from tires and motor oil; copper, nickel, and chromium from bearings and plating; and copper and asbestos from brake and clutch linings.

Shaheen estimated that close to 100 percent of the lead in urban runoff is from traffic-related sources. Chemical analyses were done by the same author on stream bottom samples taken upstream and downstream from a roadway runoff discharge. He found permanent effects upon the stream bottom sediments. He also determined that roadways were the recipients of particulate matter fall-out from industrial areas. They are more effective transporters of this fall-out than normal undisturbed terrain.

Domestic Sewage

According to Hann (37), domestic wastes in the Houston Ship Channel during 1975 accounted for 65 percent of the waste loading during normal conditions. This fact has surprised many researchers because the waste loading from ship channel-harbor complexes is normally thought to be purely from industrial sources. In Bates' (38) monitoring of the Houston Ship Channel during 1973 and 1974, he found fecal coliform counts exceeding 250,000 per 100 ml in the turning basin. The Environmental Protection Agency recommended not more than 200 fecal coliform per 100 ml for contact sports, nor more than 2,000 fecal coliform per 100 ml for shellfish. Fecal coliform indicates the presence of human wastes.

Ketchum (8) reported that even though the science of sewage disposal is very old and tremendous developments have been made, serious problems remain unsolved. He says that one of the problems is the effect of cycling and recycling the nutrients from sewage. He recommended that research be done on the effects of domestic wastes upon metabolism, diseases, parasites, and reproductive capabilities of marine life. Ketchum was also concerned about the effect of viruses which pass through sewage treatment plants, and how they may be passed from fish and shellfish to man.

Water Withdrawals and Returns

Ketchum (8) reported that the need for water has prompted 40 percent of the nations' industries to locate in the coastal zone. The concern of this report is with withdrawals and discharges that involve ports and harbors. The majority of the sea water used along the Texas Gulf Coast is for cooling, and in one instance, desalinization.

The most significant water withdrawal in ship channel-harbor complexes is once-through cooling water for power plants and industries. According to Eisenbud and Gleason (39), present day nuclear power plants produce waste heat totaling between 6,000 and 6,500 BTU per kilowatt-hour of electricity, while the average fossil fuel power plant produces waste heat at the rate of 4,200 to 4,700 BTU per kilowatt-hour of electricity generated. This heat must be dissipated to the earth, the atmosphere, or a large body of water.

Because of the economics involved, these entities prefer to discharge the cooling water directly. However, because of regulations from the Environmental Protection Agency and the Texas Water Quality Board, many heat-generating industries utilize cooling towers or cooling water ponds. Both of these devices decrease the water discharge temperature by utilizing the latent heat of vaporization. The total volume of water is decreased while the dissolved and suspended fractions remain the same, thus concentrating the discharge slightly.

According to Hann (40), the intake and discharges in a nearly stagnant body of water can be a valuable asset by increasing circulation and mixing. However, he added that the increased temperature of cooling water discharge will reduce the amount of dissolved oxygen retained by water. Because of this, large variations in temperature in the same area over a period of time will strain the habitat of the area and cause an imbalance in the ecosystem. This is the primary reason regulatory agencies restrict the thermal discharges to a maximum temperature of four degrees above ambient in the fall, winter and spring.

Ketchum (8) further explained that since deep water is used in most cooling applications and may already be low in dissolved oxygen, the act of adding heat to it may decrease the oxygen levels to the lethal point. Furthermore, increased temperature accelerates the respiration rate of both plants and animals. As a result, catastrophic fish kills may occur at night when plants are not photosynthetically active.

Ketchum (8) also reported that some cooling water users employ chlorine as a biocide to prevent or control fouling of their heat exchangers. The chlorine not only has toxic effects on entrained organisms, but also on benthic organisms.

Parker, et al. (41) explained the advantages of locating cooling intake and discharge points where minimal mixing will occur between the two. However, this creates a situation where polluted water may be used for cooling and discharged into an unpolluted area. An example of this situation exists in the Corpus Christi Inner Harbor. A cooling water user takes water from the inner harbor and discharges it in Nueces Bay. Withers' (42) and Slowey's (13) investigations showed that the discharge has perhaps spread heavy metals from the harbor into the estuary. While the flushing is an advantage in polluted areas, it could cause degradation of previously non-polluted areas.

Another withdrawal previously mentioned is desalination and chemical extraction from seawater. There are only two plants of this type, located in Texas and both are located at Freeport. The chemical extraction plant is owned by Dow Chemical and the desalination plant is owned by the United States Department of the Interior. The Dow plant has a design capacity requiring two million gallons of seawater per minute. The adjacent desalination plant receives the water after the chemicals have been removed and processes it for domestic use. Even though the future operating status of these particular plants is questionable, plants of this type will become more frequent as natural resources are depleted.

The currents and water demands caused by the withdrawals create salinity imbalances in harbors and ship channels similar to cooling water users. However, there is no thermal pollution of the magnitude often found with a once-through cooling operation.

Industrial Wastes Discharges

Part of each dollar spent on manufactured goods today goes for the prevention of industrial pollution. It has received a large portion of the research efforts in the United States during the last decade. These efforts and expenditures have not totally solved the problem of industrial pollution, but they have provided vast improvements.

Hann, et al. (40) stated that in 1971 industrial wastes discharges per day along the Texas Gulf Coast exceeded 660,000 lbs. BOD, 1,671,000 lbs. total suspended solids and 2,560,000 lbs. COD. He mentioned that the major industrial pollution sources are the industries, as a whole, along the Houston Ship Channel. They discharge in excess of 200 million gallons per day of industrial waste.

Hann explained that the major concern involving industrial pollution was its effect on the natural aquatic system. The most important chemical components of industrial waste are oxygen-demanding wastes, nutrients, inorganic chemicals and mineral substances, synthetic organic chemicals, radioactive pollutants, refractory materials, and heavy metals. The discharging of these materials in amounts exceeding the natural assimilative capacity of a body of water causes either a toxic effect or a decrease in available oxygen. Either of these effects is detrimental to aquatic systems because a valuable link in the natural food chain is broken.

Oxygen-Demanding Materials. These wastes are often a result of food processing, paper mill production, leather tanning, and various other manufacturing processes. Wastes of this type can be destroyed by bacteria, if sufficient oxygen is present. Therefore, the oxygen required to support aquatic life is consumed if there is too great a waste load. This is also referred to as exceeding the assimilative capacity of the body of water.

Nutrients. These substances are thought of as mainly consisting of nitrogen and phosphorus. They occur naturally in water in limited amounts. When mixed with water, nutrients support and stimulate aquatic vegetation such as algae, weeds, and various other plant life. An abundance of these compounds in the water will over-stimulate the growth of aquatic plant life causing several undesirable conditions, such as unsightly conditions and unpleasant odors. Nutrients are contained in runoff, sewage, industrial waste, and numerous other sources. They are a major problem because they cannot be removed by biological treatment. In fact, after biological treatment, they are transformed into a more readily usable form by the plant life.

Inorganic Chemicals and Mineral Substances. These materials include numerous metal salts, acids, solids, and numerous other chemical compounds. They are derived from agricultural runoff, oil field operations, mining and manufacturing processes, and natural sources. Hann reported that acids of a wide variety are discharged regularly by industry.

Synthetic Organic Chemicals. Hann included detergents, household chemicals, organic pesticides, synthetic industrial chemicals, and chemical manufacturing wastes in this classification. He considered many of these chemicals toxic to aquatic life and humans. Also, many of the chemicals resist most conventional waste treatment processes and exhibit an undetermined long-term effect.

Radioactive Pollutants. As planning progresses on nuclear power plants in the Gulf Coast, radioactive pollutants are going to become more important in the environmental picture. According to Hann, radioactive wastes can result from the mining and processing of radioactive ore and from the use of radioactive materials in power plants, industries, medical studies, and research. Hann added that radiation can accumulate in humans over a period of time. Therefore, he recommended that proper attention be given to the total human environment.

Refractory Materials. The synthetic organic chemical industry, according to Hann (40), produces certain chemical wastes that do not readily biodegrade in natural streams. These materials are the result of a series of highly sophisticated physical and chemical reactions, and are difficult to degrade. These resistant substances often produce foam or toxic effects in water. These substances may be carried along in currents, may end up in sediment, and may produce pollution effects many miles from their source. Their effects sometimes remain for long periods of time.

Heavy Metals. According to Ketchum (8), these pollutants are often discharged in treated effluents because they don't respond well to most waste treatment processes. Heavy metals may come originally from corrosion of in-plant process equipment, certain coatings, metal smelting, metal foundries, metal fabrication, and petrochemical by-products. The real damage from these metals is due to the fact that they may build up to hazardous levels in certain fractions of the food chain, such as in shellfish.

Effects. The effects of tremendous waste loads in the harbors and ship channels depend upon a great many factors. One factor is the flushing time of the body of water. This refers to how often existing water is replaced with new water. For example, Sparr, et al. (43) discovered that the mean flushing time for the upper fourteen miles of the

Houston Ship Channel is 26.2 days. He also found that during 10 percent of the year (probably late summer), the flushing time exceeded 80 days. He explained that during 10 percent of the year conservative (slow decaying) materials would be 80 times greater than the daily discharge rate into the system. Sparr further pointed out that when all the ship channel above Morgan's Point was considered, the mean flushing time was only 15 days. This part of the channel is subject to greater inflows, greater tidal influence and greater wind activity. Therefore, one would expect the lower part of the channel to have a greater waste assimilation capacity.

A factor worthy to be included when considering the effects of industrial pollution was studied by Hutton (44) in the Houston Ship Channel. In his study he found that 32 percent of the waste loading was eventually deposited on the bottom as sludge.

Oil Spills

According to Nelson-Smith (45) oil spills have been occurring on inland waterways for over 220 years. He also reported that ocean-going tankers began operating as far back as 1874 between other countries and the United States. The ships carried about 2000 tons (about 1,450 barrels). Sittig (46) reported that the first major oil spill incident in the United States involved a tanker named Santa Rita in San Francisco Bay in 1907. Since the 1907 oil spill, there have been many others.

Not all oil spills come from tankers. Many spills come from barges, pipelines, storage tanks, refining operations, loading and unloading terminals, offshore drilling and oil production, and from sources previously discussed in this section. The sources discussed in this part of the report will be those most likely to affect the waters and marine life of a ship channel-harbor complex.

Causes. Between January of 1973 and November of 1974, Schwartz (47) reported that there were 47 oil spills of over 50 barrels per spill in Texas. These spills amounted to over 26,000 barrels of oil. Using data from the Texas Water Quality Board files, Schwartz compiled information showing the counties in which oil spills occurred (Figure 2). There appeared to be a relationship between the amount of oil spilled and the amount shipped. As shown in Figure 3, Schwartz also determined the causes of the spills in relationship to the number of incidents and the volume of spills. Equipment failure was the most frequent cause of a spill, but did not release the oil. On the other hand, human error does not occur as often, but is usually more disastrous. A significant number of the undetermined spill sources would most likely be from moving vessels that released a small amount of oil which was not discovered until the vessel was hours away, or a spill on shore that floated in from a flowing drainage ditch.

Schwartz also displayed causes of spills versus spill quantity as shown in Figure 4. Barge accidents clearly accounted for a large majority of the oil spills caused by human error. Vandalism accounted for 1,075 barrels, or over five and one-half percent of the spill volume due to human error. Vandalism and perhaps some of the spills from ship discharges are probably the only cases of willfully discharging oil. Equipment failure, the second ranking cause of oil spills

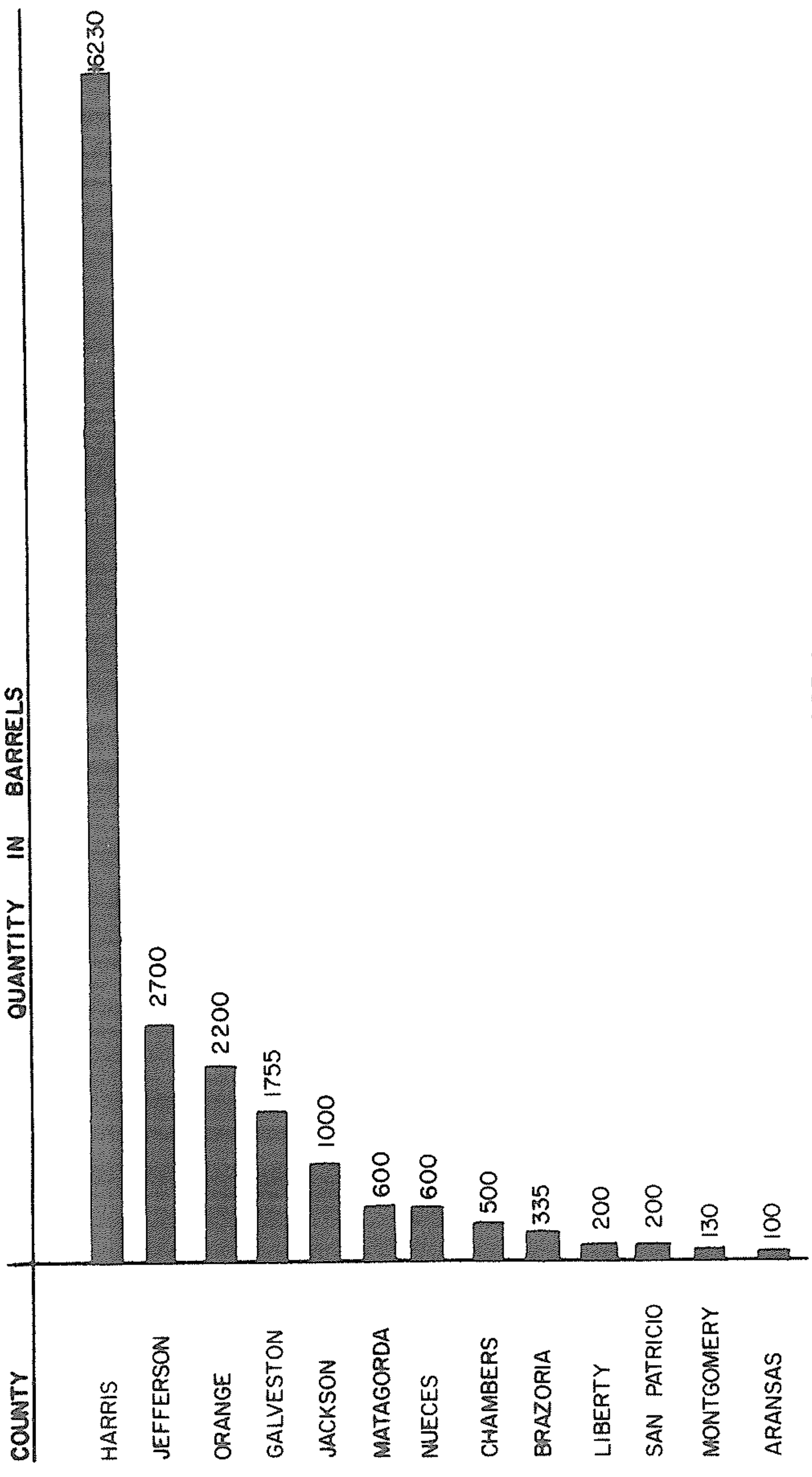


FIGURE 2
OIL SPILLS BY COUNTY
JANUARY 1973 - NOVEMBER 1974
(spills of over 50 barrels)
SOURCE: SCHWARTZ (47)

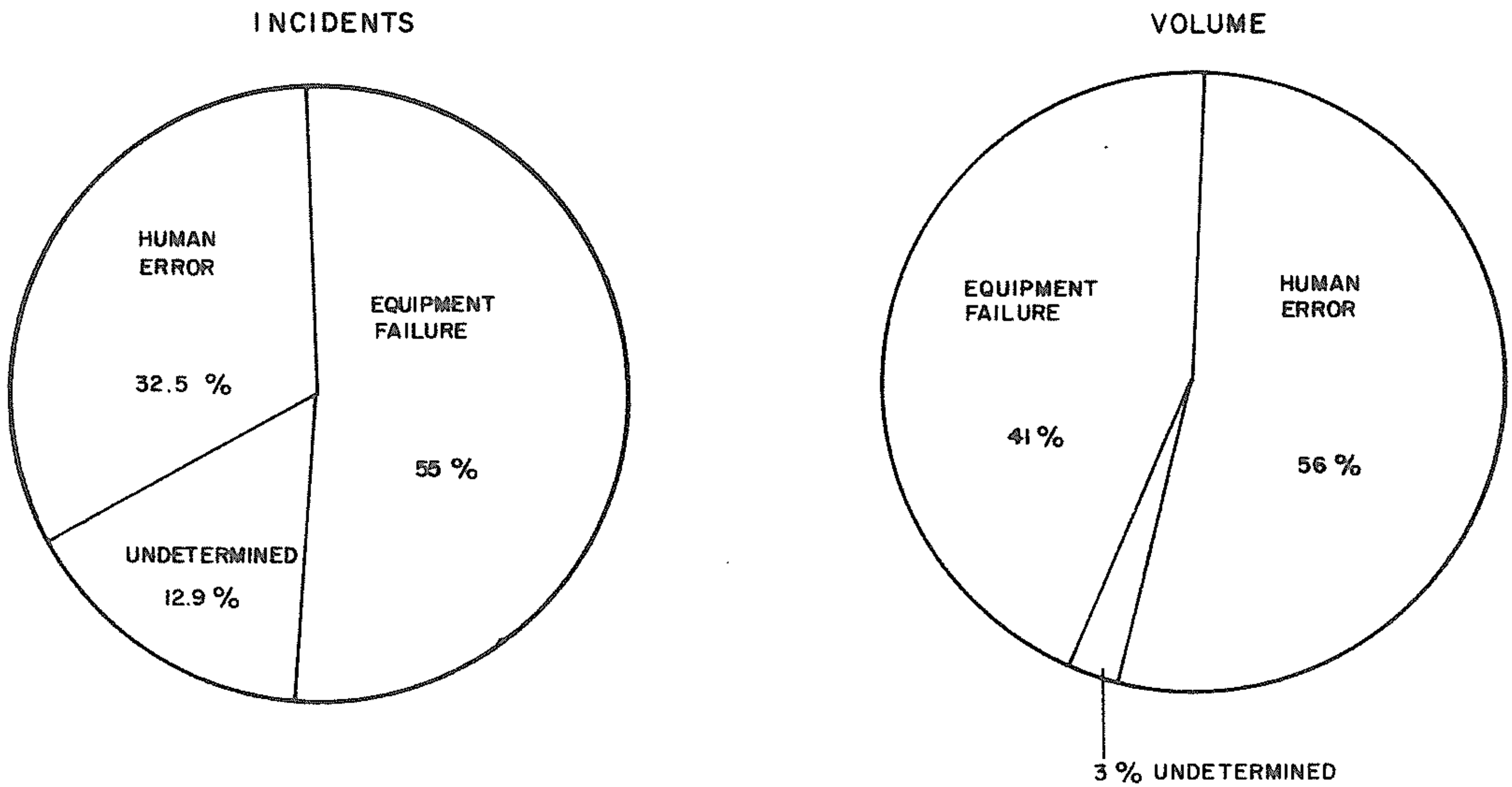


FIGURE 3

CAUSES OF SPILLS BY INCIDENT AND VOLUME
JANUARY 1973 - NOVEMBER 1974
(SPILLS OF OVER 50 BARRELS)
SOURCE: SCHWARTZ (47)

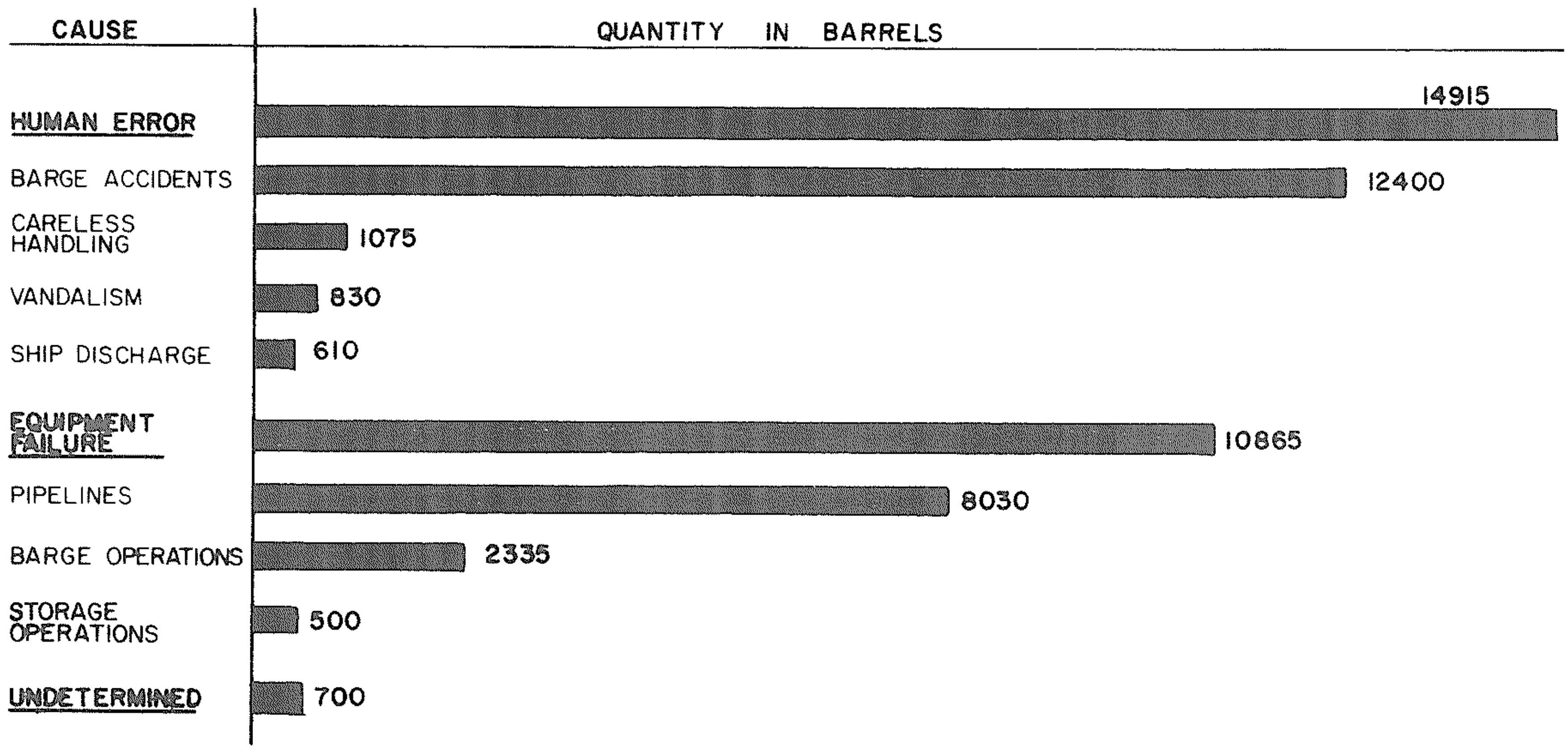


FIGURE 4
QUANTITY OF OIL SPILLED BY CAUSE
JANUARY 1973 - NOVEMBER 1974
(spills of over 50 barrels)
SOURCE SCHWARTZ (47)

by volume, is broken down into spills from pipelines, barge operations, and storage operations. Pipelines are the most significant cause of spills due to equipment failure. One might deduce that the mere nature of pipelines, with their many unattended miles and stream crossings, might be responsible. All three of the subheadings under equipment failure depend greatly on preventive maintenance for their reliability. The corrosion of metal, seals, packings, or gaskets is most often the culprit.

The magnitude of a spill may be estimated if the approximate area covered by the spill can be estimated. Table 8 lists the quantity of oil per unit area and the appearance of different thicknesses of oil slicks.

Behavior. The behavior of the oil once it is discharged upon the water is an important factor in coping with an oil-spill problem. Nelson-Smith (45) reported that the spreading of oil on water was less important than its mechanical transport by wind, tide, and currents. He added that the effect of tides is largely cancelled out by their oscillating action. He indicated that the wind is probably the most important factor in oil slick movement. Depending upon the currents involved, he cited research showing that oil slicks will drift at speeds of 2.5 to 4.2 percent of the wind speed. Sittig (46) reported that in the absence of current or debris, an oil slick will move with the wind at three to four percent of its speed.

As shown in Figure 5, Herbich (48) calculated what the shape of a 50,000 barrel per day oil spill would look like after four hours due to current only. He predicted the expected shape with no current,

TABLE 8

American Petroleum Institute Description
of the Appearance of Oil Films
on Water

	Quantity of Oil	
	gal/mile^2	liter/km^2
Barely Visible	25	44
Silvery Sheen	50	88
Trace of Color	100	176
Bright Bands of Color	200	352
Colors Dull	666	1170
Colors Dark	1332	2340

Source: Nelson-Smith (45)

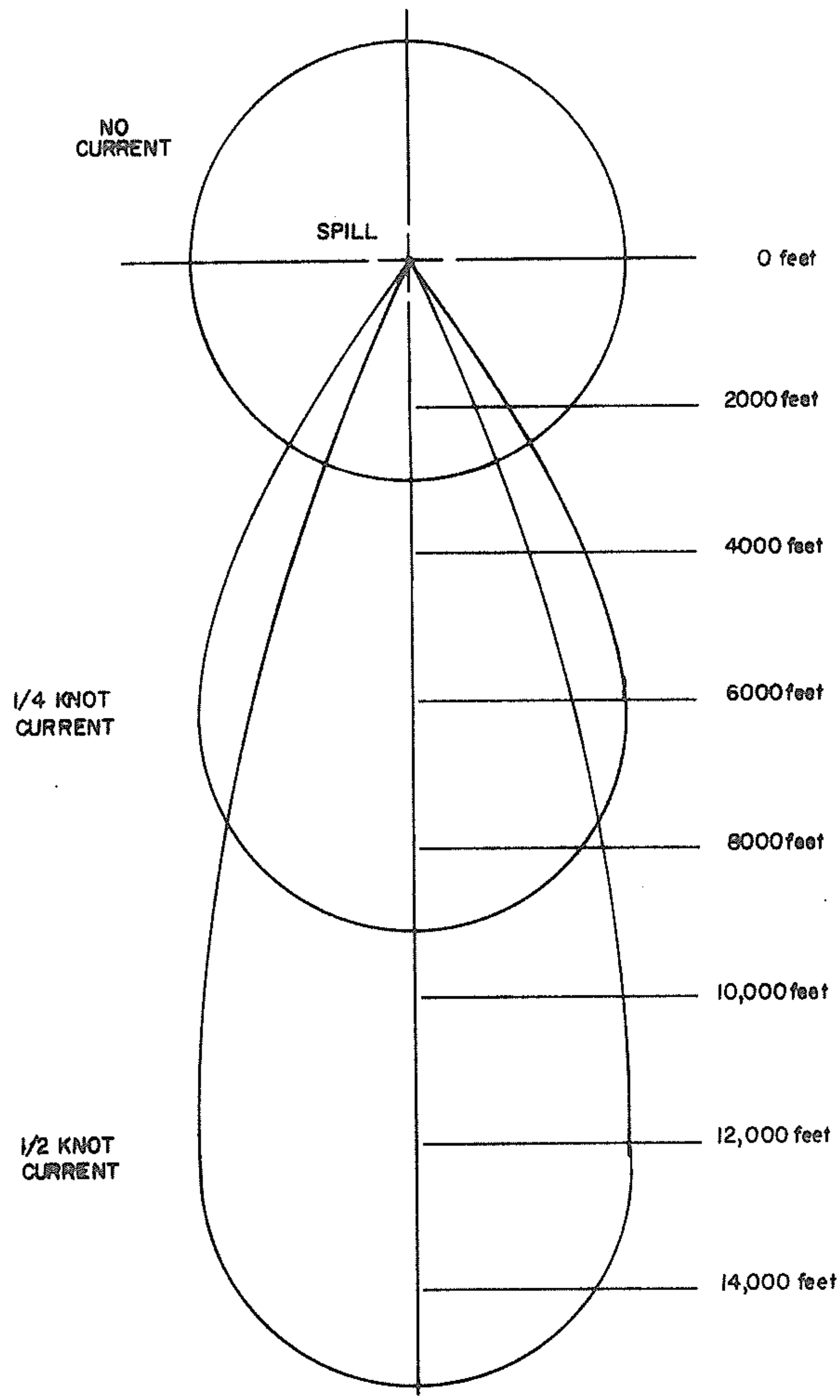


FIGURE 5
EXPECTED SHAPE OF 50,000 BARREL/DAY SPILL
AFTER FOUR HOURS

SOURCE: HERBICH (48)

with a one-fourth knot current (.287 miles per hour), and a one-half knot current (.575 miles per hour). Herbich said that a spill such as the one illustrated in Figure 5 would be typical of a tanker-type accident.

Weathering. Many people believe that no harm is done if an oil spill is cleaned up before it strikes land. This is not necessarily true. According to Sittig (46), the moment oil comes to rest upon seawater it begins to be altered chemically by evaporation, dissolution, microbial action, chemical oxidation, and photochemical reactions. He referred to these activities as weathering. The rate of weathering or degradation depends upon light, temperature, nutrients and inorganic substances, currents, tides, wind, and wave action. Weathering reactions also depend upon the composition of the oil. The more toxic fractions are not easily degraded, and may either settle to the bottom or float as tarry lumps. Naturally, said Sittig, the mass of oil may continue moving while the decomposition activities are proceeding.

Sittig said that the events taking place after an oil spill in order of occurrence are spreading, evaporation, dissolution and emulsification, auto-oxidation, microbiological degradation, sinking, and resurfacing at a later time to repeat the process.

Opinions on how long oil may persist in the ocean environment, if not blown ashore, are varied. Sittig said that lumps which settle to the bottom may remain "indeterminately". In his investigation of an oil spill from the tanker Metula in Chile, Hann (49) estimated that the effect of the spill was evident to a casual observer for five years, and to a trained observer for over ten years. From several case studies of major oil spills, Sittig (46) cited oil residence times of between two and five years. Hann explained that unrecovered oil will provide a chronic source of pollution in the area surrounding spills for years.

Effect. The effect of oil spills, oil emulsifiers and oil dispersants upon marine organisms is receiving a tremendous amount of study. According to Nelson-Smith (45), the most obvious effects of any large spill are mechanical. He explained that oils and oil emulsions clog or blanket all structures contacted, and inhibit movement, respiration and feeding of small animals. Sittig (46) explained that many of the low boiling point aromatic hydrocarbons (contained in oil) are lethal poisons, and can kill through direct contact with the organisms. Also, the water-soluble fractions of oil may have toxic effects at a later time and at a different location. Sittig also said that many forms of organisms may be destroyed while they are in the sensitive juvenile stage of growth. Some marine life may only receive sublethal doses of oil or oil fractions, and thus weaken their resistance to diseases and stresses. In addition to this, the food value of an organism may either be reduced or destroyed completely by oil, thus interrupting the entire food chain. An interruption of the food chain will certainly affect organisms higher up the food chain. Finally, Sittig said that spilled oil can introduce carcinogens (cancer-causing substances) into the food chain.

Oil can also affect waterfowl by coating them, thus destroying the insulation and buoyancy of their feathers. This results in a loss of body heat and the possible ingestion of oil or oil dispersants.

Shellfish are likely to be the most directly affected segment of marine life from an oil spill. Most types will survive oil contamination, but will develop an oily taste. Adult finfish are practically unaffected by the oil because they merely avoid it. However, oil can harm the eggs, the larvae, or the juveniles.

Hazardous Materials Spills

The term "hazardous polluting substances" was used in the Water Quality Improvement Act of 1970 in reference to a hazardous materials spill. According to the Department of Transportation and the United States Coast Guard (50), "A hazardous polluting substance includes (other than oil) such elements and compounds which, when discharged in any quantity into or upon the navigable waters of the United States or adjoining shorelines or the waters of the contiguous zone, present an imminent and substantial danger to the public health or welfare, including, but not limited to, fish, shellfish, wildlife, shorelines, and beaches." This report will use the Department of Transportation and United States Coast Guard definition when making reference to hazardous materials and hazardous polluting substances.

Hazardous polluting substances are either manufactured or consumed near the average port or harbor, and are transported upon the waters of such a facility. Therefore, these substances pose the threat of spillage in the ship channel-harbor complex. Hazardous polluting substances may be introduced into the water directly, from the air, or from shore.

Shoreside facilities such as manufacturing processes, loading docks, waste treatment plants and different methods of transportation are extremely vulnerable to spills. The mist, or vapor from manufacturing processes can also cause "fall out" from the air which can cause hazardous materials to be introduced into a body of water. Leakage, washings, and discharges from vessels can also be responsible for a hazardous material contaminating a body of water. According to Hann (51), the criteria for evaluating a spill of a hazardous polluting substance should include, but not be limited to, the following:

1. Acute and chronic effects on human beings,
2. Acute and chronic effects on aquatic organisms,
3. Contamination and spoilage of human food organisms,
4. Effects on vegetation such as irrigated crops,
5. Aesthetic effects,
6. Air pollution hazards from materials in and on the aquatic environment, and
7. Physical and chemical properties of the material.

Spills of hazardous polluting substances usually occur in much the same way as those from industrial discharges and oil spills, and details on how these materials may reach a body of water were discussed in the sections on industrial discharges. Hann (52) noted that spills of hazardous materials posed many of the same threats to the environment that an oil spill or an industrial discharge does. The most important difference is that hazardous materials may be toxic.

Two types of toxicity as described by Hann (51) are (1) acute toxicity and (2) chronic toxicity. A material is considered to be acutely toxic to an organism if, upon exposure, some organisms die in a very short time. This condition usually occurs in the immediate vicinity of a spill of considerable size, especially if the material does not readily mix or diffuse into the surrounding water. The chronic or accumulative toxicity of a material is the long-term effect on an organism. These effects may either result in death or impairment of basic functions, such as the ability to reproduce, swim, or disease resistance. The chronic toxicity condition usually follows an acutely toxic condition, but it may be the sole result of a spill.

The difficulty involved with the spill of a hazardous material is that removal or treatment of the material is extremely difficult. Also, the toxicity of various chemicals is an entire science in itself.

Floating Debris

Floating debris is not commonly thought of as pollution. However, for purposes of this report, it is considered pollution because of its accident potential, its effect on oil spill recovery, and its damage to waterway aesthetics.

According to Hancock and Jensen (53), two basic types of floating debris are (1) natural debris and (2) man-made debris. Natural debris is material that enters or grows on a waterway regardless of man's activities. Man-made debris is mostly wood, and includes pieces of shorefront structures and vessels, discarded dunnage from vessels, and dumped trash. Both natural and man-made debris are often transported to a harbor or waterway by overland runoff or exceptionally high tides.

Floating debris could cause damage to the propulsion and guidance systems of tow vessels, and also to cargo vessels containing liquids. Hancock and Jensen (53) noted that the Port of Houston has a high concentration of debris because of its lack of flushing.

They also said that complications, caused by combining floating debris with an oil spill in the channel, almost necessitated the entire removal of floating debris by hand. They also mentioned that floating liquids and floating debris usually concentrate in the same place, thus multiplying the cleaning effort. Lastly, floating debris attracts unfavorable publicity for the management of a ship channel-harbor complex.

Seafood Processing Wastes

Significance. Cobb (54) reported that Texas produces a major portion of the total United States fishery output. He listed shrimp, fish, oysters, and crabs as the main varieties caught. He predicted that commercial fish catches along the Texas Gulf Coast could be increased several times above the present level without seriously affecting the stock.

Crance (55) stated that shrimp are the most valuable seafood catch in Texas, with oysters ranking second. He said that the menhaden fishery is Texas' third most valuable fishery, and is an important source of high quality protein. Other valuable species are blue crabs, red snapper, redfish, spotted trout, black drum, and flounder. Harvests of nearly all these species are seasonal.

Mehos (56) estimated that the fishing potential in the Gulf of Mexico is 14 times the present level of harvest. This estimate, along with Cobb's, indicates that the seafood processing industry has a potential for tremendous growth. This growth will undoubtedly bring increased volumes of wastes.

Seafood Processes. Hann (40) reported that seafood caught along the Texas Gulf Coast is processed in 157 plants. The processing of seafood consists of unloading the boats, weighing, washing, evisceration, hulling, shelling or scaling, washing again, perhaps cooking, final separation of meat from waste parts, and packing. Each step removes some unwanted waste material, which is usually carried by water. Regardless of whether the product is frozen or canned, the process wastewater streams are practically the same.

Wastewater Stream Quality. Mendenhall (57) stated that the processing of crabs yields a waste equalling 85 percent of the quantity of crabs processed, whereas shrimp processing only yields a waste equalling 65 percent of the quantity of shrimp. He classified the wastes from these crustaceans to be 30 to 50 percent protein, 50 percent calcium salts, 3 to 14 percent chitin, 1 to 15 percent fat and oil, plus various amounts of moisture.

Mauldin and Szabo (58) explained that shrimp processing plants operate intermittently during the year because of regulated harvest seasons. Because the controlled seasons subject plants to very high peak operating conditions, waste discharges are usually of a high pollution strength and relatively large in volume. Mauldin and Szabo collected the BOD and suspended solids data for shrimp processing shown in Table 9.

Effects of Wastes on Natural Waters. Mendenhall explained that waste products from shellfish processing plants are eventually broken down by microorganisms in natural water bodies. These organisms demand oxygen for respiration. If this oxygen demand is great enough.

TABLE 9
Wastewater Characterization,
Shrimp Processing and Canning

Plant Operation	BOD_5 lbs/100 lbs Shrimp	% Total Discharge	Suspended Solids lbs/100 lbs Shrimp	% Total Discharge
Peeling	4.89	72	2.63	68
Deveining	0.51	7	0.45	12
Blanching	0.15	2	0.19	5
Receiving and Raw Washing	0.66	10	0.25	6
Miscellaneous	0.62	9	0.35	9
Total Discharge Processing Only (No Washdown)	6.83	100	3.87	100

Source: Mauldin and Szabo (58)

other natural organisms may be deprived of oxygen. Also, floating and suspended particles become mixed with scum from the decaying process, and therefore, become annoying. Some waste materials, such as chitin, must be in the water for long periods of time before they are degraded. Mendenhall mentioned that, if oxygen is depleted and the waste degradation process becomes anaerobic, then the degradation process will produce large amounts of nauseating gases such as ammonia, hydrogen sulfide, methane, mercaptan, and cadaverin.

Some seafood processing plants along the Gulf Coast do very little waste treatment. Other plants have extensive treatment facilities. Most of these facilities include some form of pretreatment combined with the discharging of the remaining waste to a municipal sewage system.

Vigil (59) reported that until July 1, 1977, the EPA is only requiring the use of the best available technology economically achievable. The EPA definitions of the two levels of treatment for shrimp and crabs are shown in Table 10.

Vigil also reported average effluent values for 12 shrimp processors at the Brownsville Fishing Harbor. Vigil stated that he obtained these values from Texas A&M University Research Engineer, Richard E. Withers. The effluent values are shown in Table 11.

TABLE 10
EPA Crab and Shrimp Waste Treatment Definitions

Process	Treatment Method	Parameter (kg/kkg live weight processed) BOD_5 Max. 30 day Avg.	BOD_5 Daily Max.	Tot.Susp.Solids Max. 30 day Avg.	Tot.Susp.Solids Daily Max.	Oil & Grease Max. 30 day Avg.	Oil & Grease Daily Max.
A.	Best Practicable Control Technology Available						
Conventional Blue Crab	Aerated Lagoons	0.15	0.30	0.45	0.90	0.065	0.13
Mechanized Blue Crab	Aerated Lagoons	3.0	6.0	7.4	15	1.4	2.8
Southern Non-breaded Shrimp >2 tons/day	Air Flotation	28	70	11	28	1.8	4.5
Southern Non-breaded Shrimp <2 tons/day	Screen	46	140	38	110	9	27
Breaded Shrimp > 2 tons/day	Air Flotation	50	125	28	70	1.8	4.5
Breaded Shrimp < 2 tons/day	Screen	84	250	93	280	9	27
B.	Best Available Technology Econ. Achievable						
Conventional Blue Crab	Extended Aeration	0.12	0.36	0.12	0.36	0.026	0.078
Mechanized Blue Crab	Extended Aeration	1.9	5.7	1.9	5.7	0.53	1.6

TABLE 10 (Continued)
EPA Crab and Shrimp Waste Treatment Definitions

Process	Treatment Method	Parameter (kg/kkg live weight processed) BOD_5 Max. 30 day Avg.'	BOD_5 Daily Max.	Tot.Susp.Solids Max. 30 day Avg.	Tot.Susp.Solids Daily Max.	Oil & Grease Max. 30 day Avg.	Oil & Grease Daily Max.
Southern Non-breaded Shrimp >2 ton/day	Aerated Lagoon	3.0	6.0	7.6	15	0.19	0.38
Southern Non-breaded Shrimp <2 ton/day	-	-	-	-	-	-	-
Breaded Shrimp >2 ton/day	Aerated Lagoon	4.6	9.2	12	24	0.29	0.58
Breaded Shrimp <2 ton/day	-	-	-	-	-	-	-

Source: Vigil, (59).

TABLE 11
Average Effluent Values for 12 Shrimp Processors
at the Port of Brownsville Fishing Harbor

Fecal Coliform MPN (Per 100 Ml)	29.5
pH	7.7
Temperature (^{o}F)	61.9
Alkalinity ($CaCO_3$) mg/l	188.3
BOD_5 (mg/l)	1,158.7
Total Solids mg/l	2,468.7
Total Dissolved Solids mg/l	1,638.0
Total Suspended Solids mg/l	824.8
Specific Conductance (μmhos)	2,023.3
Oil and Grease	113.1
Chlorides (as Cl) mg/l	408.2

Source: Vigil, (59).

CHAPTER III

MAGNITUDE AND IMPACT OF WATER POLLUTION

Relative Importance of the Sources

Previous Studies

In a study made during 1975, Hann (7) outlined thirteen major sources of pollution in the ship channels and estuaries he considered. He developed a matrix showing the significance of each source as a contributor to pollution. The matrix, shown in Table 12, indicated that the petrochemical industry, metal processing plants, and maintenance dredging were the most often named pollution sources. Domestic sewage, petroleum refining, and power generation were listed next in importance. The remaining sources were less frequently named as major contributors of pollution. Hann stated that his matrix is based upon information compiled from years of environmental studies.

Summary of Field Interviews

Eight ship channel-harbor complexes were visited during the summer of 1975 on a series of fact-finding missions. Key people were interviewed in detail concerning the environmental problems of their local ship channel-harbor complex. People interviewed included the top management of port authorities, the local Texas Water Quality Board Staff, the Texas Parks and Wildlife officials, and various other informed sources. Each of the persons interviewed responded in a very open and helpful manner, and displayed a genuine interest in the environmental aspects of port management.

TABLE 12
Pollution Sources for Selected Texas Estuaries

	Neches Ship Channel	Houston Ship Channel	Galveston Bay	Brazos River	Corpus Christi Inner Harbor	Corpus Christi Bay	Brownsville Ship Channel
Domestic Sewage	L	H	L	H	L		
Urban Runoff	L	H	L		L		
Agricultural Runoff	L		L	L		L	
Petrochemical Industry	H	H	H	L	H	L	L
Petroleum Refining	H	H	M		H	L	
Pulp and Paper	H	H	L				
Mining	H		L				
Metal Processing	L	H	L	H	H	H	
Fertilizer		H	L				
Power Generation	H	L	H		L	L	
Dredging of Virgin Mtls.			M			M	
Maintenance Dredging	H	H	M	M	H	H	L
Marine Commerce	L-P	L-P	P	P	P	L-P	P

H - Major Waste Source

M - Moderate Waste Source

L - Minor Waste Source

Blank - No Significant Waste

P - Potential for Major Problem from Spill Situation

Source: Hann (7)

According to the people interviewed, the top environmental problem was the disposal of dredged materials. Most sources reported that current Corps of Engineers' dredging permits required dredged materials to be deposited above the water line. In some cases, this requires the use of prime industrial land tracts or marshes. The Texas Department of Parks and Wildlife was reportedly recommending that the Corps of Engineers not permit the use of fish breeding or waterfowl habitats for dredge disposal. In some locations, very little spoils disposal area is left to choose from. This drives up the price of maintenance or new dredging. Most people felt that eventually Texas ports will be in the helpless position of having an antiquated channel with no dredged material disposal area, which is necessary for improvements.

To those interviewed, the second ranked pollution problem was industrial pollution. Some indicated that industrial pollution had improved in their area, while others noted that a few industries still had made very little progress in abating pollution. Several comments were also made concerning the problem of effectively enforcing the many discharge permits. Most agreed that better monitoring is necessary to prevent industries not in compliance from having a competitive advantage.

The third ranked problem was oil spills. There was a general consensus that too many oil spills were taking place. However, there was a disagreement on who should clean up an oil spill. If a company's identity can be determined, oil spill cleanup is legally the responsibility of the company causing it. However, some factions believe that if the violator cannot be found, then the port authority should assume responsibility. Other factions believe it is the Coast Guard's responsibility. Everyone agrees that the responsibility for pollution cleanup is poorly defined in this situation.

The fourth ranked problem was shipboard wastes, bilges, ballasts, and tank washings. These offenses were described as being the hardest to monitor and enforce, especially when the responsible ships are foreign. Several people interviewed related incidents where ships had obviously and deliberately polluted the waters of a port, and received no legal response from regulatory agencies.

The fifth ranking problem was municipal sewage. Several people thought these waste streams had received little attention from regulatory agencies. They cited instances where raw sewage was apparently bypassed into the waters of the port or where a plant discharged wastes because it was overloaded and operating in excess of 100 percent of design capacity. They also complained that the public was not sufficiently aware of problems caused by inadequate sewage treatment. Several people speculated that this was why local bond elections to finance sewage treatment plants had sometimes failed.

Most other problems cited in the interviews were administrative in nature. Port authority officials felt that public relations were a problem. Many said they were active in the Sierra Club, civic clubs, and trade or professional clubs. They felt the ports had received unfavorable publicity at times because the public was just not informed. Each person interviewed agreed that the average citizen had no appreciation for the complexity of problems facing the average deep-water port.

It was also the opinion of several port managers that the EPA and Texas Water Quality Board want port authorities to be the local sponsors for pollution improvements in the ports. This could result in the port authority monitoring and enforcing regulations concerning polluting activities. This would require more watercraft employees, laboratory facilities, and supervisory time. Several people discussed proposals requiring port authorities to maintain sufficient spill clean-up equipment to handle any spills that could not be contained by the responsible company. Most port authorities said they do not have sufficient funds nor a tax base adequate enough to generate the funds necessary for this additional responsibility. One port authority had installed waste collection and treatment systems to be financed from user's fees. This can achieve basically the same result as the well-known Gulf Coast Waste Disposal Authority in the Houston area. Still, people in other port authorities said they have no legal authority nor responsibility to enter into these activities.

Several people noted that the American Association of Port Authorities has publicly endorsed Federal Aid to ports for environmental improvements. Several public agencies, including port authorities, have received planning funds as authorized under Section 28 of Public Law 92-500.

Opinions varied when Coastal Zone Planning was discussed. Most felt that proper planning and zoning would prevent some of the serious nuisance problems they have, but they were scared that expansion might be curtailed. Most of the responses to land planning indicated that the majority of the people had not formed a solid opinion on this vital issue.

The opinions summarized in this section are the composite impressions from interviews with many different persons. These opinions should not be considered indicative of an individual's or group's position on an issue, but rather they indicate a trend in thinking and concern.

Data Collected From Previous Field Studies

Introduction

Field studies considered most beneficial for this project were those done in the Port of Brownsville and the Port of Corpus Christi. As explained earlier, these ports enable the study of water pollution problems which would be obscure in most other ship channel-harbor complexes. However, both ports possess the same basic physical layout of the average port.

Corpus Christi Ship Channel and Inner Harbor Complex

According to Hann (60), the Inner Harbor Channel at Corpus Christi is eight and one-half miles long and varies in width from two hundred feet at the upper end to one thousand feet at the lower end. The ship channel crosses Corpus Christi Bay and enters the Gulf of Mexico at Port Aransas. The Corpus Christi Bay portion of the ship channel is 40 feet deep and 400 feet wide. The channel is in the process of being deepened to 45 feet.

About 1½ miles from the mouth of the Inner Harbor Channel, Central Power and Light Company's Nueces Bay Power Station withdraws approximately 544 million gallons per day of cooling water. This cooling water is discharged into nearby Nueces Bay. The power station is responsible for nearly all the flow in the Inner Harbor Channel. Inflows into the Channel include the rainfall runoff from a 17-square-mile watershed, and industrial outfalls. Tidal heights are constant throughout the length of the channel.

Hann (60) noted that one- to two- foot tides and limited freshwater inflow caused a long flushing time for the inner harbor. To worsen its vulnerability to pollution, the Port of Corpus Christi is protected from the Gulf of Mexico by barrier islands. Hann reported that the water quality in the 8½ mile inner harbor is poor, with regard to some parameters, but is appreciably better than the major ship channels in eastern Texas.

The dissolved oxygen profile of the Corpus Christi Ship Channel-Harbor Complex, as found in 1972, is shown in Figure 6 and 7. The layout of the sampling stations in the ship channel-harbor complex is shown in Figures 8 and 9. Dissolved oxygen varied throughout the year, as temperature and salinity varied.

In 1973, Withers, et al. (61) found the dissolved oxygen profile to be very different, as shown in Figure 10. Runoff from rainfall was probably the main reason the bottom dissolved oxygen levels increased from the previous year. Improvements in treatment of industrial wastes occurred during this period also.

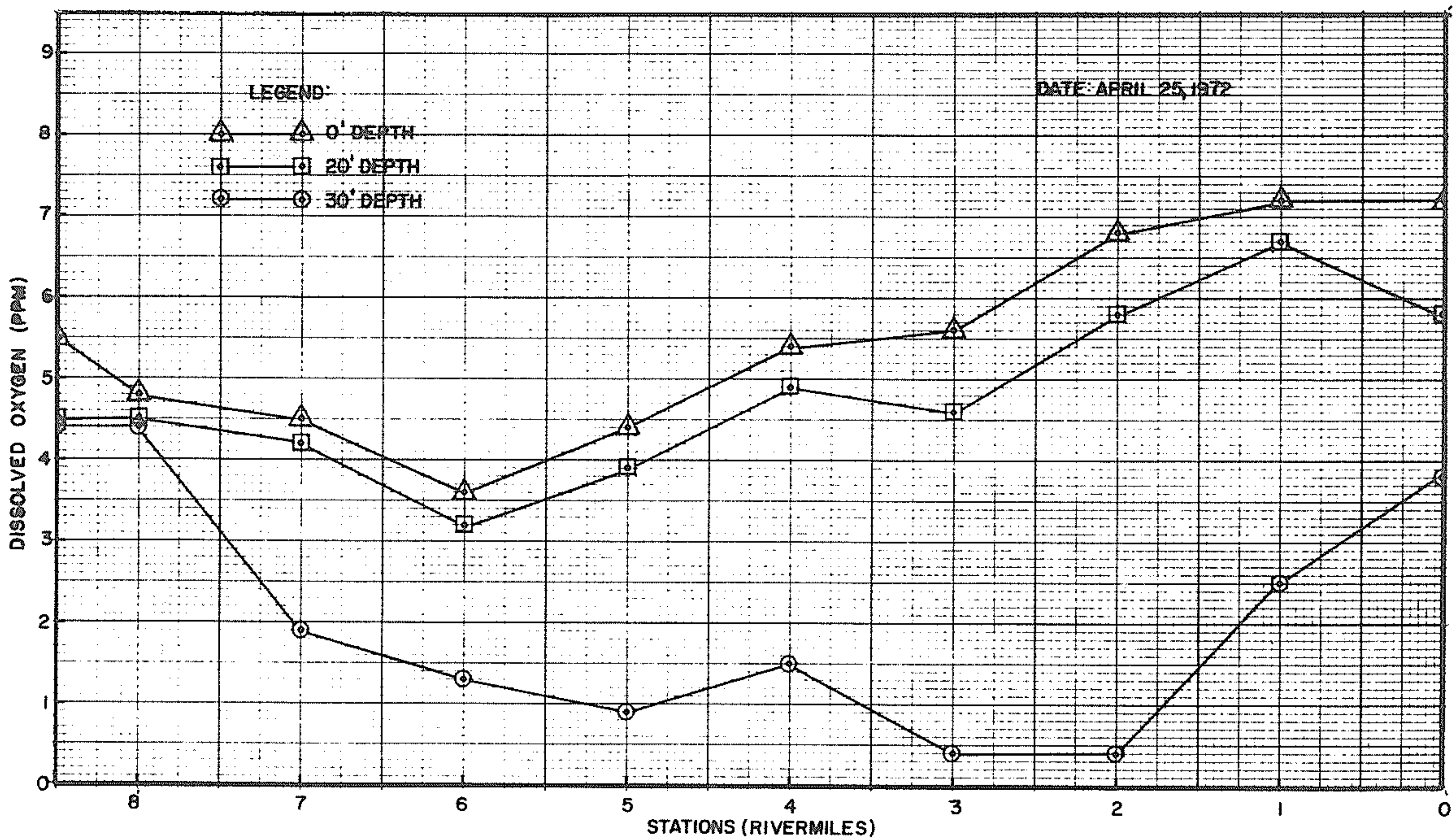


FIGURE 6
DISSOLVED OXYGEN PROFILE
CORPUS CHRISTI INNER HARBOR
SOURCE: HANN, (60).

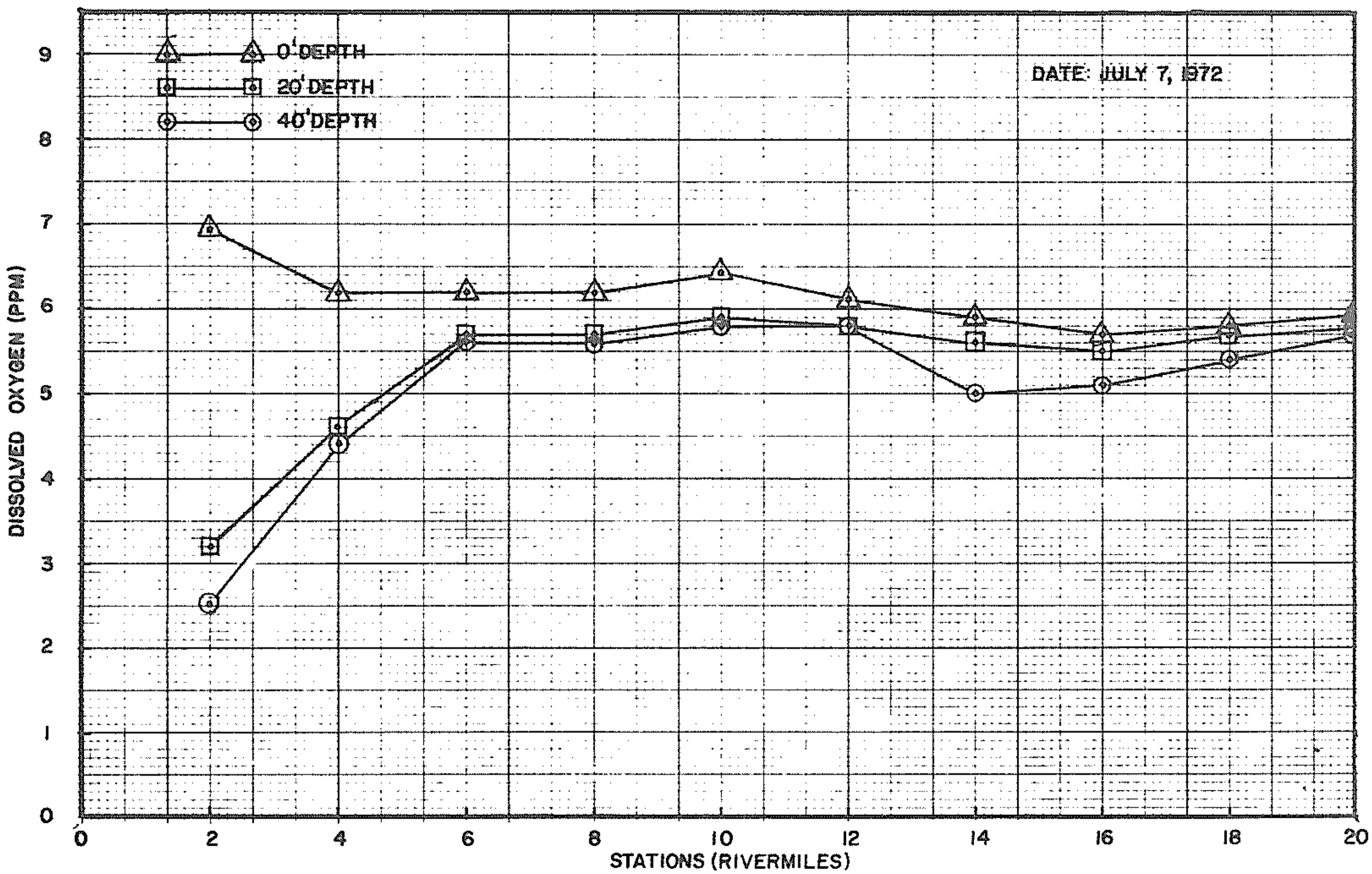


FIGURE 7
DISSOLVED OXYGEN PROFILE
CORPUS CHRISTI SHIP CHANNEL
SOURCE: HANN, (60).

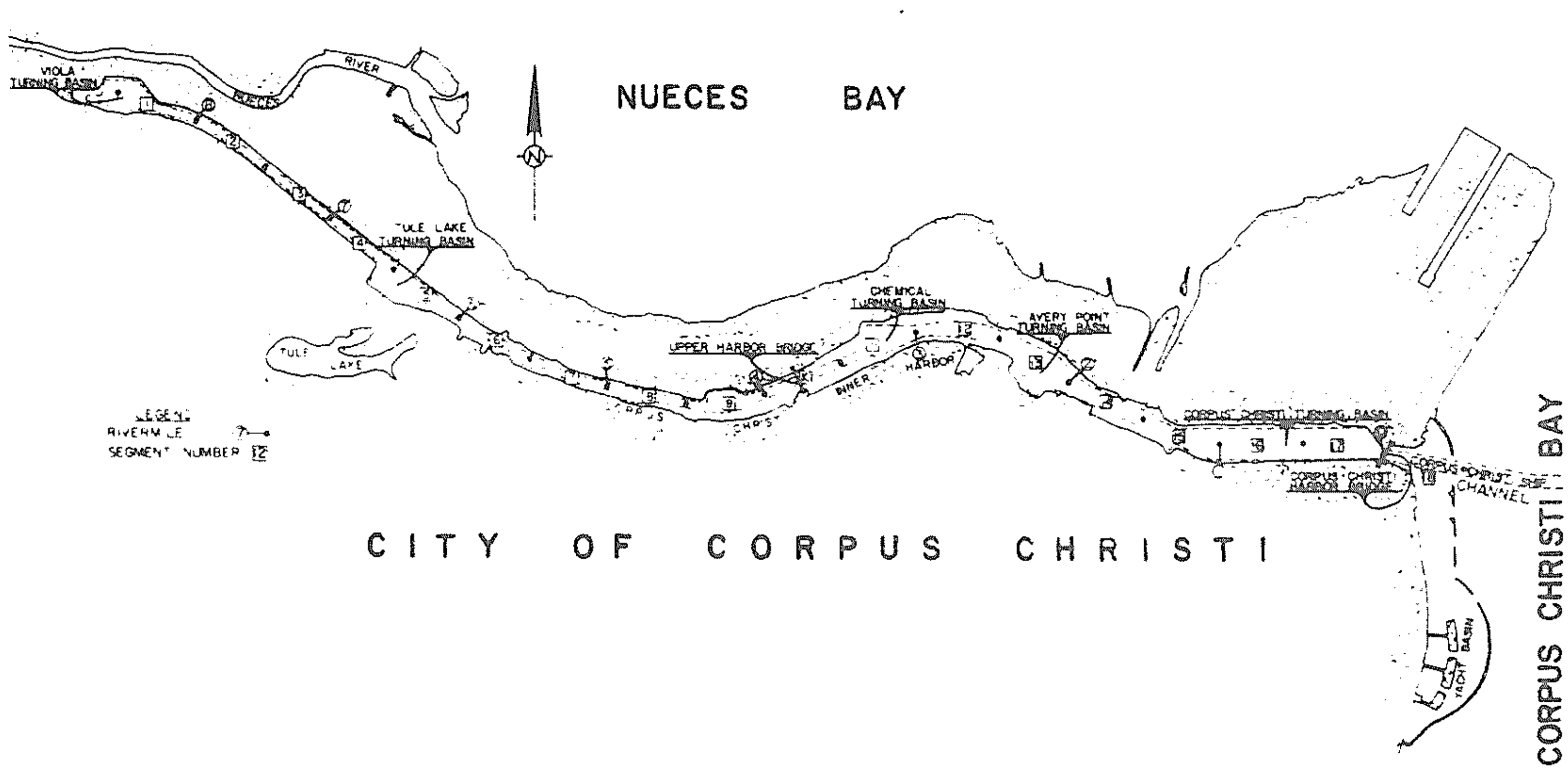


FIGURE 8

STATION AND SEGMENT LOCATIONS

CORPUS CHRISTI INNER HARBOR STUDY

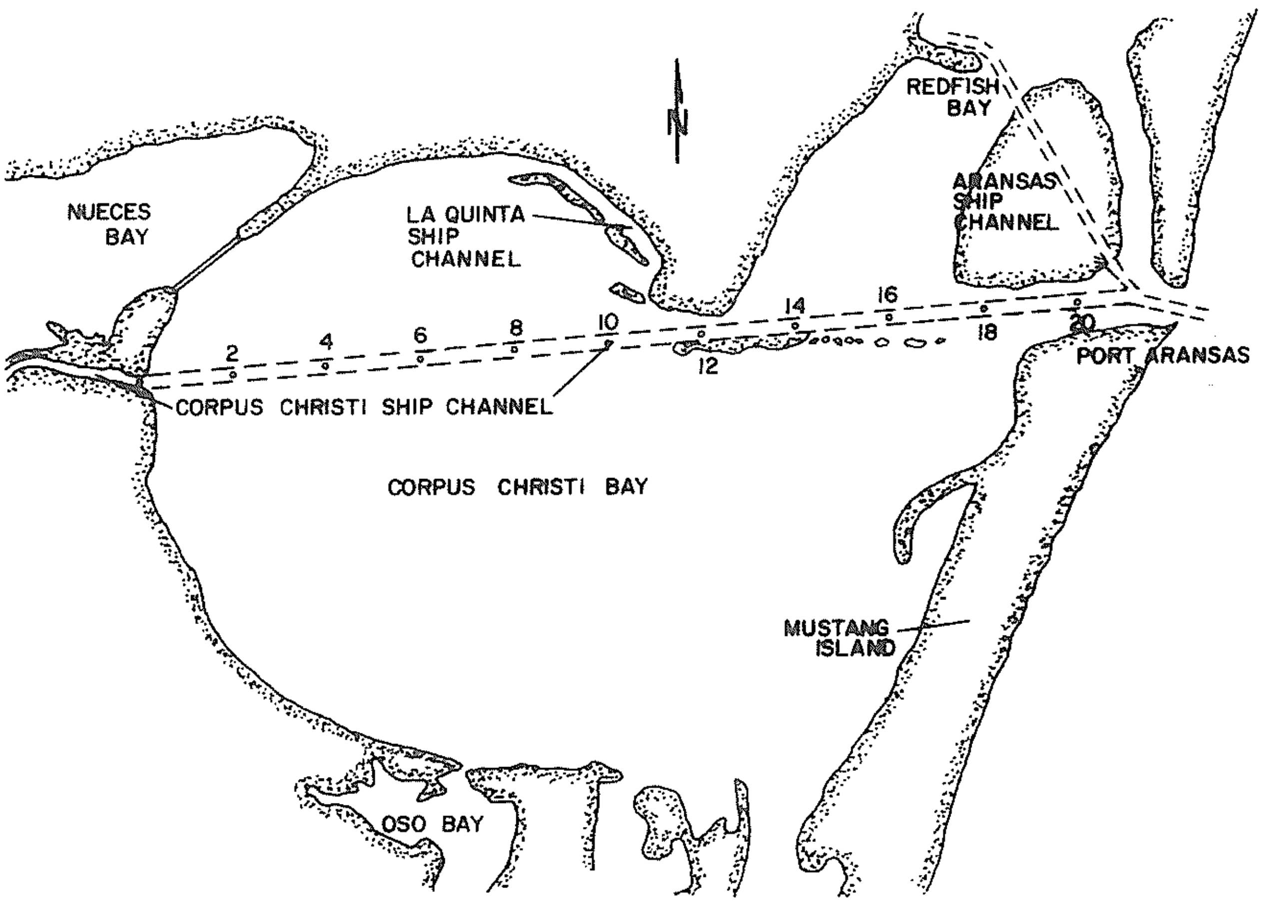


FIGURE 9
SAMPLING STATIONS
CORPUS CHRISTI BAY CHANNEL

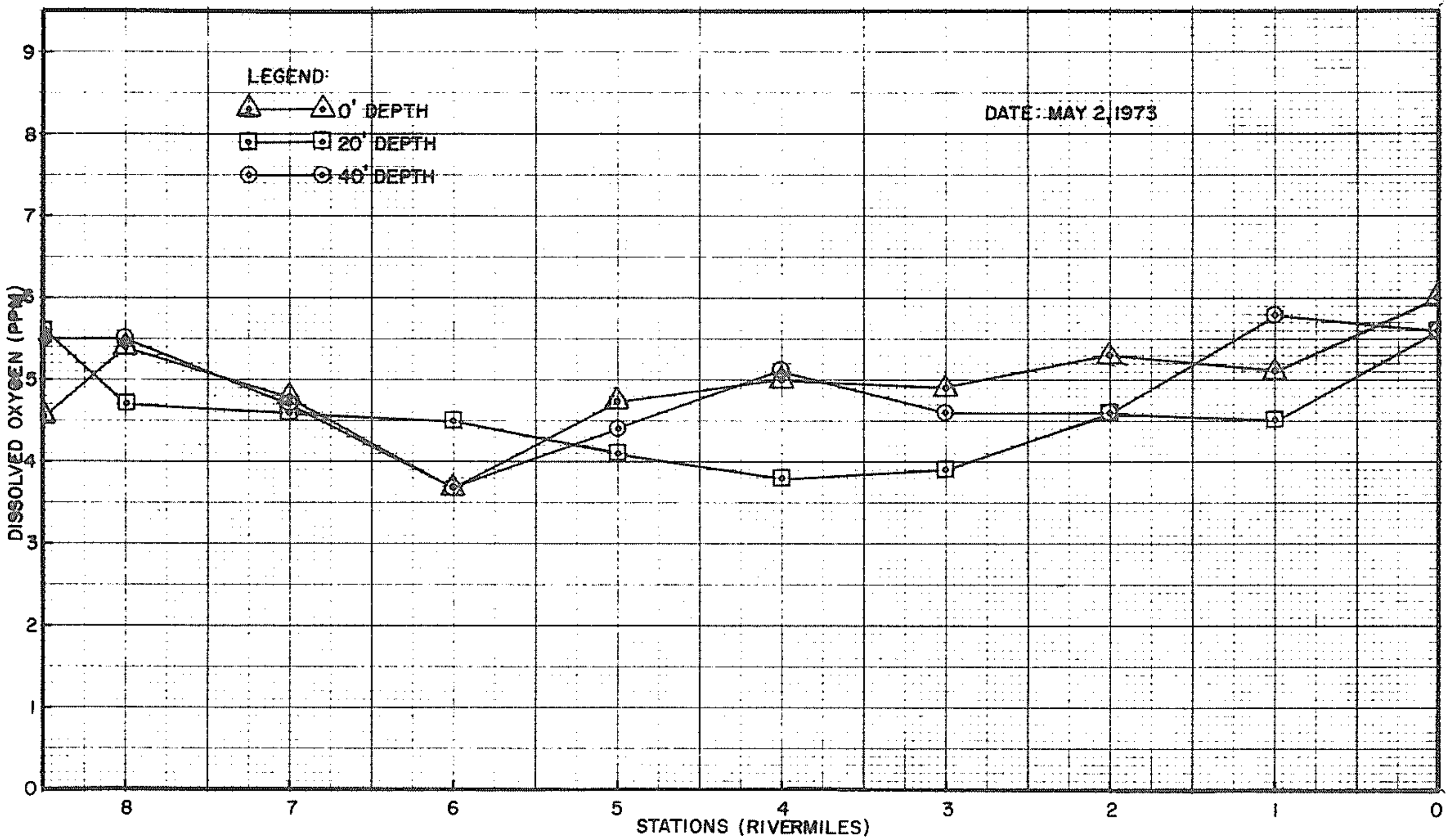


FIGURE 10
DISSOLVED OXYGEN PROFILE
CORPUS CHRISTI INNER HARBOR
SOURCE: WITHERS, etal. (61).

Withers utilized the findings of his 1973 investigations to develop a mathematical model for waste management in a ship channel-harbor complex. Withers considered runoff, salinity, temperature, tides, wind, and currents in developing and calibrating the model. He located the point source of pollution as shown in Figure 11, determined the pollution load magnitude as shown in Table 13, and determined the runoff from a five-year design rainfall as shown in Figure 12.

Withers used the mathematical model as a management tool to evaluate dissolved oxygen levels if waste loadings were increased. The results presented in Figures 13 and 14 showed that the natural assimilative capacity of the waterway would be exceeded if the waste load were doubled during the summer. However, during the winter, the natural assimilative capacity would not be exceeded until the waste load became nearly three times the original. Proper use of the analytical model is extremely valuable in long-range planning and water quality management.

Port of Brownsville Fishing Harbor

The fishing harbor operated by the Port of Brownsville is located in a dredged slip at Mile 13 of the Brownsville Ship Channel. The fishing harbor layout is shown in Figure 15 and the location is shown in Figure 16. The harbor measures 2100 feet by 1600 feet overall, including two 300-foot by 1200-foot peninsulas in the center. Access to the ship channel is provided by a 200-foot by 600-foot channel. The harbor has 10,800 feet of dock space and a design depth of 14 feet.

TABLE 13
Waste Source Quantity and
Quality for the Corpus Christi
Inner Harbor

Source	Wasteload (lbs. BOD per day)	Flow (CFS)	Salinity (PPT)	Dissolved Oxygen (PPM)
Initial		200	19.2	5.2
Suntide	675	2.28	0.5	0.0
CPC International (West)	1,723	.53	1.0	1.5
CPC International (East)	10,507	5.58	20.0	5.1
Asarco	18	0.81	0.6	4.0
Coastal States	301	1.88	1.0	5.8
PPG Industries	421	2.35	8.0	5.0
Champlin	126	0.88	8.0	5.0
Southwestern Oil	179	0.91	0.65	6.4
Broadway STP	2,637	14.28	6.0	4.70

Source: Withers, (61).

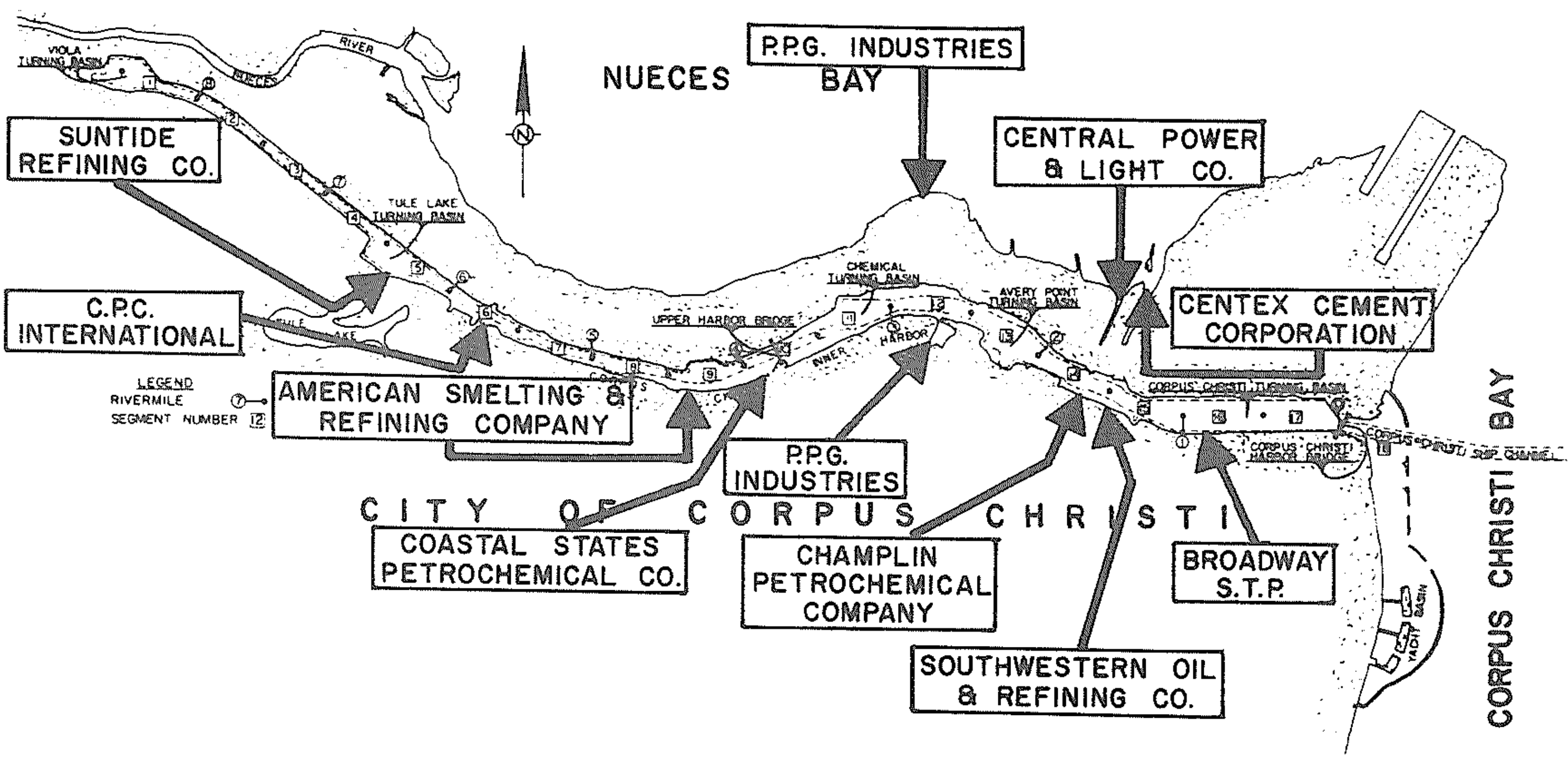
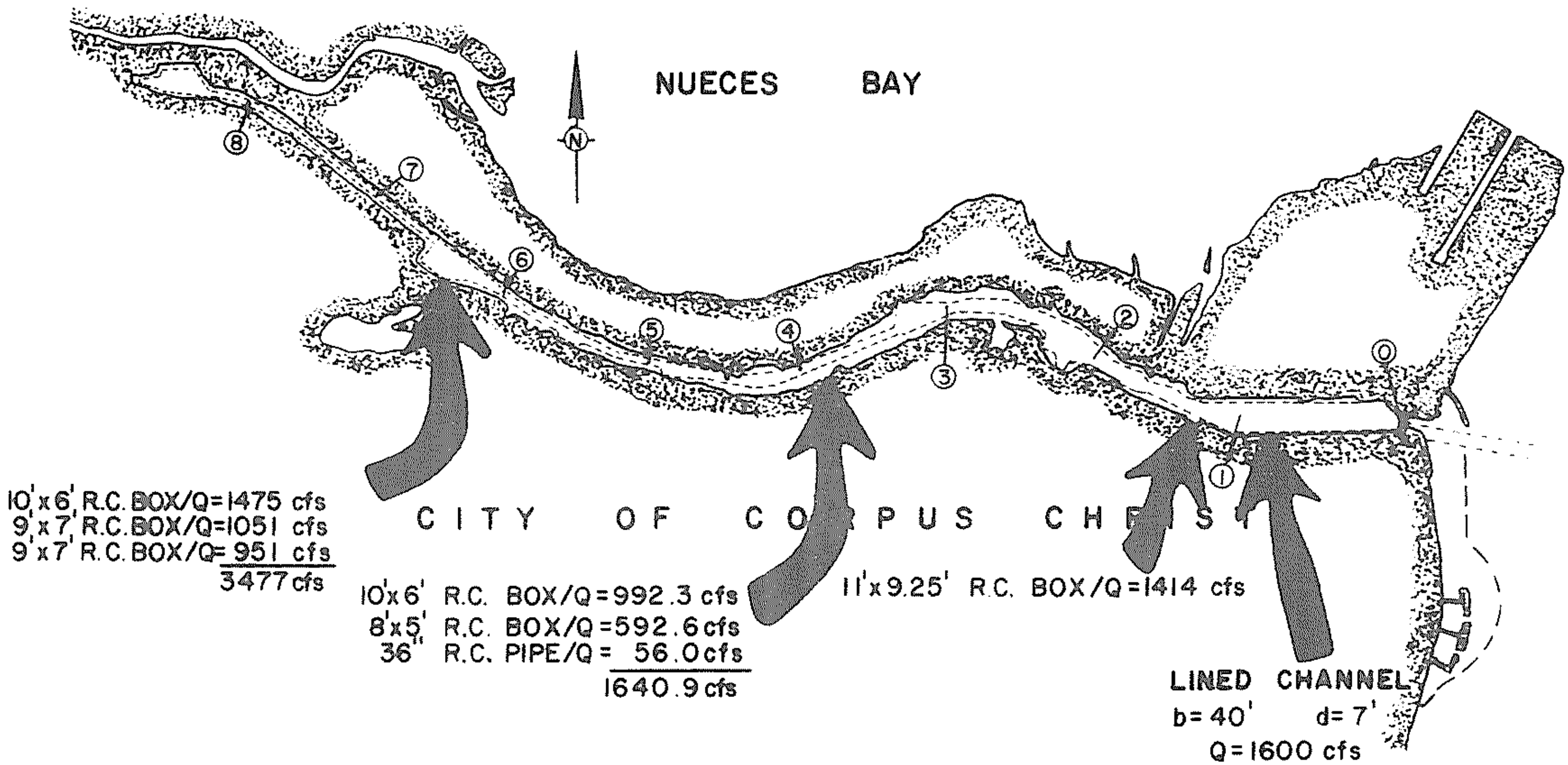


FIGURE 11

WASTE LOADING OUTFALL LOCATIONS

CORPUS CHRISTI INNER HARBOR STUDY

SOURCE: WITHERS (61)



RUNOFF FROM A FIVE-YEAR DESIGN RAINFALL
SOURCE WITHERS, (61).

FIGURE 12

STORM DRAIN STRUCTURE LOCATIONS
CORPUS CHRISTI INNER HARBOR STUDY

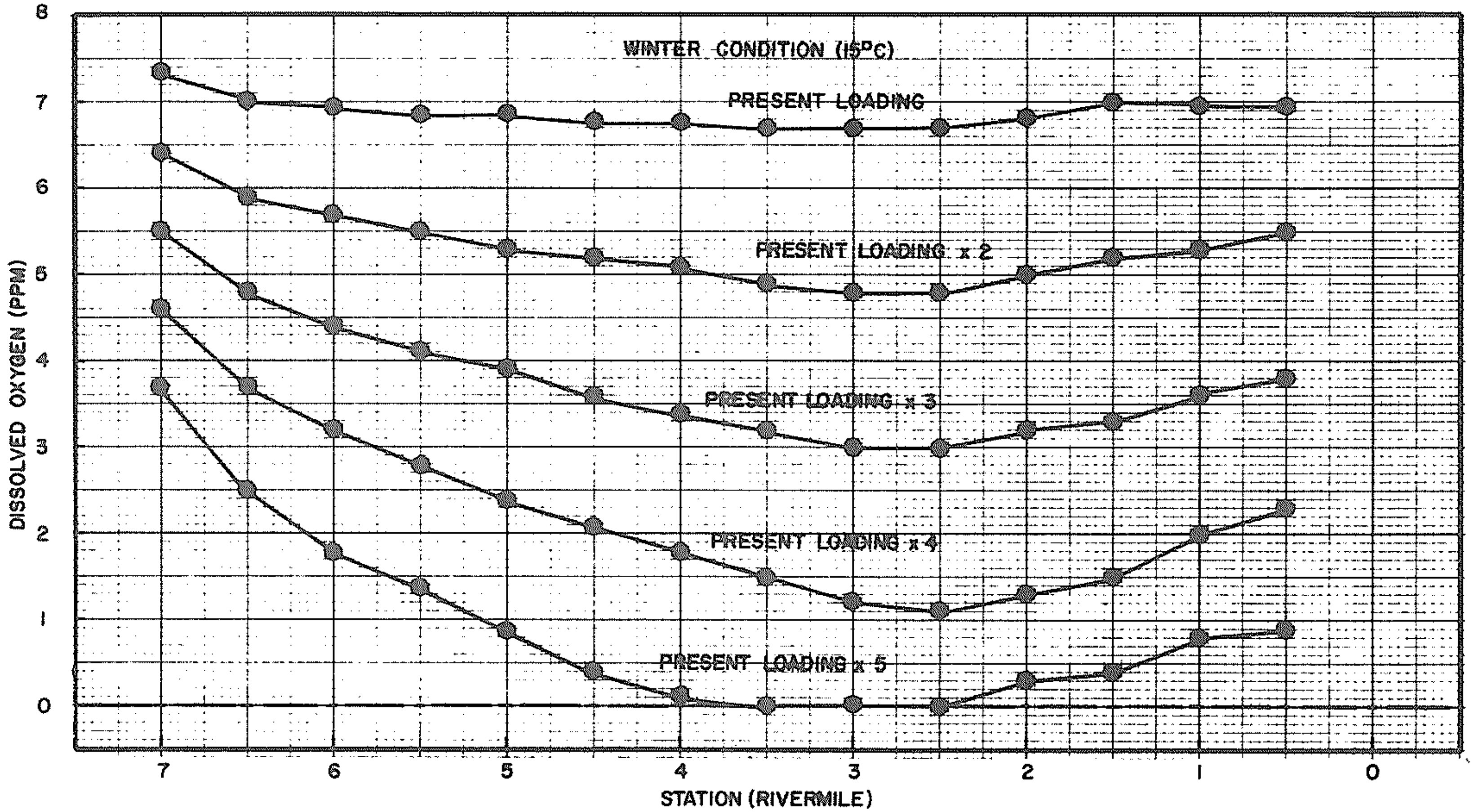


FIGURE 13
WASTE LOADING ANALYSIS-WINTER
CORPUS CHRISTI INNER HARBOR
SOURCE: WITHERS(61)

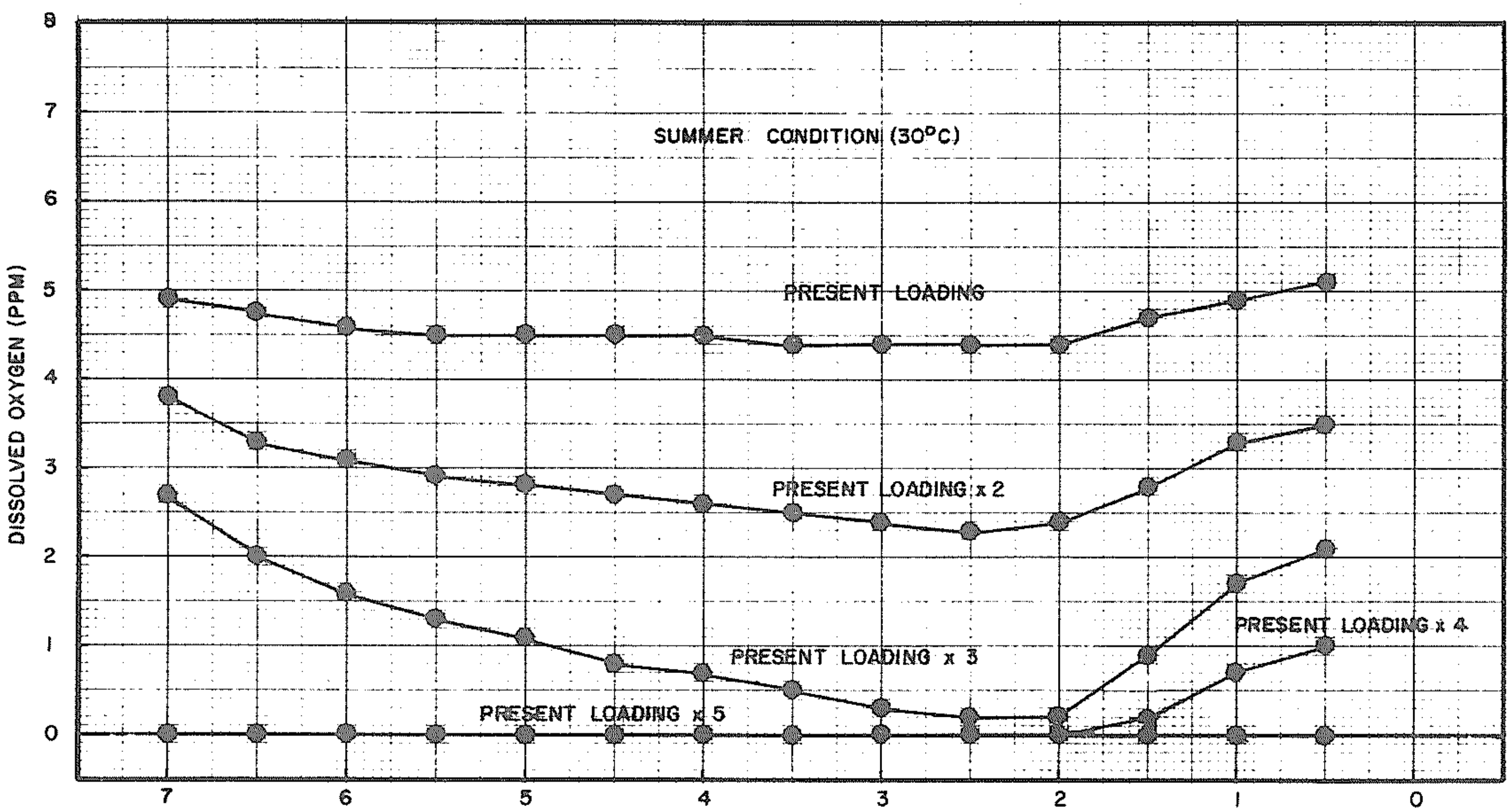


FIGURE 14

WASTE LOADING ANALYSIS-SUMMER

CORPUS CHRISTI INNER HARBOR

SOURCE: WITHERS (61)

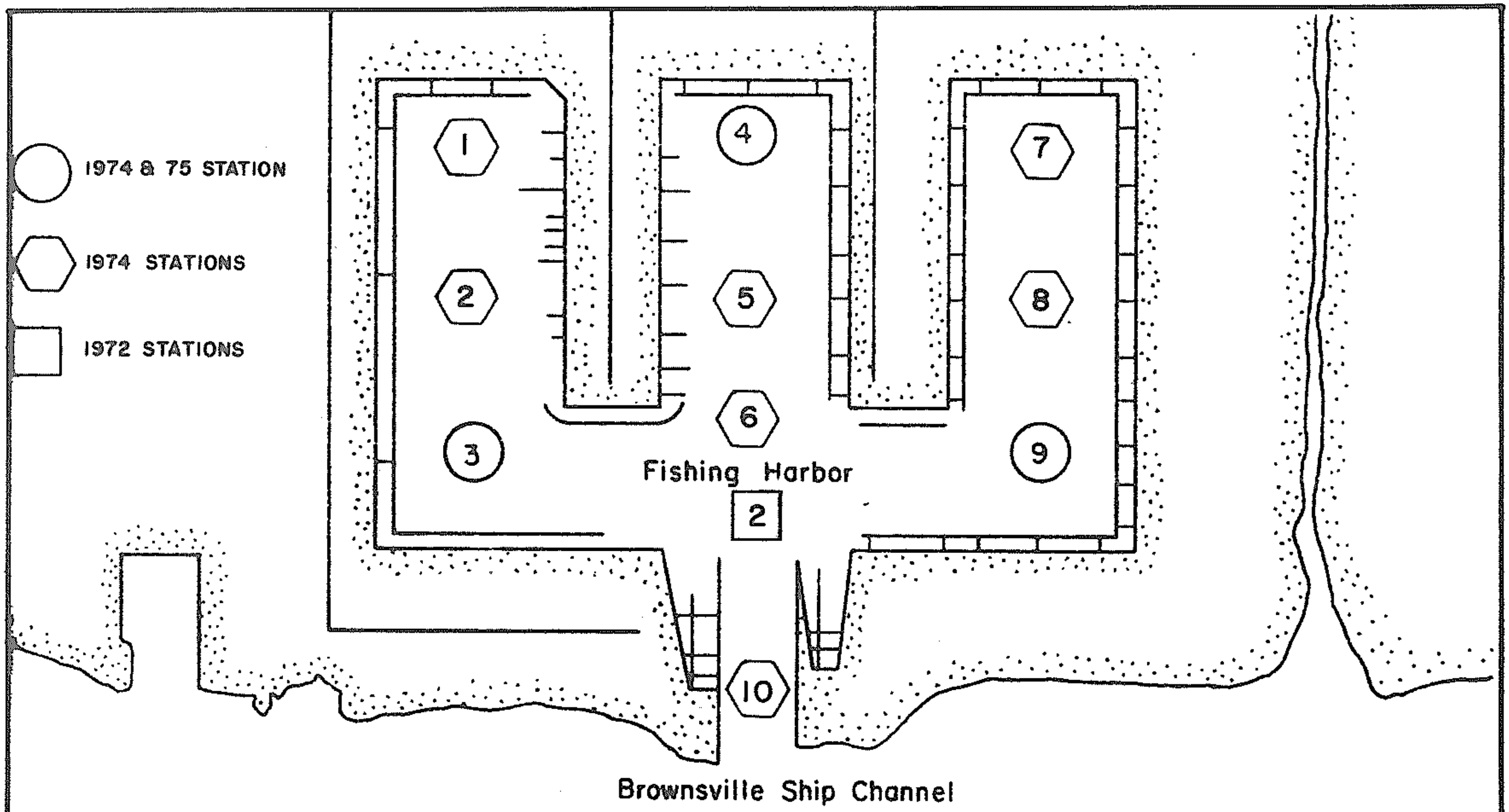


FIGURE 15
SAMPLING STATION LOCATIONS
FISHING HARBOR

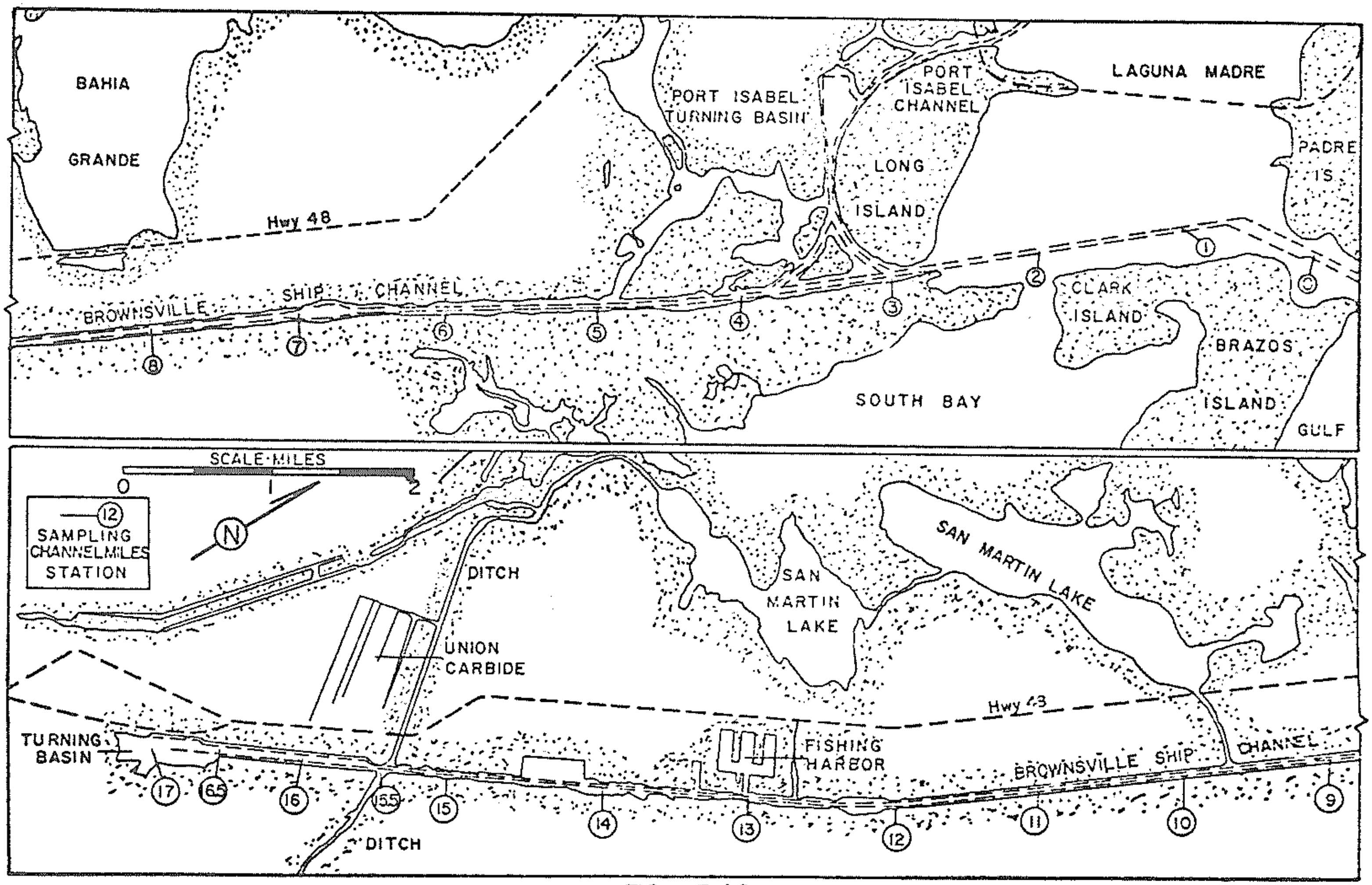


FIGURE 16
SAMPLING STATION LOCATIONS
BROWNSVILLE SHIP CHANNEL

According to Withers (62) eight active seafood processing installations existed in 1972. He found seafood processing wastes discharging through 12 outfall pipes with an average BOD_5 loading of 16,904 mg/l. All of the water quality parameters studied by Withers were typical of good quality coastal waters. Table 14 shows a comparison between BOD_5 and dissolved oxygen at three different times.

In 1972, Withers observed high copper and zinc levels in sediment of the fishing harbor. Tables 15 and 16 illustrate how these parameters, plus the others listed, compared with those in the main ship channel. Mile 0 is at the mouth of the Brownsville Ship Channel. Table 17 shows the results of sediment studies conducted during 1974. Withers noted that both the zinc and copper levels exceeded the EPA Region VI Dredged Material Driteria of 50 PPM for copper and 75 PPM for zinc. He also noted that the pattern of the sediment samples the metals were found in indicated that the cause could have been one point source or several. The zinc and copper could have come from antifouling paints used on boats or from bioaccumulation in wastes from fish and shrimp processing plants.

During 1975, a collection system was completed which collects all waste streams from boats and fish-processing operations. These waste streams are treated by land disposal at locations east of the fishing harbor.

TABLE 14
Water Quality in the Port of Brownsville
Fishing Harbor

Station	Depth	April 1972 D.O. (PPM)	April 1972 BOD_5 (PPM)	January 1974 D.O. (PPM)	January 1974 BOD_5 (PPM)	January 1975 D.O. (PPM)	January 1975 BOD_5 (PPM)
Mile 0	T	7.1	-	8.7	1.2		
	B	-	-	8.5	1.0		
Mouth of Harbor	T	7.4	-	7.0	2.4	7.0	1.5
	B	-	-	4.7	2.8	7.3	1.2
FH 4	T	3.5	-	5.7	3.8	6.8	1.4
	B	-	-	5.0	2.6	7.1	4.8
FH 9	T	5.0	-	6.6	1.8	7.0	2.2
	B	-	-	6.4	2.0	7.0	2.1
FH 3	T	2.5	-	5.2	2.6	7.7	3.0
	B	-	-	4.7	3.3	6.4	2.5
Mile 12	T	7.4	-	8.3	1.9		
	B	-	-	1.6	1.0		
Mile 16	T	7.8	-	7.7	1.9	7.8	2.1
	B	-	-	1.9	1.6	7.3	2.1
T - Top B - Bottom		Source: Withers (62)		Source: Withers, Slowey, & Garrett (63)		Source: Withers (64)	

TABLE 15
Sediment Quality Parameters for the Brownsville Ship Channel
(Dry Weight Basis)

Station	Depth (in.)	COD (mg/kg)	BOD (mg/kg)	Oil and Grease (%)	Kjeldahl Nitrogen (mg/kg)	Volatile Solids (%)
Mile 0	0-4	17,700	935	0.04	719	6.2
Mile 2	0-4	16,000	-	0.02	987	11.1
Mile 4	0-4	46,200	1,440	0.09	1,039	7.2
Mile 6	0-4	9,400	-	0.13	777	11.5
Mile 8	0-3	12,300	1,880	0.09	974	11.7
	9-12	4,500	225	0.03	210	4.3
Mile 10	0-4	11,200	-	0.14	672	8.4
Mile 12	0-3	14,200	910	0.04	557	5.3
	10-14	15,900	985	0.07	836	13.8
Mile 14	0-4	6,300	-	0.18	577	9.3
Mile 16	0-4	20,400	915	0.10	669	6.2
Mile 8.7	0-4	22,800	1,100	0.12	820	10.2
San Martin Outfall						
Fishing Harbor	0-4	43,600	2,800	0.40	983	7.4

Source: Withers, (62)

Note: Refer to Figure 16, (p. 72)

TABLE 16
Concentration of Selected Heavy Metals in Brownsville Ship Channel Sediments

Station	Depth (in.)	Metal Concentrations (PPM, dry weight)							
		As	Cr	Cu	Pb	Mn	Hg	Ni	Zn
Mile 0	0-4	<0.5	12	6	13	232	0.08	11	32
Mile 2	0-4	1.8	18	14	29	400	0.06	24	62
Mile 4	0-4	4.2	26	11	18	313	0.27	18	42
Mile 6	0-4	2.0	17	16	27	437	0.08	28	60
Mile 8	0-3	3.0	25	13	22	447	0.10	17	47
	9-12	1.4	14	6	11	152	0.07	6	20
Mile 10	0-4	0.3	17	16	27	505	0.07	19	53
Mile 12	0-3	1.9	19	10	11	189	0.31	10	27
	10-14	1.8	28	10	14	264	0.30	14	40
Mile 14	0-4	2.1	21	15	22	280	0.18	22	66
Mile 16	0-4	1.9	22	12	76	239	0.40	6	197
Mile 8.7	0-4	1.5	34	10	18	230	0.28	19	42
San Martin Outfall									
Fishing Harbor	0-4	2.5	25	465	27	200	0.19	19	116

Source: Withers, (62)

Note: Refer to Figure 16, (p. 72)

TABLE 17
Sediment Analysis Comparison
1972 & 1974
Fishing Harbor

Parameter	1972	1974 1/	1974 2/
COD	43600 mg/kg	12500 mg/kg	37000 mg/kg
BOD_5	2800 mg/kg	1450 mg/kg	3000 mg/kg
Oil and Grease	0.40%	0.19%	0.51%
Kjeldahl Nitrogen	983 mg/kg	570 mg/kg	980 mg/kg
Volatile Solids	7.4%	5.4%	8.9%
Chromium	25 PPM	11 PPM	16 PPM
Copper	465 PPM	104 PPM	150 PPM
Lead	27 PPM	23 PPM	30 PPM
Manganese	200 PPM	146 PPM	221 PPM
Mercury	0.19 PPM	0.30 PPM	0.75 PPM
Nickel	19 PPM	16 PPM	36 PPM
Zinc	116 PPM	73 PPM	224 PPM

1/ Average of Stations 6 & 10 (1974) nearest Station 2 (1972)

2/ Highest value from the 10-1974 Stations

Note: Refer to Figure 15 (p.71).

Source: Withers, et al. (63).

Field Studies Performed

Introduction

Three field studies were performed during this project to provide more data and information on various sources of pollution in a ship channel-harbor complex. This new data was necessary to supplement previous data collected by Texas A&M University and other research facilities. The combination of old and new data has made the study of the magnitude and impact of pollution sources more relevant to the Texas Gulf Coast.

Study of the Corpus Christi Inner Harbor

Field Technique. The equipment employed in a field study of the Corpus Christi Port Inner Harbor Complex included a 19-foot Power Cat outboard motor boat, a conventional water sampler, a dissolved oxygen meter, and a salinity probe. The party consisted of four members. One member piloted the boat and supervised the instrument operation. Another member assisted with navigation and kept data. The two remaining members collected samples; checked them for D.O., salinity, and conductivity; and set up samples for the Winkler test.

Figure 8 (p. 62) shows the location of sample stations and segments. Mile 0.0 is at the channel mouth and mile 8.5 is at the turning basin. Stations sampled were at mile 8.5, 7.0, 6.0, 4.0, 3.0, 2.0, 1.0, 0.0, and across the channel from the CP&L Power Plant intake.

Summary of Activity. The party did not observe any spills or oil slicks. Grain chaff was observed on the water surface between stations 6 and 4. Some of the chaff could have come from grain-loading facilities. The rest was probably particulate fallout from the air. Ships were observed closely, but no violations were noted.

Parameters Measured, Sampled, and Analyzed. During the Corpus Christi Port and Inner Harbor Complex field study, water quality parameters measured included temperature, dissolved oxygen, salinity, and conductivity. Samples collected were analyzed in the field lab for alkalinity and BOD_5. Other samples were analyzed at the main campus for nitrates, nitrites, and Chlorophyl A. Procedures used for the analyses were taken from Standard Methods for the Examination of Water and Wastewater (65).

Results of the physical analyses are displayed in Table 18 and results of the chemical analyses are displayed in Table 19. Surface and bottom temperature profiles, salinity profiles, and dissolved oxygen profiles are displayed in Figures 17, 18, and 19, respectively.

Study of the Port of Brownsville Fishing Harbor

Field Technique. The equipment employed in a field study of the Port of Brownsville Fishing Harbor included a 14-foot Monark flat-bottom boat with a 25-horsepower motor, a conventional water sampler, a dissolved oxygen meter, and a salinity probe. Salinity, conductivity, temperature, and dissolved oxygen were determined at the stations directly from the instruments. Water samples were collected and taken to a temporary field laboratory where they were analyzed for Eh, pH, ammonia, turbidity, alkalinity, and BOD_5. The samples were then frozen and carried to laboratories in the Environmental Engineering Division at Texas A&M University, where they were analyzed for total organic

TABLE 18
Physical Analysis
Corpus Christi Inner Harbor Water

Date	Time	Station Rivermiles	Depth	Cond. (μmhos/cm)	Sal. (PPT)	Temp. (^{o}C)	D.O. (PPM)
5/25/75	1745	Mile 8.5	T	39100	19.2	29.4	7.7
			B	38500	21.5	29.4	5.2
	1850	Mile 7.0	T	40500	20.0	30.0	7.5
			B	38700	17.0	32.0	4.2
		Mile 6.0	T	40000	20.9	30.0	5.9
			B	37000	20.0	27.5	4.4
		Mile 4.0	T	39800	19.8	29.0	6.2
			B	39600	20.0	28.0	3.6
	1910	Mile 3.0	T	41100	19.6	30.3	7.2
			B	40000	17.0	28.0	4.4
		Mile 2.0	T	41500	20.1	30.0	6.2
			B	38000	19.5	28.8	4.6
	1945	CP&L	T			28.0	8.8
			B				8.8
	2000	Mile 1.0	T	38200	19.5	28.5	6.5
			B	26000	19.7	27.5	5.6
	2035	Mile 0.0	T	38000	21.0	29.0	7.4
			B	37800	19.0	27.7	5.1

T- Top
B- Bottom

TABLE 19
Chemical Analysis
Corpus Christi Inner Harbor Water

Date	Station	Depth	Chlorophyl A (PPB)	Alk. (PPM)*	BOD_5 mg/l	NO_2 mg/l	NO_3 mg/l
5/25/75	Mile 8.5	T	2.3	149	3.4	.08	.230
		B	1.9	157	2.4	.08	.210
	Mile 7.0	T	2.3	149	3.5	.09	.150
		B	5.7	155	2.3	.09	.190
	Mile 3.0	T	4.8	149	3.2	.08	.150
		B	5.2	153	2.3	.04	.030
	Mile 2.0	T	5.7	151	2.2	.06	.100
		B	5.3	157	2.3	.08	.068
	Mile 0.0	T	8.6	130	2.6	.03	.060
		B	10.0	157	2.4	.03	.005

* Total Alkalinity - PPM as $CaCO_3$

T - Top

B - Bottom

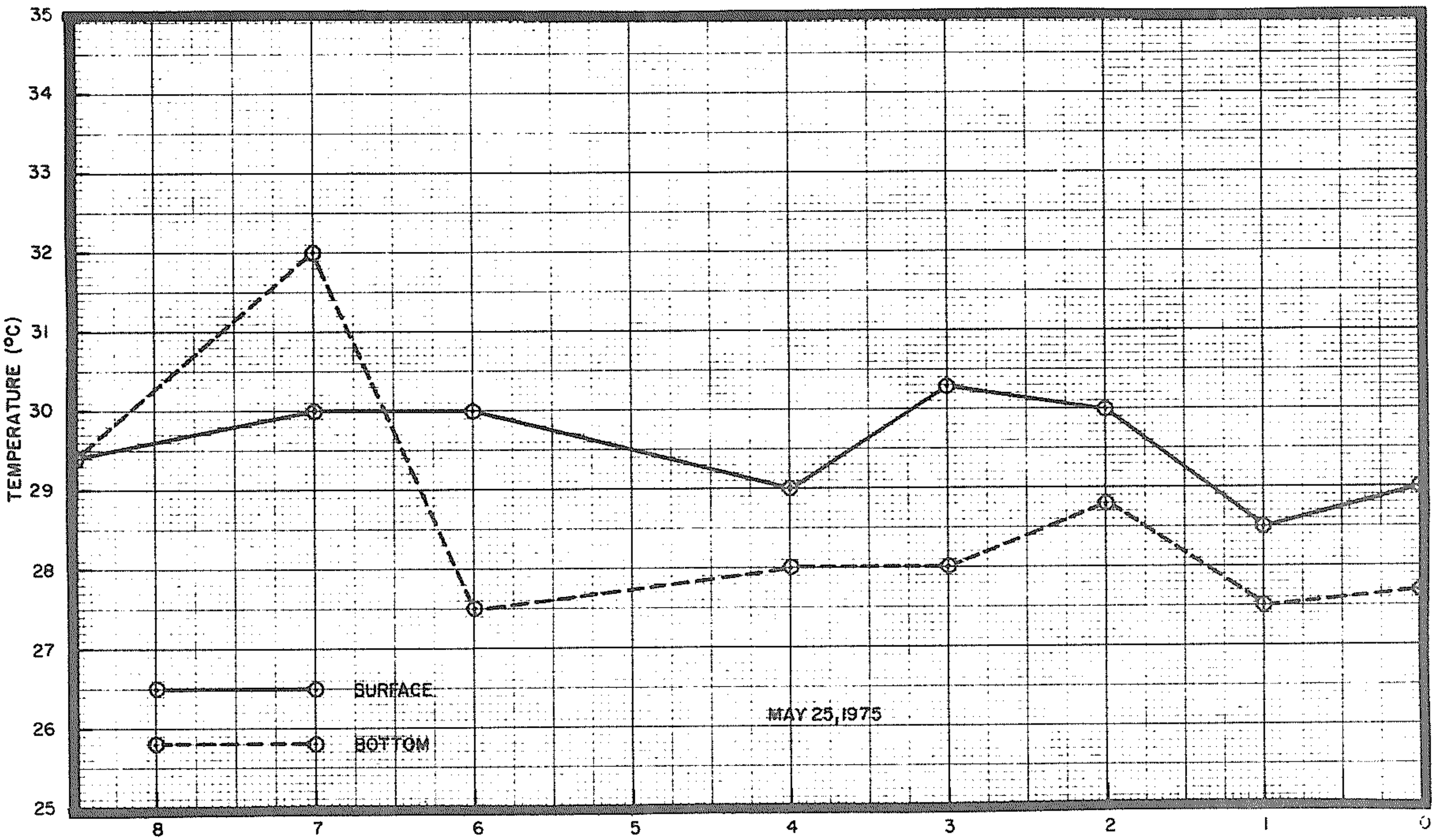


FIGURE 17
SURFACE & BOTTOM TEMPERATURE PROFILES
CORPUS CHRISTI INNER HARBOR

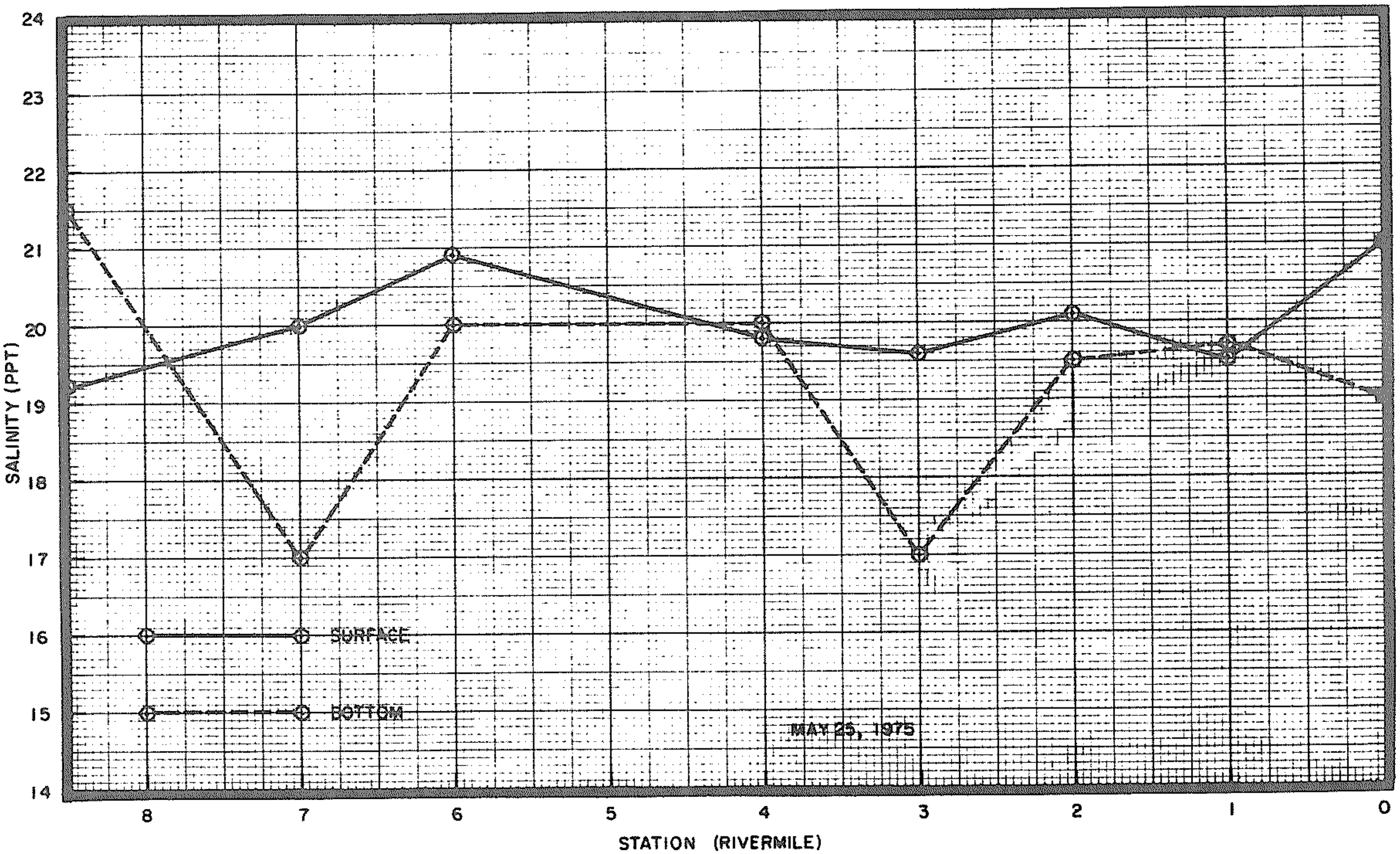


FIGURE 18

SURFACE & BOTTOM SALINITY PROFILES
CORPUS CHRISTI INNER HARBOR

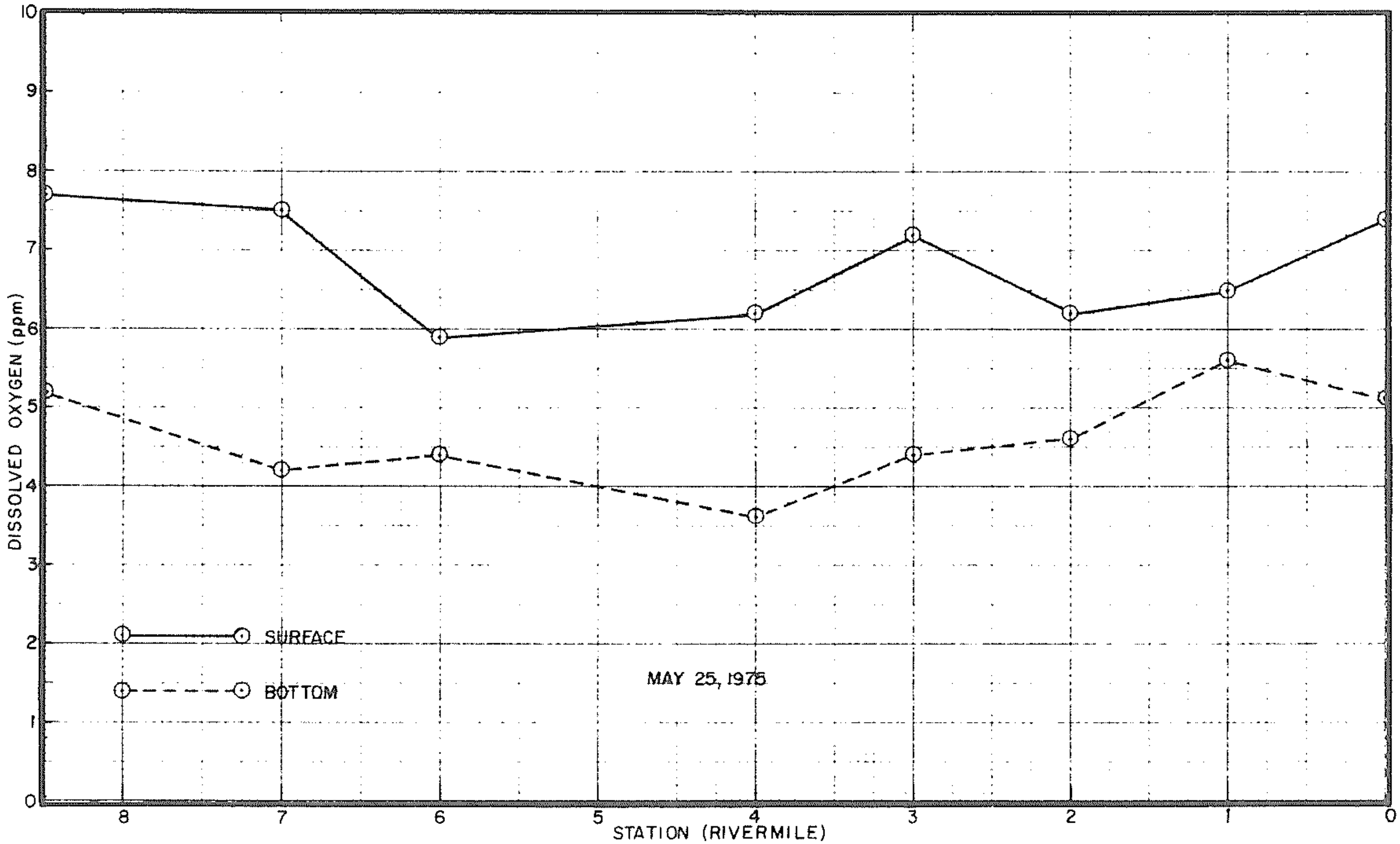


FIGURE 19
SURFACE & BOTTOM DISSOLVED OXYGEN CONCENTRATION
CORPUS CHRISTI INNER HARBOR

carbon (TOC), suspended solids, and nutrients. Procedures used were as outlined in Standard Methods for the Examination of Water and Wastewater (65). Figure 15 (p. 71) shows the sample station locations.

Summary of Activity. The party did not observe any spills, discharges, or floating matter. Shrimp-boat traffic was pretty heavy and probably averaged about one boat every 10 to 12 minutes. Near the harbor entrance, men were observed sanding rust and paint from boat hulls. The wind was mild and blowing from the south.

Data. Three stations were sampled in the ship channel and compared with three stations in the fishing harbor. All stations in the fishing harbor were found to have adequate dissolved oxygen (greater than 4 PPM). The pH was approximately equal to 8 which is acceptable. The high turbidity reading of 52.0 FTU's at Station 3 was probably caused by disturbing the bottom silt with the water sampler. This data is shown in Table 20. The chemical analysis data, shown in Table 21, are all within acceptable ranges. The Chlorophyll A concentrations probably indicate the presence of algal activity. The nutrient analysis data, shown in Table 22, indicated concentrations equal to or less than normal. In the past, the main concern in the fishing harbor has been the presence of high copper and zinc concentrations in the sediment. Data shown in Table 23 indicated that copper concentrations in the water, which had been approaching 55 PPB, had been reduced to 37 PPB. Also, zinc concentrations in the water which had been approaching 25 PPB in January 1974 according to Withers (63), ranged as high as 31 PPB during this study. This indicated that an active source of copper and zinc still existed.

TABLE 20
Physical Analysis
Water Quality Brownsville Fishing Harbor

Date	Station	Depth	Cond. (μmhos/cm)	Sal. (PPT)	Temp. (°C)	D.O. (PPM)	pH	Eh (mv)	Turb. (FTU)*
5/27/75	FH 3.0	T	46000	23.5	28.0	6.5	8.0	404	6.8
		B	47200	24.5	27.5	4.3	7.8	409	52.0
	FH 4.0	T	44000	22.3	29.0	6.6	7.9	414	7.1
		B	46000	23.5	29.0	5.6	7.7	409	8.0
	FH 9.0	T	46000	23.5	28.0	6.4	8.1	440	4.4
		B	46200	24.0	27.0	5.4	8.0	420	15.0
	BSC 0.0	T	46000	25.0	26.0	7.0	-	-	-
		B	45200	24.2	26.0	7.7	-	-	-
	BSC 12.0	T	46500	24.5	28.0	6.7	-	-	-
		B	48700	26.2	26.5	4.9	-	-	-
	BSC 16.0	T	45700	23.6	28.0	7.0	-	-	-
		B	47200	25.0	25.0	4.8	-	-	-

*Formazin Turbidity Units

T - Top
B - Bottom

FH - Fishing Harbor
BSC - Brownsville Ship Channel

TABLE 21
Chemical Analysis
Water Quality Brownsville Fishing Harbor

Date	Station	Depth	BOD_5 (PPM)	TOC (mg/l)	S.S† (PPM)	Alk. (PPM)*	Chlor. A. (PPB)
5/27/75	FH 3.0	T	2.5	44	40	137	9.5
		B	2.7	56	460	146	5.5
	FH 4.0	T	3.2	22	50	139	7.6
		B	2.4	22	118	137	6.2
	FH 9.0	T	1.7	23	58	144	6.2
		B	1.4	22	67	126	4.8

* Total Alkalinity - mg/l as $CaCO_3$
† Suspended Solids
T Top
B Bottom

TABLE 22
Nutrient Analysis
Water Quality Brownsville Fishing Harbor

Date	Station	Depth	NH_3-N (PPM)	NO_2-N (PPM)	NO_3-N (PPM)	Kj-N (PPM)	PO_4 (PPM)
5/27/75	FH 3.0	T	0.05	<0.005	<0.01	0.1	0.03
		B	0.36	0.012	0.03	1.0	0.01
	FH 4.0	T	0.06	<0.005	<0.01	0.4	0.30
		B	0.42	0.018	0.04	0.3	-
	FH 9.0	T	0.06	<0.005	<0.01	0.1	0.02
		B	0.38	0.010	0.01	0.9	0.01

T Top
B Bottom

TABLE 23
Heavy Metal Analysis
Water Quality Brownsville Fishing Harbor

Date	Station	Depth	Cd (PPB)	Cu (PPB)	Ni (PPB)	Pb (PPB)	Zn (PPB)
5/27/75	FH 3.0	T	<1.0	15.0	5.0	4.0	18.0
		B	<1.0	37.0	<3.0	2.0	24.0
	FH 4.0	T	<1.0	8.0	<3.0	<2.0	2.0
		B	<1.0	15.0	5.0	<2.0	31.0
	FH 9.0	T	<1.0	6.0	<3.0	3.0	17.0
		B	<3.0	12.0	<3.0	3.0	15.0

FH Fishing Harbor
T Top
B Bottom

New estimates of waste loadings were made by applying the values in Table 9, (p. 48) to the 1975 shrimp catch of 7,360,199 lbs. as reported by Ersel Lantz of the Brownsville Navigation District. These loadings were 521,143 lbs. of BOD_5 per year and 295,289 lbs. of suspended solids per year.

Brownsville Ship Channel System Non-Point Source Study

Introduction. The results of a non-point source study along the Brownsville Ship Channel system were used in evaluating the contribution of pollutants from sources other than the point sources adjacent to the channel. A great need exists for this type of research along the Texas Gulf Coast, but it needs to be done in much more detail than what was done in this study. Information provided in this initial study will provide some base data and will be valuable in planning more detailed future studies.

Two battery-powered sequential samplers were located at the stations as shown on Figure 20. These sample stations will be referred to as the Ag Ditch Sample Point and the San Martin Number Five Sample Point. The watersheds draining through these two sample points are shown in Figure 21. The San Martin Lake Watershed-North drains through the San Martin Number Five Sample Point. The San Martin Lake Watershed-South drains first through the Ag Ditch Sample Point, and later through the San Martin Lake Number Five Sample Point. The Brownsville Ship Channel Watershed-Upper End was not studied.

Both watersheds studied are contained completely within Cameron County, Texas and are both a part of the Rancho Viejo Watershed.

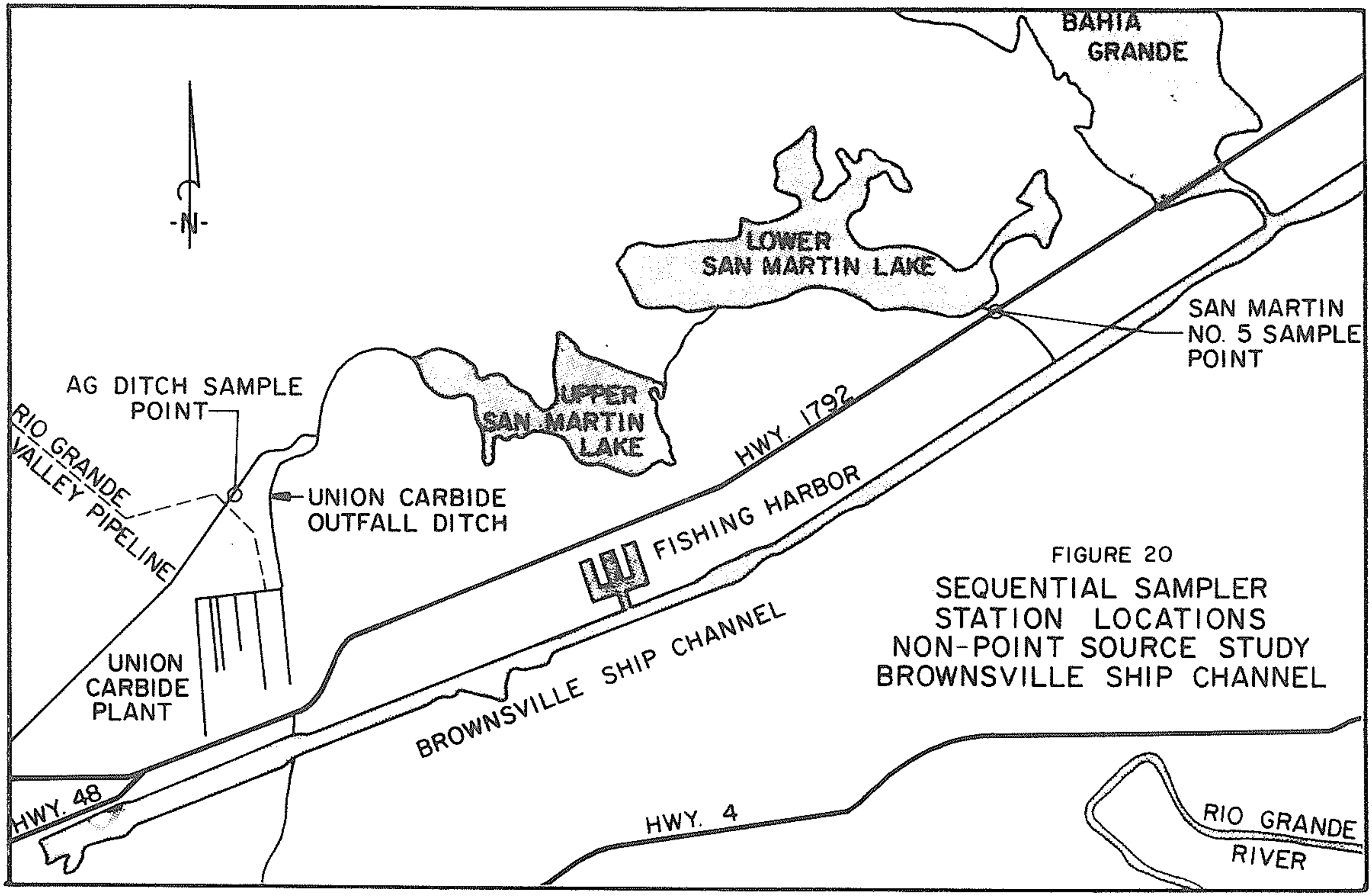


FIGURE 20
SEQUENTIAL SAMPLER
STATION LOCATIONS
NON-POINT SOURCE STUDY
BROWNSVILLE SHIP CHANNEL

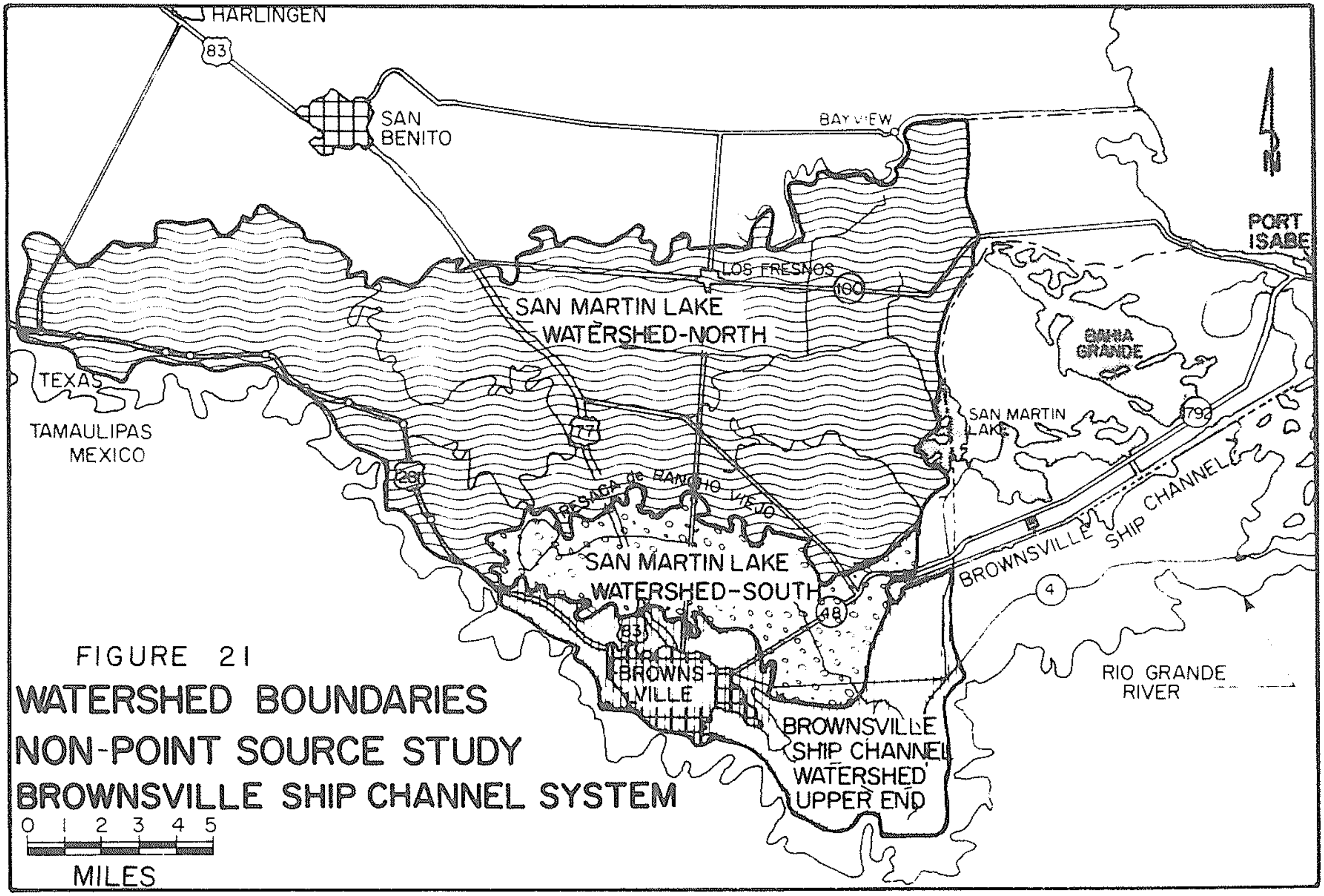


FIGURE 21

WATERSHED BOUNDARIES
NON-POINT SOURCE STUDY
BROWNSVILLE SHIP CHANNEL SYSTEM

According to United States Department of Agriculture, Soil Conservation Service Soil Maps, the majority of soils in the lower ends of both watersheds are classified as being of the Sejita-Lomalta-Barrada Association. The remainder of the soils on both watersheds are made up of equal parts of four other soil categories. One part contains soil from the Laredo, Saline-Lamalta Association, while another section contains soil from the Laredo-Olmito Association. The two remaining types, found most in the upper end of the watersheds, are the Harlingen-Benito Association and the Harlingen Association. All of the classifications contain silty clay loam and silty clay soil.

The San Martin Lake Watershed-South contains some of the outer urban areas of Brownsville, citrus orchards, miscellaneous croplands, and pastures. The San Martin Lake Watershed-North contains some small urban areas, marshes, citrus orchards, croplands, and pastures. The associated drainage ditch systems may contain tail-water from the flood-type irrigation system used in most citrus groves. The San Martin Lake System serves as a series of oxidation ponds in the polishing process for the Union Carbide Plant effluent.

The area of the San Martin Lake Watershed-North was found to be approximately 138 square miles, while the San Martin Lake Watershed-South contains approximately 27 square miles.

Technique. The sequential samplers were fully portable, self-contained, and weather-proof. They both utilized a 12-volt finger-type tubing pump powered by a rechargeable lead-acid battery. The pump controls were fully automatic and adjustable. Variable adjustments allowed control over the pumping cycle duration and the length of time available in the sampler at any one time. Sixteen gauge metal boxes were fabricated to totally enclose the samplers and prevent vandalism. These boxes were locked and secured by lengths of one-half-inch steel chain and padlocks to any available immovable object. The samplers were equipped with 15 feet of one-quarter-inch Tygon tubing with a weighted strainer on the intake end.

Since only two of these expensive sequential samplers were available, it was decided to only monitor the effects of non-point pollution sources on the San Martin Lake System. Unfortunately, the project was attempted during a very dry year in the Rio Grande Valley, and only limited results were obtained. Another complication was the fact that the study site is nine hours by car from the main campus of Texas A&M University.

The only sampling was done during and shortly after one rainfall, which ranged between one-half inch in some areas and one-quarter inch in other areas and lasted about one hour. The rain fell mostly to the north of Brownsville, and was concentrated upon the San Martin Lake Watershed-South.

Seven 400 milliliter samples were collected from each sampler every four hours. The samples collected during the four hours were composited into one sample, and returned to the field laboratory as soon as possible. Field analyses included conductivity, salinity, dissolved oxygen, five-day biochemical oxygen demand, turbidity, Eh, pH, and alkalinity. The nutrient analyses were done in the Environmental Engineering Laboratory at Texas A&M University. Procedures used in all analyses were according to Standard Methods for the Examination of Water and Wastewater (65).

The flow in the Ag Ditch was approximately three and one-half cubic feet per second. The method used to determine the flow was the surface float method. According to Linsley and Franzini (66), the mean velocity of a stream is assumed to be 0.85 times the surface float velocity. Field measurements determined the cross-sectional area of the ditch to be 11.6 square feet and the mean velocity to be 0.3 feet per second. There was no tidal influence in the ditch.

The quantity of flow past the San Martin Number Five Sample Point was more difficult to measure because of a definite tidal influence. However, the two contributors to the flow are the Ag Ditch and the Union Carbide Plant. Union Carbide discharges 25 cubic feet per second (67) and the Ag Ditch adds three and one-half cubic feet per second. Thus, an estimate of flow from San Martin Lake into the Brownsville Ship Channel would be 28.5 cubic feet per second.

Data. Data from the 24-hour non-point source study are shown in Tables 24 and 25. A staff gauge placed in the Ag Ditch indicated that the ¼ to ½ inch rainfall did not produce appreciable runoff. Only one BOD_5 value was successfully recorded because of the influence of algal organisms on the BOD test. All other parameters indicated that the rain produced no variations throughout the period of sampling. The only noteworthy data fluctuations were in the ammonia concentrations at 0800 hours and at 2400 hours. The extremely limited data indicated that the Ag Ditch released less than 40 pounds of BOD_5 per day to the San Martin Lake System and eventually to the ship channel.

TABLE 24
Non-Point Source Study Physical Analysis
Brownsville Ship Channel System
MAY 1975

Station	Date	Time	Cond. (μmhos/cm)	Sal. (PPT)	D.O. (PPM)	BOD_5 mg/l	Turb. (FTU)
Ag Ditch	28 May 75	0400	10000	5.0	6.9	*	22
		0800	10000	5.0	5.7	*	16
		1200	10000	5.0	7.2	*	17
		1600	10000	5.0	-	-	22
		2000	10000	5.0	7.0	*	22
		2400	10000	5.0	7.4	2.1	21
San Martin	28 May 75	0030	43000	21.8	6.8	1.7	24
		0430	43000	21.8	7.8	*	23
		0830	43000	21.8	7.7	1.2	21
		1230	43000	21.8	7.4	1.2	28
		1630	43000	21.8	6.1	< 1.0	32
		2030	43000	21.8	6.8	1.8	21

* Results show influence of algal organisms.

TABLE 25
Non-Point Source Study Chemical Analysis
Brownsville Ship Channel System
MAY 1975

Station	Date	Time	Eh (mv)	pH	Alk. (ppm)*	NH_3 (mg/l)	NO_2 (mg/l)
Ag Ditch	28 May 75	0400	385	8.0	234	0.06	0.026
		0800	405	7.8	225	0.32	0.025
		1200	395	7.6	225	0.08	0.027
		1600	-	-	210	-	-
		2000	383	8.0	200	0.08	0.044
		2400	415	8.1	210	0.36	-
San Martin	28 May 75	0030	415	7.8	160	0.06	0.020
		0430	415	7.9	162	0.20	0.020
		0830	415	7.7	150	0.08	0.020
		1230	420	7.7	166	0.06	0.027
		1630	425	7.6	155	0.04	-
		2030	430	8.1	150	0.06	0.040

* Total Alkalinity - mg/l as $CaCO_3$

The data from the San Martin Number Five Sample Point showed very little fluctuation throughout the sample period. Field observations confirmed that no rain fell directly on the lake and that very little, if any, came from runoff. Therefore, the only net influence upon the flow past the sample point was the Ag Ditch and the Union Carbide outfall.

Significance of the Field Studies Performed

Port of Corpus Christi Inner Harbor

The Port of Corpus Christi Inner Harbor was chosen for a field study to provide information from a body of water that receives various types of waste, yet abounds in fish and marine life. During the field trip of May 25, 1975, fishermen were observed at different locations along the channel and questioned about their catch. Most of them reported average catches of game fish regularly. This is an example of a waterway where the wasteload does not exceed the natural assimilative capacity of inner harbor waters. This condition could be obtained in other ship channels with proper action.

Port of Brownsville Fishing Harbor

The Port of Brownsville Fishing Harbor is probably the best example of a harbor devoted solely to fishing craft and associated processing plants and businesses. It was noted that there was an increase only in zinc, an impact one might not expect. The effects of the Navigation District cleaning up the operations to decrease pollution in the fishing harbor were evident. This was a project undertaken by the Port of Brownsville as an interim solution prior to completion of their waste collection system in mid-1975.

Brownsville Ship Channel System Non-Point Source Study

The study of non-point pollution sources is a relatively new one to the Texas Gulf Coast. Most research efforts are directed towards problems considered to have greater significance. Few researchers are convinced that non-point source pollution has an impact upon most waterways. The Brownsville Study was inconclusive within itself because the study period fell during a dry season and water samples were only collected during one 24-hour period. However, it does provide base data for later research. There is a great need for conclusive long-term non-point source pollution studies along coastal ship channels.

CHAPTER IV

GENERAL SOLUTION

Identification of Problems

Introduction

The environmental problems of eight major ship channel-harbor complexes along the Texas Gulf Coast were studied during this project. It was not the objective of this project to determine the ship channel-harbor complex with the most serious environmental problems, nor was an attempt made to specifically solve each port's environmental problems. This section will discuss what is defined as a "typical port" on the Texas Gulf Coast. While it is agreed that no such typical port exists, it is possible to consider a composite case. This composite-typical case is based on the assumption that the port management's philosophy includes a planned destiny of continued success and growth.

Problems

The environmental problems discussed throughout this paper basically have followed the same pattern of development as the port. In other words, the highly developed industrialized port will very likely have the most industrial pollution problems.

Before a plan of action can be formulated, a list of water pollution problems within a typical ship channel-harbor complex, arranged according to their priority, should be developed. This was done and the list is presented in Table 26. Some ports may have solved several of these problems, or they may have never had them. If this is the case, then that particular problem may simply be deleted from that port's planning activities. The priority list considers both the present and potential environmental threat of the problem, and was developed entirely from information gathered during this project.

Dredging and dredged materials are the most serious environmental problem limiting the success and growth of ports. If something is not done about the pollution load of dredged materials, the majority of the ports on the Gulf Coast will be unable to obtain dredging permits in the near future. Permits to dredge are more difficult to obtain each year, mainly because of contaminated dredged materials. Data cited in Chapter II indicated that approximately 32 percent of the waste loading in a ship channel ends up as sediment. This means that all entities concerned with the future growth and viability of a ship channel-harbor complex must be interested in controlling the components making up the waste loading.

Industrial wastes are listed second in the priority list. Even though tremendous advances have been made in controlling industrial wastes, they still constitute a significant pollution problem because little natural flushing exists in most ship channels. Also, some industries are still lagging behind in developing waste treatment facilities.

Because of their potential for causing pollution, oil spills are listed third in priority. They presently occur almost daily in some

TABLE 26
Water Pollution Problems in a Ship Channel-Harbor Complex Listed According To Priority

1. Dredging and dredged materials
2. Industrial wastes
3. Oil spills
4. Rural and urban runoff
5. Hazardous materials spills
6. Shipboard wastes
7. Domestic waste from shore
8. Ship bilge water
9. Ship ballast water
10. Ship tank and barge washings
11. Seafood processing
12. Water withdrawals and returns
13. Floating debris

areas, but very rarely in others. However, the potential for a huge spill is great in areas where petrochemical plants and refineries are highly concentrated.

Rural and urban runoff is rated as the fourth priority problem. When rain falls on industrialized areas, the runoff carries large amounts of waste products directly into adjacent channels. This run-off comes in contact with slabs, buildings, loading areas, waste dumps, and miscellaneous areas where waste accumulations from various sources are found. Rural areas are considered important because of the relatively large watersheds that drain through some ship channels. Run-off from residential areas is also important because of its quantity and quality. Residential runoff creates waste loadings that are often compared to sewage.

Hazardous materials spills are considered fifth on the priority list because of their pollution potential. Once they are spilled, these materials are almost impossible to clean up. Therefore, preventive measures deserve a great deal of attention.

Shipboard wastes are listed sixth in priority, and present the same pollution effect as highly concentrated domestic sewage. These wastes are often, by mistake, thought to be insignificant.

Domestic wastes from shore areas are in seventh place on the priority list. In some areas, they may possibly be first. However, the typical port considered in this section would most likely be surrounded by municipalities proficient in the age-old science of sewage treatment.

Ship bilge water is listed eighth on the priority list. Many private industrial plants provide facilities into which ships can pump their bilge water. Several ports even provide this service for ships. This is an annoying problem, and it desires more attention.

Ship ballast water is listed ninth in priority. As with ship bilge water, many facilities are provided for collecting ballast water discharge from ships. There still is a need for better enforcement, and additional receiving and collection facilities are needed.

Ship tank and barge washings are listed tenth in priority. Studies cited in Chapter II indicated that large industries are doing an adequate job of collecting and treating this waste, but that some commercial barge washers need additional improvements.

Even though research in the Brownsville Fishing Harbor revealed that seafood processing wastes can be properly handled by the port's new collection system, these wastes are listed eleventh in priority. Data collected during this study indicated that sea food processing wastes can make a significant pollution contribution, if left uncontrolled.

Water withdrawals and returns are listed as twelfth on the priority list. Because increased temperatures of cooling water decrease its capacity to adsorb oxygen, this problem may be much higher up the priority list in some areas. However, research along the Texas Gulf Coast indicates that the increased flushing caused by water withdrawals is of benefit to most bays and estuaries. One problem is that water withdrawals and returns can transport pollutants into unpolluted areas.

Floating debris is thirteenth and last on the list. It is mainly a navigation hazard. However, in combination with an oil spill it could cause untold removal and aesthetic problems.

Additional environmental problems and pollution sources could be listed for each specific port. This is why careful research and engineering is required for long-range planning and management of environmental problems.

Solutions

Introduction

A long-range plan is necessary for the success and longevity of virtually any activity. The environmental problems facing entities concerned with managing a ship channel-harbor complex require broad-based solutions and the development of proper management strategies.

General Solutions

General solutions to various water pollution problems may be obtained from the problem/solution matrix shown in Table 27. Preparing a list of solutions is much easier than paying for them. However, for long-range planning purposes it is assumed that all solutions are feasible. The solutions to water pollution problems listed in Table 27 are not to be used in detailed project planning, but used to formulate plans of action. Most environmental problems

TABLE 27
Problem/Solution Matrix for
the Environmental Management
of a Ship Channel-Harbor Complex

	Engineering Solutions							Administrative Solutions				
	Control at Source	Improved Treatment	Preventive Measures	Routine Maintenance	Improved Utilization & Conservation Practices	Better Operation	More Research Required	Better Management	Closer Cooperation Between Agencies	Contingency Plans	Long-Range Planning	Better Enforcement
1. Dredging and Dredged Materials			*		*		*	*	*		*	
2. Industrial Wastes	*	*			*	*	*					*
3. Oil Spills			*	*						*		
4. Rural and Urban Runoff	*				*		*	*				*
5. Hazardous Materials Spills			*	*			*			*		
6. Shipboard Wastes	*											*
7. Domestic Waste from Shore		*				*						*
8. Ship Bilge Water	*											*
9. Ship Ballast Water	*											*
10. Ship Tank and Barge Washings	*	*				*						*
11. Seafood Processing	*	*			*							
12. Water Withdrawals and Returns				*	*						*	
13. Floating Debris	*			*								

confronting a ship channel-harbor complex can be solved using existing technology along with improved operations.

Dredging. Dredging produces tremendous quantities of dredged materials that are especially difficult to dispose of if contaminated with waste material. In Chapter II of this report, a study was cited showing that 32 percent of the wasteload in a channel ends up as sediment. If wasteloads can be decreased at their source, then dredged materials might, in the future, be easier to dispose of. Dredged materials are disposed of in several ways. Disposal usually consists of dumping the dredged materials either above or below the water line. New ways of utilizing and managing the dredged materials areas are available, and more are being developed. Proper long-range planning could insure that the dredged materials sites cause minimum environmental damage. Closer cooperation between agencies involved in dredge permitting could lead to fewer delays and unnecessary expenditures.

Industrial Wastes. Tremendous advances have been made in industrial waste treatment during the past years. However, field studies still show that better treatment, conservation, and management at the source is necessary. Industrial wastes still exist that are difficult to treat by known methods. Also, some industries still try to get by without proper waste treatment.

Oil Spills. Cleaning up an oil spill has become a highly developed science. However, in some areas, a major oil spill could not be handled with the available men and equipment. More and better contingency planning seems necessary. Much needed and necessary attention has been given to prevention of spills, but there are still deficiencies in the design of some vessels, transfer facilities, storage areas, and guidance systems that require attention.

Rural and Urban Runoff. The quantity of runoff in this problem area is so great that treatment is hardly practical. Better housekeeping in industrial areas along with enforcement could improve the situation in most ship channels. Improved up-stream water management and conservation practices could also make a significant contribution to pollution prevention. Research is needed in all areas, including the runoff from residential districts where the water quality has been compared to sewage.

Hazardous Materials Spills. This is mainly a problem of prevention, because once hazardous substances enter a body of water, they are difficult to remove. Improved contingency plans are necessary to insure that the substance is identified and proper steps are taken to treat or clean up the spill.

Shipboard Wastes. Shipboard wastes are mainly a very concentrated sewage. They should be retained on ship until they can be discharged into a collection system. Enforcement is difficult, especially when many of the ships are foreign. Improved enforcement would be beneficial.

Domestic Wastes from Shore. Some municipalities are still using vastly overloaded facilities and outdated techniques. Improvements in the operation of treatment plants could probably upgrade some effluent discharges. Other discharges will be improved only when the public votes bonds to pay for new treatment plants. With their existing staff, monitoring all discharges is a tough job for enforcement agencies. Better monitoring would certainly improve the situation. Advanced waste treatment should also be considered.

Ship Bilge and Ballast Water. Ship bilge and ballast water is collected and treated in most cases. Adequate facilities for the collection of these wastes need to be available. Enforcement could be improved with the use of analytical instruments.

Ship Tank and Barge Washings. These wastes need to be treated just like other industrial waste materials. The quantity of water to be treated could be decreased with careful operation. Some waste treatment systems could be improved also.

Sea food Processing Wastes. This waste can be collected and treated by various proven methods. Some treatment facilities only provide primary treatment and could be improved. Operations inside the processing plant could be changed to significantly reduce the volume of wastewater.

Water Withdrawals and Returns. This category includes cooling water as well as consumptive uses. Return of cooling water to channels should be designed to accomplish an acceptable temperature rise. Often, if deemed necessary, cooling ponds and towers can be utilized to decrease the temperature rise prior to discharge. If done properly, long-range planning could utilize the currents caused by intakes and discharges to cause an environmental advantage.

Floating Debris. Floating debris can be controlled at the source by proper housekeeping. If debris gets into a channel in significant quantities, it should be mechanically removed on a routine basis.

Plan of Action

Questions

The logical questions to be asked now are: who is responsible for the plan of action; what kind of organization should administer the program; when is this action required; where is this plan of action necessary; and how should this feat be accomplished? These questions and their answers will vary somewhat from port to port, and will depend upon the environmental conditions, the location, the stage of development, the community support, the polluter's concern, and the attitude of the port authority or navigation district's management. Alternative answers to the listed questions are briefly enumerated for consideration of concerned entities.

Who? The answer to this question must be someone who will gain from successful environmental management. Also, it must be someone with excellent management and leadership. It could be an agency within some level of government or an organization such as an area planning commission. Other alternatives for management include the local port authority or a waste disposal authority. Whatever management body takes the initiative in solving a ship channel-harbor complex's environmental problems will control its destiny.

What? The organization providing pollution control can be the private company causing the problem or a publicly financed organization serving all or part of the polluters. Either method of control is fine, if it provides adequate results. However, there are some monetary, managerial, and operational advantages in using centralized publicly financed efforts.

When? The timing of environmental management at each particular ship channel-harbor complex depends on the degree of development, the present environmental degradation, and plans for future expansion. Even though the Port of Brownsville is in a relatively early stage of development, it is constructing a centralized waste treatment system to insure uninhibited growth.

Where? Every area needs some form of environmental planning. If an area has no present environmental problems, then planning is necessary to prevent future ones.

How? The "how" must be compatible with all previously listed questions. This topic is discussed more in the next paragraph.

Proposed Plan

Before any long-range plans are drafted, planners should obtain legal advice from an experienced environmental attorney. Environmental legislation is lengthy and complex. An overview of legislation concerning ship channel-harbor complexes is provided in Tables 28 and 29. Not only are there at least thirteen laws and acts pertaining to the environment of a port, but there may be several court interpretations of each.

Since devising a legally correct plan is vitally important, close cooperation with the responsible governmental agencies is necessary. An agency may have been created for the sole purpose of administering certain legislation. However, many agencies become involved because they are asked to review permits from other agencies. Therefore,

TABLE 28

Principal Federal Environmental Legislation Concerning Ship Channel-Harbor Complexes

ENVIRONMENTAL LEGISLATION / POLLUTION SOURCE	River & Harbor Act of 1899	Public Health Service Act of 1912	P.L. 92-500 F.W.P.A. Act of 1972	Marine Protection, Research & Sanctuaries Act of 1972	National Environmental Policy Act of 1972	Coastal Zone Management Act of 1972	Fish & Wildlife Coordination Act of 1965	Dept. of Transportation Act of 1968	Deepwater Port Act of 1974	Ports & Waterways Safety Act of 1972	Oil Pollution Act of 1961	Estuarine Areas Act of 1968	Occupational Safety & Health Act
1. Dredging													
A. New	*		*	*		*	*			*		*	
B. Maintenance			*	*		*	*			*		*	
2. Waste from Ships													
A. Sanitary Sewage		*	*										
B. Solid Waste	*		*										
3. Ship Bilge Wager			*								*		
4. Ship Ballast Water			*										
5. Ship Tank & Barge Washings			*		*						*		
6. Non-Point Source Pollution													
A. Rural Runoff			*				*						
B. Urban Runoff			*				*						
7. Municipal Sewage		*	*		*								
8. Water Withdrawals & Returns			*	*	*		*						
9. Industrial Waste Discharges	*		*		*	*							
10. Oil Spills	*		*					*	*	*	*		
11. Hazardous Matls.	*		*					*	*	*			*
12. Floating Debris	*		*										
13. Seafood Processing	*		*		*	*							

Source: Environmental Protection Agency (69)

TABLE 29

Principal State Environmental
Legislation Concerning Ship Channel-
Harbor Complexes in Texas

POLLUTION SOURCE / ENVIRONMENTAL LEGISLATION	Texas Water Quality Act of 1967	Solid Waste Disposal Act of 1969	Texas Coastal Waterways Act of 1975	Coastal Public Lands Management	Texas Open Beaches Act	Texas Oil & Hazardous Substances Spill Prevention and Control Act	Texas Deepwater Ports Procedures Act	Coastal Resources Management Program	Senate Fresh Water Inflows Resolution for Bays & Estuaries
1. Dredging									
A. New	*		*	*	*			*	
B. Maintenance	*		*	*	*			*	
2. Waste from Ships									
A. Sanitary Sewage	*		*						
B. Solid Wastes	*	*	*						
3. Ship Bilge Water	*		*						
4. Ship Ballast Water	*		*						
5. Ship Tank & Barge Washings	*		*						
6. Non-Point Source Pollution									
A. Rural Runoff				*				*	*
B. Urban Runoff				*				*	*
7. Municipal Sewage	*		*						
8. Water Withdrawals & Returns	*		*					*	*
9. Industrial Waste Discharges		*							
10. Oil Spills	*		*			*	*		
11. Hazardous Materials	*		*			*	*		
12. Floating Debris	*	*	*						
13. Seafood Processing	*		*						

Source: Schwartz (70) and Texas Water Quality Board (71).

environmental regulations administered by all agencies must be observed. Proper collaboration with regulatory agencies during long-range planning can make the task of obtaining a construction permit for a new industry much simpler. Providing an environment with the capacity to accept new industries is instrumental to the growth of a port.

A list of the main environmental agencies and types of pollution they are concerned with is shown in Table 30. One advantage in consulting an agency early for long-range planning would be the purchase of additional dredged materials area. The Texas Department of Parks and Wildlife could advise a port authority on acceptable dredged materials area locations, and land purchases could be made in advance.

The first step in a plan of action should be to obtain the interest and support of the directly involved entities. A lot of arguments and reasons could be used to justify this difficult objective. Perhaps one of the best reasons is that current newspaper stories (68) reflect a trend toward legislation proposing moratoriums on industrial expansion in polluted areas.

The second step in the plan should be to involve all governmental agencies, planning commission, authorities, and councils. Their support and assistance would surely prove to be valuable.

The third step logically should be to determine the level of involvement necessary for achieving the long-range objectives. When this is completed, a new or existing organization must be designated to undertake pollution management responsibilities in the area.

TABLE 30

Major Agencies Responsible for the Environment of a Ship Channel-Harbor Complex

POLLUTION SOURCE \ POLLUTION CONTROL AGENCY	Environmental Protection Agency	Council on Environmental Quality	Corps of Engineers	Texas Water Quality Board	Coast Guard	Texas Railroad Commission	Texas Dept. of Health	Texas Water Dev. Board	Texas Dept. of Parks & Wildlife	Texas Gen. Land Office
1. Dredging										
A. New	R/P	P	P	E					C	
B. Maintenance	R/P	P	P	E					C	
2. Wastes from Ships										
A. Sewage	R/P				P/E					
B. Solid	R				E		E			
3. Ship Bilges	R				E					
4. Ship Ballast	R				E					
5. Ship Tank &	R/P			P/E	E					
Barge Washings	R/P			P/E	E					
6. Non-Point Source Pollution										
A. Rural										
B. Urban										
7. Municipal Sewage	R/P		C	P/R/E					C	
8. Water Withdrawals &	R/P	P	C	R/P/E						
Returns	R/P	P		R/P/E						
9. Industrial Wastes	R/P		C	R/P/E		E/P/C			C	E
10. Oil Spills	R			E		E/P/C				E
11. Hazardous Materials	R			R/E	E	E	E			E
12. Floating Debris	R				E		E			
13. Seafood Processing	R/P			R/P/E					C	

P - Permitting Agency R - Regulation-Making Agency

C - Consulted on Permit E - Enforcement Agency

Source: Hill (72)

Once the responsible organization begins planning, federal funds can be obtained to pay for planning projects. This fourth step in the plan is, of course, the first solid action taken toward solving the environmental problems of a ship channel-harbor complex. Only concentrated studies and research on specific and unique problems can determine the following steps of action. They should be positive, realistic, and compatible with long-range projections.

Step five should be a concentrated research effort to define the sources contributing pollutants to the bottom sediments of ship channel-harbor complexes. This could be accomplished by a thorough analysis of the waste from each source and comparing the results to a complete sediment analysis. Studies could also be done on the watershed involved to determine if erosion control practices could be improved. This research could contribute greatly to solving the problem of dredged materials disposal.

Step six would utilize the information gained from step five, combine it with a mathematical model calibrated to the waterway, and develop management techniques for curbing the discharge of harmful substances from point sources. In-plant technical and operations personnel could be utilized when considering industrial sources. If effluent requiring specialized treatment could be treated directly at its in-plant source before it became mixed with other wastes, then the overall task could be accomplished much easier. When considering the feasibility of a centralized treatment system, it may be discovered that the wastes from one plant could supply the nutrient needs for the biodegradation of another waste. If mixing the wastes does not prove to be an advantage in laboratory studies, then the advantages of improved management, operations, economies of scale, and a tax advantage should be thoroughly researched.

The seventh step should include contingency planning for oil and hazardous materials spills. This step should have equal ranking with steps five and six because of the great potential for spills and the severity of the environmental impacts when they occur. Planning and equipping for oil and hazardous materials spills could be combined with planning for other disasters. However, equipment and manpower are not the only problems when planning for spills. The environmental effects of many chemicals stored and transported along today's waterways are unknown. Contingency planning should involve having fast and immediate access to scientists knowledgeable with each hazardous material. Adequate disaster handling equipment is a prime necessity for preventing hazardous materials spills. Failsafe materials conveying and transporting systems should be developed in areas where the potential for spills exist.

The eighth step in environmental planning for a ship channel-harbor complex includes domestic sewage treatment. Studies aimed at reducing or pretreating wastes from small industries and commercial businesses should begin. Some of these effluents should be diverted to centralized industrial treatment plants, if they exist, and thereby relieve the load on domestic plants. Sewage rate charges need to be adjusted to make these changes advantageous to the customer. Advanced waste treatment should be considered in many areas of high urban concentrations.

Rural and urban runoff planning should be included as the ninth step of the proposed plan. This planning should include erosion control measures and better water resources engineering. The overall watershed should be studied to find major contributors, if any, to the pollution load. Information gained should be used to correct existing situations, and to plan for new land developments and land usages that will prevent the occurrence of these problems. Some solutions could be quite simple when developed at the beginning and incorporated into new construction.

The tenth step in the proposed plan for pollution control concerns water withdrawals and returns. This case is mainly associated with cooling water for power plants and major industries. Thermal pollution studies have been used for years to control cooling water discharges. What is needed in the future is to develop long-range planning for utilizing the currents caused by these plants to an environmental advantage. The currents caused by water withdrawals and returns could be used for flushing nearby stagnant ship channels.

Local planning efforts of specific organizations involved with pollution must determine the steps to follow. The steps listed here are presented only for basic use and direction. Naturally, planning emphasis will change from location to location. The utilization of specific studies and information for each location will allow individualized and novel solutions to be used.

Various public and private entities are engaged in research and planning projects related to environmental matters. An example of the expertise available at a typical university is given in Table 31. The Center for Marine Resources can be contacted for further information about research at Texas A&M University.

TABLE 31

Typical University Resources Available for
Ship Channel-Harbor Complex Related
Environmental Projects

TEXAS A&M UNIVERSITY ENTITIES \ RESEARCH TASKS	Pollution Models	Env. Management Studies	Env. Quality Studies	Shoreline Ocean & Wave Research	Hazardous & Toxic Materials	Environmental Assessments	Economic Studies	Ecological Studies	Environmental Planning Studies	Waste Treatment Studies	Air Pollution
Center for Marine Resources†	*	*	*	*	*	*	*	*	*	*	
Agricultural Economics							*				
Agricultural Engineering		*	*							*	*
Animal Science					*			*			
Biochemistry & Biophysics					*			*			
Entomology					*			*			
Forest Science			*						*		
Plant Science								*			
Range Science			*		*			*			
Recreation and Parks							*	*	*		
Soil and Crop Sciences		*	*		*			*			
Wildlife Science			*		*	*		*			
Architectural Research Center									*		
Urban & Regional Planning									*		
Landscape Architecture								*	*		
Accounting							*				

†Coordinates marine-related research activities at Texas A&M.

TABLE 31

(Continued)

TEXAS A&M UNIVERSITY ENTITIES / RESEARCH TASKS	Pollution Models	Env. Management Studies	Env. Quality Studies	Shoreline Ocean & Wave Research	Hazardous & Toxic Materials	Environmental Assessments	Economic Studies	Ecological Studies	Environmental Planning Studies	Waste Treatment Studies	Air Pollution
Chemical Engineering										*	*
Civil Engr.-Environmental	*	*	*	*	*	*	*		*	*	*
Civil Engr.- Coastal & Ocean		*		*							
Civil Engr.-Hydraulic Engr.									*		
Electrical Engineering		*									
Industrial Engineering					*				*		
Mechanical Engineering				*					*	*	
Geography								*			
Geology			*	*		*			*		
Meteorology	*						*		*		*
Oceanography			*	*	*	*		*			
Tectonophysics				*							
Economics							*				
Journalism									*		
Philosophy									*		
Psychology					*						

TABLE 31

(Continued)

TEXAS A&M UNIVERSITY ENTITIES / RESEARCH TASKS	Pollution Models	Env. Management Studies	Env. Quality Studies	Shoreline Ocean & Wave Studies	Hazardous & Toxic Materials	Environmental Assessments	Economic Studies	Ecological Studies	Environmental Planning Studies	Waste Treatment Studies	Air Pollution
Sociology & Anthropology								*			
Biology			*		*			*			
Chemistry			*		*						*
Physics		*	*		*			*			*
Texas Transportation Inst.									*		
Texas Water Resources Center			*						*		
College of Veterinary Med.					*			*			

Source: Mazzaccaro(73)

CHAPTER V

SUMMARY AND CONCLUSIONS

Summary

Purpose

The purpose of material presented in this paper was to provide a broader understanding of environmental problems confronting management entities responsible for ship channel-harbor complexes. The increased understanding and suggested plan of action will help these entities make competent decisions for the future.

Information Presented

The information presented within the study includes a general description of activities and environmental problems associated with channel-harbor complexes along the Texas Gulf Coast. This includes an explanation of cargoes handled, structure of port authorities, and environmental modifications of ports. Secondly, an extensive literature search was done to gather information on the quality, quantity and discharge frequency for various pollution sources in a ship channel-harbor complex. The best information currently available on various pollution problems is discussed in the second chapter. A priority list for pollution sources was developed in the fourth section. The pollution sources, in their order or priority, were dredged materials, industrial wastes, oil spills, rainfall runoff, hazardous materials spills, shipboard wastes, domestic wastes, ship bilge and ballast water, ship tank and barge washings, seafood processing, water withdrawals and returns, and floating debris. These environmental problems are discussed as to their applicability and significance to the Gulf Coast in general and the Texas Gulf Coast in particular.

Previous field reports and studies on relevant pollution problems are included in this report. In addition, three field studies on pollution problems along the Texas Gulf Coast were completed during this project. One of the previous studies cited was a report written about pollution problems and solutions in estuaries of the Texas Gulf Coast. Other studies cited include two reports about pollution in the Port of Corpus Christi. One of these demonstrates the use of a mathematical model for environmental management, and the other presents information accumulated for calibrating the mathematical model. The fourth previous field report cited was an environmental study of the Port of Brownsville Fishing Harbor.

Field studies completed especially for this project included water quality studies of the Port of Corpus Christi and the Port of Brownsville Fishing Harbor. The data and information obtained was compared with that of previous studies, so that trends and changes in environmental conditions could be recognized. Environmental studies at the Port of Corpus Christi indicated that its wasteload capacity is much less than its assimilative capacity. A third field study was a non-point source study of two watersheds draining into the Brownsville Ship Channel. It was impossible to schedule this activity during a period of significant runoff. Results from a ¼ to ½ inch rainfall were obtained. This data can be useful in planning future research efforts on non-point source pollution.

A fourth field activity considered necessary for determining the magnitude and impact of different pollution sources was to interview the management of eight ports. Personnel from regulatory agencies were also interviewed. These interviews yielded problems that the management entities were most concerned with; which coincided with the previously listed priority pollution problems. The people interviewed added several other problems to the list, such as public relations, financing, Federal Aid, Coastal Zone Planning and availability of qualified personnel.

Once the major problems were ranked in a priority list, general solutions were formulated and discussed for each problem. A problem/solution matrix was provided to illustrate suggested solutions. These solutions were followed by an outline of a proposed plan of action. The plan of action was not intended to be used in specific circumstances, but rather to be used as a guide for direction and planning.

The proposed plan of action included the initial organization, the initial involvement of regulatory agencies, the level of involvement by the organization in pollution problem solving, the organizational planning, the attack upon contaminated dredged materials, control of point sources, contingency planning for spills, control of domestic sewage, research in rural and urban runoff problems, and managing water withdrawals and returns.

Conclusions

The ship channel-harbor complexes of the Texas Gulf Coast have been mainly responsible for the State's stable and healthy economy. Even with diminishing oil and gas reserves, Texas still has an opportunity to experience greater economic growth in the future. For this growth to materialize, it will be necessary for entities interested in and responsible for the ship channel-harbor complexes to begin long-range environmental planning.

Some of the environmental degradation accompanying highly industrialized ports may seem pretty hopeless to the casual observer. However, it is notable that neither references from the literature nor other sources used during this project even suggested that the problems were insurmountable. Solutions to environmental problems are not simple or cheap, but are mandatory if an area wishes to retain a viable economic climate. Federal laws require greatly reduced pollution discharges within the next decade. Increased attention on environmental assessments for all activities will surely have an effect on industrial growth. A current example is the difficulty most ports are now encountering in obtaining permits to dredge. Dredged materials contaminated with various wastes are considered too hazardous to the environment to be disposed of by normal procedures. Needless to say, a navigation district that cannot dredge cannot continue to meet the needs of present or potential customers.

Solutions

Suggested solutions have been presented for each of the 13 pollution sources this project has addressed. These solutions are quite general and are mainly used to illustrate the direction specific studies should follow.

Proposed engineering solutions include controlling the pollutant at its source through process changes or treatment. The next solution is to improve present treatment methods and possibly provide advanced waste treatment. Other solutions include preventative measures and better routine maintenance. A fifth solution, and the one with the most possible side benefits, is that of improved utilization and conservation of materials involved in the process. Following this comes better operation of existing and new facilities to achieve their full design potential. The last and possibly the most important solution proposed is more research. This will assure that the necessary science continues to grow as needs increase. More research would be extremely helpful in all facets of pollution problems. However, in Table 27 (p. 106), research is only indicated for the highest priority problems.

Another very necessary part to the solution of environmental problems is administrative input. The first administrative solution is that of better environmental management. The next solution is closer cooperation between agencies. This means simply, better communication. The third solution is that of improved contingency planning for spills. A good example of a step toward improved contingency planning is the Corpus Christi Area Oil Spill Association. Another administrative solution that could have great impact in the future is that of long-range planning. The fifth solution is that of better enforcement. This solution will not hurt companies that have been conscientious about following environmental regulations, but it will perhaps make the regulations more equable.

Plan of Action

A proposed plan of action is considered necessary to achieving any reasonable future objectives. A brief outline of a proposed plan of action is presented in Table 32. This plan is proposed to fit the basic needs of a typical/average port, and may need extensive revisions and additions when applied to a particular case. It is recommended that this proposed plan be supervised by entities having the port's best interests at heart. This would insure that plans include the coexistence of economic prosperity and a clean environment.

The data, information, and proposed plans presented should not be interpreted as a critique of present and past pollution control planning, but rather as a tool to initiate thinking about future action.

TABLE 32

Outline of a Proposed
Plan of Action for Planning
The Environmental Management of
a Ship Channel-Harbor Complex

1. Get interest and support of the groups involved in and responsible for the ship channel-harbor complex.

2. Involve all agencies, planning commissions, authorities, and councils.

3. Decide what level of involvement is necessary to achieve the long-range objectives and what organization will shoulder management responsibilities.

4. Obtain funds for planning.

5. Launch research effort concerned with sources contributing to dredged materials disposal.

6. Treat the wastes from step five and other sources. Consider the options; in-plant treatment, cooperative-centralized waste treatment,or in-channel aeration.

7. Develop contingency plans for spills.

8. Curb domestic sewage discharges.

9. Investigate pollution control for rural and urban runoff.

10. Plan for using water withdrawals and returns for flushing.

REFERENCES

1. Quinn, Alonzo De F., Design and Construction of Ports and Marine Structures. McGraw-Hill Book Company, Inc., New York, New York, (1961).

2. Bird, James H., Seaports and Seaport Terminals. Hutchinson University Library, London, (1971).

3. Hann, Roy W.,et al., Sea Dock Literature Review. Texas A&M Research Foundation, College Station, Texas, (1973).

4. Miloy, John, et al., Analysis of the Role of the Gulf Intracoastal Waterway in Texas. Texas Ports Assoc., Texas Coastal and Marine Council, and Sea Grant, TAMU-SG-75-203, Texas A&M University, College Station, Texas, (1975).

5. Bradley, James R., Ed., Marine Resources Activities in Texas. Industrial Economics Research Division, Texas Engr. Exp. Station, Texas A&M University, College Station, Texas, (1969).

6. Etter, W. E., and Graham, R. C., Financial Planning for the Texas Port System. Sea Grant Report, TAMU-SG-74-210, Texas A&M University, (1974).

7. Hann, R. W., "Industrial Waste Pollution and Gulf Coast Estuaries." National Estuary Report to the Congress of the United States of America, Environmental Engineering Div., Civil Engineering Dept., Texas A&M University, (1975).

8. Ketchum, B. H., editor, The Water's Edge: Critical Problems of the Coastal Zone. The M.I.T. Press, Cambridge, Mass., (1972).

9. Slotta, L. S., and Williamson, K. J., "Estuarine Impacts Related Dredge Spoiling." Proceedings of the Sixth Dredging Seminar, Sea Grant Report, TAMU-SG-74-104, Texas A&M University, (1974).

10. Bassi, D. E., and Basco, D. R., Field Study of an Unconfined Spoil Disposal Area of the Gulf Intracoastal Waterway in Galveston Bay, Texas. Sea Grant Report, TAMU-SG-74-208, Texas A&M University, (1974).

11. Holmes, C. W., et al., "Migration and Redistribution of Zinc and Cadmium in a Marine Estuarine System." Environmental Science and Technology, 8, 255, (1974).

12. Hann, R. W., Jr. and Slowey, J. F., Sediment Analysis - Galveston Bay. Estuarine Systems Project Tech. Report No. 24, Environmental Engineering Div., Civil Engineering Dept., Texas A&M Univ., (1972).

13. Slowey, J. F., et al., Natural Background Levels of Heavy Metals in Texas Estuarine Sediments. Environmental Engineering Div., Civil Engineering Dept., Texas A&M University, (1973).

14. Robins, J. H., et al., Development of On-Shore Treatment Systems for Sewage from Watercraft Waste Retention Systems. F.M.C. Corp., San Jose, Calif., (1974).

15. Weinheimer, J. E., and Hooper, M. W., Management of Wastes Generated During the Loading and Discharging Operations of Non-Liquid Bulk Cargo Vessels. Presented to Texas Section ASAE, University of Houston, (1971).

16. Hooper, M. W., and Myrick, H. N., Shoreside and Mobile Marine Systems to Receive, Process, and Reclaim Waste Discharges from Federal, Commercial, and Recreational Watercraft. Presented to Texas Section ASCE, University of Houston, (1971).

17. Ball, J. B., et al., Management of Tank Washings in Marine and Coastal Commerce. Sea Grant Report, TAMU-SG-74-221, Texas A&M University, (1975).

18. Reinhorn, T., and Animelech, Y., "Nitrogen Release Associated with the Decrease of Soil Organic Matter in a Newly Cultivated Field." Journal of Environmental Quality, 3, 10, (1974).

19. Saxton, K. E., "Hydrology and Erosion of Loessial Watersheds." Journal of Hydraul. Div., ASCE., 97, 1835, (1971).

20. Romkens, J. M., and Nelson, D. W., "Phosphorus Relationships in Runoff From Fertilized Soils." Jour. Envr. Quality, 3, (1974).

21. Dornbush, J. N., Andersen, J. R., and Harms, L. L., Quantification of Pollutants in Agricultural Runoff. Envr. Protection Agency, Washington D. C., EPA-660/2-74-005, (1974).

22. Muir, J., Sein, E. C., and Olson, R. A., "A Study of Factors Influencing the Nitrogen and Phosphorus Content of Nebraska Waters." Jour. Envr. Quality, 2, 466, (1973).

23. Benson, R. D., "The Quality of Surface Runoff From a Farmland Area In South Dakota During 1969." M.S. Thesis, South Dakota State Univ., Brookings, S.D., (1970).

24. McCarl, T. A., "Quality and Quantity of Surface Runoff From a Cropland Area in South Dakota During 1970." M.S. Thesis, South Dakota State Univ., Brookings, S.D., (1971).

25. Weidner, R. B., Christianson, A. G., Weibel, S. R., and Robeck, G. G., "Rural Runoff as a Factor in Stream Pollution." Journal Water Poll. Control Fed., 41, 377, (1969).

26. White, E. M., and Williamson, E. S., "Plant Nutrient Concentration from Fertilized Cultivated Erosional Plots and Prairie in Eastern South Dakota." Journal Envr. Quality, 2, 453, (1973).

27. Klausener, S. D., Zwerman, P. J., and Ellis, D. E., "Surface Runoff of Soluble Nitrogen and Phosphorus Under Two Systems of Soil Management." Jour. Envr. Qual., 3, (1974).

28. Thomas, G. W., and Crutchfield, J. D., "Nitrate-N and Phosphorus Content of Streams Draining Small Agricultural Watersheds in Kentucky." Jour. Envr. Qual., 3, 46 (1974).

29. Willrich, T. L., and Smith, G. E., Agricultural Practices and Water Quality. The Iowa State University Press, Ames, Iowa, (1970).

30. Weibel, J. R., et al., "Urban Land Runoff as a Factor in Stream Pollution." Jour. Water Poll. Control Fed., 36, 914, (1964).

31. Dragoun, F. J., and Miller, C. R., "Sediment Characteristics of Two Small Agricultural Watersheds." Transact. Amer. Soc. Ag. Engr., 9, 66, (1966).

32. Thoman, J. R., and Nicholson, H. P., "Pesticides and Water Quality." Presented 2nd Sanitary Engr. Conf., Vanderbilt University, Nashville, Tenn., (1963).

33. Van Sickle, Donald, "Characteristics of Urban Runoff." Turner, Collie, and Braden, Inc., Consulting Engineers, Houston, Texas, (1968).

34. Colston, N. V., Jr., Characteristics and Treatment of Urban Land Runoff. Envr. Protection Agency, Washington, D.C., EPA-670/2-74-096, (1974).

35. McElroy, A. D., Chiu, F. Y., and Aleti, A., Analysis of Nonpoint Source Pollutants in the Missouri Basin Region. Envr. Protection Agency, Washington, D.C., EPA-600/5-75-004, (1975).

36. Shaheen, D. G., Contributions of Urban Roadway Usage to Water Pollution. Envr. Protection Agency, Washington, D.C., EPA-600/2-75-004, (1975).

37. Hann, R. W., et al., Houston Ship Channel Data Summary. Estuarine System Projects Tech. Report No. 9, Environmental Engineering Div., Civil Engineering Dept., Texas A&M University, College Station, Texas (1974).

38. Bates, Bert, Houston Ship Channel Monitoring Program. Special Report No. SR-3, District 7, Texas Water Quality Board, Austin, Texas, (1975).

39. Eisenbud, M. and Gleason, G., Electric Power and Thermal Discharges. Gordon and Breach, Science Publishers, New York, New York, (1969).

40. Hann, R. W., Compiler, Waste Management in the Texas Coastal Zone Environmental Engineering Div., Civil Engineering Dept., Texas A&M University, College Station, Texas, (1973).

41. Parter, F. L., and Krenkel, P. A., Engineering Aspects of Thermal Pollution. Vanderbilt University Press, Nashville, Tenn., (1969).

42. Withers, R. E., Jr., et al., Field and Analytical Studies of the Corpus Christi Ship Channel and Contiguous Waters. Environmental Engineering Division, Civil Engineering Dept., Texas A&M University, (1973).

43. Sparr, T. M., Sprague, C. R., and Hann, R. W., A Study of the Flushing Times of the Houston Ship Channel and Galveston Bay. Estuarine Systems Projects Technical Report No. 12, Environmental Engineering Division, Civil Engineering Dept., Texas A&M University, (n.d.).

44. Hutton, W. S., Hann, R. W., and Smith, R. H., A Quantitative and Qualitative Survey of Benthal Deposits Contained in the Houston Ship Channel. Environmental Engineering Division, Civil Engineering Dept., Texas A&M University, (1973).

45. Nelson-Smith, A., Oil Pollution and Marine Ecology. Plenum Press, New York, (1973).

46. Sittig, M., Oil Spill Prevention and Removal Handbook. Noyes Data Corporation, Park Ridge, New Jersey, (1974).

47. Schwartz, A. R., Chairman, Oil Spill Primer. Texas Coastal and Marine Council, Austin, Texas, (1975).

48. Herbich, John B., Control of Oil Spills. Sea Grant Report, TAMU-SG-72-102, Texas A&M University, (1972).

49. Hann, R. W., Follow-up Field Study of the Oil Pollution From the Tanker "Metula". Environmental Engineering Div., Civil Engineering Dept., Texas A&M University, (1975).

50. Benkert, W. M., Chief, CHRIS Hazard Assessment Handbook. Dept. of Transportation, U. S. Coast Guard, Washington, D.C., (1974).

51. Hann, R. W., Panel Chairman, "Definition and Classification Panel Hazardous Substances Pollution Symposium, Summary Report." Environmental Engineering Div., Civil Engineering Dept., Texas A&M University, (1970).

52. Hann, R. W. "Comments Relating to an Oil and Hazardous Material Control Bill." Environmental Engineering Div., Civil Engineering Dept., Texas A&M University, (1975).

53. Hancock, J. A., and Jensen, D., "Waterborne Debris in Marine Pollution Incidents." 1975 Conference on Prevention and Control of Water Pollution, American Petroleum Institute, Washington, D.C., (1975).

54. Cobb, B. F., "The Fisheries View." Sea Grant Report, TAMU-SG-70-115, Texas A&M University, (Aug. 1970).

55. Crance, J. H., "The Coastal Fisheries of Texas." Texas Agricultural Extension Service, College Station, Texas, TAMU-SG-71-107, (1971).

56. Mehos, John, "Fishery Resources." Texas Marine Resources and the Sea Grant Program Conference Proceedings, Texas A&M University Sea Grant Program, Publication No. 102, (Oct. 1969).

57. Mendenhall, Vivian, Utilization and Disposal of Crab and Shrimp Wastes. University of Alaska Sea Grant Program, Bulletin No. 2, (March 1971).

58. Mauldin, F. A., and Szabo, A. J., "Gulf Shrimp Canning Plant Wastewater Processing." Proceedings Fifth National Symposium on Food Processing Waste, EPA, Washington, D.C., EPA-660/2-74-058, (June 1974).

59. Vigil, S. A., "Shrimp Processing Wastes." Environmental Engineering Division, Civil Engineering Dept., Texas A&M University, College Station, Texas, (1974).

60. Hann, R. W., et al., Pilot Field and Analytical Studies of the Corpus Christi Ship Channel and Contiguous Waters. Environmental Engineering Division, Civil Engineering Dept., Texas A&M University, (1972).

61. Withers, R. E., et al., Field and Analytical Studies of the Corpus Christi Ship Channel and Contiguous Waters. Environmental Engineering Division, Civil Engineering Dept., Texas A&M University, College Station, Texas, (1973).

62. Withers, R. E., et al., Field Report Miscellaneous Field Studies in the Brownsville Ship Channel and the Intracoastal Waterway. Environmental Engineering Division, Civil Engineering Dept., Texas A&M University, College Station, Texas, (1973).

63. Withers, R. E., Slowey, F. J., and Garrett, R. L., Environmental Study of the Brownsville Ship Channel and Contiguous Waters, Environmental Engineering Division, Civil Engineering Dept., Texas A&M University, College Station, Texas, (1974).

64. Withers, R. E., Environmental Study of the Brownsville Ship Channel and Contiguous Waters. Environmental Engineering Division, Civil Engineering Dept., Texas A&M University, College Station, Texas, (1975).

65. Standard Methods for the Examination of Water and Wastewater. Thirteenth Ed., American Public Health Assoc., American Water-Works Assoc., and the Water Pollution Control Fed., Washington, D.C., (1971).

66. Linsley, R. K., and Franzini, J. B., Water Resources Engineering. Second Ed., McGraw-Hill, New York, New York, (1972).

67. Maldonado, R. J., "Field Report-Water Quality Routing, Fishing Harbor-San Martin Network." Environmental Engineering Division, Civil Engineering Dept., Texas A&M University, College Station, Texas, (1975).

68. Scarlett, Harold, "Changes to Air Act Threaten Industrial Growth, Board Told." The Houston Post, January 28, 1976, Sec. 3A.

69. The Environmental Protection Agency, Current EPA Laws. Revision 208, The U.S. Government Printing Office, Washington, D.C., (1973).

70. Schwartz, A.R., Texas Coastal Legislation. 2nd Ed., Texas Coastal and Marine Council, Austin, Texas, (1975).

71. Texas Water Quality Board, A Ready Reference on Major Texas Water Pollution Control Legislation. No. 71-01, Austin, Texas, (1972).

72. Hill, J.G., "Protecting the Environment in Texas." Lyndon B. Johnson School of Public Affairs, the University of Texas, Austin, Texas, (1973).

73. Mazzaccaro, T., Inventory of Environmental Research at Texas A&M University. Texas A&M University Environmental Quality Program, (June 1973).