A CONCEPTUAL REPORT ON

THE MANAGEMENT OF BAY AND ESTUARINE SYSTEMS — *phase I*

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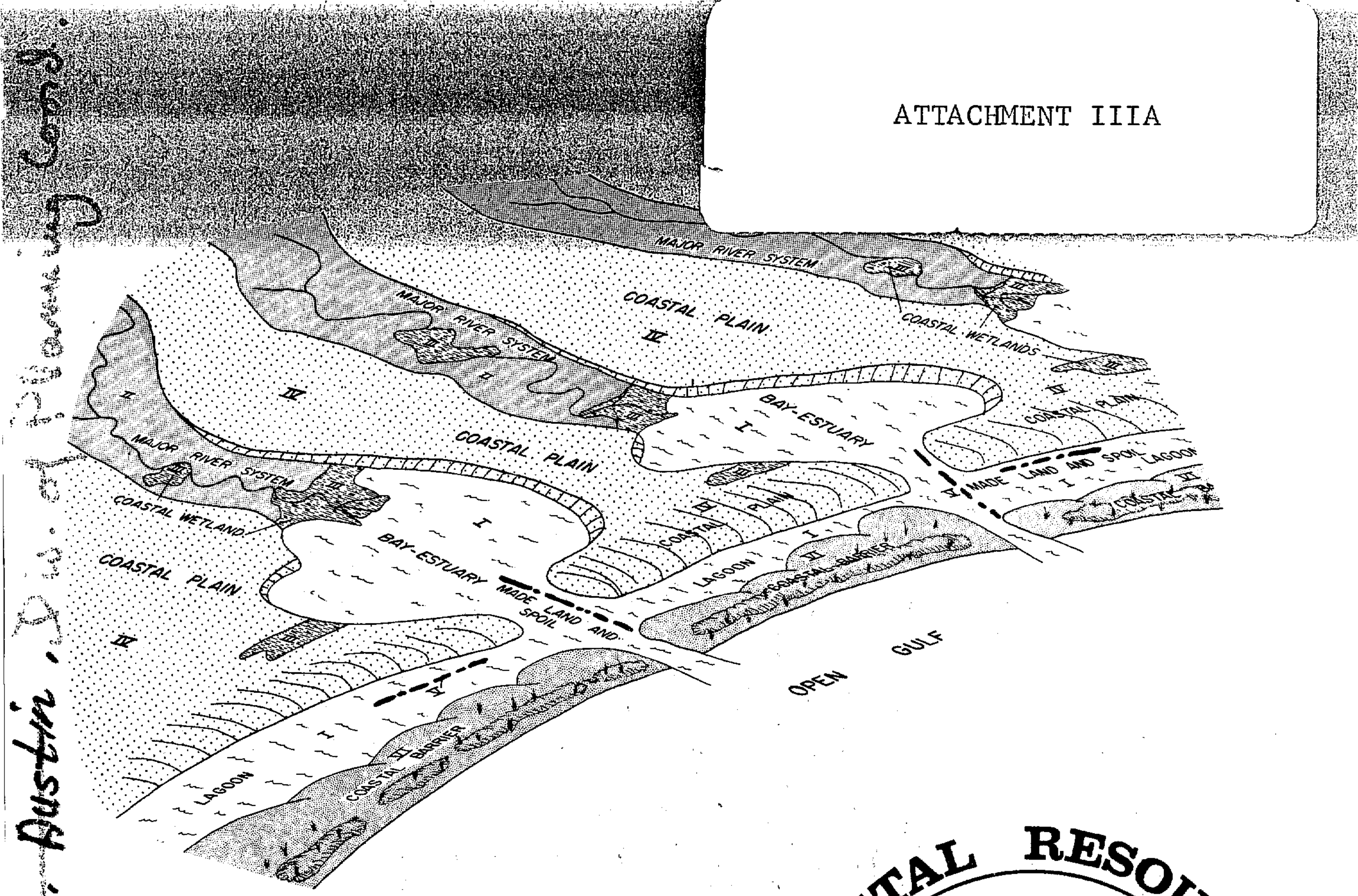

Texas, University of, Austin, Div. of Planning Coord.

DIVISION OF PLANNING COORDINATION

OFFICE OF THE GOVERNOR

Preston Smith, Governor

COASTAL RESOURCES MANAGEMENT PROGRAM

MARCH 1972

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THE MANAGEMENT OF BAY AND ESTUARINE SYSTEMS – *phase I*

THE INTERAGENCY COUNCIL ON
NATURAL RESOURCES AND THE ENVIRONMENT

This Report was Prepared for and in Cooperation with:
THE COASTAL RESOURCES MANAGEMENT PROGRAM
DIVISION OF PLANNING COORDINATION
OFFICE OF THE GOVERNOR

by

THE DIVISION OF NATURAL RESOURCES AND THE ENVIRONMENT
THE UNIVERSITY OF TEXAS AT AUSTIN

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DIVISION OF NATURAL RESOURCES AND THE ENVIRONMENT
THE UNIVERSITY OF TEXAS AT AUSTIN

by a Special Interdisciplinary Team
E. Gus Fruh, Project Director

Contributions by:

CENTER FOR RESEARCH IN WATER RESOURCES
E. Gus Fruh
Robert D. Clark

INSTITUTE OF MARINE SCIENCE
Carl Oppenheimer
Kenneth Gordon

BUREAU OF ECONOMIC GEOLOGY
William L. Fisher
L. Frank Brown
Albert W. Erxleben

ENVIRONMENTAL HEALTH ENGINEERING LABORATORIES
Joseph F. Malina, Jr.
Camilo Guaqueta

DEPARTMENT OF ECONOMICS
Jared E. Hazleton
Roger N. Neece

Prepared for

INTERAGENCY COUNCIL ON NATURAL RESOURCES AND THE ENVIRONMENT

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Staff Assistance Provided by the Natural Resources
Section of the Division of Planning Coordination

Joe B. Harris - Coordinator of Natural Resources
Joe C. Moseley II - Project Director, Coastal Resources
Management Program
Charles E. Cooke - Planning Analyst

EXECUTIVE DEPARTMENT
DIVISION OF PLANNING COORDINATION
BOX 12428, CAPITOL STATION
AUSTIN, TEXAS 78711
PHONE 512 475-2427

PRESTON SMITH
GOVERNOR

ED GRISHAM
DIRECTOR

Governor Smith, Members of the Legislature, and Fellow Texans:

One of the major problems facing us today is that of how to manage our valuable Coastal Zone resources. This issue has received much attention and generated substantial interest. The general problem can be stated in alarmingly simple terms:

> *How do we utilize our estuarine areas for certain valuable economic uses, such as oil and gas production or transportation upon which our society depends, and yet at the same time, protect these areas as fish and wildlife habitats, recreational uses, and aesthetic purposes, both for this and future generations?*

Coming to grips with the many detailed decisions which must be made is very difficult. In fact, it has not yet been done. However, if the many problems and conflicts facing us are to be resolved, it must be done. The 61st Texas Legislature recognized the need for such applied research coupled with implemention guidelines when they passed Senate Concurrent Resolution No. 38 in 1969. That Resolution authorized that a broad study be done of the State's coastal resources and a comprehensive report be presented to the 63rd Legislature in December, 1972. The contents of this report represent one part of that effort.

The Coastal Resources Management Program, under the leadership of Governor Preston Smith, in striving to meet its legislative mandate, currently has six projects underway. These include: (1) Bay and Estuarine Management; (2) Legal/Institutional Structure; (3) Economic Development; (4) Waste Management; (5) Transportation; and (6) Power Plant Siting. This report represents an initial effort in the Bay and Estuarine Management; presently the work begun in this effort is being carried forward by the same research team.

Actual research and development of the techniques presented herein was performed by an interdisciplinary team at the University of

Texas at Austin. It consisted of Dr. E. Gus Fruh (Project Director) and Dr. Joseph F. Malina, both from Environmental Health Engineering; Dr. Bill Fisher, Director of the Bureau of Economic Geology; Dr. Carl Oppenheimer, Director of the Marine Science Institute at Port Aransas; and Dr. Jared Hazleton of the Economics Department. Staff support was provided by Mr. Bob Clark and Dr. Ken Gordon. The work was performed under the auspices of the Division of Natural Resources of the University of Texas at Austin, a broad alliance consisting of the Center for Research in Water Resources (Environmental Health Engineering), the Bureau of Economic Geology, and the Marine Science Institute. The Division was formed to deal with broad, interdisciplinary, environmentally related problems such as coastal resources management.

Valuable assistance was provided by the member agencies of the Interagency Council on Natural Resources and the Environment, all of which continually provided guidance, advice, and assistance when called upon. However, two agencies provided technical assistance; these were the Texas Water Quality Board and the Texas Water Development Board.

At the request of the Coordinator of Natural Resources, the Water Development Board placed two of its staff members on loan to the Coastal Resources Management Program to prepare a special report on "Estuarine Modeling." A brief version of that report is included as Appendix C.

The Texas Water Quality Board provided substantial amounts of data and related information as well as continual technical assistance and guidance. Such data appears throughout the report.

Initiative and original direction for this project came from the Natural Resources Section of the Division of Planning Coordination, in which the Coastal Resources Management Program is staffed. This group worked very closely with the research team during its formation and the subsequent effort to accomplish the work described herein. Funding for the project was also provided by the Coastal Resources Management Program.

At this time, work is vigorously continuing on this effort, as well as the other projects which comprise the overall Coastal Resources Management Program effort. Reports covering these other projects will soon be completed and can be obtained by contacting this Office.

Sincerely,

Ed Grisham

Ed Grisham
Director

SUMMARY

The Texas Coastal Zone, while representing many areas of the Gulf of Mexico and other similar geographic areas in the world, has its integral interdisciplinary associations that are unique. It embraces a wide variety of natural environments definable by biological, physical, and chemical characteristics. A wide spectrum of activities associated with the concentration of industry and population in this area are superimposed on the environment. Development of prudent land- and water-use management policies is imperative--if an appropriate balance of environmental quality and requisite resource use is to be achieved.

THE MANAGEMENT OF BAY AND ESTUARINE SYSTEMS represents the initial effort of an interdisciplinary team of biologists, economists, engineers, and geologists attempting to define, largely in a qualitative manner, certain criteria and methodology basic to the development of a coastal resources management program. This conceptual and descriptive report focuses on the bays and estuaries of the Coastal Zone as well as important features of the surrounding land areas. A basic analytical framework identifies the major economic sectors of the Zone and the activities that affect the environment. These activities are evaluated in terms of major environmental events in the Zone. The interrelationships among the major elements of the analytical framework required a conceptual approach to a resource-management program; thus, the natural framework of the Coastal Zone is defined in terms of major land- and water-resource or environmental units. The varying capabilities of these natural units to sustain use or activity provide a flexible baseline for management consistent with resource use and environmental quality. Further quantification is required for development of a realistic coastal resources management program.

A series of appendices to the report consider in varying detail specific important features or inputs to the Texas Coastal Zone. Municipal and industrial wastes with their disposal problems, treatment costs, and environmental impact are summarized. Criteria for bay and estuarine uses, emphasizing water quality, are itemized. The effects of environmental changes on present and projected activities are estimated according to the economic aspects of environmental planning. A description of the present use of models as a planning tool in the management of bays and estuaries emphasizes the state of the art in the Texas Coastal Zone. Finally, the coastal wetlands, a major natural resource of the Texas Coastal Zone, is evaluated in detail.

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CHAPTER I

INTRODUCTION

The anticipated future growth of population and industry in Texas' Coastal Zone will have a signficant effect on the natural resources of that area of the state. It will also be associated with greater potential sources of environmental pollution. Thus, the State of Texas must develop and maintain a coordinated plan for the judicial use and protection of its coastal air, water and land resources as well as their mineral and living components.

A multi-disciplinary research team at The University of Texas was formed at the request of the Governor's Office acting in concert with the Interagency Council on Natural Resources and the Environment. It was charged with enumerating the various uses of coastal resources as well as the resultant effects of those uses. The long range goal of that initial charge is the development of operational guidelines for effective management of the Texas coastal zone.

This report concludes the introductory phase of the team's effort which was completed during the summer of 1971. The specific goal of this phase was the development of an interdisciplinary and systematic approach to an understanding of problems relative to the management of the Texas Coastal Zone. Because of time limitations, emphasis was placed on management problems relative to bays and estuaries. No primary data were collected to fulfill this goal. Reliance was placed on existing, retrievable data in the files of State and federal agencies, universities and other investigators, and on the considerable prior estuarine experience of the multi-disciplinary team.

REPORT CONTENTS

The interdisciplinary team sees in its task of developing a methodology for coastal environmental planning and management the function of public service that should be part of any university's secondary mission. Each team member already was active in matters of the coastal environment largely expressed through papers at his discipline's scientific meetings and through interim and final reports of discipline oriented research projects. However, few viable communication links had been developed between disciplines. Hence, it appeared desirable to produce a report aimed at all who wish to use a similar team approach to help solve the complicated environmental problems of today.

For the benefit of those readers unfamiliar with the unique Texas coastal environment and its problems, a general description is presented in Chapter II. A glossary of technical and environmental terms as well as a general reading list are provided at the end of the report.

It quickly became established that because of its geological, chemical and biological uniqueness, one of the undesirable uses of nearly all the Texas Coastal Zone is the disposal of inadequately treated waste materials. A general description is given in Appendix A of the quantity and quality of municipal and industrial solid waste discharges and their characteristics.

Management guidelines for decision makers are necessary for all of the Coastal Zone, but the bays and estuaries are recognized presently as having a higher priority for a number of reasons. Water quality and its criteria are examined in Appendix B relative to effects on non-biological as well as biological uses of the bays and estuaries. How the decision makers (such as the state and Federal agencies) developed and revised their criteria as well as how they interact to protect bay and estuaries uses are described briefly. The models of the estuarine phenomena now available to the decision makers are reviewed as regards their usefulness as planning tools. A detailed state of the art of estuarine modeling in Texas is presented in Appendix C.

Various possible techniques for evaluating benefits in a socio-economic sense from pollution control while retaining a more than adequate measure of environmental and social gains and/or losses are described in Appendix D. Socio-economic techniques for estimating future population, economic level and land uses also are presented.

The next step in the summer's work was the development of a basic analytical framework which would provide an interdisciplinary approach with which to attack the problem. From the framework, the various investigators could see how the disciplines needed to interact to function effectively. The framework development essentially was a short course for each of the investigators in the problem solution techniques of the other disciplines as well as their diverse terminologies and environmental philosophies. The framework is by no means complete but is sufficiently detailed at this time to serve as a starting point for other multidiscplinary groups attempting to develop a coordinated attack on other environmental management problems.

The establishment of guidelines for proper land and water use along the Texas coastline depends to a great degree on; 1. the recognition, delineation and classification of significant land- and water-use coastal units, 2. their limiting characteristics and properties, and 3. an understanding of the effects that various use practices will have on the environmental quality of these fundamental coastal units. In chapter IV, thirty-four land- and water-use coastal units are defined and discussed in terms of the basic factors or properties exhibited by these units which limit or restrict their capability or uses. Because of immediate problems regarding its use, a detailed literature review was conducted on the effect of man's activities on one land- and water-use coastal unit--the coastal wetlands. (See Appendix F).

The report summarizes the limitations imposed upon coastal zone management stemming from a lack of primary or retrievable secondary data. Recommendations are made to fulfill these data needs.

INTERDISCIPLINARY APPROACH

The explosion of knowledge to which the world has been subjected during the past 25 years has given rise to specialization. However, recognizing the need for orderly progress, we have placed high priorities on general and comprehensive plans and programs. Concern over environmental integrity has emphasized communication between disciplines as a substitute for increasing their scope. That emphasis has given rise in recent years to the use of multidisciplinary teams.

The typical multidisciplinary approach has fallen short of expectations for a number of reasons. Many studies are merely divided into component elements, each of which is accomplished by a single specialty. Such studies have the disadvantage of being disconnected and not written nor read in an interdisciplinary fashion. Other studies take on the flavor or bias of either the strongest personality on the team or the discipline with the most verifiable data.

A multidisciplinary team was formed at The University of Texas in Austin to conduct this study as part of the Coastal Resources Management Program of the Interagency Council on Natural Resources and the Environment located in the Office of the Governor. The team was composed of specialists in geology, engineering, water quality, biology and economics. In addition, active participation of affected State agencies expanded the team to include regulatory, data gathering, planning and administrative offices in public administration.

It was hoped that this team could avoid the problems normally associated with multidisciplinary efforts. Team members were each assigned one graduate student or research assistant to work on the member's contributions. Meetings of the team were held bi-weekly for progress reports on assigned work elements and feedback on that progress from all disciplines. The initial phase of the summer work was characterized by redefinition of project goals. Communication was hampered by the differences in terminology and philosophy of the different disciplines. Once the analytical framework presented in Chapter III was developed, each team member could more clearly see the interactions needed to enable the team to function more effectively in its approach to the problem.

The final product has been developed so that each chapter would contain elements of all disciplines conducting the study and so that no conclusions were reached without full consideration by all team members. The informal channels of communication have expanded to nearly supersede the formal ones originally established. The team has developed into a cohesive, unified body moving to fulfill the same program objectives.

CHAPTER II

TEXAS COASTAL ZONE

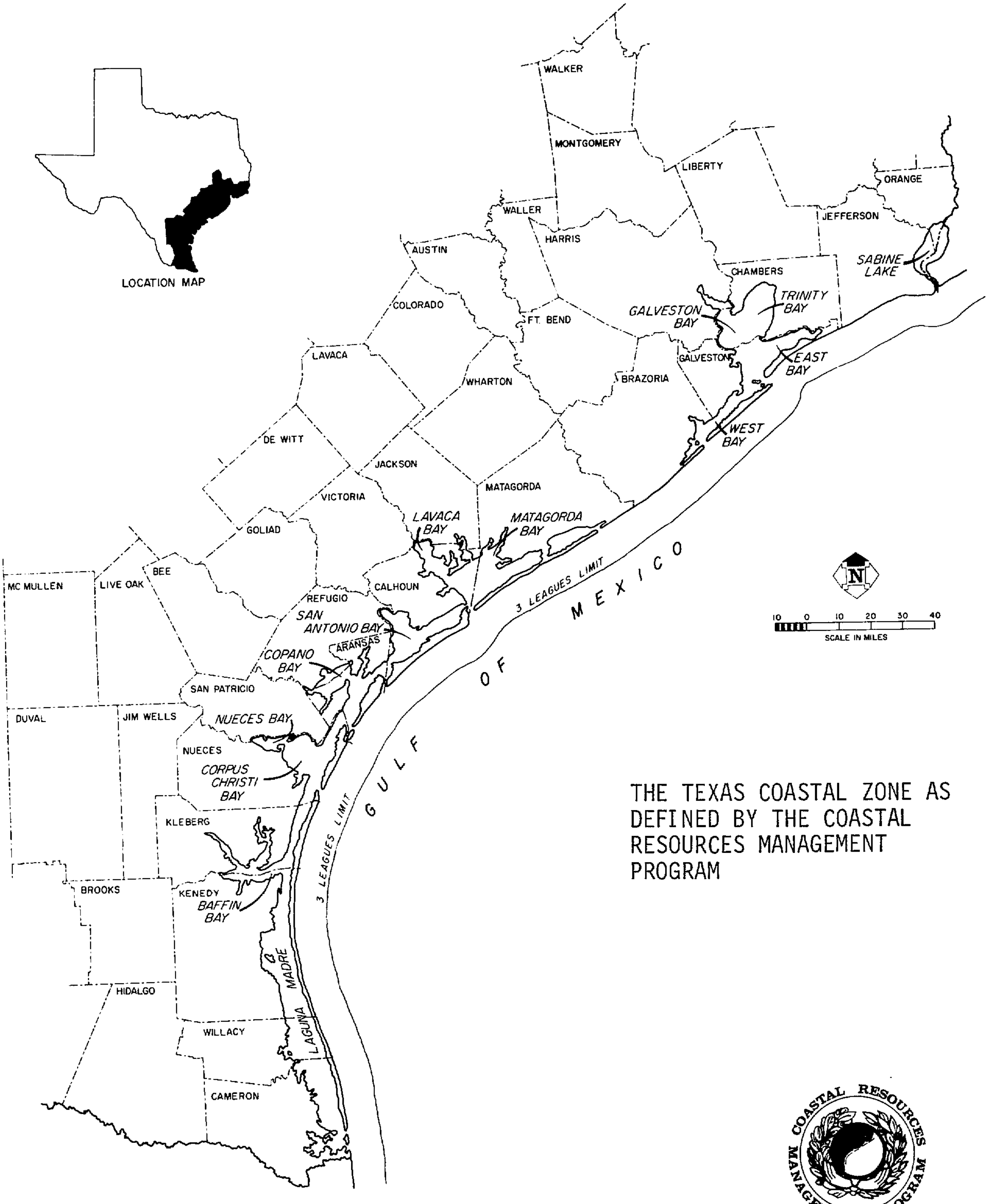
The Texas Coastal Zone, as defined in this study, extends from the Sabine River at the Louisiana-Texas border on the north to the Rio Grande River at the Texas-Mexico border on the south. The Zone extends inland to include not only the 18 coastal counties but an additional 18 adjacent counties, and extends outward to 10.35 miles in the Gulf of Mexico. Figure II-1 indicates these geographic limits.

There are an estimated 1,890 miles of shoreline in the Texas Coastal Zone, of which 1,419 miles front bays and estuaries while 373 miles face the Gulf (Fisher and Flawn, 1970). The Texas Coast is quite diverse. It has been estimated that Texas has approximately 1,080 miles of shoreline suitable for recreation, divided into 300 miles of beaches, 420 miles of low bluffs, and 360 miles of marsh. None of the other 27 coastal states can match this relatively balanced proportion.

The Coastal Zone includes 25,394,003 acres, of which the Federal Government owns about 2 percent, the State of Texas 16 percent, local governments 2 percent, and private owners 80 percent (McKann, 1970). In the 18 counties adjoining the coast, there are an estimated 622 square miles of coastal marsh, 2,100 square miles of bays and estuaries, and 213 square miles of formally designated wildlife refuges (Fisher and Flawn, 1970a).

PHYSICAL FEATURES OF THE COASTAL ZONE

The climate of the Texas Coastal Zone is in general subtropical with long warm to hot summers and short, mild winters. The average annual temperature shows a fairly regular decrease with latitude from about 74 degrees F at Brownsville to about 70 degrees F at Sabine Pass. The average precipitation varies from about 26 inches at Brownsville to about 55 inches at Sabine Pass. There are four climatic belts along the Coastal Zone (Kane, 1970).



THE TEXAS COASTAL ZONE AS DEFINED BY THE COASTAL RESOURCES MANAGEMENT PROGRAM

FIG; II-1

1. Humid (from Louisiana westward to Galveston Bay),
2. Wet sub-humid
3. Dry sub-humid (from Galveston Bay to Corpus Christi Bay),
4. Semi-arid (from Corpus Christi to the Rio Grande).

The 36-county study area is located in the Coastal Plain physiographic province, a segment of the greater Gulf Coastal Plain that extends from Florida to Mexico. The Coastal Prairie or lower Coastal Plain is a flat, low-relief surface, except where locally disected by streams. It consists dominantly of a series of abandoned sand-filled deltaic channels and interchannel clay deposits.

Texas is drained by ten major river systems which enter the Coastal Zone either through the bays and estuaries or directly into the Gulf. These are (from northeast to southwest): the Sabine, Neches, Trinity, San Jacinto, Brazos, Colorado, Guadalupe, San Antonio, Nueces, and Rio Grande. In addition to these major systems, there are many minor coastal drainage systems which feed directly into the Gulf or the coastal embayments. Of the major rivers, only the Brazos, Colorado, and Rio Grande empty directly into the Gulf with the others forming estuaries at their mouths. The Rio Grande normally has little or no flow at its mouth because of heavy demands in its lower reaches for industrial, municipal, and irrigation water.

The Texas coast consists of an almost continuous series of bays, estuaries, and lagoons from Sabine Lake through Laguna Madre. The central depth of these embayments range from about four to thirteen feet except for areas near inlets, where local tidal currents may scour channels 30 to 40 feet deep, and for dredged channels.

Texas bays extend about 30 miles inside the outer coast to the "bay line" where the gentle slope of the coastal plain limits inland progress of the bays. The bays are generally headed by alluvial plains and deltas which usually support marshes. On the seaward side of the bays are barrier islands which protect them from the open Gulf. The shores of many bays, as well as the open coast and both sides of the barrier islands and spits have many miles of fine sand beaches, tidal flats, or marshy areas, each of which constitutes a valuable resource in its own right.

The semi-permanent long shore currents along the Texas Coast are governed by the main stream of the North Equatorial Current which enters the Gulf of Mexico through the Yucatan Channel. The eastern part of this flow turns to the right to form the loop current which then flows out through the Florida Straits. The western part divides into two currents, one of which flows westward along the upper coast of Texas while the other flows northward past the Mexican coast and continues along the lower Texas coast. These two currents meet along the coast south of Corpus Christi in a convergence zone. The two semi-permanent long shore currents along the Texas Coast as well as the convergence zone remain fairly constant from year to year, but shift in location and relative strength in response to seasonal changes in the prevailing wind. Winds and tides resulting from hurricanes and other tropical cyclones temporarily alter these current patterns.

BIOLOGICAL FEATURES OF THE COASTAL ZONE

In a biological sense, the coastal zone, and in particular the bays and estuaries, are characterized by complex activity. Participants range in size from bacteria to large vertebrates, from terrestrial to marine forms, and in numbers ranging from the nearly extinct red wolf and American alligator to the myriads of phytoplankton in the rivers, marshes, and estuaries. (Suter, 1970, Fisher and Flawn, 1970b). Habitats include four major types:

1. Coastal prairie,
2. Gulf Coast marshlands,
3. River systems, and
4. Bays, lagoons, and estuaries

Vegetation

The climax vegetation of the Gulf Prairies is largely grassland (tall grass prairie) or post oak savannah. However, much of the area has been invaded by trees and brush such as mesquite, live oaks, prickly pear, and several acacias. The principal climax plants are tall bunch grasses such as big bluestem, seacoast bluestem, Indian grass, eastern gamagrass, species of

Panicum and others. Some invading plants, other than brush species, include yankee weed, broomsedge, smutgrass and many annual weeds and grasses.

Introduced grasses, such as Bermuda and carpet grass, are common in tame pastures and some have escaped into uncultivated areas. The salt marsh areas typically support several species of sedges and rushes, several cord grasses, and seashore saltgrass.

The river bottoms which cross the Gulf Prairies contain a flora quite distinct from the prairies themselves. Here, trees predominate such as oaks, hackeberry, willows, ash trees, cottonwoods, anacua and others. Dwarf Palmeto are also found in these river bottom lands.

Conifers are not an important family in the coastal zone. However, in the eastern counties, some representative species occur such as the shortleaf pine, the longleaf pine and the loblolly pine. The bald cypress is found in swamps and along rivers from Brazoria County eastward.

On barrier islands, especially on Padre and Mustang Islands, the predominant vegetation is sea oats, marsh-hay, cord grass and the creeping vines of morning glory. Sunflowers are common on these treeless expanses of sand dunes.

Aquatic plants abound in the coastal zone. Among these are parrot's feather, pondweeds, duckweeds, duck meat and arrowheads. In bays and open water along the Gulf Coast are to be found such species as manatee-grass, widgeon-grass, shoalgrass, turtle-grass and others.

Attached and semi-attached red, brown, and green algae, some with calcareous features abound in the bays and man-made structures. Blue-green algal mats are common in the tidal flats.

Estuarine Animals

Although it is difficult to categorize estuarine organisms, particularly the highly mobile fishes, in relation to a single environmental factor, it is reasonable to provide the following salinity-related general classification scheme (Abbot, et al., 1971):

- Freshwater forms that occassionally enter brackish water.
- True estuarine species that are confined to the estuary.

- Anadromous (species that go up the estuaries and rivers to spawn) and catadromous (species that go down the river and out to sea to spawn).
- Marine species that seasonally enter estuaries, usually as adults.
- Marine species that utilize the estuary as a nursery.
- Occasional marine visitors with apparently no estuarine environment.
- Micro-fauna in all areas.

All but freshwater species and the last category are estuarine dependent in that they utilize the estuary at some stage in their life history. Most of the Texas fishery is based upon estuarine-dependent species such as: menhaden, shrimp, and oysters.

Pelagic species tend to inhabit the upper portions of the water column, whereas demersal forms live on or near the bottom. Estuarine fishes are extremely varied in size ranging from gobies which at maturity measure less than one inch long to sharks and the fearsome but harmless, manta rays.

Although some species spend their entire lives in estuaries, most species are estuarine-dependent at some stage but not restricted to the estuary throughout life. Many of the dominant estuarine-dependent species of the Gulf of Mexico, such as the croaker and mullet, exhibit a rhythmic, seasonally correlated, estuary-offshore migratory pattern.

Crustaceans and mollusks are a conspicious segment of the estuarine fauna. Shrimp and oysters support 80 percent of all Texas fisheries. Extensive mollusk communities of oysters, clams and coquinas provide sedimentary niches in the embayments and beach areas. The fiddler and ghost crabs are abundant along the shores.

Waterfowl and Migratory Birds

The Texas coastal zone bridges two major migratory routes: the eastern part is at the terminus of the great Mississippi Flyway and the rest is crossed by the Central Flyway. As a result, the region abounds with migratory birds, both waterfowl and otherwise.

Five formal wildlife refuges (four federal and one state) exist primarily for waterfowl protection. Many undeveloped areas and rice farmlands provide additional habitat.

Ducks and geese constitute a very valuable resourse as game birds. The two most common species of ducks are the pintails and redheads; it has been estimated that 78% of all redheads winter in the Laguna Madre. Canadians are the predominant geese.

A vast array of non-game birds abound in the coastal zone. The best known is the very rare and endangered whooping crane which winters at the Aransas National Wildlife Refuge. Some 400 species plus approximately 150 sub-species are found in the coastal zone.

Estuarine Microbiota

Population statistics derived from serial dilution counts indicate that gross populations of bacteria in a balanced bay, lagoon, or estuary are uniform because of mixing in the water but may be markedly increased at the top of the sediment and at the surface of the bay waters. Normal bottom surface density is in the order of 10^8 bacteria/ml. Typical bacteria from the water column will be gram negative rods and cocci. Motile bacteria tend to be in the water column while non-motile forms tend to be in the bottom muds or attached to particulate materials. Other microorganisms include the diatoms, numerous species of dinoflagellates, photosynthetic organisms, protozoa, fungi, and yeasts.

Estuarine organisms are affected by pathogens and parasites. Pathogens from liquid wastes are predominantly bacteria, fungi, and parasites. Few diseases of humans can be related to the marine environment or to parasites and diseases of animals which inhabit the estuaries. All pathogenic organisms affecting man come from terrestrial sources; however, estuarine organisms can carry pathogens such as those which cause hepatitus by concentrating the viruses.

Chemical Considerations

As a result of geological and geographical features, the chemical aspects of the Texas Bays are varied. Salinities range from fresh water, with minerals from several geographical land features, to hypersaline bays with little fresh water input. The distribution of elements will vary as a result of adjacent land masses, concentration effects due to evaporation and input from man. Turbidity of the water is usually large with little light penetration. This may regulate benthic algae to a depth no greater than three feet. The turbidity is due to clays, mixing effects of the wind on bottom muds, and primary productivity.

SOCIO-ECONOMIC CHARACTERISTICS OF THE COASTAL ZONE

Population Features

The 18 counties bordering the coast had a 1970 population of 2.95 million and an additional .55 million people lived in the 18 adjacent inland counties (Fisher and Flawn, 1970b). Thus 3.5 million persons or nearly one out of every three Texans lived in the Coastal Zone in 1970. The Coastal Zone region is largely urbanized with 84 percent of the population residing in cities of 2500 or more population, as compared with 80 percent for the state as a whole. Within the Coastal Zone population is concentrated in a series of five Standard Metropolitan Statistical Areas (SMSA's) running from Beaumont-Port Arthur-Orange on the north to Houston, Galveston-Texas City, Corpus Christi, and Brownsville-Harlingen to the south.

The Coastal Zone is one of the most rapidly growing areas in the state, experiencing a 21.5 percent increase in population between 1960 and 1970 as compared with 16.9 percent for the state and 14.2 percent for the nation. This growth was not evenly experienced across the Coastal Zone; seventeen of the Coastal Zone counties lost population between 1960 and 1970, but nineteen gained population. Included in the latter group were three counties which were among the eleven counties in the state experiencing a growth rate in excess of 40 percent over the decade. The growth in population between 1960 and 1970 in the Coastal Zone was almost entirely in the urbanized areas.

Economic Features

Economic growth in Texas has been directly related to access to the Gulf of Mexico and to the rich mineral resources found along the Texas Gulf Coast. The estimated "effective buying income" (personal income less taxes) for the Coastal Zone counties as of December 31, 1970, was $9.7 billion, representing over 28 percent of the "effective buying income" of the State.

The Texas coastline, totaling approximately 1,890 miles, provides inexpensive water transportation to Texas industry and agriculture. It has been estimated that more than $1.3 billion in revenues were generated by the 11 deep draft ports and $140 million in revenues were generated by the 13 shallow draft ports along the Texas coast in 1968. Marine transportation industries were directly responsible for the employment of more than 18,000 persons and had an estimated $439 million in sales (Doyle and Kneese, 1970, Miloy and Capp, 1970).

Port activity, industrial location, and regional growth are highly interrelated. Industries located along the Houston Ship Channel are estimated to employ 100,000 persons generating over one-half billion dollars in annual income. In Galveston, 61 percent of the total wage and salary income of the city was estimated to be generated by the Port of Galveston. In 1968, nearly 18,000 workers were directly involved in employment as a result of the Port of Galveston.

The coastal area of Texas is also one of the world's major oil and natural gas production centers (Fisher and Flawn, 1970a). In addition, other minerals of value, including sulfur, salt, and shell are produced in the Coastal Zone. The 36 counties in the Texas Coastal Zone account for about one-third of the state's total value of mineral production. The 18 counties bordering the coast have accounted for nearly 20 percent of the total crude oil production of the state with cumulative production through 1968 of 5.7 billion barrels. Daily production from this area amounts to approximately 561, 000 barrels or about one-sixth of the daily average production for the state. Of the 47 petroleum refineries in the state, 32 are located in the 18 coastal counties. One of the most rapidly growing activities in the state is offshore mining. It has been estimated that offshore mineral industries in Texas in 1969 employed more than 23,000 persons and had sales of more than $972 million

In addition, near-shore waters along the Texas Coast constitute the major spawning and nursery areas for more than 70 percent of the fish population in the Gulf of Mexico (Miloy and Capp, 1970) It has been estimated that approximately 750,000 Texans currently engage in recreational fishing throughout Texas coastal waters. In the process, they catch about 40 million pounds of speckled trout, redfish, flounder, drum, and shrimp which is conservatively estimated to produce "net economic benefits" to Texas of over $19 million annually. Untold additional millions are generated by other recreationists and tourists from Texas and the rest of the nation who visit the Coastal Zone each year.

Texas also accounts for a significant portion of the total United States fisheries output. In 1968, nearly 148 million pounds of finfish and shellfish were landed at Texas ports, representing a total market value of $49.5 million. It has been estimated that direct sales of commercial fisheries in Texas in 1968 amounted to approximately $219 million, providing direct employment to more than 12,500 persons.

CLOSURE

Thus, the Coastal Zone of Texas is diverse and productive, both in terms of natural resources and man's activities. These activities are in some cases compatible with the natural physical and biological processes while in other cases they are not. This gives rise to the urgent need for the intelligent, balanced management of our coastal resources.

In order to address such a complicated situation, it is necessary to utilize all the knowledge available. However, before one can utilize such knowledge, one must have a broad framework available which will couple the many individual pieces together into a useable package. This has not been available in the past, nor is it available today. The development of just such a broad analytical approach is an aim of the entire project of which this report forms the initial phase. In the next chapter, "Analytical Framework," the key components of just such a broad strategy are presented and demonstrated.

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ANALYTICAL FRAMEWORK

The specific objective of this phase of the project is the development of a systematic and interdisciplinary approach to an understanding of problems relative to management of the Coastal Zone. A systematic approach requires the following steps:

1. An evaluation of the various environmental units within the Coastal Zone in terms of basic properties which restrict or limit some of man's activities;
2. An identification of man's activities in the Coastal Zone and the spatial distribution of these activities;
3. A projection of changes in the nature and level of man's activities and the corresponding change in their distribution;
4. An estimate of the air, water and solid wastes resulting from man's activities and the costs required to treat them to various quality levels;
5. An evaluation of the environmental impact caused by man's activities and subsequent waste inputs; and
6. An estimate of the effect of environmental changes on present and projected activities of man.

Appendices A through D present background information on each of the outlined steps.*

The most difficult task in implementing such a systematic approach is defining objectively the various socio-economic and environmental interactions that occur within the above six steps. For one man or

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*Appendix A *Municipal and Industrial Wastes*
Appendix B *Criteria for Bay and Estuarine Uses*
Appendix C *Modeling of Estuarine Transport Processes*
Appendix D *Economic Aspects of Environmental Planning*

discipline to have a complete understanding of such interactions is impossible. Hence, an interdisciplinary approach is needed. But before the disciplines can function together effectively, they must have a basic understanding of the problem solving techniques of the others. However, the terminology and philosophy used in dealing with the environment is different for each discipline. Some mechanism is required for breaking down this communication barrier.

For instance, the resource economist begins with the socio-economic forces that affect coastal development (which he terms sector development). He also desires to know the effect of these sectors on the environment. However, the water quality expert, biologist and geologist deal with the effects of wastewater disposal, construction of highways, etc. on the environment. Thus, it is necessary that the sectors be related to man's activities if the interdisciplinary team is to effectively function. Other problems must be addressed in the same fashion.

Figure III-1 in schematic form presents the interdisciplinary framework that the group developed to pinpoint the interactions arising in the systematic approach. The applicable sectors of the economy are outlined in Table III-1. (It should be noted that the breakdown into sectors was made in accordance with the importance of their effects on the coastal environment rather than on their magnitude with respect to the national economy. Also, the manufacturing sector is broken into 21 industrial classes; but, because of the scope of this phase of the project, it will be treated as one sector.) Table III-2 delineates seventeen activities of man resulting from sector development. (Note that for the needs of the team the construction activity is treated by location site rather than by type of activity.) Table III-3 identifies the environmental changes brought about by man's activities. Because of the emphasis in this phase of the study on man's uses of the bays and estuaries, particular attention is given to various surface water quality characteristics.

INTERACTION MATRICES

A matrix is a rectangular grid for showing relationships between two or more items. Although they are most frequently used for depicting quantitative relationships, matrices are equally applicable for showing qualitative interactions. Figures III-3, III-4, and III-5 are each used to show such "yes-no" relationships between the items listed along the rows and columns. Collectively they can be used in a

FIG. III-1; Generalized Analytical Framework.

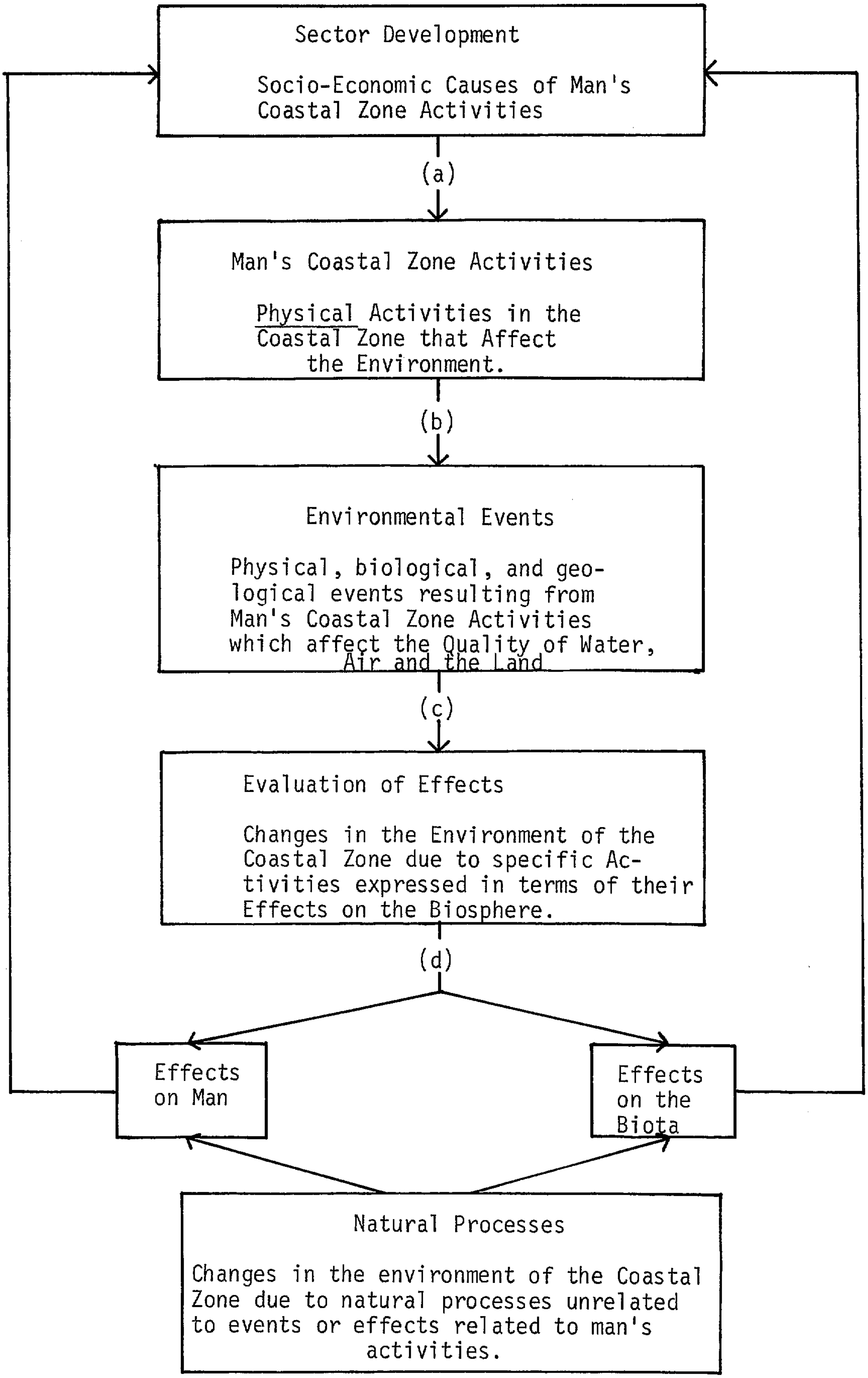

TABLE III-1

Sectors of the Coastal Economy

A. *Extractive*

1. Fishing
   a. Shell Fishing (1) - commercial activities
   b. Fin Fishing (2) - commercial activities

2. Mining
   a. Surface Mining (3) - sand and gravel, shell, clays
   b. Subsurface Mining (4) - petroleum, sulfur, natural gas, salt

3. Agriculture
   a. Irrigated Agriculture (5) - rice and other
   b. Mariculture (6) - farming of marine organisms
   c. All Other Agriculture (7) - dry land agriculture, other agriculture including lands managed for wildlife purposes and fresh water aquaculture

B. *Transportation*

1. Navigation (8) - water transport

2. Ports (9) - physical port facilities and related servicing activities to navigation above

3. Pipelines (10) - construction and use

4. Highways, Railroads, and Airports (11) construction and use

C. *Utilities*

1. Electric and Gas Utilities (12) - production and distribution

2. Water Supply and Wastewater Treatment (13) - both municipal and industrial, including distribution

D. *Recreation*

1. Contact and Non-contact Recreation (14)

E. *Other*

1. Non-Manufacturing (15) - services and trades

2. Manufacturing (16) - can further be broken in 21, two-digit SIC groupings

3. Residential Construction (17)

A. *Waste Disposal*

1. Liquid Waste Disposal (1) - disposal of any waste in liquid form into the environment
2. Gaseous Waste Disposal (2) - disposal of gaseous waste into the environment
3. Solid Waste Disposal (3) - disposal of solid wastes into the environment

B. *Construction*

1. Offshore Construction (4) - construction in bays and estuaries, continental shelf
2. Coastal Construction (5) - construction on shoreline, barrier islands, and fish passes
3. Inland Construction (6) - construction in coastal plain

C. *Canal Development*

1. Land Canals (7) - land cuts which disrupt shoreline or immediately adjacent coastal plain
2. Offshore Channels (8) - canals in bays and estuaries and cuts through barrier islands

D. *Dredging and Spoil Disposal* (9) - relocation of bottom sediments or shell from natural environments; relocation of sediments from any type of channelization

E. *Excavation* (10) - on land relocation of soil

F. *Drainage* (11) - alteration of natural drainage systems affecting runoff

G. *Filling* (12) - placing of solid materials into low lying areas

H. *Draining* (13) - removing water from low lying areas (such as marshes)

I. *Well Development* (14) - includes petroleum, sulfur, natural gas, salt, and water extraction and injection

J. *Devegetation* (15) - destruction or alteration of natural vegetation

K. *Traversing with Vehicles* (16) - dune buggies and other offroad vehicles, boats not used for navigation and commercial activities

L. *Use of Fertilizers and Biocides* (17) - application on land or water of fertilizers and biocides

TABLE III-2

Man's Coastal Zone Activities

A. *Effects on Water Quality*

1. Surface Water Quality
   a. BOD (1)
   b. Dissolved Oxygen (2)
   c. Nutrients (3)
   d. Pathogens (4)
   e. Floatables (5)
   f. Odors and Tastes (6)
   g. Color (7)
   h. Toxicity (8)
   i. Dissolved Salts (9) - i.e., salinity
   j. Suspended Solids (10) - particles in aqueous suspension
   k. Radiological (11)
   l. Temperature (12)
   m. PH Buffering (13)
2. Ground Water (14)

B. *Effects on Air Quality*

1. Particulates (15)
2. Gases (16)

C. *Physical Processes*

1. Erosion (17)
2. Deposition and Accretion (18) - deposition in bays and estuaries and accretion in rivers
3. Subsidence (19)
4. Hydraulics (20) - water flow and circulation, to include storm surge and fresh water input
5. Devegetation (21)
6. Infiltration (22) - (i.e., sediment infiltration)
7. Ponding (23)

D. *Biological Processes*

1. Photosynthesis (24)
2. Consumers/Food Chain (25)
3. Decomposition (26)
4. Predation (27)

**The numbers in parentheses refer to the event's position in the listing in Figure II.*

TABLE III-3

Environmental Events

sequential manner to trace the repercussions of a socio-economic occurrance through the physical activities of man and the related environmental events up to the occurrance of eventual impact on the biosphere and the possible impairments of other uses.*

Figure III-2 is a diagram showing how Figures III-3, III-4, and III-5 inter-relate amongst themselves. Using the interaction matrices as indicated there, it is possible to trace the impact of a change in the level of activity of any sector through man's associated activities and the environment. It is also possible to identify probable resultant environmental feedback effects on other sectors. A detailed example of how this procedure can be applied will be presented later in this chapter after each figure is individually discussed.

FIGURE III-3: Man's Activities Arising from Sector Development

This figure shows the qualitative interactions between the 17 Coastal Zone socio-economic sectors** and the 17 man-executed physical activities** that occur in response to socio-economic development. Or, stated another way:

> If it is possible to satisfactorily project growth patterns by sector, then an estimate of the physical activities man will undertake in support of, or response to, those growth patterns can be made. For example, if he is to develop residential housing communities, the relationships presented in Figure III-3 indicate the expected associated physical activities (waste disposal, draining, filling, etc.).

Sectors are listed along the row margins and activities appear as column headings. To read the chart, begin with a sector, scan that row, and if an "●" appears, then that sector may be expected to produce a significant amount of the activity represented by that column. A void cell (no entry) indicates that there is an insignificant relationship between that particular pair.

While it is possible to make generalizations about the relationships between sectors and the resultant activities, each condition will be somewhat unique. Thus, for thorough interpretation and

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**All these relationships are qualitative at this time. However, it is the goal of this continuing effort (of which this report is only a first phase) to develop and demonstrate the methodology for quantifying these relationships.*

***As given in Tables III-1 and III-2 respectively.*

and understanding, separate analysis would be required for each particular situation. Table III-4 provides a brief verbal description of the relationships shown in Figure III-3.

FIGURE III-4: Environmental Events Resulting from Man's Activities

Figure III-4 shows how each of man's activities as identified in the previous section, may produce a particular environmental event. An "environmental event" is here defined as a change in a parameter or process commonly used to describe environmental conditions or interactions. As broadly delineated for the Texas Coastal Zone, and the bays and estuaries in particular, there are four categories of such environmental events (water quality, air quality, physical processes and biological processes) which are in turn further divided into the 27 items as shown in Figure III-4.

The row headings list the 17 items representing man's activities in the Coastal Zone. These correspond to the column heading on the previous figure. Vertically, there is a column corresponding to each of the 27 environmental events mentioned above.

If a cell contains an "●" then there is a significant relationship between the activity and the event represented by that row and column. A blank indicates the lack of a significant interaction.

Table III-5 provides a verbal description of the relationships indicated in Figure III-4. These are provided to aid in the interpretation/understanding of that material. Reading this table is the reverse of reading the previous one. Instead of listing each activity and then enumerating all possible events which might occur, it lists the environmental events then mentions what activities might result in that event.**

FIGURE III-5: Implications of Environmental Effects on Man's Uses of Bays and Estuaries

Once the environmental events that arise from man's various activities have been determined, the next logical step is to

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**For the purposes of the project described herein, the interdisciplinary team found this particular scheme applicable and satisfactory. For other situations involving different objectives, resource bases, and/or teams, a different breakdown may be applicable.*

***This approach saves much repetition. Consider event #11, "suspended solids." If enumerated by activities, it would be repeated 12 times. However, since most sources of suspended materials are construction related, classification by the event only required the explanation that "suspended solids may be effected by waste disposal and all forms of coastal construction.*

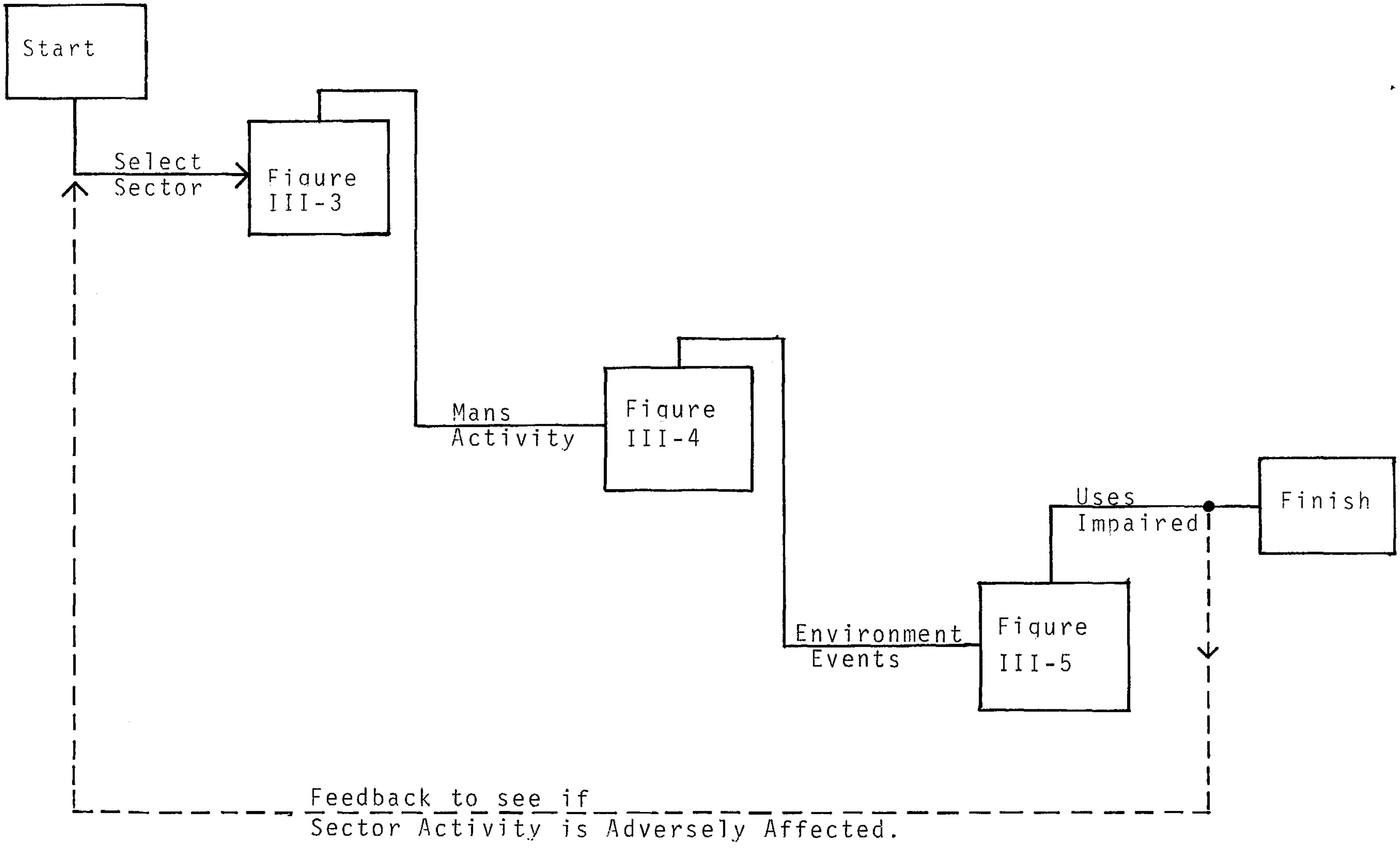

FIG. III-2; Overview of analytical procedure.

COASTAL ZONE ACTIVITIES SECTORS	1. Liquid Waste Disposal	2. Gaseous Waste Disposal	3. Solid Waste Disposal	4. Offshore Construction	5. Coastal Construction	6. Inland Construction	7. Land Canals	8. Offshore Channels	9. Dredging and Spoil Disposal	10. Excavation	11. Drainage	12. Filling	13. Draining	14. Well Development	15. Devegetation	16. Traversing With Vehicles	17. Use of Fertilizers and Biocides
1. Shell Fishing	●		●		●												
2. Fin Fishing	●				●												
3. Surface mining					●	●	●		●	●			●		●		
4. Subsurface Mining	●	●	●	●	●	●			●	●			●	●	●		
5. Irrigated Agriculture						●	●				●		●	●	●		●
6. Mariculture	●				●	●				●	●		●				●
7. Other Agriculture	●		●			●					●	●	●		●		●
8. Navigation				●	●	●	●	●	●			●				●	
9. Ports	●		●	●	●	●	●	●	●			●	●				
10. Pipelines					●	●	●		●	●					●	●	
11. Highways, Railroads & Airports	●	●	●		●	●				●	●	●	●		●		
12. Electric and Gas Utilities	●	●	●	●	●	●	●	●	●	●	●	●	●		●	●	
13. Water Supply & Wastewater Treatment	●	●	●		●	●	●		●	●	●	●	●	●			
14. Recreation	●		●		●	●				●	●	●	●		●	●	●
15. Non-Manufacturing	●	●	●		●	●											
16. Manufacturing	●	●	●	●	●	●	●	●		●	●	●	●	●			
17. Residential Construction	●		●		●	●				●		●	●		●		

SECTOR DEVELOPMENT AND MAN'S COASTAL ZONE ACTIVITIES

FIGURE III-3

1. *Shell Fishing*
   Shell Fishing may involve waste disposal (1, 3)* and may result in coastal construction (e.g., piers, docks, processing plants) (5).

2. *Fin Fishing*
   The only Coastal Zone Activities that can be directly related to Fin Fishing are coastal construction of facilities (e.g., piers, docks, processing plants) (5) and liquid waste disposal from processing plants (1).

3. *Surface Mining*
   Surface Mining generally involves excavation (10) which in turn may result in devegetation (15), and may require inland construction (6), coastal construction (5), land canals (7), dredging and spoil disposal (9), and draining (13).

4. *Subsurface Mining*
   Subsurface Mining requires well development (14). Also it may require offshore construction such as platforms (4), coastal or inland construction (5, 6), dredging and spoil disposal (e.g., to put in platforms) (9), excavation (e.g., brine pits) (10), and filling and draining (12, 13), may result in devegetation (15), and results in liquid, gaseous, and solid wastes (1, 2, 3).

5. *Irrigated Agriculture*
   Irrigated Agriculture requires the construction of land canals (7), inland construction (e.g., dykes, pumping facilities) (6), and devegetation (15), may involve well development (14), draining of low lying areas (13), and drainage projects (11). Of particular concern is the application of fertilizers and biocides (17) and the runoff of these materials into rivers, bays, and estuaries.

6. *Mariculture*
   Mariculture generally involves drainage alterations (11), draining (13), excavation (10), and application of fertilizers and biocides (17). It may also result in coastal and inland construction of related facilities (5, 6), and in liquid waste disposal (1).

7. *Other Agriculture*
   Other Agriculture generally involves devegetation (15), the application of fertilizers and biocides (17), inland construction (6), and drainage alterations, filling, and draining (11 12, 13). Animal feed lot operations result in both liquid and solid waste disposal (1, 3).

8. *Navigation*
   Navigation might involve offshore channels (8), offshore, coastal, and inland construction (4, 5, 6), inland canals (7) and traversing with vehicles (16). It might also involve dredging and spoil disposal (9) and filling (12).

9. *Ports*
   Port construction offshore might involve development of offshore channels (8), offshore construction (4), and dredging and spoil disposal (9). Construction of ports onshore usually involve development of land canals (7), coastal and inland construction (5, 6), filling (12), and draining (13). The operation of any port would increase liquid and solid waste disposal (1, 3).

10. *Pipelines*
    Development of Pipelines involves offshore construction (4), coastal construction (5), inland construction (6), dredging (9), and might involve excavation (10), devegetation (15), and traversing with vehicles (16).

11. *Highways, Railroads, and Airports*
    Expansion or development of Highways creates additional auto traffic resulting in gaseous wastes (2).

    Construction of Highways, Railroads, and Airports involves excavation (10), drainage (11), filling (12), draining (13), inland construction (6), coastal construction (5) and devegetation (15).

    Expansion or development of Airports creates additional air traffic resulting in increased gaseous wastes (2). In addition, Airport operation results in liquid and solid wastes (1, 3).

12. *Electric and Gas Utilities*
    Development and expansion of Electric and Gas Utilities involves liquid, gaseous, and solid waste disposal (1, 2, 3). Construction of electric and gas utilities, including both production and distribution facilities, might involve offshore construction (4), offshore channels (8), dredging and spoil disposal (9), coastal and inland construction (5, 6), land canals (7), excavation (10), drainage (11), filling (12), draining (13), devegetation (15), and traversing with vehicles (16).

13. *Water Supply and Wastewater Treatment*
    Water Supply and Wastewater Treatment involve liquid, gaseous, and solid waste disposal (1, 2, 3). Construction of Water Supply and Wastewater Treatment might involve coastal and inland construction (5, 6), land canals (7), dredging and spoil disposal (9), excavation (10), drainage (11), filling (12), draining (13), and well development (14).

14. *Recreation (includes Contact and Non-Contact Recreation)*
    Recreation involves liquid and solid waste disposal (1, 3).

    Some forms of Recreation may involve traversing with vehicles (e.g., motor boats, mini bikes, dune buggies) (16).

    Development and expansion of Recreation may require coastal and inland construction (5, 6).

    Reservoir construction to provide recreation opportunities might involve excavation (10), drainage (11), filling (12), draining (13), and devegetation (15).

    Improvement of fish and wildlife habitat might involve the use of fertilizers and biocides (17).

15. *Non-Manufacturing (includes Services and Trade, and Banking, Insurance, and Commerce)*
    Development or expansion of Non-Manufacturing might involve liquid, gaseous, and solid waste disposal (1, 2, 3).

    Development or expansion of Non-Manufacturing might involve coastal and inland construction (5, 6).

16. *Manufacturing (includes all SIC's listed in Table 1)*
    Development or expansion of Manufacturing might involve liquid, gaseous, and solid waste disposal (1, 2, 3).

    Development or expansion of Manufacturing might involve offshore, coastal, and inland construction (4, 5, 6), land canals (7), offshore channels (8), excavation (9), drainage (10), filling (12), draining (13), and well development (14).

17. *Residential Construction*
    Development or expansion of Residential Construction involves liquid and solid waste disposal (1, 3).

    Development or expansion of Residential Construction involves coastal and inland construction (5, 6) and related excavation (10), filling (12), draining (13) and devegetation (15).

TABLE III-4

Description of Relationships Between Sector
Developments and Mans' Activities

**The numbers in parenthesis refer to the specific activities affected and denote a column heading on Figure III-3.*

ENVIRONMENTAL EVENTS / ACTIVITIES	WATER QUALITY														AIR QUALITY		PHYSICAL PROCESSES							BIOLOGICAL PROCESSES			
	1. BOD	2. Dissolved Oxygen	3. Nutrients	4. Pathogens	5. Floatables	6. Odors and Tastes	7. Color	8. Toxicity	9. Dissolved Salts	10. Suspended Solids	11. Radiological	12. Temperature	13. Ph Buffering	14. Ground Water	15. Particulates	16. Gases	17. Erosion	18. Deposition and Accretion	19. Subsidence	20. Hydraulics	21. Devegetation	22. Infiltration	23. Ponding	24. Photosynthesis	25. Consumers/Food Chain	26. Decomposition	27. Predation
1. Liquid Waste Disposal	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●		●	●	●		●	●	●	●
2. Gaseous Waste Disposal															●	●					●			●	●	●	●
3. Solid Waste Disposal	●	●	●	●	●	●	●	●	●	●	●		●	●	●	●				●	●	●	●	●	●	●	●
4. Offshore Construction	●	●						●		●							●	●		●				●	●	●	●
5. Coastal Construction	●	●							●	●							●	●		●	●			●	●	●	●
6. Inland Construction	●	●								●				●			●	●		●	●	●	●	●	●	●	●
7. Land Canals									●	●		●		●			●	●		●	●	●	●	●	●	●	●
8. Offshore Channels									●	●		●					●	●		●	●			●	●	●	●
9. Dredging and Spoil Disposal	●	●	●			●	●	●	●	●		●	●				●	●		●	●	●	●	●	●	●	●
10. Excavation										●				●			●	●			●	●	●	●	●	●	●
11. Drainage	●	●	●	●	●	●	●	●	●	●	●	●	●	●			●	●		●	●	●	●	●	●	●	●
12. Filling										●				●			●	●		●	●	●		●	●	●	●
13. Draining	●	●	●		●	●	●		●	●		●	●	●			●	●	●	●	●	●		●	●	●	●
14. Well Development									●					●					●			●		●	●	●	●
15. Devegetation	●	●	●							●				●			●	●		●	●	●		●	●	●	●
16. Traversing With Vehicles	●	●			●	●	●	●		●					●	●	●	●			●			●	●	●	●
17. Fertilizers/Biocides	●	●	●					●						●	●						●			●	●	●	●

ENVIRONMENTAL EVENTS RESULTING FROM MAN'S ACTIVITIES
FIGURE III-4

TABLE III-5

Description of Figure III-4:

Environmental Events Resulting From Mans' Activities

WATER QUALITY (1-14)

1. *Biochemical Oxygen Demand (BOD)*
   When organic materials undergo aerobic biological degradation, the decomposing organisms require oxygen in order to function. This is called BOD, and exerts a demand on the dissolved oxygen (DO) resources of the water body. Most BOD arises from waste disposal (1, 3) but some comes from construction and related activities (4, 5, 6, 9, 11, 13, 15), certain agricultural practices (17),* and boats (16).

2. *Dissolved Oxygen (DO)*
   The DO of a water body usually drops because of the input of soluble and solid oxygen demanding materials as discussed under BOD above (1, 3, 4, 5, 6, 9, 11, 13, 15, 16, 17). Other actions/processes affecting the DO level include water temperature, reaeration, dissolved salts, and upsets in the photosynthesis-respiration cycle.

3. *Nutrients*
   Most nutrient inputs (such as nitrogen and phosphorus) result from waste disposal (1, 3). Normal secondary wastewater treatment does not remove significant portions of these substances. Certain activities (9, 11, 13) and the use of fertilizers (17) may change the nutrient concentration. Devegetation (15) would aid the input of nutrients by erosion.

4. *Pathogens*
   These usually come from the disposal of wastes (1, 3) but may also result from river drainage (11).

5. *Floatables*
   Improper waste disposal (1, 3), as well as runoff (11), reclamation (13), and excessive vehicular activity (16) can generate inputs of floatables in the bays and estuaries.

6. *Odors and Tastes*
   These most generally result from waste disposal (1, 3), but can also result from certain construction-related activities (9, 11, 13), and vehicles (16).

7. *Color*
   Possible sources of color are about the same as for odors and tastes, namely waste disposal (1, 3) and others (9, 11, 13, 16).

8. *Toxicity*
   Toxic materials may be extremely varied in nature, including both organic and inorganic materials, some of which quickly degrade while others are extremely persistant. Most common sources are waste disposal (1, 3), agriculture (17), and drainage (11). Construction activity (4, 9) may introduce some toxic substances.

9. *Dissolved Salts*
   Well development (14), certain construction work (5, 7, 8, 9, 11, 13), waste disposal (1, 3) account for all significant contributions of dissolved salts.

10. *Suspended Solids*
    Almost any activity of man in, or adjacent to the bays and estuaries can result in the introduction of suspended solids into the estuarine system. Chief contributors are virtually any kind of construction and related activity (4, 5, 6, 7, 8, 9, 10, 12, 13, 15), waste disposal (1, 3), drainage (11), and vehicular activity (16).

11. *Radiological*
    This most likely results from waste disposal (1, 3) but could also be transported into the estuarine system by the natural process of run-off (e.g., drainage, 11).

12. *Temperature*
    Liquid wastes (1), including cooling water, can produce significant, localized temperature changes. Other activities which alter the basic physical configuration and/or flow regimes (7, 8, 9, 11, 13) of bays may also alter the natural temperature conditions.

13. *pH Buffering*
    Alterations of this phenomenon are most likely to result from waste disposal (1, 3), and in particular certain petrochemical or steel operations. However, other activities (9, 11, 13) which may introduce foreign or agitate in situ substances may alter this delicate balance.

14. *Ground Water***
    Ground water resources can be adversely affected by waste disposal (1, 3), inland construction and related activities (6, 7, 10, 11, 12, 13, 15), well development (15), and certain agricultural practices.

AIR QUALITY

15. *Particulates*
    Waste disposal operations (1, 2, 3) account for much of the atmospheric particulates, whether these be industrial facilities, residential trash burning, or transportation operations. Some construction (6), traversing with vehicles (16), and agricultural practices (17) may make additional contributions.

16. *Gases*
    Most gaseous materials which are released into the atmosphere are the waste (1, 2, 3) by-products from some combustion process, be it an industrial or a private automobile (16).

PHYSICAL PROCESSES

17. *Erosion*
    Almost any endeavor of man, be it waste disposal (1) or virtually any form of activity (4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 15, 16) alters any part of the physical environment, can--if unwisely done--trigger devastating erosional process.

18. *Deposition and Accretion*
    Like erosion, almost anything that man does in or adjacent to estuarine areas, may upset the natural balance between these processes (1, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 15, 16).

19. *Subsidence*
    The over pumpage of water-supply aquifers (14) is the most common cause of subsidence; however, in certain cases, some has been blamed on oil production (14). The draining of wetlands (13) may also contribute to localized subsidence.

20. *Hydraulics*
    The hydraulics, or flow regime of an estuarine system can be altered by waste (1, 3) inputs if their flow is sufficient. Most common changes occur as a result of construction and related practices (4, 5, 6, 7, 8, 9, 11, 12, 13, 15) which change the original flow patterns.

21. *Devegetation*
    Loss of surface cover can result from improper waste disposal (1, 2, 3), certain construction and related practices (5, 6, 7, 8, 9, 10, 11, 12, 13, 15) vehicular activity (16) and agricultural endeavors (17).

22. *Infiltration*
    Improper waste disposal (1, 3) certain construction and related activities (6, 7, 9, 10, 11, 12, 13, 15) and faulty well development (14) may result in infiltration of undesirable substances into a good aquifer.

23. *Ponding*
    Ponding may result from certain construction and related activities (6, 7, 9, 10, 11) or poor solid waste disposal practices (3).

BIOLOGICAL PROCESSES

24. *Photosynthesis*

25. *Consumers/Food Chain*

26. *Decomposition*

27. *Predation*
    Almost each physical activity has an effect on the various biological processes. Hence man must institute environmental controls so that these processes are not significantly upset or provide an altered environment in which these biological processes perform functions that provide greater socio-economic benefits to man than the original environment.

**Other possible sources for BOD loadings do exist, but the reader should recall that while this analysis is general, it is oriented toward Texas' bays and estuaries. Thus its nature reflects the collective knowledge of its authors toward that specific situation.*

***The quality parameters discussed in the above 13 sub-sections can all apply to some degree to ground water as well as surface water. Since our primary concern in this report is bay and estuarine management, the discussion of ground water is greatly abbreviated.*

find out what possible uses of the bays and estuaries may be impaired. Figure III-5 shows the major interactions between the environmental events and these potential uses.

The rows give the possible environmental events as outlined in the previous section; thus, these correspond to the column headings on Figure III-4. The column headings on Figure III-5 indicate nine possible uses that man can make of bays and estuaries. Note that these bear a definite relationship to the sector heading listed on Figure III-3 and described in Table III-1. That previous sector grouping, with its 17 classifications, includes all activities in, around, or remotely adjacent to the bays and estuaries which might have some impact upon the estuarine systems. This includes those activities, which while they may have pronounced effect on the bays, are themselves independent of the bay's conditions. For example, the indiscriminate dumping of untreated industrial wastewaters at the head of an estuary has a direct, definite impact on the estuary, but the condition of the estuary itself does not affect the functioning of that industry.* This is the reason that certain sectors, such as manufacturing and irrigated agriculture which are present in Figure III-3 are dropped from consideration on Figure III-5.

A similar line of thought can be used to explain the dropping of some sectors that have been aggregated since the implications of environmental events on their practice are indistinguishable from one another. For example navigation, ports, pipelines, etc. have all been lumped under the single heading "transportation," since the effects of environmental changes are essentially the same on all of them.

By beginning on the left side of the Figure III-5 with a particular "environmental event" row, one can read across the matrix and, by noting the "●'s", determine what uses of the estuary might be affected. Conversely, one can begin with the columns and thus determine what environmental events might possibly upset each given potential use.

As with the two previous interaction matrices, the entries noting the existence or lack of a significant relationship are subjective in that they reflect the knowledge and experience of the analyst involved as well as a specific study region. Table III-6 provides a brief verbal narrative describing certain of these relationships.

**If that industry is utilizing the estuary as a source of cooling water, this independence will possibly no longer exist.*

POSSIBLE USE RESTRICTIONS ENVIRONMENTAL EVENTS		1. Aesthetics	2. Commercial Fishing	3. Mining	4. Mariculture	5. Transportation	6. Utilities	7. Recreation	8. Residential Construction	9. Preservation of Fish & Wildlife
WATER QUALITY	1. BOD		●		●			●		●
	2. Dissolved Oxygen		●		●			●		●
	3. Nutrients		●		●			●		●
	4. Pathogens		●		●			●		●
	5. Floatables	●	●		●	●		●		●
	6. Odors and Tastes	●	●		●			●		●
	7. Color	●	●		●			●		●
	8. Toxicity		●		●			●		●
	9. Dissolved Salts		●	●	●			●		●
	10. Suspended Solids	●	●		●			●		●
	11. Radiological		●		●			●		●
	12. Temperature		●		●		●	●		●
	13. Ph Buffering		●	●	●			●		●
	14. Ground Water				●					●
AIR QUALITY	15. Particulates	●						●		●
	16. Gases	●						●		●
PHYSICAL PROCESSES	17. Erosion		●	●	●	●	●	●	●	●
	18. Deposition and Accretion					●		●	●	●
	19. Subsidence			●	●	●	●		●	●
	20. Hydraulics		●		●	●	●	●		●
	21. Devegetation	●								●
	22. Infiltration									●
	23. Ponding				●					●
BIOLOGIC PROCESSES	24. Photosynthesis	●	●		●			●		●
	25. Consumers/Food Chain	●	●		●			●		●
	26. Decomposition	●	●		●			●		●
	27. Predation	●	●		●			●		●

POSSIBLE USE RESTRICTIONS RESULTING FROM ENVIRONMENTAL EVENTS
FIGURE III-5

TABLE III-6

Description of Figure III-5

Possible Use Restrictions Resulting From Environmental Events

1. *Aesthetics*
The aesthetic value of a bay or estuary may be adversely affected in a direct manner by any substances altering its appearance such as floating materials (5), unusual color (7), or high turbidity due to suspended solids. Likewise, unusual odors and tastes (6) are undesirable. A significant change, either natural or man-induced, in any biological process (24, 25, 26, 27) may impair the aesthetic value. Also air pollution (15, 16) and devegetation (21) are undesirable from an aesthetic point of view.

2. *Commercial Fishing*
This usage may be affected by any significant surface water quality change (1 through 13). Alteration of bay and estuarine circulation patterns caused by significant changes in freshwater inflow, barrier island passes, and dredging or spoil deposition adversely affects commercial fishing (20). Water quality and circulation patterns are affected by erosion processes (17). Naturally commercial fishing productivity is a function of the four major biological processes (24, 25, 26, 27).

3. *Mining*
Dissolved solids (9) and pH buffering (13) could possibly impair this use if water was needed for secondary recovery operations; certain physical processes (17, 19) could also have an adverse effect.

4. *Mariculture*
The lowering of quality conditions (1 - 14) and some physical processes (17, 19, 20, 23) could affect biological phenonema upon which a mariculture operation is based.

5. *Transportation*
Changes in a number of physical processes (17, 18, 19, 20) could severely impair transportation if not properly attended to. Floatables (5) are the only water quality condition likely to impair a water body's utility as a transportation medium, and then only under extremely rare conditions.

6. *Utilities*
The use of water as a heat sink by the utilities could be adversely affected by temperature (12), erosion (17), subsidence (19) and hydraulics (20).

7. *Recreation*
Recreational uses which cover a broad spectrum ranging from fishing to contact sports to boating, can be impaired by most water quality conditions (1 through 13). All biological processes (24, 25, 26, 27) play a significant role, as do certain physical processes (17, 18, 20), and air pollution (15, 16).

8. *Residential Construction*
Indirectly residential construction may be adversely affected by any environmental event which reduces the aesthetic or recreation uses of a water or land resource. However, the only direct effects come from certain physical processes (17, 18, 19).

9. *Preservation of Fish and Wildlife*
Virtually any environmental change (1 - 27) may affect the use of a resource for the preservation of fish and wildlife. However, if properly managed, these changes could be beneficial rather than harmful.

APPLICATIONS OF INTERACTION MATRICES

The preceeding section has presented three interaction matrices, each showing a different set of relationships. These relationships can be used in a sequential manner beginning with identifying socio-economic sector development, determining man's related activities, then deleniating the significant environmental occurrances, and eventually terminating with a feed-back to these original sector activities indicating others which may be affected by the original use. Thus, this procedure can indicate the consequences on future uses arising out of any present use of the bays and estuaries.

How does the entire process fit together, and how can it be used as a system to understand real problems? Possible applications are many and varied, with some of the more obvious including the following:

1. Assessing quickly what major problems are apt to occur as a result of any sector development,
2. By understanding the likely consequences of various Coastal Zone activities, designing environmental studies and comprehensive long-range data collection systems more efficiently,
3. Identifying the many associated social and economic considerations in order to be better able to design/ develop institutional arrangements and implementation policies for achieving balanced bay and estuarine management.

DEVELOPMENT OF ECOLOGICAL STUDY DESIGNS USING INTERACTION MATRICES

All of the information presented thus far has been purely qualitative; the next logical--and necessary--step is the quantification of these relationships. The qualitative interactions constitute an invaluable starting point for gathering the necessary quantitative information. In this section, an example problem will be posed and then the interaction matrices previously presented and discussed will be used to determine which topical areas need more study for proper management of the affected resource.

Statement of the problem:

In a particular estuary there is a potential aggregate supply in the form of a deposit of oyster shells overlain by a relatively thin layer of sand and silt. At the present time, this estuary has only seen limited development. Specifically, it has a few producing oil wells near its mouth, one moderate size metal processing plant near the river's mouth, and some limited recreational development. In the past it has been generally recognized as a "clean" estuarine area, and is known to be a rather important nursery/breeding area for fish, shrimp and certain birds.

We are charged with determining what scientific studies should be carried out in order to provide a sufficient information base for the future management of that area. Such an endeavor must produce guidelines for the establishment of those controls required to develop the aggregate resources and yet preserve the bay for other uses as well. In this first phase, we are limited to (a) determine what sub-units or factors are most important, (b) identify the linkages between these sub-units and factors apt to be affected, and (c) specify what studies are needed, in order to properly and adequately accomplish a and b.

The flow of the analytical procedure is as follows:*

1. Enter Figure III-3 with the sector where development is to occur and obtain the resultant man's activities.

2. Take these activities and enter Figure III-4 to get the likely environmental events, and

3. Finally enter Figure III-5 to determine what bay and estuarine uses might be impaired by the original sector development/expansion activity.

For our example problem, we enter Figure III-3 along row #3, surface mining. Continuing across the page, we find "●'s" in 7 columns, representing coastal construction (5), inland construction (6), land canals (7), dredging and spoil disposal (9), excavation (10), draining (13), and devegetation (15). This tells us that if we are to have the development of "surface mining under which shell dredging is classified, we might expect to have man engaging in one, several, or possibly even all seven of these activities.

The subjective decisions, depending heavily on the analyst's knowledge of the problem, to be made at each step are not so easy to spell out.

While, for any specific case one is not likely to engage in all seven, he is apt to carry on more than one of them. In order to set the entire process in perspective, we will introduce a new concept called a "decision-tree". This is a conceptually simple graphical analytical tool for illustrating a sequential decision process, where each decision presents a new array of possibilities, but excludes others.

Figure III-6 shows a decision tree for this example. One begins on the left-hand side in the box entitled "surface mining". It is then straightforward to follow this branch into 7 limbs, each corresponding to the 7 possible activities of man listed above. Five of these now terminate whereas the other two continue to branch out. The five that terminated were inland construction (6), land canals (7), excavation (10), draining (13), and devegetation (15). In making these terminations, the analyst must be problem-specific and use his own judgement. In this hypothetical case, neither of these possible activities were applicable because the mining operation is well out in the bay, thus none of the following activities would occur; devegetation*, draining, excavation, land canals, and inland construction.**

The next step in the analysis consists of determining what environmental events are likely to be triggered by each of the two applicable man's activities. Figure III-4 is used to determine this. One begins with the two applicable Coastal Zone activities (5 and 9) and scans the rows across each of these headings. This reveals that each of these activities can possibly produce many environmental events; in fact, collectively they trigger 20 of the 27 possible events as shown on Figure III-6. In some cases, both activities may cause the same event, but in others only one may do so.

Decisions again must be made based on the specific set of circumstances at hand. The list of events caused by each activity is carefully scrutinized using the best information available and the researcher's experience. Those environmental events that are judged to be significant are retained for consideration and the others are dropped. An investigation of the branching portions under the heading "Environmental Events" on Figure III-6 shows all possible events resulting from both coastal construction and dredings and spoil disposal. The ones considered insignificant terminate with an "x" while the others branch still further. Those that continue are suspended solids (10), deposition/accretion (14), photosynthesis (24), and consumers/food chain (25). It is important that the branches representing the two activities of coastal

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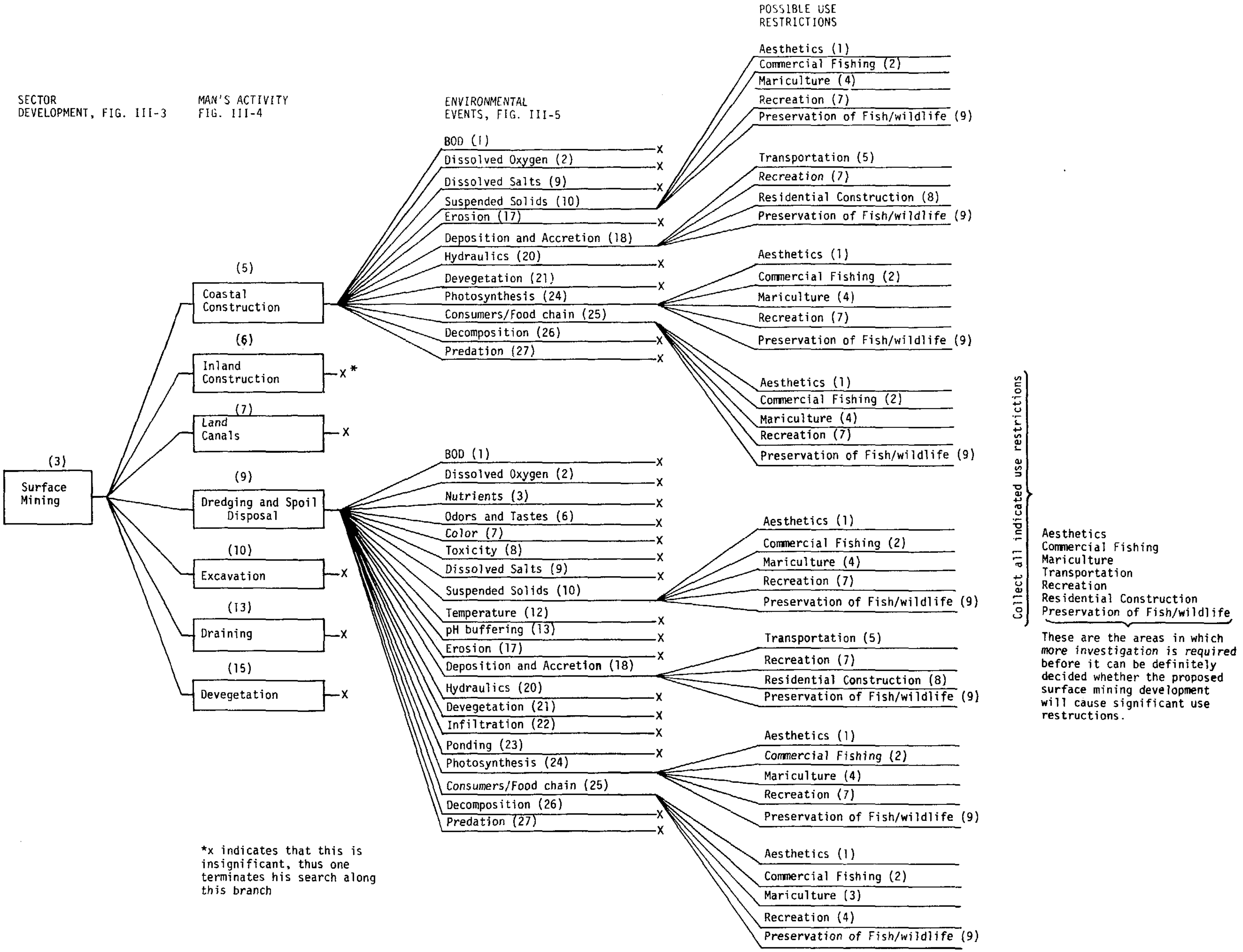
**As used here, devegetation means the destruction of rooted non-aquatic plants.*

***This is the only detailed explanation that will be given as to why a branch is not followed. Such side-discussions would only detract from the purpose of this explanation: namely, to present the analytical methodology.*



These are the areas in which more investigation is required before it can be definitely decided whether the proposed surface mining development will cause significant use restructions.

*x indicates that this is insignificant, thus one terminates his search along this branch

FIG III-6: DECISION TREE SHOWING APPLICATION OF INTERACTION MATRICES construction and dredging and spoil disposal are still kept separate. This is done because while both may generate suspended solids, they will do so in a different manner, thus possibly requiring two different approaches to quantify the load and its action mechanism.

The next step is the determination of what uses of the bays and estuaries may be impaired by these significant environmental events. This amounts to closing the feedback loop indicated in Figures III-1 and III-2. The relationships constituting this linkage are given by the matrix shown in Figure III-5. Figure III-6 shows the decision-tree branches for the same.

For our example, those potential impairments may include aesthetics (1), commercial fishing (2), mariculture (4), transportation (5), recreation (7), residential construction (8), and the preservation of fish and wildlife (9). Once these have been revealed, we can complete our "assignment" in this particular problem: the delineation of the necessary scientific investigations. By utilizing the information gained through this analysis, we can conclude that we should channel our limited energies in the following lines:

STEP 1: Man's Activities

1. Perform modeling experiments to gain a knowledge of the hydrodynamic behavior of the estuary under various conditions.

2. Conduct field experiments to determine *in-situ* patterns of sediment distribution under typical conditions.

3. Hueristically, couple the two in order to obtain the best available picture of the most likely sediment distribution patterns

STEP 2: Environmental Events

1. Analysis should include special provisions for determining the impact of the altered transport processes upon the natural phenomena of deposition and accretion.

2. The potential sediments should be carefully analyzed in order to determine their potential nutrient contribution to the estuarine system.

3. The impact on photosynthesis and decomposition from nutrient release, sedimentation, turbidity, etc. should be closely scrutinized.

STEP 3: Potential Uses Impaired

1. Fish and wildlife maintenance may be significantly affected; thus, studies should be done to determine things such as (a) how much nursery areas will be adversely affected by sedimentation process, (b) will the turbidity severely upset aquatic communities, and, if so, over how big an area, and (c) what, of any, significant effects will nutrient release/alterations in the photosynthetic process have?

2. Trace the impact of the disturbances determined in the immediately preceeding analysis in order to describe their effects on commercial and sports fishing.

3. Determine if the repercussions of the aggregate mining will be spatially widespread and severe enough to injure the bay's aesthetic amenities and recreational activities.

4. Compare the predicted sediment distribution patterns with existing navigation facilities and determine if such deposition will interfere with those arteries.

The above type of analysis will provide one with qualitative insights into the system functioning. Such knowledge should enable him to channel his efforts along the most crucial/significant routes possible in the next step, that of quantifying the interactions and effects.

The above example is an oversimplification of reality; however, it should provide insight into how the qualitative relationships identified by the interdisciplinary team can be applied. Other examples have been explored; unfortunately space and time constraints preclude their inclusion here.

CLOSURE

This chapter has presented a basic methodology for identifying mans' activities and qualitatively determining their subsequent impact, both on the environment and ultimately on man's own activities. Qualitative inter-action matrices were developed and demonstrated for a hypothetical problem formulated for a specific situation.

The next chapter will present the first step necessary for a systematic and interdisciplinary approach to the problem--an evaluation of the environmental units within the Coastal Zone in terms of their physical properties which limit or restrict some of man's activities. The reader is strongly encouraged to develop a general understanding of the analytical approach presented in this chapter; then, as he moves through the following material to consider that information within the context of the analytical framework presented here.

REFERENCES

Isard, et al. 1968. On the Linkage of Socio-Economic and Ecologic Systems. Papers of Regional Science Association. Vol. 21, p. 79.

National Estuary Study. 1970. Some Economic Factors Affecting the Estuarine Zone Including Market Outlooks for Selected Products. Vol. 5, Appendix E.

CHAPTER IV

COASTAL WATER BODIES AND LANDS: USE CAPABILITIES AND LIMITATIONS

The establishment of guidelines for proper land and water use along the 400-mile Texas coastline depends to a great degree on the recognition and delineation of proper land and water use units, their limiting characteristics and properties, and an understanding of the effects that various use practices will have on the environmental quality of these fundamental coastal units. This chapter discusses the following:

- Nature of the land and water use capability units,
- Basic factors or properties exhibited by the units that limit or restrict their capability or use,
- Land and water use practices common to the coastal zone in relation to these basic factors or properties, and
- Evaluation of 34 land-capability units defined in terms of restraining or limiting land and water use practices.

Table IV-1 shows the resource capability units of the Texas Gulf Coast. Table IV-2 lists the major activities in the Coastal Zone. Figure IV-1 illustrates the general geologic nature and setting of the typical coastal land use capability units.

NATURE OF WATER AND LAND CAPABILITY UNITS

The land and water use capability classification introduced in this chapter is based on approximately 130 environmental geologic units defined and mapped by geologists of the Bureau of Economic Geology during preparation of the "Environmental Geologic Atlas of the Texas Gulf Coast." * Environmental geologic units of the

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Appendix E contains a listing of the major publications from which much of the data were extracted.

Bays, lagoons, and estuaries

1. River-influenced bay
2. Enclosed bay
3. Oyster reefs and adjacent reef flank and inter-reef areas (living)
4. Oyster and serpulid reefs and adjacent reef flank and inter-reef areas (dead)
5. Grassflats
6. Mobile bay-margin sands
7. Tidally influenced open bay
8. Subaqueous spoil
9. Tidal inlet and tidal delta
10. Wind-tidal flats

II. *Coastal plains*

1. Highly permeable sands
2. Moderately permeable sands
3. Impermeable muds
4. Broad, shallow depressions
5. Highly forested upland areas
6. Steep lands
7. Stabilized (vegetated) dunes and sand flats
8. Unstabilized (unvegetated) dunes
9. Fresh-water lakes, ponds, sloughs, playas
10. Mainland beaches
11. Areas of active faulting and subsidence

III. *Major floodplain systems*

1. Point-bar sands
2. Overbank muds and silts
3. Water (including related lakes and sloughs)

IV. *Coastal wetlands*
Salt marshes, fresh-water marshes, swamps

V. *Made land and spoil*

VI. *Coastal barriers*

1. Beach and shoreface
2. Fore-island dunes and vegetated barrier flats
3. Washover areas
4. Active dunes (back-island dune fields and blowouts)
5. Tidal flats
6. Swales

TABLE IV-1

Resource Capability Units,
Texas Coastal Zone

---

1. Liquid waste disposal
2. Solid waste disposal
3. Gaseous wastes
4. Offshore construction
5. Coastline construction
6. Inland construction
7. Land canals
8. Offshore channels
9. Dredging
10. Excavation (land)
11. Drainage
12. Filling (development)
13. Draining
14. Well development
15. Devegetation
16. Traversing with vehicles
17. Use of herbicides, pesticides, and insecticides

TABLE IV-2

Major Activities, Texas Coastal Zone

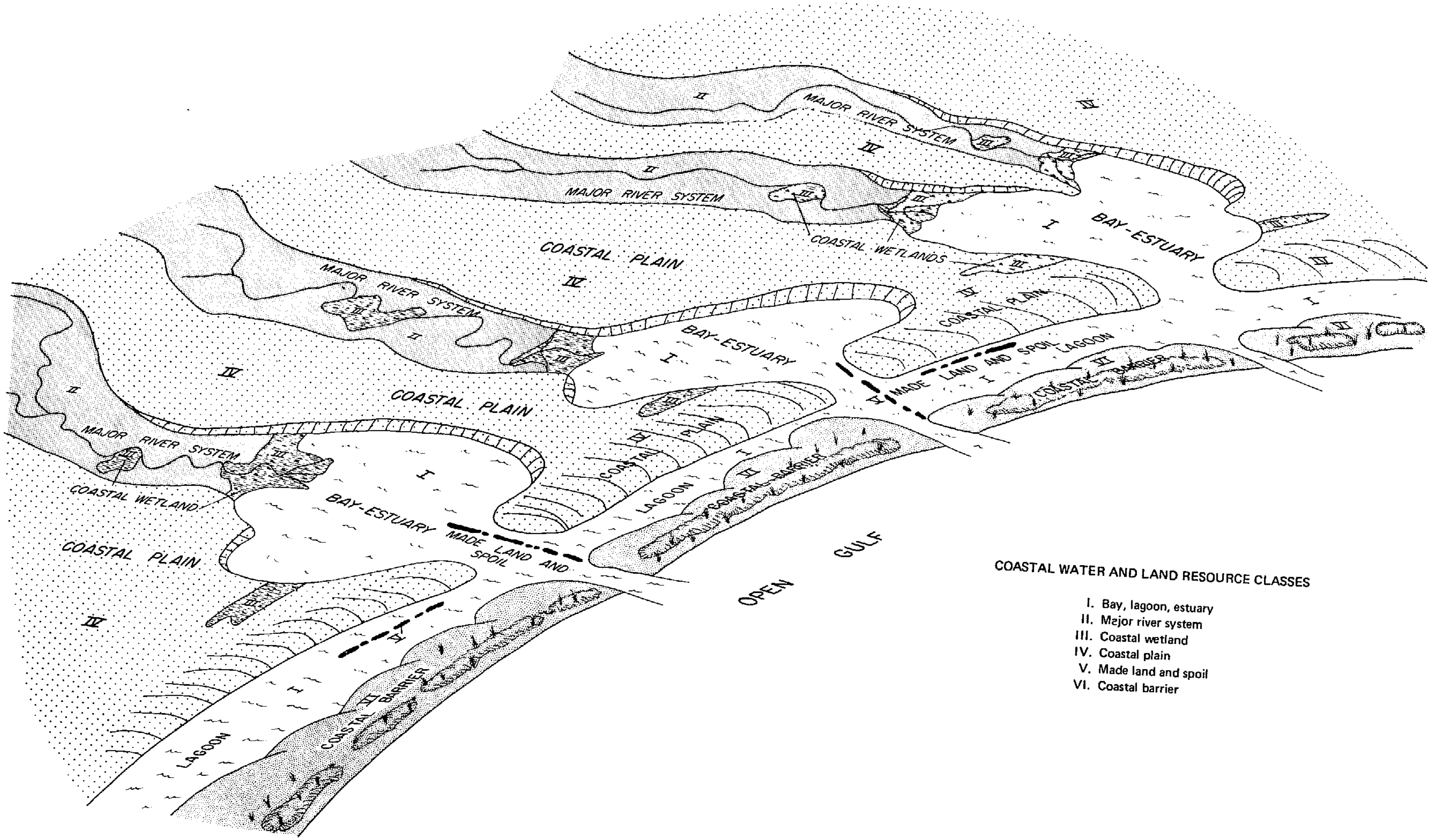

MAJOR RIVER SYSTEM
II
IV
MAJOR RIVER SYSTEM
III
COASTAL WETLANDS
BAY-ESTUARY
I
COASTAL PLAIN
IV
MAJOR RIVER SYSTEM
BAY-ESTUARY
COASTAL PLAIN
MADE LAND AND SPOIL
LAGOON
COASTAL BARRIER
VI
V
COASTAL PLAIN
MAJOR RIVER SYSTEM
COASTAL WETLAND
BAY-ESTUARY
MADE LAND AND SPOIL
LAGOON
COASTAL BARRIER
COASTAL PLAIN
OPEN GULF
LAGOON
COASTAL BARRIER
COASTAL WATER AND LAND RESOURCE CLASSES
I. Bay, lagoon, estuary
II. Major river system
III. Coastal wetland
IV. Coastal plain
V. Made land and spoil
VI. Coastal barrier

FIG: IV-1

coastal zone are units which are of first-order importance in the environmental framework of the region. Land units were selected to include the following:

- Sediment substrate such as shell, sand, and mud where the physical properties of these materials are of primary importance;
- Process-defined units such as storm-washover channels, tidal passes, beaches, and surf zones, where active physical processes are dominant environmental factors;
- Biologic factors such as plant community types and animal populations; and
- Man-made units such as spoil heaps, spoil wash, dredged channels, and made land, where man's activity has resulted in important environmental modification.

The bay-lagoon systems constitute very dynamic and diverse environments. Based upon this fact, a set of closely interrelated variables were adopted which help in categorizing natural units within the aqueous ecosystem. Each major Texas bay-lagoon-estuary complex was considered in the light of distribution of sediment types, overall salinity patterns, circulation, tidal influence, depth variations, turbidity, fresh-water influx, and distribution of biologic communities (particularly benthonic communities). In addition, other broad factors such as climatic conditions (including frequency of hurricane activity), water chemistry (pH, Eh, BOD, DO, nutrients supplied, etc.), types of sediments surrounding the bays-lagoons-estuaries, and extent of human activities and modifications in and around these areas were considered as over-riding influences on the total structure.

The 130 or so environmental geologic units have been grouped into 34 land and water use capability units based on those factors which limit their use. These 34 units define six major coastal capability classes:*

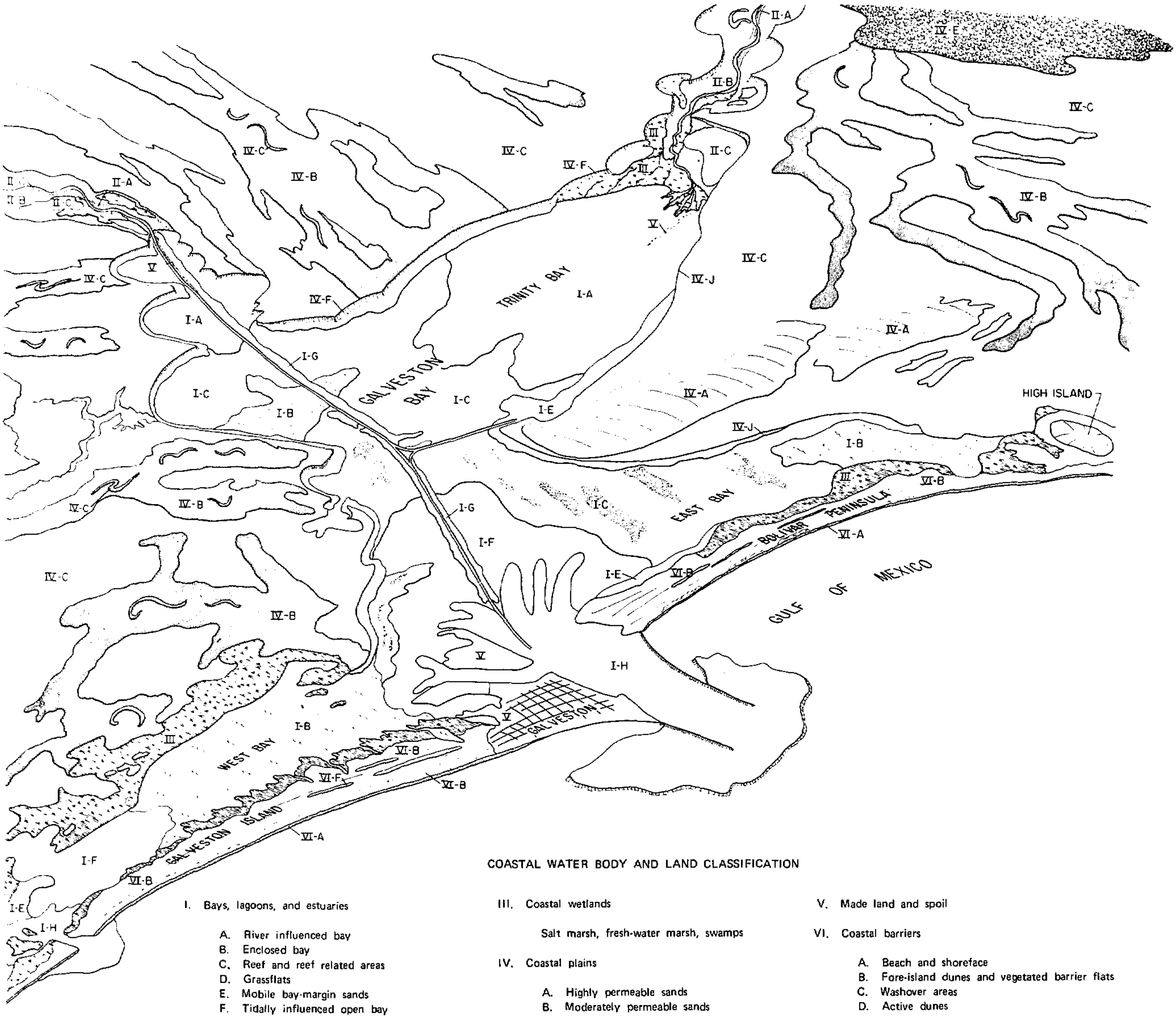
I. Bays, lagoons, and estuaries,

II. Coastal plains

III. Major Floodplain systems

IV. Coastal Wetlands

**These six classifications correspond to those presented in Table IV-2 and graphically portrayed in Figures IV-1 through IV-4.*



COASTAL WATER BODY AND LAND CLASSIFICATION

I. Bays, lagoons, and estuaries
- A. River influenced bay
- B. Enclosed bay
- C. Reef and reef related areas
- D. Grassflats
- E. Mobile bay-margin sands
- F. Tidally influenced open bay
- G. Subaqueous spoil
- H. Tidal inlet and tidal delta
- I. Wind-tidal flats

II. Major river systems
- A. Point-bar sands
- B. Overbank muds and silts
- C. Water (including related lakes and sloughs)

III. Coastal wetlands

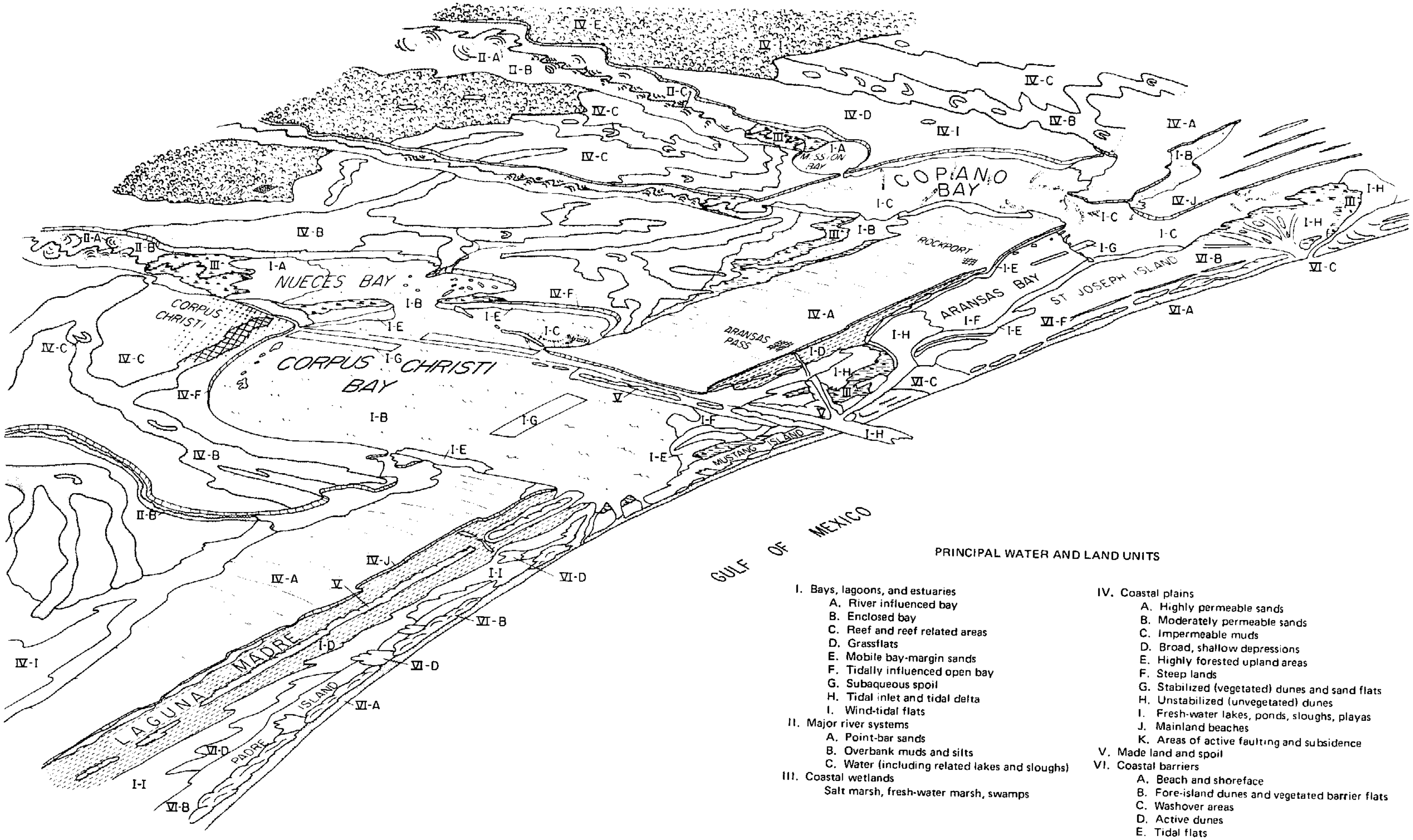
Salt marsh, fresh-water marsh, swamps

IV. Coastal plains
- A. Highly permeable sands
- B. Moderately permeable sands
- C. Impermeable muds
- D. Broad, shallow depressions
- E. Highly forested upland areas
- F. Steep lands
- G. Stabilized (vegetated) dunes and sand flats
- H. Unstabilized (unvegetated) dunes
- I. Fresh-water lakes, ponds, sloughs, playas
- J. Mainland beaches
- K. Areas of active faulting and subsidence

V. Made land and spoil

VI. Coastal barriers
- A. Beach and shoreface
- B. Fore-island dunes and vegetated barrier flats
- C. Washover areas
- D. Active dunes
- E. Tidal flats
- F. Swales

FIG: IV-2



PRINCIPAL WATER AND LAND UNITS

- I. Bays, lagoons, and estuaries
  - A. River influenced bay
  - B. Enclosed bay
  - C. Reef and reef related areas
  - D. Grassflats
  - E. Mobile bay-margin sands
  - F. Tidally influenced open bay
  - G. Subaqueous spoil
  - H. Tidal inlet and tidal delta
  - I. Wind-tidal flats
- II. Major river systems
  - A. Point-bar sands
  - B. Overbank muds and silts
  - C. Water (including related lakes and sloughs)
- III. Coastal wetlands
  - Salt marsh, fresh-water marsh, swamps
- IV. Coastal plains
  - A. Highly permeable sands
  - B. Moderately permeable sands
  - C. Impermeable muds
  - D. Broad, shallow depressions
  - E. Highly forested upland areas
  - F. Steep lands
  - G. Stabilized (vegetated) dunes and sand flats
  - H. Unstabilized (unvegetated) dunes
  - I. Fresh-water lakes, ponds, sloughs, playas
  - J. Mainland beaches
  - K. Areas of active faulting and subsidence
- V. Made land and spoil
- VI. Coastal barriers
  - A. Beach and shoreface
  - B. Fore-island dunes and vegetated barrier flats
  - C. Washover areas
  - D. Active dunes
  - E. Tidal flats
  - F. Swales

FIG: IV-3

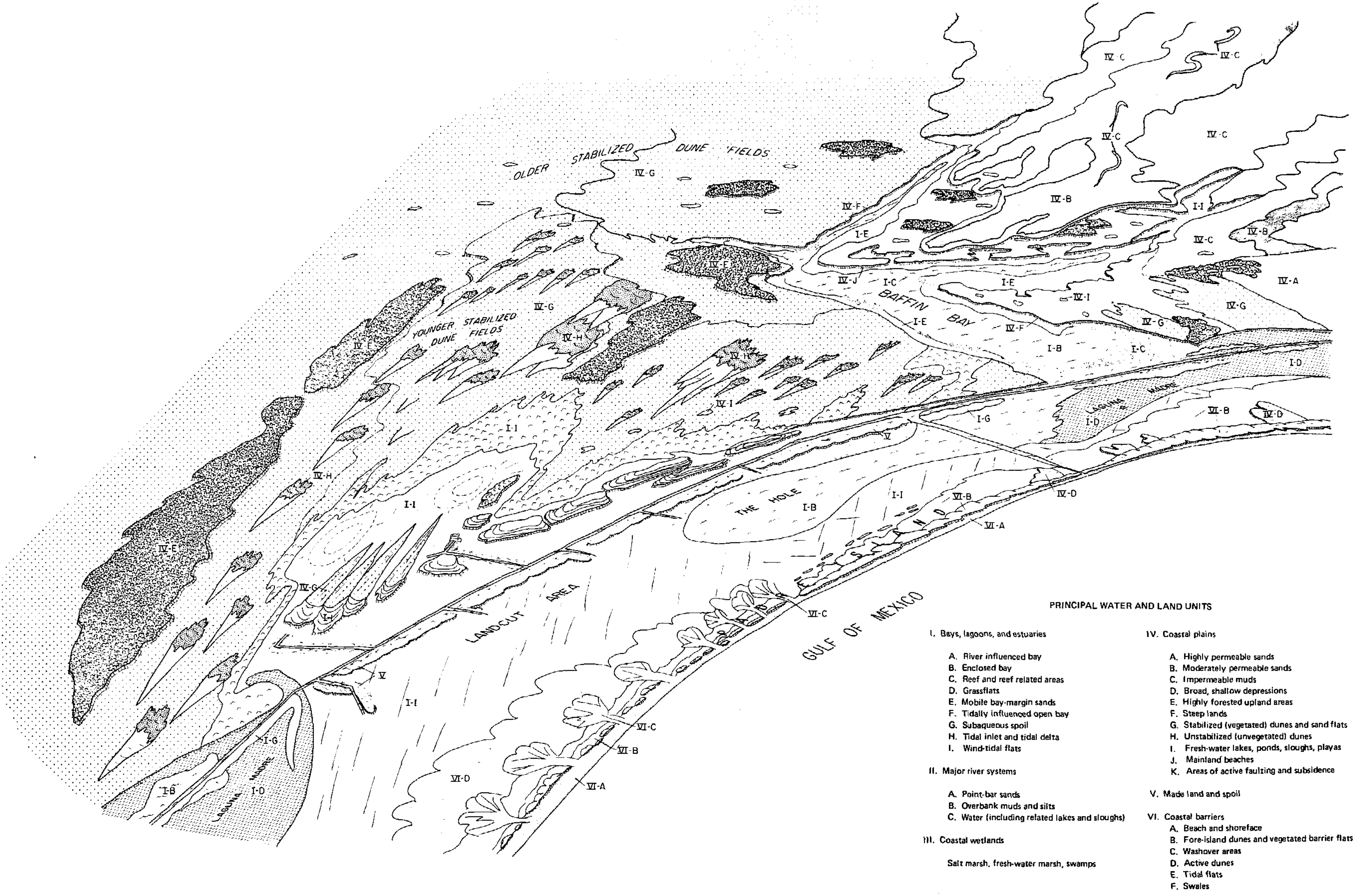

OLDER STABILIZED DUNE FIELDS
YOUNGER STABILIZED DUNE FIELDS
BAFFIN BAY
LAGUNA MADRE
THE HOLE
LANDCUT AREA
GULF OF MEXICO
IV-C
IV-B
IV-A
IV-G
IV-F
IV-J
IV-E
IV-H
IV-I
IV-D
I-E
I-C
I-B
I-D
I-G
I-I
VI-A
VI-B
VI-C
VI-D
V
PRINCIPAL WATER AND LAND UNITS
I. Bays, lagoons, and estuaries
A. River influenced bay
B. Enclosed bay
C. Reef and reef related areas
D. Grassflats
E. Mobile bay-margin sands
F. Tidally influenced open bay
G. Subaqueous spoil
H. Tidal inlet and tidal delta
I. Wind-tidal flats
II. Major river systems
A. Point-bar sands
B. Overbank muds and silts
C. Water (including related lakes and sloughs)
III. Coastal wetlands
Salt marsh, fresh-water marsh, swamps
IV. Coastal plains
A. Highly permeable sands
B. Moderately permeable sands
C. Impermeable muds
D. Broad, shallow depressions
E. Highly forested upland areas
F. Steep lands
G. Stabilized (vegetated) dunes and sand flats
H. Unstabilized (unvegetated) dunes
I. Fresh-water lakes, ponds, sloughs, playas
J. Mainland beaches
K. Areas of active faulting and subsidence
V. Made land and spoil
VI. Coastal barriers
A. Beach and shoreface
B. Fore-island dunes and vegetated barrier flats
C. Washover areas
D. Active dunes
E. Tidal flats
F. Swales

FIG: IV-4

V. Made land and spoil

VI. Coastal Barriers

SPECTRUM OF WATER AND LAND PRACTICES

Possible land use practices along the Coastal Zone are essentially unlimited, but certain practices, exploitation, and modification dominate within the zone. Each of these uses of the land and water has been considered interms of the factors which control or limit land-water use on the 34 fundamental capability units. These human activities are also self-explanatory. Seventeen principal coastal activities considered in the report include the following specific uses: disposal of solid waste material; disposal of liquid waste material (shallow subsurface); disposal of liquid waste materials in surface pits or holding ponds; disposal of spoil; disposal of gaseous wastes; of offshore platforms, placement of buried pipelines and cables; construction of buildings; construction of jetties, groins, piers, and seawalls; highway construction; construction of industrial complexes; excavation including surficial extraction of economic materials; filling of many types of depressed areas and wetlands; devegetation including physical destruction, burning, and overgrazing; drainage of various wetlands, damming of river systems; flooding through dam construction; surficial and shallow subsurface effects of drilling wells; irrigation; development of feed lots; crop cultivation and drainage problems; traversing areas in dune buggies, airboats, and motorcycles, and application of pesticides, insecticides and herbicides.

FACTORS AFFECTING WATER AND LAND CAPABILITY

More than a dozen primary factors determine the capability of a coastal land unit, including factors which may severely restrict the land for certain practices. The factors are essentially self-explanatory. They include potential for hurricane-surge flooding; potential for fresh-water flooding, both overbanking from streams and ponding on the flat coastal plains, capacity for shrink-swell conditions in certain muds; tendency for co-rosion of pipes and conduits placed in certain substrates; high permeability which allows transmission of pollutants into ground-water aquifers and nearby surface-water bodies; steep slopes which are susceptible to gravity failure and extreme erosion from runoff; extremely flat lands which are poorly drained and which pond water following excessive rainfall; impermeability which exaggerates ponding and drainage problems; persistent winds in arid areas which result in wind erosion and migration of sediment in the form of dunes; tidal flooding of broad, low-lying flats by wind driven water from bays, lagoons, and estuaries, vegetation on coastal sand bodies which maintains the stability of the sand in the high wind and water energy environments; wave energy dissipated along shorelines with resulting erosion and redistribution of sediment; active faulting aggravated by ground water withdrawal; inherent erosional susceptibility of various sediment types to wind, water, and wave erosion; and biologic assemblages as they relate to productivity and thus to environmental and economic considerations. Each land-water capability unit has been evaluated in terms of these capability factors.

UNDESIRABLE USES

The term "undesirable use" as employed in this chapter is qualitative and subjective. It is used simply to call attention to certain activities, as they relate to certain water and land capability units, that may create environmental imbalance. With proper engineering design, the effects of an undesirable use may be negated.

BAYS, LAGOONS, AND ESTUARIES

Bays, lagoons, and estuaries are water masses which occupy ancient river valleys and elongate areas between barrier islands and the mainland, and are inseparably part of a more complex coastal system including sediment substrate, marginal sources of sediment and fresh water, subaqueous vegetation, benthonic, nektonic, and planktonic organisms, tide and wind generated currents and waves, dissolved salts, and suspended colloidal sediment particles. Proper management of the system depends upon a balanced approach which considers all facets of the system as well as its relationship to the terrestrial systems in adjacent areas. Bays and estuaries occupy a position that is physically, biologically, and chemically transitional between the open marine environment and the fluvial system. Shifting and sometimes subtle interfaces exist within the shallow water bodies; rapid and potentially irreversible changes can occur within the delicately balanced system. Geologically, bays and estuaries are evolving, transient environments which display slow but natural change; biologically these areas and adjacent marshes are highly productive, delicately balanced ecosystems; and chemically the water mass is susceptible to external modification resulting from man's activities on the land and in shallow waters. The bay and estuarine system is highly complex, displaying numerous, interdependent subsystems, all of which are capable of reacting either positively or negatively to induced changes. The system naturally evolves but man can significantly alter the natural processes resulting in economic, esthetic and cultural benefits or losses.

Most species of commercial and sport fish are estuarine dependent at some stage of their life history, but are not restricted to the estuary throughout life. Many of the commercially valuable species of the Gulf of Mexico such as the croaker *(Micropogon)*, spot *(Leistomus)*, menhaden *(Brevoortia)* and mullet *(Mugil)* exhibit a rhythmic, seasonally correlated inshore-offshore migratory pattern. Adults move out of the estuaries in late summer and early winter and spawn in the Gulf. Postlarval and juvenile species appear in the upper reaches of the estuaries in early spring. As they grow, they tend to move toward the middle and lower estuarine reaches. The migration tends to be from lower to higher salinities and toward more favorable temperature regimes, but there is no conclusive evidence to support the theory that temperature-salinity characteristics are the only causative factors. Subordinating or entirely overlooking the other physical, chemical and biological factors presents at best a very limited knowledge of why estuarine dependent organisms migrate as they do.

The complexity of the bay and estuary system is not always appreciated, primarily because the precise nature of the estuarine environment is poorly understood. Despite absence of extensive biologic, geologic, and chemical data and understanding, general relationships between certain human activities and observed impacts on the natural system have been formulated. Cause and apparent effect relationships must be investigated, and eventually adequate steps must be taken to prevent permanent environmental damage. In the meantime, empirical, pragmatic caution is warranted in order to preserve the system.

Numerous attempts have been made to formulate definitions of the estuaries, but considerable disagreement exists. Most contemporary definitions appear to reflect the disciplinary specialty of each authority. Some estuaries are defined as ecological units only, without regard to geological and physical characteristics. Others define estuaries within the physical oceanographic context only. Legal definitions are equally inconclusive. For example, the Estuarine Areas Bill (H.R. 25, 90th U. S. Congress) provides a legal definition that, by even conservative judicial interpretation, would include the entire coastline of the United States.

River Influenced Bay

Definition - These are low salinity areas (less than 10‰) at the heads of bays where rivers discharge fresh water and nutrients. Bottom sediments adjoining river mouths are primarily laminated prodelta muds and sandy muds with mottled mud distal of the prodelta. These areas generally grade into open bay and display a low species diversity. Common clams include *Rangia, Palymesoda,* and *Macoma.* The snail *Littoridina* is common in some localities. Crustaceans include *Callinectes* and *Marcobrachium.* Ostracods are abundant on the soft, muddy, organic rich bottoms. Foraminifers are not abundant in this zone, but a few including *Candona, Darwinula,* and *Physocypria* are characteristic of the prodelta subfacies in some bays. The brown shrimp *(Penaeus aztecus)* and white shrimp *(P. setiferus)* use these areas (along with the associated marsh) for development through the juvenile stages. Destruction of these upper bay shallows or significant changes in the quality of the fresh water discharge, particularly changes in temperature or the introduction of toxins, could promote extinction of valuable commercial and recreational species.

Depths in these upper bay areas range from 3 to 7 feet. Turbid waters entering these areas from the associated rivers cause a decrease in light penetration and thus a lower level of photosynthetic activity. These fresh waters are usually high in humic acids from upstream runoff. Turbidity, low salinity, and low pH values from humic acids preclude significant growth of oysters and other sessile benthonic shellfish. On the other hand, these conditions are favorable for young shrimp which feed largely on fine organic ditritus flushed in from the rivers.

Limiting use factors - Submergence precludes most uses except after highly undesirable filling. The value of these areas (along with associated marsh) as nursing grounds for about 85% of the commercially valuable species should not be ignored.

Undesirable uses - Undesirable uses include any activities such as filling, disposal of solid and/or liquid wastes, and restriction of circulation by construction of hurricane barriers, which tend to make the area unusable by or inaccessible to postlarval and juvenile shrimp, crabs, fish, and other organisms.

Enclosed Bay

Definition - These are bay areas (3 to 8 feet in depth) away from tidal or river influence which display generally poor circulation, an abundance of fine sediment, low species diversity, and large numbers of individual organisms. Benthonic organisms are mainly infaunal deposit feeders which burrow through and churn the sediments to produce mottled, organic-rich muds. Some bay areas (i.e., Baffin Bay), however, display a very low species diversity and a small number of individual organisms due in part to hypersaline conditions. In these areas, the fine bottom sediments have not been bioturbated and thin (1-4 mm) undisturbed laminae remain intact.

Since enclosed bay areas are characterized by poor circulation, high or low salinity extremes are often reached. Areas of poor circulation near heads of bays sometimes display brackish water conditions (less than 35‰). Restricted bays, such as Baffin Bay, along the arid South Texas coast, however, are hypersaline much of the year due to the high evaporation rate, low rainfall, and the resultant concentration of dissolved solids in the remaining water. Poor circulation causes deficiency in dissolved oxygen content in many enclosed bay areas with consequent reducing conditions near the sediment-water interface. High salinities and concentration of organic acids (due to reducing conditions) contribute to the low pH of these areas.

Common living species include the clams *Mulinia* and *Nuculana*. Hypersaline enclosed bays and lagoons (i.e., Baffin Bay and parts of Laguna Madre) are thickly populated by the clams *Anomalocardia, Mulinia,* and *Tellina*. The snail *Cerithium* is also common in these areas.

Limiting use factors - Placement of structures is hampered by the unstable ooze which floors these areas. Poor circulation makes these areas highly unsuitable for waste disposal, since pollutants tend to pond and saturate bottom sediments. Restricted bays are poorly flushed by tidal or flood action resulting in low water exchange with the open Gulf.

Undesirable uses - Undesirable uses would include (a) placement of structures without pilings or other stabilizing foundations, and (b) any disposal of solid and/or liquid waste materials in excessive quantities.

Reef and Reef Related Areas - Living

Definition - These submerged mounds, elongate ridges and adjacent flanking areas (up to several miles in length) of the colonial oyster *Crassostrea virginica* and associated reef organisms occur in varying concentration in all major bays with the exception of Laguna Madre and Baffin Bay. Reefs are ridged structures which locally baffle or restrict circulation and commonly exhibit orientation perpendicular to prevailing currents. Reef crests may grow to the water surface and may be exposed during low tide. Oyster reefs and associated areas serve as valuable feeding grounds for many varieties of commercial and game fish and crabs. These are productive environments economically and constitute one of the major resource areas of the bay ecosystem.

The bulk of a reef is composed of the shells of dead oysters and other organisms, but epifaunal, nektonic, and some vagrant benthonic organisms inhabit the living reef surface. Along with the oysters are many associated molluscs including *Anomia, Anachis, Mitrella;* several epizoans including barnacles *(Balanus)* and *Brachidontes;* and several varieties of coral and bryozoans. Normal oyster reef salinities range from 10 to 30% with water depths of up to 8 feet. Oysters can live and grow in normal marine salinities of 30 to 35‰, but under these conditions several oyster predators, including the oyster drills *Thais* and *Urosalpinx,* also flourish. High salinity oyster reefs contain *Ostrea equestris*. Associated reef areas include the following:

·Reef flank areas are composed of shell debris dislodged during storms, along with lesser numbers of living oysters. Some sand and mud may be mixed with shell debris during hurricanes. Epizoans are fewer in this less favorable environment, and scavengers subsist on organic debris derived from the adjacent reef.

·Inter-reef areas are relatively flat, subaqueous plains (at about 6 feet in depth) within a reef complex where some individual clumps or small oyster colonies occur, growing upward from a sandy or muddy shell substrate. New reefs originate where these colonies flourish, and they grow to become shoal areas. Significant vertical growth is principally controlled by the ability of the bottom strata to support the growing reef mass. Compaction and subsidence of sediment may eventually be stabilized and provide the foundation for a new reef. Vagrant and infaunal (burrowing) benthonic organisms predominate within the inter-reef areas.

Limiting use factors - Submergence precludes most uses. The high productive capability of these areas should limit any destructive uses.

Undesirable uses - Any activity which disrupts the natural ecology of live oyster reefs (such as dredging, dumping of spoil, discharge of waste, restriction of bay circulation patterns, and construction in reef areas) is undesirable and should be avoided in a balanced bay-estuary management program.

Reef and Reef-Related Areas - Dead

Definition - These dormant reefs may be expressed as submerged mounds and elongate ridges or they may be buried at shallow depths beneath the sediment-water interface. They are composed principally of *Crassostrea virginica* shells, but Baffin Bay reefs are exclusively serpulid (Annelida) mounds up to 130 feet long. Serpulid reefs in Baffin Bay are now dead, possibly the result of a recent increase in salinity in this restricted bay. Serpulid reefs, like oyster reefs, are composed of calcium carbonate secreted by the organism. Other invertebrates and some vertebrate organisms, inhabit abandoned reefs and compose an ecologic assemblage adapted to this protective reef structure. These reef masses are slowly disintegrated by storm waves, and slowly overlapped by reef flank and inter-reef sediment, especially in areas where poorly compacted substrate allows continued subsidence. The assemblage of organisms inhabiting reef-flank areas between dormant reefs slowly changes as the character of the reef is modified. Dead reef areas may shoal during low water and are often navigational hazards.

Limiting use factors - Submergence precludes most uses of this unit. Activities such as dredging of shell should be limited by the fact that circulation patterns can be drastically altered, turbidity can be increased, and biotic communities (both proximal and distal) can be irreparably damaged. Reefs may also provide a baffle to hurricane surge.

Undesirable uses - Undesirable uses include removal of shell material, which severely alters water circulation patterns and increases turbidity, thus potentially changing the estuarine environment. Navigation through these areas is limited especially during low water periods. Removal ofthe baffling effects of reefs may also increase the impact of hurricane surge in upper bay-estuary areas.

Grassflats

Definition - These are shallow subaqueous flats (1 to 5 feet in depth) principally along the margins of bays and lagoons, although grassflats extend across the entire shallow northern Laguna Madre bottom. Next to marshes, marine grassflats produce more in terms of species diversity and standing crop than any other estuarine zone. Practically all motile estuarine and most sessile forms can be found at or near the grassflats. At one time or another literally hundreds of vertebrate and invertebrate species use the grassflats as a home, or as a retreat, where they can rest, eat, and escape predators.

Grassflats are composed of moderate to dense growth of *Ruppia, Thalassia,* and *Diplanthera* marine grasses. A calcareous green alga, *Acetabularia,* is common in these areas. Temperatures may vary considerably but the dense grass aids in maintenance of satisfactory ranges for many organisms. Such areas have salinities ranging from 20 to 35‰ and are characterized by a diverse mollusk assemblage, including the grazing and carnivorous snails *Cerithium, Cerithidea, Modulus, Vermicularia,* and *Melampus.* Common clams include *Atrina, Tagelus, Laevicardium, Cytropleura, Tellina,* and *Amygdalum.* Grassflats are feeding grounds for numerous aquatic animals including many commercial and game fish, such as menhaden *(Brevoortia),* croaker *(Micropogon),* spot *(Leiostomus),* mullet *(Mugil),* and trout *(Cynoscion).* Valuable crustaceans include postlarval and juvenile white shrimp *(Penaeus setiferous),* brown shrimp *(P. aztecus),* and pink shrimp *(P. duararom).* The blue crab *(Callinectes),* spends a major part of its life history feeding on organic detritus available in the marine grassflat.

Grassflats are physically "low energy" environments where currents are baffled and the sand and muddy sand substrate is stabilized by rooted vegetation. Spotted concentrations of shell debris in these zones are due partly to the shell cracking feeding habits of the Black Drum *(Pogonias cromis)* and other bottom feeding fishes. Grassflats are extensive from Copano Bay south to Mexico and constitute a most important, highly productive ecological unit.

Limiting use factors - Submergence precludes any land use except after highly undesirable filling with spoil. The high biologic productivity of these areas should be a principal limiting factor.

Undesirable uses - Destruction of natural biologic communities through dredging, dumping of spoil, and dumping of solid and liquid wastes is very undesirable. Grassflat areas are indispensable to the natural bay and estuarine ecosystem and should be maintained.

Mobile Bay-Margin Sands

Definition - These shallow bay-margin areas (depth to 6 feet) of high current activity and rapid sand transport are sites of significant deposition. The sand supply is predomintly from eroded flood tidal deltas, storm washover fans, and older eroded coastal plain sediments incised by bay waves. These marginal areas support locally sparse marine grasses *(Thalassia, Diplanthera)* and display variable temperatures and salinities. The rather diverse pelecypod fauna includes *Aequipecten, Trachycardium, Mercenaria, Chione, Curtopleura, Tagelus,* and *Ensis*. The two clams, *Mulinia* and *Anomalocardia,* inhabit these shallow sandy areas in Baffin Bay. Many carnivorous and grazing snails, such as *Thais* and *Busycon,* are also present. Crustaceans including isopods, ostracodes, *(Cytherura, Paradoxostoma, Perissocytheridea),* mud shrimp *(Callianassa),* and a variety of crabs, including *Callinectes,* inhabit these shoal areas. Fish such as Black Drum *(Pogonias cromis)* feed here on molluscs. Species diversity increases near tidal inlets where there is greater mixing of bay waters with the more normal marine waters of the Gulf.

Great seasonal variation exists in the composition of these shallow, bay-margin assemblages. There is marked migration of many of the epifaunal and mobile invertebrates into deeper water during periods of extreme high or low temperatures and/or salinities.

Included within this unit are sand *spits*, which are elongate depositional features developed locally on the back sides of barrier islands and on mainland shores. Here currents are controlled by local bathymetry and shoreline configuration. Spits are areas of very rapid shoreline accretion.

Limiting use factors - Limiting factors include (a) strong current activity and (b) rapid sand transport and deposition, and (c) high wave energy during storms.

Undesirable uses - Undesirable uses include restriction of natural sand movement by construction of jetties, groins, piers, and offshore platforms, which tends to cause local erosion and restriction of sand nourishment to other environments along the bay-estuarine shoreline.

Tidally Influenced Open Bay

Definition - These areas (6 to 12 feet in depth) encompass the lower ends of bays where tidal influence is great and salinities range from 20 to 35‰. They display good circulation, and the substrates generally are mottled mud. Species diversity is relatively high. The number of species increases and the number of individuals of each species decreases as the salinity increases. In some bays a few species of Foraminifera make up large percentages of the bottom sediment. Benthonic filter feeders and burrowers (deposit and filter feeders) are important organisms in this estuarine area, and bottom sediments are strongly bioturbated. Common infaunal deposit feeders include the clams *Nuculana, Mulinia,* and *Abra. Nassarius, Polinices,* and *Retusa* are probably the most abundant snails in open bays.

Limiting use factors - This is an area of fairly thick soft mud accumulation which gives poor support to structures. Structures (platforms) placed here would need pilings or thick shell pads, and they would tend to restrict circulation in these physically dynamic areas. Normal salinity (35‰) sea water circulates through this environment to reach other estuarine areas. The placement of structures that would seriously alter the thermohaline structure, or impair the transport processes, would seriously affect the estuarine environment.

Undesirable uses - Undesirable uses include placement of platforms or other structures (hurricane barriers) without special preparation.

Subaqueous Spoil Areas

Definition - These are areas of man-made, mixed substrate along dredged channels and near dredged oyster shell areas. Sediments are commonly poorly sorted sand, silt, shell, and some mud, with a biologic assemblage depending upon age and position of the spoil within the bay. Shallow subaqueous spoil areas and subaerial spoil mounds and ridges along dredged channels tend to compartmentalize bays and estuaries by restricting natural circulation patterns. This causes many of the natural bay-estuary environments to become locally enclosed, restricted basins with low pH and high anaerobiosis and with consequent lowering of their productivities. Spoil areas supply vast amounts of sediment to the bay-estuarine sediment disposal system and expose poorly consolidated sediment to the effects of storm waves. Suspension of winnowed fine sediments result in turbid conditions, locally effecting photosynthesis and dissolved oxygen content.

Limiting use factors - Further disturbance of these areas only adds to turbidity and increases compartmentalization and restriction of natural estuarine systems.

Undesirable uses - Undesirable uses would include further dredging and any other activity, such as disposal of waste materials, which would lead to increased instability of these areas.

Tidal Inlet and Tidal Delta

Definition - Tidal inlets or passes are channel areas of sediment transport with intense current energy connecting the bays with the open Gulf. Associated with the inlets are depositional areas termed ebb and flood tidal deltas occurring at the Gulf and bay ends of tidal passes respectively. Inlets are channel areas of sediment transport with shifting, localized erosion and deposition where sediments are mostly winnowed sand and shell detritus. A diverse faunal assemblage characterizes the inlet environment including the molluscs *Crassinella, Lucina, Tellidora, Anachis, Polinices,* and others. Common echinoderms include *Luidia, Mellita,* and *Ophiolepis.* Most estuarine vertebrate predators including the porpoise *(Tursiops)* pass through the tidal inlet enroute to and from the open sea. Many small encrusting epifauna such as corals and bryozoans live attached to the various molluscs. Clams and snails alike are often attacked by the boring clionid sponges.

Species diversity decreases on the shoal water (to 10 feet) tidal delta areas which are dominated by shallow infaunal species, and echinoderms such as *Mellita.* Here the southern flounder, *Paralichthys lethostigma,* also lives and feeds in abundance. Flood tidal deltas are subaqueous and emergent, marsh-covered sand areas where deposition occurs when tidal-induced currents wane, within the adjacent bay. Ebb and flow tidal channels lace through the ebb deltas exchanging water and nutrients daily. Salt marshes on ebb deltas are areas of high productivity. Ebb tidal deltas on the Texas Gulf Coast are subaqueous and are poorly developed because sand temporarily deposited at the Gulf end of the tidal inlet is rapidly dispersed along the barrier islands by long-shore currents.

Passes or inlets provide communication between the open Gulf and bays or lagoons for fish migration and water exchange. Large schools of mullet *(Mugil)* pass through this zone on the way to their spawning grounds in the Gulf. During tropical storms and hurricanes, as well as during mainland floods, extensive exchange of marine and fresh water, respectively, occurs through these passes. Under normal tidal conditions, however, water exchange is minimal. Natural water depths in these passes range up to 40 feet, but most of these areas are maintained by dredging for navigation purposes. Salinities range from 10 to 40‰, depending upon current flow conditions; normal salinities for these areas lie in the 30-35‰ range.

Limiting use factors - Limiting factors include (a) high current energy, especially during storms, and (b) excessive erosion and deposition. A very important factor is the exchange of waters which occurs through these areas, allowing flushing of bay pollutants and natural migration of organisms.

Undesirable uses - Care should be taken to avoid (a) obstruction of natural circulation and sediment transport through construction and (b) liquid waste disposal in these areas, inhibiting fish and shrimp migration.

Wind-Tidal Flats

Definition - These extensive flats occur on the back side of barrier islands south of St. Joseph Island and on the landward side of Laguna Madre from mean sea level to about plus 3 feet. Flats are flooded by wind-driven lagoon and bay water either during northers, or by persistent southeasterly spring and summer winds. These areas are dominantly sand, although they become muddy in depressed areas in the "land-cut" portion of the coast immediately south of Baffin Bay. Algal blooms during intermittent inundation result in thin algal mats which bind the sediment into a tough substrate; gypsum and other salts are common in the more depressed and/or restricted areas. High temperatures in the thin sheet of water on the tidal flats restrict biologic activity.

Limiting use factors - Limiting factors include (a) frequent tidal and hurricane flooding and (b) moderate permeability.

Undesirable uses - Undesirable uses include (a) waste disposal, (b) construction, because of frequent tidal flooding and potential hurricane damage, and (c) excessive channeling and canalization which block tidal circulation.

COASTAL PLAINS

Coastal plains are flat uplands which occur landward from bays, lagoons, or open Gulf and extend from sea level to an elevation of approximately 100 feet; they display a slight coastward inclination and are underlain predominantly by ancient deltaic, fluvial, and barrier-strandplain sediments. Local relief is produced by headward-eroding streams and salt domes. In most areas, the coastal plain is traversed by elongate sand belts with very slight topographic relief. Coastal plains are cut by several major river systems; some like the Trinity and Nueces, are deeply incised, while the Brazos and Colorado systems flow within broad, shallow valleys. Other sandy belts up to 3 miles wide are oriented approximately parallel to the present coastline and represent ancient sand barriers and strandplains. Much of the more arid South Texas coastal plain consists of an extensive wind blown sand sheet.

Highly Permeable Sands

Definition - These sand belts are oriented parallel or subparallel to the coastline and represent ancient barrier islands or strandplain deposits. These clean, highly permeable sand belts, which are 2 to 8 miles wide and 20 to 40 feet thick, occur intermittently from the Louisiana border to Baffin Bay; the sands being locally absent where crossed by major river systems. These ancient barrier sand bodies are surrounded by impermeable muds and are important fresh-water aquifers.

Limiting use factors - Limiting factors include (a) high permeability, (b) high erosion potential (water and/or wind), and (c) importance as a source of fresh water.

Undesirable land uses - Land uses which may result in detrimental environmental effects include (a) liquid waste disposal, (b) solid waste disposal, (c) disposal in surface holding ponds (brine, sludge), (d) development of feed lots, (e) septic tank use except with careful monitoring, (f) extensive excavation (such as drainage canals, developments, and landcuts) and development of steep slopes in these noncoherent sediments, which accelerate erosion, and (g) devegetation in the area south of Corpus Christi, which results in wind erosion and migrating dune development.

Moderately Permeable Sands

Definition - These moderately permeable sand deposits from 20 to 100 feet thick occur in higher elevations of the coastal plain and locally extend coastward in narrow belts from 1 to 5 miles wide.

These sands represent ancient river and deltaic deposits, and they commonly overlie and are flanked by impermeable muds: They are significant shallow, ground-water aquifers.

Limiting use factors - Limiting factors include (a) moderate permeability, (b) moderate erosion potential (wind and water), and (c) importance as a local source of fresh water.

Undesirable land uses - Undesirable land uses are the same as those for highly permeable sand, but the effects are generally less severe.

Impermeable Muds

Definition - Extensive, impermeable mud prairies extend inland from marshlands to thick sand belts. The muds were deposited on ancient deltas and along ancient rivers. This unit comprises 60 to 70 percent of the coastal plain and includes most agricultural areas.

Limiting use factors - Limiting factors include (a) impermeability which results in poor internal drainage, (b) high shrink-swell potential, (c) high corrosion potential, (d) unstable steep slopes, especially when wet, and (e) low shear-strengths resulting in foundation problems.

Undesirable land uses - Potentially troublesome land uses include (a) construction, which is limited by severe shrink-swell problems, (b) burial of pipes and cables that are subject to corrosion, (c) development without proper drainage systems, (d) construction on steep slopes in upper coastal areas that are subject to failure, and (e) use of muds for fill without prior stabilization treatment.

Broad, Shallow Depressions

Definition - These low-lying areas adjacent to river courses occupy abandoned and partially filled ancient stream channels and other low, depressed areas such as ancient floodplain lakes. They may result from local subsidence or damming by man-made features such as highways and railroad right-of-ways.

Limiting use factors - These areas are (a) frequently flooded and (b) are subject to many of the same problems described for impermeable muds.

Undesirable land uses - Land-use limitation includes development or agriculture without proper drainage systems.

Highly Forested Upland Areas

Definition - These wide belts of pine and hardwood occur predominately on ancient fluvial sands and muds north and east of Houston. South and west of Houston, in areas of lesser rainfall, forests are dominately hardwoods on ancient fluvial sands with live-oaks concentrated on ancient barrier sands and older wind deposits. In more arid coastal areas, forests are restricted to thicker ancient sand deposits. Forested areas are concentrated on thick, permeable, well-drained sand substrate.

Limiting use factors - This unit generally coincides with and has land-use limitations similar to those of highly permeable sands; devegetation aggravates these problems, especially as it affects erosion.

Undesirable land uses - Excessive deforestation results in (a) water erosion, (b) increased runoff resulting in decreased ground water charge, and (c) extensive wind erosion in south coastal areas.

Steep Lands

Definition - These lands occur as erosional bluffs and steep slopes along stream valleys and bay margins. Steep eroded lands are commonly developed on muds and sandy muds with some development on sand deposits. Storm-wave erosion along bay margins and erosion-slope retreat are significant geological processes.

Limiting use factors - Limiting factors include (a) critical need for vegetation, (b) slopes from 5 to 75 degrees, and (c) potential for slump failure.

Undesirable land uses - Undesirable practices include (a) oversteepening of slopes, which will accelerate erosion and slump, (b) devegetation, which will accelerate erosion, and (c) construction that is limited by potential slump failure, especially in higher rainfall areas of the upper coast.

Stabilized, Vegetated Dunes and Sand Flats

Definition - Densely vegetated, stabilized dunes and associated sand flats covered by live oaks *(Quercus virginiana)*, mesquite *(Prosopis reptans* and other species*)*, or more rarely grasses and associated plants, occur between Baffin Bay and Arroyo Colorado from the landward side of Laguna Madre inland for more than 50 miles. These dunes have local relief up to 30 or 40 feet and consist of highly permeable sands locally cemented by caliche. These old dune fields are characterized by a locally high ground water table.

Limiting use factors - Limiting factors include (a) high permeability, (b) critical need for vegetation, and (c) susceptibility to wind erosion.

Undesirable land uses - Severe problems may arise from (a) solid waste disposal, (b) liquid waste disposal, (c) construction of surface waste ponds, (d) devegetation, which accelerates wind erosion, and (e) road construction or other excavation without adequate revegetation.

Unstabilized, Unvegetated Dunes

Definition - These are broad areas of active wind-driven dunes migrating inland between Baffin Bay and Arroyo Colorado. Until stabilized by adequate vegetation, dunes may move northwestward up to tens of feet per year. Dune orientation is essentially parallel with the prevailing southeasterly winds. The dunes are highly permeable sands with local relief up to 30 or 40 feet. Depth of wind erosion is controlled by the height of the ground water table as well as by the nature of subjacent material. Dune migration becomes more active with drought conditions.

Limiting use factors -Limiting use factors include (a) high permeability, (b) dune movement, and (c) wind erosion.

Undesirable land uses - Undesirable practices include (a) construction on or downwind from dunes, (b) the waste disposal limitations as for stabilized dunes, and (c) road construction through dunes, which may result in severe maintenance problems due to blowing sand.

Fresh Water Lakes, Ponds, Sloughs, Playas

Definition - Lakes, ponds, and sloughs, which represent ancient river cut-offs and abandoned channels, are concentrated on ancient fluvial deposits. Sloughs occupy ancient abandoned channel courses, while lakes and ponds are commonly ancient flood basins and meander cut-offs. Playas are restricted to arid regions south of Corpus Christi where there is insufficient rainfall to maintain permanent lakes. Alternate wet and dry conditions result in playa salt deposits and associated clay dunes.

Limiting use factors - The primary limiting factor is the value of fresh water storage in these reservoirs, both as surface supply and ground water recharge.

Undesirable land uses - Undesirable uses involves (a) filling of the reservoir to the extent that ground water recharge is severely hampered, and (b) resource development adjacent to these reservoirs of improper disposal facilities that would pollute the fresh water.

Mainland Beaches

Definition - These low energy beaches along mainland sides of bays are composed of sand, shell, and caliche fragments. Storm berms composed of bay mollusks are common, particularly along marshy shorelines. There is a minimum of sand transport along these beaches, and beach deposits are normally thin and overlie older muds and muddy sands of the coastal plain.

Limiting use factors - Limitations include (a) erosional susceptibility and (b) daily tidal activity.

Undesirable land uses - Undesirable uses include large scale construction and/or excavation that would significantly modify the natural sediment dispersal processes.

Area of Active Faulting and Subsidence

Definition - *Faults* in the coastal region are linear features along the coastal plain commonly oriented parallel to subparallel to the shoreline along which some vertical displacement has occurred. Faults may be currently active (displacement in inches per 10 years) or may be temporarily inactive. Faulting is principally the result of compaction of thick wedges of ancient, water-saturated deltaic muds. Fault movement is along a curved surface that commonly extends thousands of feet into coastal sediments. Areas of unusually rapid *subsidence* normally result from extensive withdrawal of ground water. These areas may be several miles in diameter, and subsidence may also activate faults in the area. Withdrawal of oil and gas may also result in land subsidence. The only coastal plain area of significant subsidence at the present is near Houston, where withdrawal of ground water has resulted in 4 or 5 feet of subsidence southeast of Houston.

Limiting use factors - The limiting problems are: (a) potential damage to foundations or other structures by fault movement or subsidence and (b) potential flooding of subsided areas during hurricanes and tropical storms or gradual flooding by marine water if the subsidence occurs along the shoreline.

Undesirable land uses - Severe problems arise from the (a) construction of any sort (buildings, pipelines, cables, streets, and railroads) across faults without special design and maintenance and (b) construction within any subsiding area without proper drainage.

MAJOR FLOODPLAIN SYSTEMS

Major river systems include through-flowing streams and associated lakes and sloughs, point bar sands, and overbank or floodplain muds and silts; excluded are headward eroding streams which originate within the coastal plain. These major river systems have extensive inland drainage basins and have been active for thousands of years. Each system incised its present valley during the last low sea level stand (ice age), and filling began about 18,000 years ago when sea level began to rise. Valleys are filled with point bar sands and floodplain muds and silts. Except for the Colorado, Brazos, and Rio Grande, these incised valleys have not been entirely filled by alluvial sediments. Bays and estuaries are segments of the drowned valleys which have not been filled, although small estuarine deltas such as the Trinity, Nueces, and Guadalupe have been building slowly into the estuaries for the past 5,000 years.

Point Bar Sands

Definition - These are bodies of highly permeable sand that are currently being deposited by lateral accretion on the convex bank of modern stream meanders and similar sand bodies that were deposited by earlier streams within the same valleys. These lens-like sand bodies normally grade abruptly into muds. Coarser and more highly permeable sand and gravel occur near the base of point bars. These bodies are normally charged with fresh water. Older exposed point bars are vegetated primarily by willows, oaks, and other water-tolerant hardwoods.

Limiting use factors - Limiting factors include (a) high permeability, (b) erosional susceptibility to running water, (c) the need to maintain the fresh water within these aquifers, and (d) susceptibility to flooding.

Undesirable land uses - Undesirable uses include (a) liquid and solid waste disposal, (b) construction of surface holding ponds for brine or sludge, (c) development of feed lots, (d) placement of septic tanks except with carefully monitoring of aquifer,

(e) extensive excavation and development of steep slopes which accelerate erosion, and (f) devegetation which permits erosion of these sands.

Overbank Muds and Silts

Definition - These units are sheetlike bodies of impermeable to moderately permeable sediment that were deposited on modern floodplains during flood stage. Valley fill also contains similar sediments deposited in earlier stages of development of the river system. The upper surfaces of modern floodplains slope gently away from levees flanking the rivers. Valleys are filled by lenses of point bar sands dispersed within the less permeable deposits. Vegetation is primarily water-tolerant hardwoods in northern coastal areas; less vegetation occurs south of Corpus Christi.

Limiting use factors - Limiting factors include (a) impermeability resulting in poor drainage, (b) high shrink-swell potential, (c) moderate to low shear strengths resulting in foundation problems, and (e) unstable steep slopes, especially when wet.

Undesirable land uses - Undesirable land use includes (a) construction of any kind which is affected by shrink-swell problems such as cracking of foundations, (b) burial of pipes and cables that are subject to corrosion, (c) use of mud from these areas as fill without proper stabilization treatment, and (d) holding ponds that may be inundated during flood stage.

Water

Definition - Through flowing streams and their water discharge, dissolved solids, suspended load, and bed load are controlled by the size and substrate of the drainage basin, agricultural practices, climate, pollutants introduced into the drainage basin, and the presence of artificial reservoirs.

Limiting use factors - (See definition, above.)

Undesirable land uses -Significant problems can arise from (a) improper waste disposal, especially poorly treated chemical wastes and sewage discharge, (b) excessive dredging and straightening of natural channels, and (c) restriction of sufficient flow to maintain river and deltaic accretionary processes, as well as nutrients and fresh water for maintenance of normal bay-estuarine systems.

COASTAL WETLANDS

Definition - Wetlands include saltwater marsh, freshwater marsh, and swamp. *Salt marsh* is flooded daily by tidal action and contains plants such as cordgrass *(Spartina alterniflora)*, glasswort *(Salicornia perennis)*, maritime saltwort *(Batis maritima)*, seepweed *(Suaeda sp.)*, and sea-oxeye *(Borrichia frutescens)*, inland from the shoreline to higher marsh areas, respectively. Along the Texas coast, salt marsh commonly occurs on the back sides of barrier islands north of Baffin Bay, along the margins of ancient deltas of the coastal plain, and on modern, presently active deltas. Major subcategories include the following:

- Freshwater marsh is maintained by a permanently high water table and/or high rainfall, and it is characterized by plants such as coastal sacahuista *(Spartina spartinae)*, marsh hay cordgrass *(Spartina patens)*, big cordgrass, *(Spartina cynosuroides)*, bullrush *(Scirpus sp.)*, cattail *(Typha sp.)*, and rushes *(Juncus sp.)*. Freshwater marsh occurs in the lower portions of river valleys, in swales on the modern barrier islands, in some abandoned stream channels, surrounding some coastal lakes, and inland from salt marsh on modern deltas and bay margins.
- Swamps are areas of entirely fresh water and are maintained by rainfall and a high water table. They occur in active stream valleys inland from freshwater areas and locally in ancient stream channels and cut-offs. Swamps are characterized by dwarf palmetto *(Sabal minor)*, cypress *(Cupressus)*, elm *(Ulmus)*, bay mulberry, water oak *(Quercus nigra)*, gum, grapevine *(Vitis)*, and yaupon *(Ilex vomitoria)*.

Limiting use factors - Limiting factors include (a) standing water and frequent storm flooding, (b) need to maintain local ground water recharge by freshwater marsh and swamps, and (c) the importance of the vegetation and physical environment for survival of many marine and terrestrial organisms, principally because of the extremely high plant productivity.

Undesirable land uses - Undesirable environmental affects may arise from the (a) dredging and/or construction of excessive canals or channels, (b) filling of wetland areas and/or blocking of tidal channels that connect wetlands with the bay-estuary environment,

(c) improper waste disposal in wetlands or in adjacent areas draining into wetlands, (d) destruction of a significant area of wetlands by construction of artificial reservoirs, (e) excessive traverses by marsh buggies and by air boats, (f) excessive devegetation of wetland areas, which decreases productivity and alters the food chain, and (g) draining of a substantial portion of wetlands.

MADE LAND AND SPOIL

Definition - *Made land* includes areas composed of dredged bay, barrier, marsh, and deltaic sediments (sand, mud, and shell) used to fill shallow bay areas and wetlands for development and industrial purposes. Permeability of this fill material is highly variable as are its other physical properties. *Spoil* is waste sand, mud, and shell dumped into the bay or on adjacent lowlands during channel and canal dredging and oyster shell production. In most bays, spoil occurs as circular to elongate islands which protrude up to 20 feet above sea level. Most spoil disposal areas parallel adjacent dredged channels. Margins of spoil islands may be highly reworked by wave and current activity, concentrating shell and transporting finer sediment into adjacent bay-bottom environments such as subaqueous grassflats.

Limiting use factors - Limiting factors include (a) commonly high permeability and (b) erosional susceptibility to running water and waves or currents.

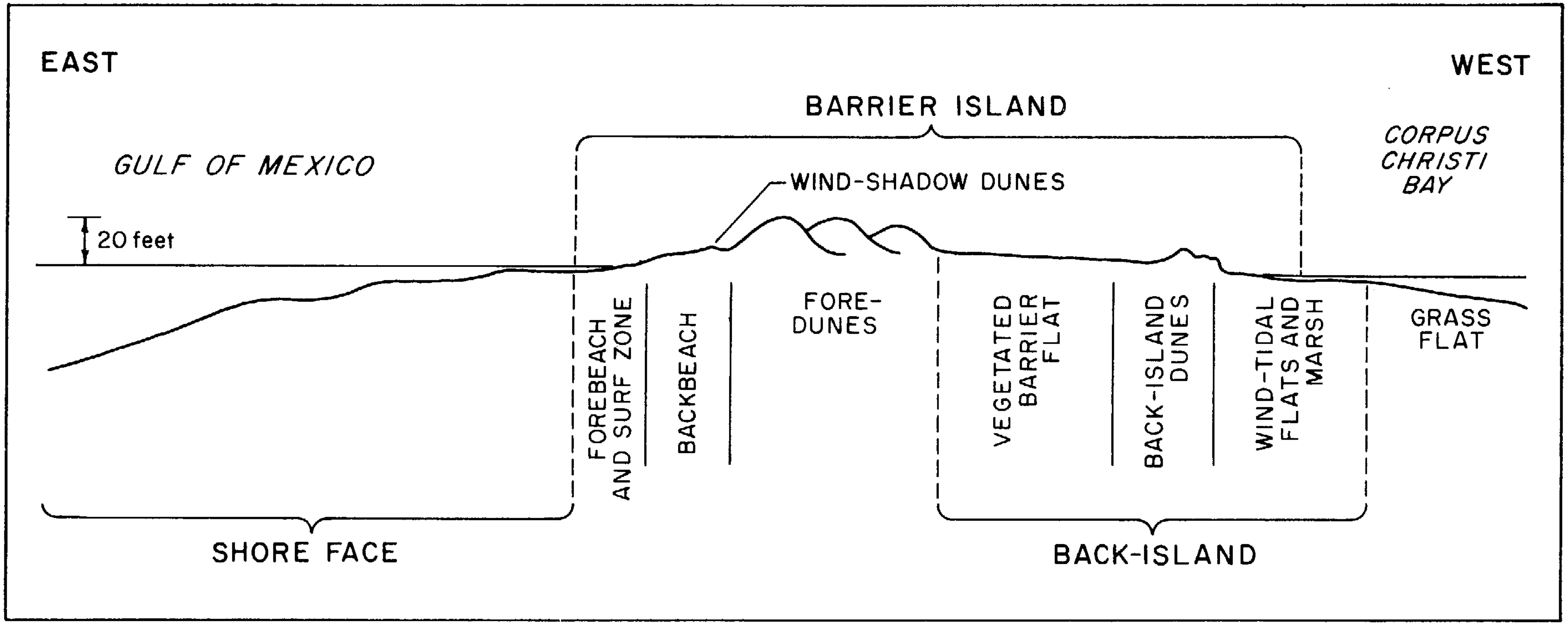
Undesirable land uses - Liquid and/or solid waste disposal.

COASTAL BARRIERS

These highly permeable sand bodies are elongate parallel to the shoreline and are separated from the mainland by lagoons and estuaries. Local relief of the islands is from sea level to 50 feet; width is from 0.5 to 3 miles. Barriers are composed of a variety of wind, vegetational, and storm units. (See Figure IV-5.)

Beach and Shoreface

Definition - This is an area of high wave and current energy along the Gulf side of barrier islands characterized by sand and shell. Shoreface extends from low tide to 30 feet depth. The lower shoreface is an area of strong biological activity characterized by abundant burrowing animals (crustaceans, molluscs, worms, echinoderms) and by minor sand transport. This zone displays an upward increase in sand content from muddy deposits at the toe


EAST
WEST
BARRIER ISLAND
GULF OF MEXICO
CORPUS CHRISTI BAY
WIND-SHADOW DUNES
20 feet
FOREBEACH AND SURF ZONE
BACKBEACH
FORE-DUNES
VEGETATED BARRIER FLAT
BACK-ISLAND DUNES
WIND-TIDAL FLATS AND MARSH
GRASS FLAT
SHORE FACE
BACK-ISLAND

FIG; IV-5

of the shoreface to clean beach sands above. The upper shoreface is a zone of very active sediment transport with shifting bars 2 to 4 feet high. The beach extends from low tide inland to the vegetation line and is characterized by clean, highly permeable sand and shell. The lower beach is subjected to daily swash and backwash. The upper beach is subjected to inundation by spring tides and storm tides and to modification by wind activity. Upper beaches supply sand for maintenance of fore-island dunes.

Limiting use factors - Limiting factors include (a) high permeability, (b) potential storm damage and continuously high physical energy, (c) tidal inundation, and (d) erosional susceptibility (wind, waves), with some beaches displaying erosion and others deposition.

Undesirable land uses - Undesirable uses include (a) waste disposal (solid and/or liquid), (b) construction on beaches, because of potential loss of life and property during hurricanes, (c) construction of piers, groins, and jetties on erosional beaches where they may be undercut, resulting in recreational hazards as well as locally accelerating erosion, and (d) excavation or mining of sand which reduces the local sand budget and provides potential storm beach sites.

Fore-Island Dunes and Vegetated Barrier Flats

Definition - These units are grass-covered, stabilized dunes (from 5 to 50 feet high) and sand flats between the beach and bayside marshes or tidal flats. This area includes most of the exposed barrier island. Low rainfall and persistent wind prohibit growth of stabilizing grasses on central and southern Padre Island. Fore-island dunes are also absent to poorly developed on Matagorda Peninsula where the beach and barrier flat are in juxtaposition. Stabilized blowouts occur behind fore-island dunes, producing a hummocky, ramplike surface. Vegetation consists of salt-tolerant grasses, rare mesquite *(Prosopis)*, and live oak *(Quercus virginiana)* trees.

Limiting use factors - Limiting factors include (a) critical need for stabilizing vegetation, (b) erosional susceptibility (wind, storm tides), (c) high permeability, (d) potential for loss of life and property during hurricanes, and (e) local, isolated freshwater aquifer which is easily contaminated.

Undesirable land uses - Undesirable uses include (a) devegetation which accelerates wind and water erosion, (b) excavation of sand, (c) proliferation of access roads through fore-island dunes, (d) solid and/or liquid waste disposal, (e) surface sludge or brine pits, (f) modification of, or construction on, fore-island dunes, and (g) overgrazing, especially during drought years.

Washover areas

Definition - These are local areas from 1/4 mile to 3 miles wide which channel hurricane flood tides across the barrier islands into bay areas. Many washovers occupy sites of abandoned tidal channels; others are caused by storm tides where fore-island dunes are poorly developed or weakened by blowouts. During major storms, these are areas of intense current activity with scour of large volumes of sand on the seaward side of the island and deposition in the channels and/or on the back side of the island.

Limiting use factors - Limiting factors include (a) intense hurricane flooding and high current energy, (b) high permeability, and (c) erosional susceptibility.

Undesirable land uses - Undesirable uses include (a) construction of any sort, because these are sites of intense hurricane activity, and (b) solid waste disposal, because materials are excavated and washed back into lagoons and bays by storm currents.

Active Dunes

Definition - These are areas of actively moving sand resulting from devegetation or storm breach of *fore-island dune ridge*. On Padre Island, *blowouts* supply sand to back island areas resulting in dune fields 2 or 3 miles wide and tens of miles long. *Back island dunes* eventually migrate into bay and lagoonal areas; blowouts are eventually revegetated and stabilized. Dunes and blowouts are aligned with prevailing southeasterly winds and are composed of highly permeable sand.

Limiting use factors - Limiting use factors include (a) erosional susceptibility to wind and water, (b) high permeability, and (c) movement of dune sands with prevailing winds.

Undesirable land uses - Problems can arise from (a) construction on or downwind from dunes, (b) solid waste disposal, and (c) proliferation of roads and highways through dune areas.

Tidal Flats

Definition - These are flat areas subject to daily inundation by astronomical tides. They occur predominantly in the area of Sabine Pass, where mudflats rather than sandy beaches front the Gulf of Mexico. This area of relatively low wave activity is a shallow submerged flat occupied by a prolific burrowing fauna of mollusks, worms, crustaceans, and other organisms.

Limiting use factors - The principal limiting use is the daily tidal inundation.

Undesirable land uses - The principal undesirable use is construction of any sort, for daily tidal inundation precludes almost all land use activities, particularly liquid and solid waste disposal.

Swales

Definition - These features are narrow, elongate troughs oriented parallel or subparallel to the strandline; they are from 10 to 100 feet wide and up to several miles long. The troughs are mud lines and may contain fresh water and a marsh flora. They occur between ancient or recently formed sand beach ridges; local relief from the top of adjacent ridges is up to 5 feet.

Limiting use factors - The only limiting factor is the need to preserve these swales as natural holding basins for fresh-water recharge of permeable sand beneath the mud floor.

Undesirable land uses - Because of their value as ground water recharge basins undesirable uses include (a) filling, (b) disposal of liquid and/or solid wastes, and (c) drainage.

AVAILABILITY AND QUALITY OF DATA

This classification of coastal lands and water bodies is based on environmental geologic mapping of genetic substrate, vegetation, process and man-made units at a scale of 1:24,000 using topographic maps, aerial photographic mosaics, field work, and aerial reconnaissance. These units are also confirmed by engineering and soil test data and limited published reports. Data for the classification, however, are primarily that generated from first-order research based on about 6 man-years of research. Published reports are either entirely classical and, therefore, commonly irrelevant, or reports are of very local nature and of limited scope. These local data are, however, capable of extrapolation and interpolation among and within similar genetic units, thus extending the data available to their maximum utilization.

The environmental geologic units which are the basis of the land and water capability units are plotted on compiled 7 1/2-minute photographic mosaics and topographic maps filed at the Bureau of Economic Geology, Austin, Texas. The information has been cartographically reduced to 1:125,000 scale on seven maps covering the entire 20,000 square-mile coastal zone. These maps are currently in preparation for printing and will be available for purchase at cost from the Bureau of Economic Geology.

Biologic data, especially for bay and estuary capability units, is needed to define more thoroughly these subaqueous environments. A start on the development of water quality threshold limits for preservation of estuarine organisms is presented in Appendix B. Similar data are needed for wildlife and vegetation in land areas.

Additional engineering, bay process, and salinity information will better document the capability units. More detailed surveys of land-use and water-use effects in the coastal zone will provide better guides to precision in delineating cause and effect relationships which are endangering the natural system.

Such data are of long-range nature and must be generated principally from field work and first-order collection from bioassays, cores, samples, trenches, surveying and field observation. Little library or literary data are available or of pertinence, to the goals of the project.* Both long- and short-range monitoring and sampling on the ground, in the bays, and from aerial reconnaissance photography will eventually supply most of the raw data for ultimate refinement of the land and water capability system.

The following inventory includes principal data available at this time, either resulting from first-order generation involving field and laboratory research, or compiled from other state, federal or private sources. In addition, data that are needed for an adequate land and water capability classification are noted. Data availability is considered in the format of each of the 17 principal coastal activities described elsewhere in the report.

Liquid Waste Disposal

Data Available	*Data Needed*
1. Septic tank and other liquid waste suitability maps	1. Current distribution of disposal sites, major septic systems, and surface brine and waste storage

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**Appendix F, a literature review of marsh management, presents a series of case studies dealing with that particular problem.*

Data Available (con't)	*Data Needed (con't)*
2. Slope-terrain maps	2. Additional data on ground water--distribution of aquifers, nature of reservoirs.
3. Limited ground water data (quality and position of water table)	3. Quantitative data on ground water quality vs. specific kinds of discharge.
4. Most municipal waste disposal sites and/or treatment plants (1960)	4. Increased understanding of deep basin reservoirs
5. Growing volume of data on deep basin discharge reservoirs	5. Increased monitoring of quality and volume of discharge and effects on bay-estuary water quality
	6. Detailed maps of pipelines, production sites in bays, and plugged wells

Solid Waste Disposal

Data Available	*Data Needed*
1. Solid waste disposal suitability maps	1. Current distribution of sites with differentiation of sanitary sites vs. open dumps
2. Slope-terrain maps	2. Additional ground data
3. Limited ground water data (quality and position of water table)	3. Quantitative studies of effect of leachates on various land units
4. Solid waste disposal sites (1968)	4. Increased monitoring of water quality in site areas (ground and surface water)

Gaseous Wastes

Data Available	*Data Needed*
1. None	1. Documentation of effect of various discharges on plant and animal communities, especially on devegetation potential

Offshore Construction

Data Available	*Data Needed*
1. Limited data on location of pipe lines and off-shore platforms	1. Accurate pipeline and platform maps
2. Limited substrate properties within bays and shoreface-inner shelf relative to engineering requirements	2. Quantitative data on effect of certain construction on bay and shoreface construction (and other processes)
3. Some data on effects of hurricanes	3. Documented effects, if any, of subaqueous construction on ecology of various biologic communities
4. Some qualitative data on effects imposed by construction on coastal processes (i.e. erosion, transport and deposition)	
5. Bathymetry of bays and Gulf	
6. Maps showing distribution of subsqueous environments and biologic assemblages	

Coastline Construction

Data Available	*Data Needed*
1. Maps of man-made coastal features	1. More extensive, quantitative data on circulation, sediment transport, erosion, and deposition; need documented effect of groins, piers and other structures on these processes
2. Physical properties of coastal substrates	2. Improved hurricane flooding prediction models
3. Active process maps showing areas of hurricane flooding and washover, shoreline erosion and deposition, and potential sites of faulting	3. Quantitative data on sites of subsidence and active faulting
4. Maps showing distribution of environments and biologic assemblages	4. Environmental vs. economic effects of fish pass construction
	5. Quantitative data on biologic chemical and geologic effects of hurricane barrier construction

Inland Construction

Data Available	*Data Needed*
1. Maps of man-made features	1. Increased data on terrestrial plant and animal communities, and specifically the effect of construction on these communities
2. Physical properties of inland substrates	2. Additional quantitative engineering or physical properties data

Data Available (con't)	*Data Needed (con't)*
3. Topographic maps	3. Documentation of active sites of faulting and subsidence
4. Maps showing distribution of environments and biologic assemblages	

Land Canals

Data Available	*Data Needed*
1. Maps showing distribution of canals and channels	1. Documented effects of canal construction on biologic communities
2. Physical properties of substrates	2. Documented biologic and geologic effects of modifying natural streams for transportation purposes
3. Maps showing distribution of environments and biologic assemblages	3. Effects of canals on the marsh system

Offshore Channels

Data Available	*Data Needed*
1. Maps showing distribution of channels and associated spoil	1. Quantitative documentation of effect of channel and related spoil on all aspects of bay systems
2. Maps of subaqueous environments and biologic assemblages	2. Feasibility study of legal implications in limiting construction, as well as sharing channel facilities
3. Qualitative effects of channels on circulation, sediment supply, temperature salinity, and increased turbidity	

Dredging

Data Available	*Data Needed*
1. Maps of made lands and potential shell dredging areas (excluding buried or mudshell)	1. Documented effects of dredging on adjacent biologic communities
2. Maps of subaqueous environments and biologic assemblages	2. Quantitative documentation of circulation and its effects on distribution of spoil
3. Qualitative information on effect of dredging on turbidity, circulation and other bay processes	

Excavation (Land)

Data Available	*Data Needed*
1. Maps of pits, quarries, mines	1. Specific reserves, especially in areas of urban development, in order to encourage utilization before development.
2. Maps of physical properties showing relative susceptibility to erosion	
3. Topographic maps	
4. Maps of environments and biologic assemblages	

Drainage

Data Available	*Data Needed*
1. Maps of natural and artificial water systems	1. Quantitative data on runoff and stream discharge
2. Limited gauging station data on discharge	2. Increased information on water quality of drainage from areas of various use (i.e. runoff from urban storm drainage system vs. agricultural areas)

Data Available (con't)	*Data Needed (con't)*
3. Maps of permeability which allow some prediction of runoff resulting from man-made features	
4. Topographic maps	
5. Land use maps	

Filling (Development)

Data Available	*Data Needed*
1. Extent and distribution of made and reclaimed land	1. Quantitative data on productivity of marshes and other environments which are potential development areas
2. Maps of subaqueous and wetland environments and biologic assemblages	2. Quantitative effects of filling on bay-estuary system
3. Qualitative information on modification of circulation patterns	
4. Very general information on productivity loss in filled marshes and marginal bay areas	

Draining

Data Available	*Data Needed*
1. Maps of wetlands (marshes and swamps)	1. Economic per acre value or productivity of various marsh units or other wetland or subaqueous lands which may be potentially drained

Data Available (con't)	*Data Needed (con't)*
2. Maps of environments and biologic assemblages	2. Effect of wetland destruction on both bay-estuary--open Gulf commercial and game fish, as well as effect on wildlife such as geese and ducks
3. Land use maps	
4. Maps of natural and artificial water systems	

Well Development

Data Available	*Data Needed*
1. Maps of oil fields and major offshore platforms	1. Complete inventory of unlined, surface brine and sludge pits
2. Maps of physical properties of all potential drilling sites	2. More detailed knowledge of shallow ground water aquifers
3. Maps of environments and biologic assemblages	3. More complete inventory of pipe lines (especially minor production systems), tanks, and offshore sites (many without platforms in shallow areas
4. Limited knowledge of shallow ground water	

Devegetation

Data Available	*Data Needed*
1. Maps of environments and biologic assemblages (plants on land)	1. Need documentation of surface disposal of brine
2. Maps of physical processes	2. Studies on revegetation of different climatic areas of the coast

Data Available (con't)	*Data Needed (con't)*
3. Maps of physical properties showing erodability of sediment	3. Research on specific effects of various activities such as gaseous waste on devegetation

Traversing with Vehicles

Data Available	*Data Needed*
1. Maps of environments and biologic assemblages	1. Research on revegetation of damaged areas
2. Physical properties maps showing susceptibility of vehicular effect	

Use of Herbicides, Pesticides and Insecticides

Data Available	*Data Needed*
1. Environments and biologic assemblages maps	1. Specific information on relationship of these chemicals to water system, to sedimentary deposits (fixation) and biologic systems
2. Physical properties maps showing permeability and potential for fixing pollutants by organic or clay particles	2. Effect of recycling chemicals stored in bay-estuary bottom sediments
3. Water systems maps	
4. Land use maps showing agriculture, range and other related areas	

SUMMARY

The basic land-water resource capability units considered here are only qualitatively defined, based on their major characteristics. Later work will attempt to quantify and expand definitions and factors which limit or control the use of these areas. Table IV-3 has been included in this study to summarize graphically various undesirable human activities on the 34 coastal land-water resource capability units. This table does not indicate the effects of an activity on a land or water area, but rather indicates the activities which are undesirable (from the human standpoint or from the standpoint of preserving a stable environment) or which might cause problems in specific areas. Blank boxes indicate that an activity either does not normally take place in the specific land-water unit or that the activity does not cause any particular problems. Table IV-3 can be used as a quick guide or reference by those making decisions concerning coastal activities.

ACTIVITIES / RESOURCE CAPABILITY UNITS			Liquid Waste Disposal			Solid Waste Disposal		Coastal Construction			Inland Construction											
			Surface Disposal of Untreated Liquid Wastes	Disposal of Untreated Liquid Wastes, Subsurface, Shallow	Maintenance of Feed Lots	Disposal of Solid Waste Materials	Construction of Offshore and Bay Platforms	Construction of Jetties, Groins, Piers	Construction of Storm Barriers and/or Seawalls	Placement of Pipelines and/or Subsurface Cables ▲	Light Construction	Construction of Highways	Heavy Construction	Flooding (through dam construction)	Dredging of Canals and Channels, and Spoil Disposal ★	Excavation (includes extraction of natural materials)	Filling for Development	Draining of Wetlands	Well Development	Devegetation	Transversing with Vehicles (marsh buggies, air boats, dune buggies, motorcycles)	Use of Herbicides, Pesticides, Insecticides
WATER CAPABILITY UNITS	Bays, Estuaries, and Lagoons	River Influenced Bay Areas Including Prodelta and Delta Front	X	X		X	O	O	X	O					X		X		O			
		Enclosed Bay Areas	X	X		X	O		X	O					O		O		O			
		Living Oyster Reefs and Related Areas	X	X		X	X	X	X	X					X		X		X			
		Dead Oyster and Serpulid Reefs and Related Areas	X	X		X	O	O	X	O					X		X		O			
		Grassflats	X	X		X	X	X	X	X					X		X		X			
		Mobile Bay-Margin Sand Areas	X	X		X	X	X	X	X					X		X		O			
		Tidally Influenced Open Bay Areas	X	X		X	O	O	X	O					X		X		O			
		Subaqueous Spoil Areas	X	X		X	O	O		O							O		O			
		Inlet and Tidal Delta Areas	X	X		X	X	X	X	X					X		X		O			
		Tidal Flats	X	X		X			X	X	X	X	X		O	X	X		O			
LAND CAPABILITY UNITS	Coastal Wetlands	Salt-Water Marsh	X			X	X		X	X	X	X	X	X	X	X	X	X	O	X	X	X
		Fresh-Water Marsh	X			X			X	O	X	X	X	X	X	X	X	X	O	X	X	X
		Swamps	X			X				O	X	X	X	X	O	O	X	X	O	X	O	X
	Coastal Barriers	Beach and Shoreface	X	X		X		X	O		X	X	X		X	X			X		O	
		Fore-Island Dunes and Vegetated Barrier Flats	X	X	X	X			X		+	+	+		X	X			O	X	X	X
		Washover Areas	X	X	X	X		X	X	X	X	X	X		X		X		X			
		Blowouts and Back-Island Dune Fields	X	X		X				O	X	X	X		X				X			
		Wind Tidal Flats	X	X		X					X	X	X		O		X		O			
		Swales	X	X		X					X	X	X		X	X	X	X		X		X
	Man-Made	Made Land and Spoil	X	X	X	X							O							X		
	Coastal Plains	Highly Permeable Sands	X	X	X	X									O	X			O	X		X
		Moderately Permeable Sands	X	X	X	X									O	X			O	X		X
		Impermeable Muds	O							O	O	O	O						O			O
		Broad Shallow Depressions *	O								X	O	X						O			O
		Highly Forested Upland Areas *												X					O	X		X
		Steep Lands, Locally High Relief	X			X					O		O			X				X		O
		Stabilized Dunes	X	X	X	X						O			X	X			O	X	X	X
		Unstabilized, Unvegetated Dunes	X	X		X				O	X	X	X		X				X			
		Fresh-Water Lakes, Ponds, Sloughs, Playas	X			X									X		X	X	O			X
		Mainland Beaches	X	X		X		X	X		X	X	X		X	X	X		X	O		
		Areas of Active Faulting and Subsidence	O	O		O				X	O	O	X						O			
	Major Floodplain Systems	Point-Bar Sands	X	X	X	X					O				X				O	X		X
		Overbank Muds and Silts	X	X	X	X				O	O	O	O	O								O
		Water	X			X								O	X							X

X Undesirable (will require special planning and engineering)
O Possible problem(s)
\+ Barrier Flat only (no construction on dunes)

* Substrate variable
▲ Also occurs in Offshore Construction
★ Also occurs in Offshore Canals and Dredging

TABLE IV-3

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

The multidisciplinary team was charged by the Governor's Office with enumerating the various uses of coastal resources and identifying the resultant effects of those uses. The long range objective of this charge is the development of operational guidelines for effective coastal resources management. The specific goal of this initial phase of the project was the development of an interdisciplinary and systematic approach to an understanding of problems relative to the management of the Texas Coastal Zone.

CONCLUSIONS

- A systematic approach to coastal resources management has been initiated which consists of: 1. evaluation of basic environmental units in terms of their capabilities/limitations to support man's activities; 2. delineation of the spatial distribution of these activities; 3. projection of changes in the magnitude, nature and distribution of these activities; 4. estimation of waste production by these activities; 5. evaluation of the environmental impact of these activities and their associated wastes; and 6. identification of the possible restrictions on other uses which may occur as a result of these activities.

- To effectively utilize such a systematic approach an interdisciplinary methodology was developed: 1. seventeen economic sectors applicable to the Coastal Zone were delineated; 2. seventeen specific activities of man were identified as resulting from development of the economic sectors; 3. twenty-seven environmental events which are affected by these activities were identified; and 4. nine potential bay and estuarine uses which probably would be impaired by these activities were identified. These four groupings were coupled using a set of qualitative relationships termed "Interaction Matrices," and a strategy was developed for applying these relationships in a sequential manner to aid in the solution of a specific problem.

- A detailed evaluation was made of thirty-four Coastal Zone environmental units in terms of natural properties which may limit or restrict some of man's activities on these particular units. Attention has been called to certain activities which may cause an environmental imbalance within each of these thirty-four units. These activities require special scientific and engineering investigation before implementation.

RECOMMENDATIONS

- Resource capabilities of the thirty-four specific environmental units need to be quantitatively defined in terms of natural properties, dimension, and process rates. Such a quantitative analysis needs to be on a pilot basis, designed for specific areas in the Coastal Zone for which sufficient baseline controls and secondary data exist. Guidelines developed in pilot areas then should be extended to comparable units elsewhere in the Coastal Zone.

- The past patterns of economic development in the Coastal Zone should be delineated on a spatial and temporal basis. The location, composition, extent, and rate of growth should be identified along classifications comparable to those economic sectors set forth in the analytical methodology. Key relationships between economic growth, transportation and land use need to be quantified so that projections of changes in nature, magnitude, and spatial distribution of man's activities in the Coastal Zone can be made.

- The Texas Input-Output Model currently being completed should be used to trace the impact of various levels of alternative sector development through the regional and state economy. The location, make-up, and timing of resources and services that will be needed to support specific sector developments subsequently can be estimated for planning purposes from this economic model.

- Based upon the results of the economic projections, the expected waste generation must be estimated. Alternative waste management schemes including construction and operating costs for not only currently used waste treatment practices but also for future technologically feasible recycle options need to be developed. Because of the priority of the bays and estuaries, emphasis must be placed on water quality, but solid wastes and air pollution also must be examined because of the highly developed linkages between the air, land and water environments.

- A careful analysis of present criteria for various uses of the bays and estuaries needs to be undertaken. In particular some of the criteria currently used as standards for the preservation of aquatic life by state and federal agencies were not developed from scientifically reliable data obtained from the rather unique Texas coastal environment and, thus, require re-evaluation.

- Better coordination of data collection must be undertaken so that present modeling of coastal hydrodynamics and transport processes can be improved for use as a planning tool. The modeling procedure appears to be the necessary linkage for evaluating the waste loadings required to meet the water quality criteria established for various bay and estuarine uses.

- Many important decisions concerning Coastal Zone Management must be made within the overall context of a comprehensive land and related resource management practice. Land use practices are a possible method of control and efforts on the state level should be increased to investigate the many complex considerations involved with such a type of management.

- Any real benefit from operating guidelines developed by this team depends upon their eventual implementation and this will be achieved only if such guidelines are institutionally feasible and politically sound. The Institute of Coastal and Marine Law (a consortium of legal scholars at Texas' law schools) should continue efforts to examine the many complex legal-institutional problems involved in achieving a viable Coastal Zone management program.

- Plans should be formulated for a demonstration project to illustrate the feasibility of the operating guidelines which will be developed by this project. The demonstration project should be in an area that has most of the economic sectors found anywhere in the Coastal Zone as well as the typical problems of development and pollution.

CLOSURE

Ultimate application of the concepts and technical guidelines developed by this project depend upon the cooperation of the public and usage by the many State agencies who have been granted the statutory responsibilities. Thus, the Interagency Council on Natural Resources and the Environment is strongly urged to encourage all member agencies (acting through the Coastal Resources Management Program) to participate in the development, critique, and evaluation of the operating guidelines to be proposed by the project.

APPENDIX A

MUNICIPAL AND INDUSTRIAL WASTES

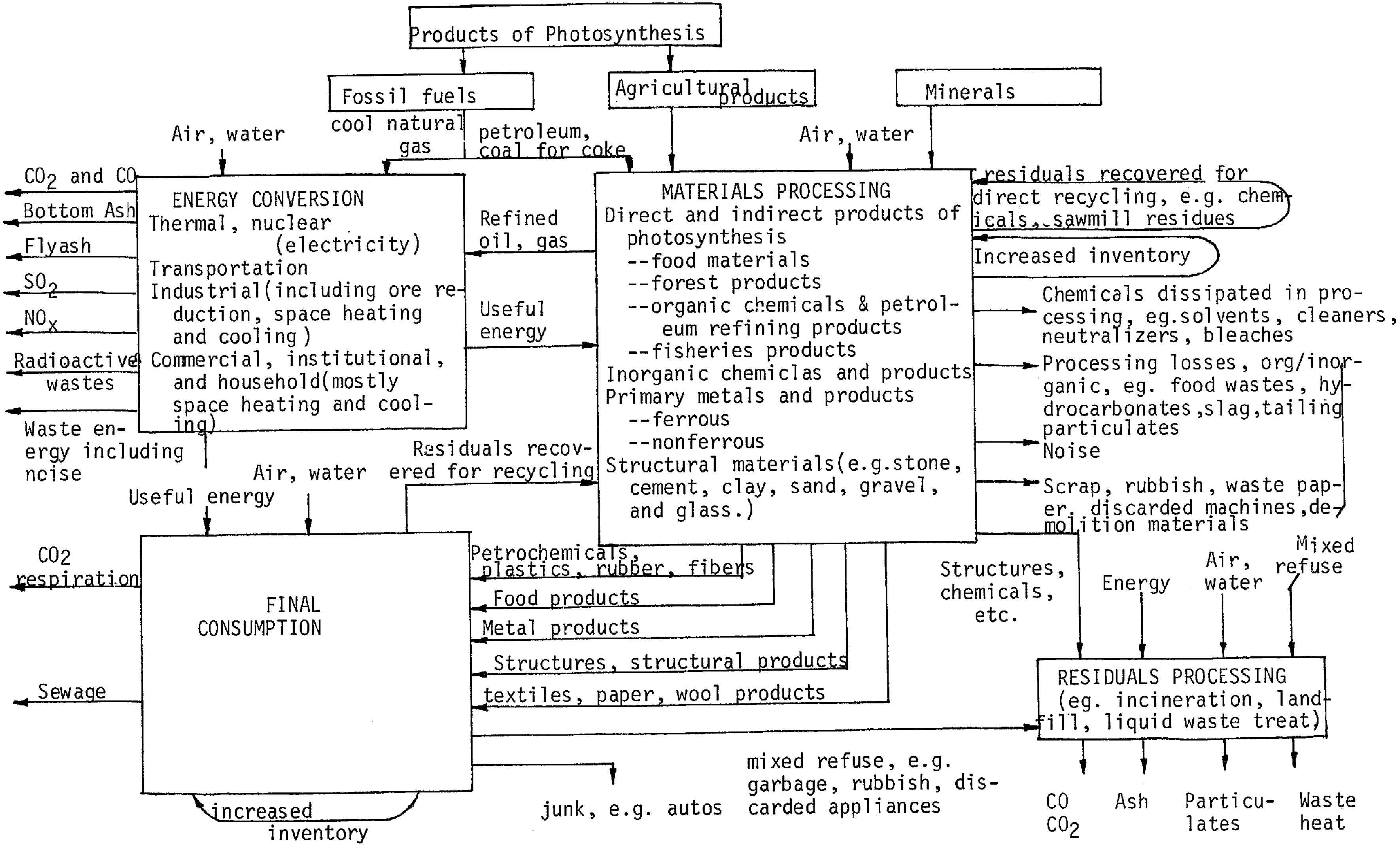
During the production of any consumable good or service, there is a residual or leftover that accumulates and requires disposal. These residuals or wastes are by-products of the technology and urbanization trends of our present society.

Waste production is a direct function of the raw materials input to the process, be it a manufacturing plant or a municipality. In Figure A-1 the materials flow for the U.S. economy is shown, assuming no importation or exportation taking place. As shown in Figure A-1, waste production is necessary to maintain the technological level of the U.S. economy; what is not necessary is the amount of wastes produced or the fashion in which these are released to the environment. There are three ways to lower the waste inputs to the environment: a) improving materials use effectiveness; b) high quality waste treatment within the limits of the source considered; and c) recycle and reuse.

To alleviate the waste load to the environment recycling of useful secondary materials can be made. The recycling not only reduces the waste loading to the environment, but it also requires that fewer new natural resources be exploited in order to maintain a given standard of living. Unfortunately, present levels of technology, costs of recycling processes, and the lack of public interest combine to preclude full-scale recycling operations.

Specific data on various sources and quantities of wastewater, solid waste and air pollution as well as urban and agricultural runoff in the Coastal Zone have been summarized elsewhere by Malina (1970). Because the primary interest of this report is the management of bays and estuaries, the emphasis in this appendix has been placed on municipal and industrial liquid and solid waste discharges and their treatment.

FIG A-1; Schematic Depiction of Materials Flow
From: Kneese, et al; 1970.



MATERIALS BALANCE

The natural environment provides three important services for man:

- It is the source of his raw materials;
- It provides space for waste accumulation and for regeneration and assimilation of chemically and biologically active wastes; and
- It is a principal determinant of health levels and life style.

As ecologists have long recognized, these services are not separable but are highly interdependent.

In the early stages of economic development, there may exist only a few instances where these roles conflict. However, as increased population and industrialization place more pressures on the environment's ability to provide raw materials and to store, dilute and degrade waste products, the capacity of the environment to provide a satisfactory basis for a high quality life is also threatened. If current trends in population and economic growth are continued over the next thirty years, it is inevitable that conflicts between man's economic activities and the state of the natural environment will become more intense.

These concepts are easily understood if we view the economy in a "materials balance" framework. In its simplest form, this view considers the economy to be a "black box" with inputs of fuels, foods and raw materials and outputs to the environment of the residuals from production and consumption.

A much more realistic and complex framework can be constructed if we relate the materials flow concept to broad classifications of economic sectors which will be generally consistent with the Standard Industrial Classification system used in Chapter III. Figure A-1 charts the materials flow of the type we have in mind for the U.S. economy, with the assumption of a closed (that is, no exports or imports) system. (Kneese, et al. 1970)

One advantage to viewing the economy in this way is to emphasize that there is no such thing as final consumption--witness the piles of junk automobiles which dot our countryside. When we speak of consumption of certain commodities, we are actually referring to the consumption of the services rendered by them. Their material substance remains in existence, either to be reused or discharged into the environment. In an economy which is closed and where there is no net accumulation of stocks (plants, inventories, equipment, consumer durables and buildings etc.), the amount of residuals which are returned to the environment must be approximately equal to the weight of basic inputs to the production and processing system, plus oxygen taken from the air. In the U.S. economy as a whole, accumulation accounts for about 10-15 percent of basic annual inputs. There also is a net importation of raw and partially processed materials which accounts for about 4-5 percent of domestic production. Thus, total U.S. residuals equal about 90 percent by weight of basic inputs.

Almost all of the materials flows shown in Figure A-1 can be further disaggregated. Table A-1 gives a reasonable estimate of total basic material inputs to the U.S. economy. Figures A-2, A-3 and A-4 are schematic diagrams which detail the residuals and production materials flows for photosynthetic processes, thermal energy production, and household consumption in the U.S. economy (Ayers & Kneese, 1968). Isard, et al. (1968) have also done work toward specifying biological and industrial material flows in an input-output context.

The implications of the materials balance approach for environmental controls are clear.

1. Production of goods and services inevitably results in residuals. Reduction of the total weight of wastes can only be accomplished by lowering the amount of materials "throughput" in the economy or by recycling.

2. The wastes from production-processing and consumption must inevitably reside in environmental sinks in the land, air, or water.

Assuming a constant technology, efforts to reduce the volume of residuals disposed of in one environmental media can only succeed by

Fig. A-2 Production and Disposal of Products of Photosynthesis
from Kneese et al; 1970

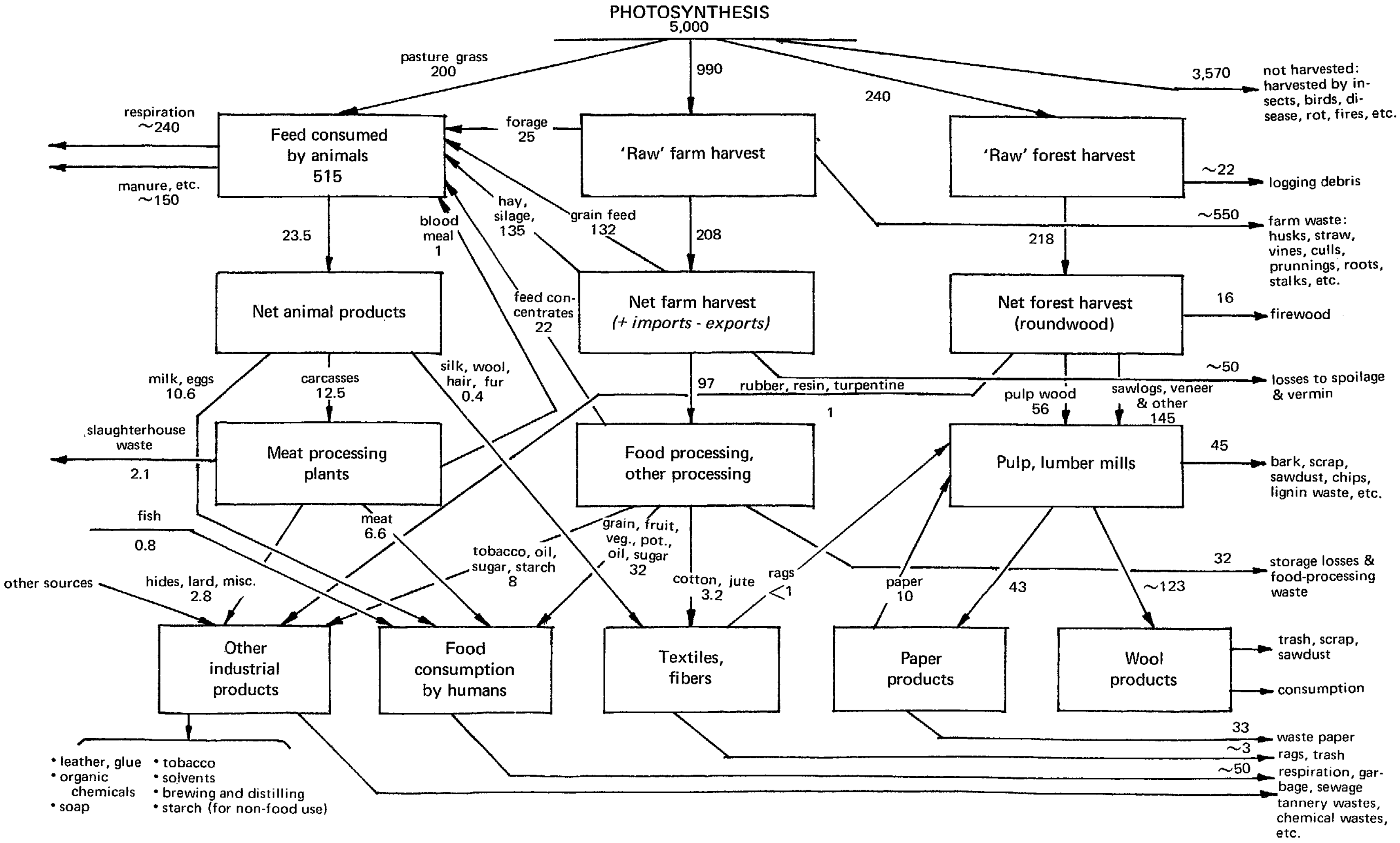
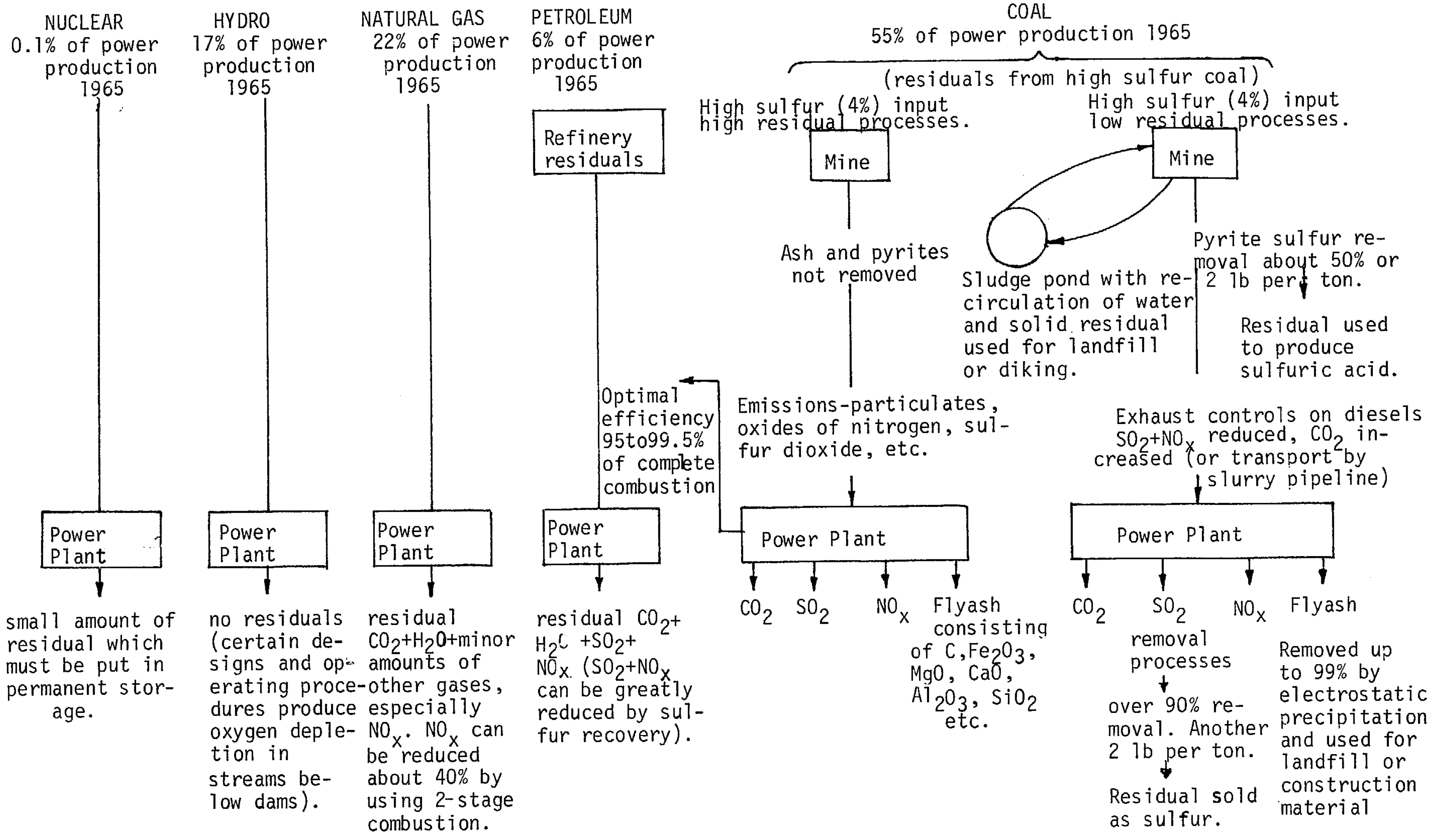


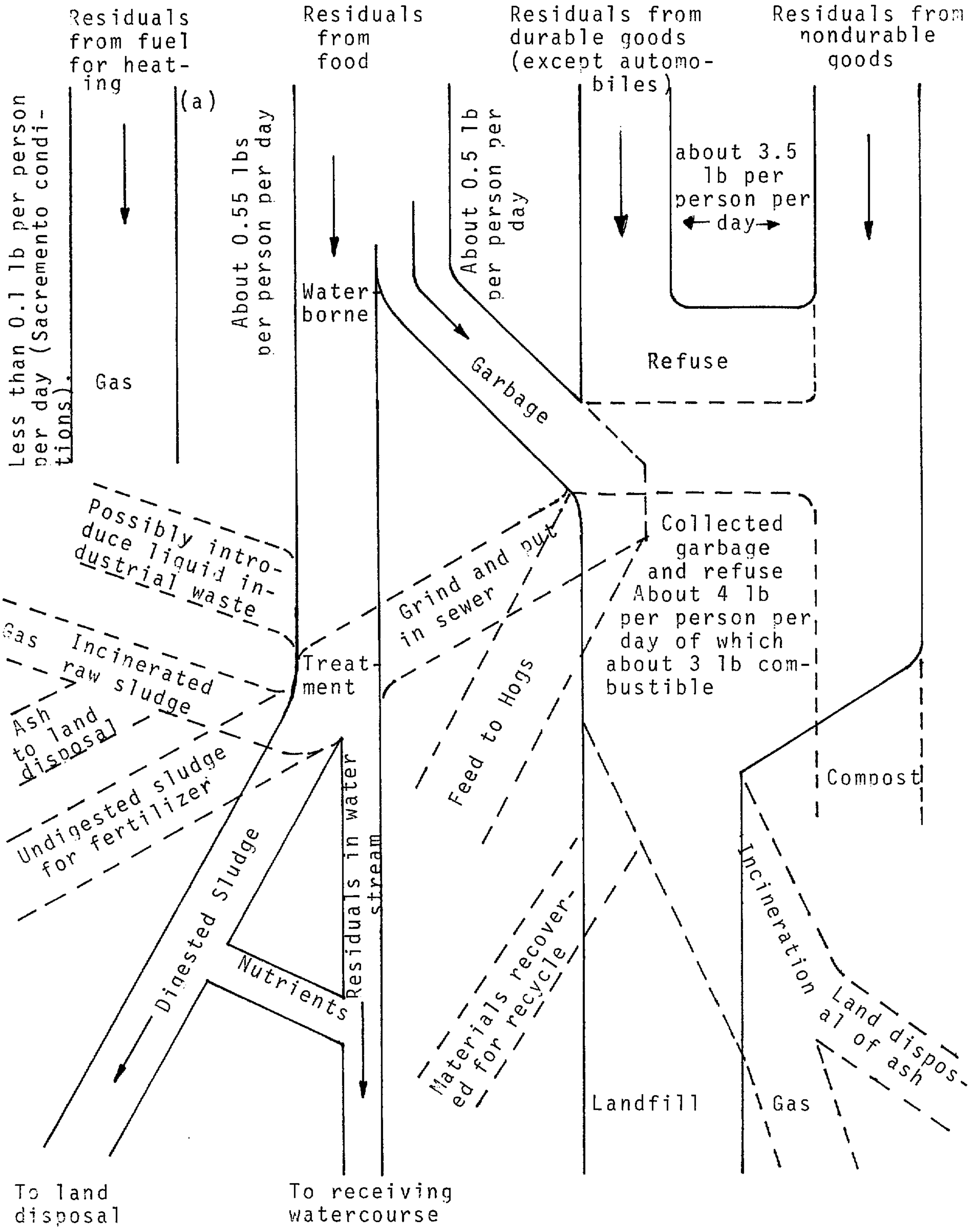
FIG. A-3; Residuals from the Thermal Electric Industry



FROM: Kneese, et al; 1970.

FIG. A-4; Household Residual Materials Flow (Per Capita)

From: Kneese et al, 1970.



(a): this stream is cut out if electricity is used. The waste stream then appears in the electric power sector.

shifting these residuals to other sinks. As a consequence problems of residuals and pollution cannot be properly dealt with by considering any of the environmental media--the air, land, and water--in isolation.

WASTEWATER CHARACTERISTICS

Municipal and industrial wastewaters contain suspended and dissolved organic and inorganic materials which affect the quality of the receiving waters in different ways. Some constituents are reactive and undergo biological decomposition or enter into chemical reactions in the aquatic system. The settleable solids will accumulate on the bottom of estuaries or bays, and the organic material in the sediments will decompose. These substances are nonconservative and the concentration of these materials will decrease with time. Other components are nonreactive and persist in the water, in sediments, or in aquatic organisms for long periods of time.

One type of pollution is characterized by an oxygen demand. Wastes are classified in terms of a Biochemical Oxygen Demand (BOD), a Chemical Oxygen Demand (COD), or a Total Oxygen Demand (TOD). Wastewaters are also characterized in terms of the Total Organic Carbon (TOC) content which can be related to one of the oxygen demand parameters.

The Biochemical Oxygen Demand (BOD) is the quantity of oxygen utilized in the microbial oxidation of biodegradable organic material in a specific time (usually 5 days) and at a specified temperature (usually $68^{o}F$). The BOD usually indicates the oxygen required for the biological oxidation of biodegradable carbonaceous substances and in some cases for the degradation of nitrogenous materials.

The Chemical Oxygen Demand (COD) represents an estimate of the organic and inorganic materials which can be chemically oxidized. The Total Oxygen Demand (TOD) is a relatively new parameter which provides an estimate of all demands.

The analytical procedures available for evaluating the parameters used to characterize the oxygen demand of wastewaters have some limitations. A detailed discussion of all the procedures is beyond the scope of this report. However, it is important to note that extreme caution is advisable in evaluating data relating to these parameters, and the type of analytical procedure used should always be stated.

Particulate and conservative dissolved substances also effect water quality. Deposition of suspended material on the bottom of streams can cause sludge banks and accumulation of dissolved solids in the water can limit the use of the water. The solids in wastewaters are categorized below.

- Settleable solids are the suspended matter which will settle by gravity under quiescent conditions.
- Suspended solids are those materials which float on the surface or are in suspension in water.
- Total solids are defined as the residue remaining after the water is evaporated and the residue dried to a constant weight.
- Dissolved solids are therefore the difference between the total solids and the suspended solids, and
- Volatile solids are that fraction of the solids which is lost upon ignition of the dried residue.

Wastewaters also contain phosphorous and nitrogen which are nutrients required by bacteria, algae, and other microorganisms and have been associated with the occurrance of undesirable algal blooms in estuaries and bays. Other sources of these nutrients include agricultural and urban runoff.

Some inorganic ions and organic compounds in wastewaters are toxic to fish, other aquatic animals, algae, and bacteria. Acute toxicity manifested exposure to sublethal concentrations can have more subtle affects on the biota. Algae tend to accumulate and concentrate some toxic substances. Predator fish feeding on these algae could ingest lethal doses of toxicants. Inorganic ions which have toxic effects include cyanides, mercury, copper, cadmium, chromium, zinc, and nickel among others. Some other compounds and petrochemicals usually involved in reports of acute toxicity are acids, caustics, ammonia, chlorine, phenolic compounds, organic solvents, synthetic organic compounds, oil field brines, pesticides and detergents to list only a few.

MUNICIPAL WASTEWATER

The quantity and quality of municipal wastewater is affected by the land use of the drainage area, the extent to which sanitary and storm water are separated, the amount of infiltration, the rainfall pattern and the type of industrial waste ordinance enforced by the municipality. The wastewater generated in a particular area is related to the water use pattern which in turn is established by the price of water and the type of development of the land. For example, the water use pattern is different for single family residences, apartments, commercial and industrial developments. Industries which operate only seasonally or those which have batch processes and institutions which have large transient populations such as universities can markedly effect the quantity of municipal wastewater which must be treated.

The total flow generated by a community and the composition of the wastewater are a function of the population and the industrial development of the particular municipality. The data in Figure A-5 indicate the relationship between population served and the average wastewater flow for communities of populations between 2,000 and 50,000 in the State of Texas. The range of average wastewater flows for communities of the same population is wide. A statistical evaluation of the available data can be used to determine the design flow. Graphical analyses of return flow data are presented in Figure A-6. These data represent strictly municipal flow with very little or no industrial flow included. The per capita flow increases as the population served increases. The quantity of wastewater generated per person in Texas varies from less than 70 to 100 gallons per capita per day with an average of 88.9 gallons per capita per day.

Water use in small communities which have very little industrial usage can be estimated at 85 - 100 gallons per capita per day (gpcd). However, the water use for larger communities in which commercial and industrial water usage is relatively high will reflect these other water demands and the average water use will be increased to approximately 150 gpcd or greater depending on the type of industry.

The return flow which enters the collection system accounts for 60 to 70 percent of the water use. This percentage can be used to estimate the return flow when other information is not available.

The quantity of wastewater also is markedly affected by rainfall. Runoff into combined systems is directly through the catch basins.

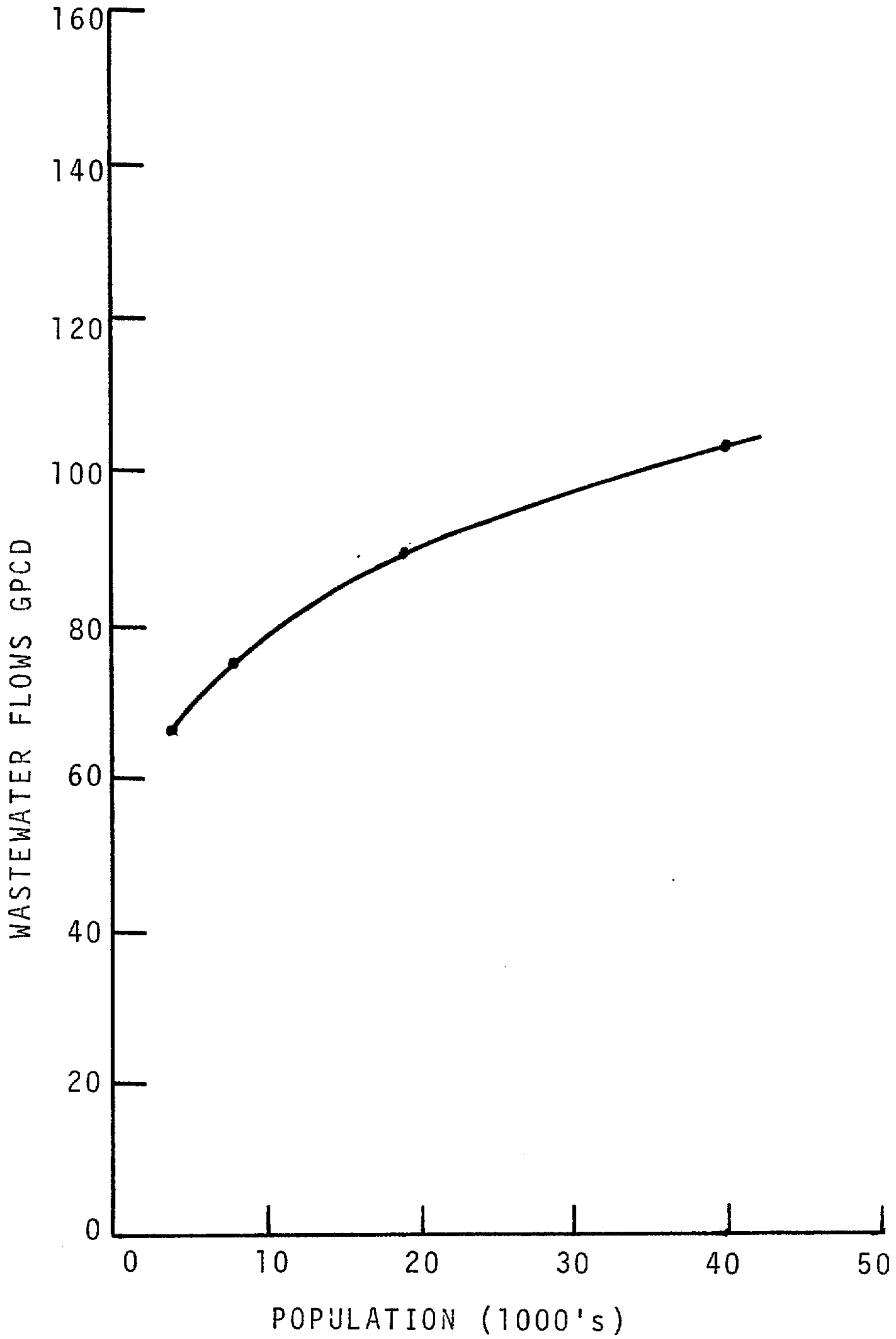


FIG. A-5

EFFECTS OF POPULATION ON WASTEWATER FLOWS

From: Williamson, 1971

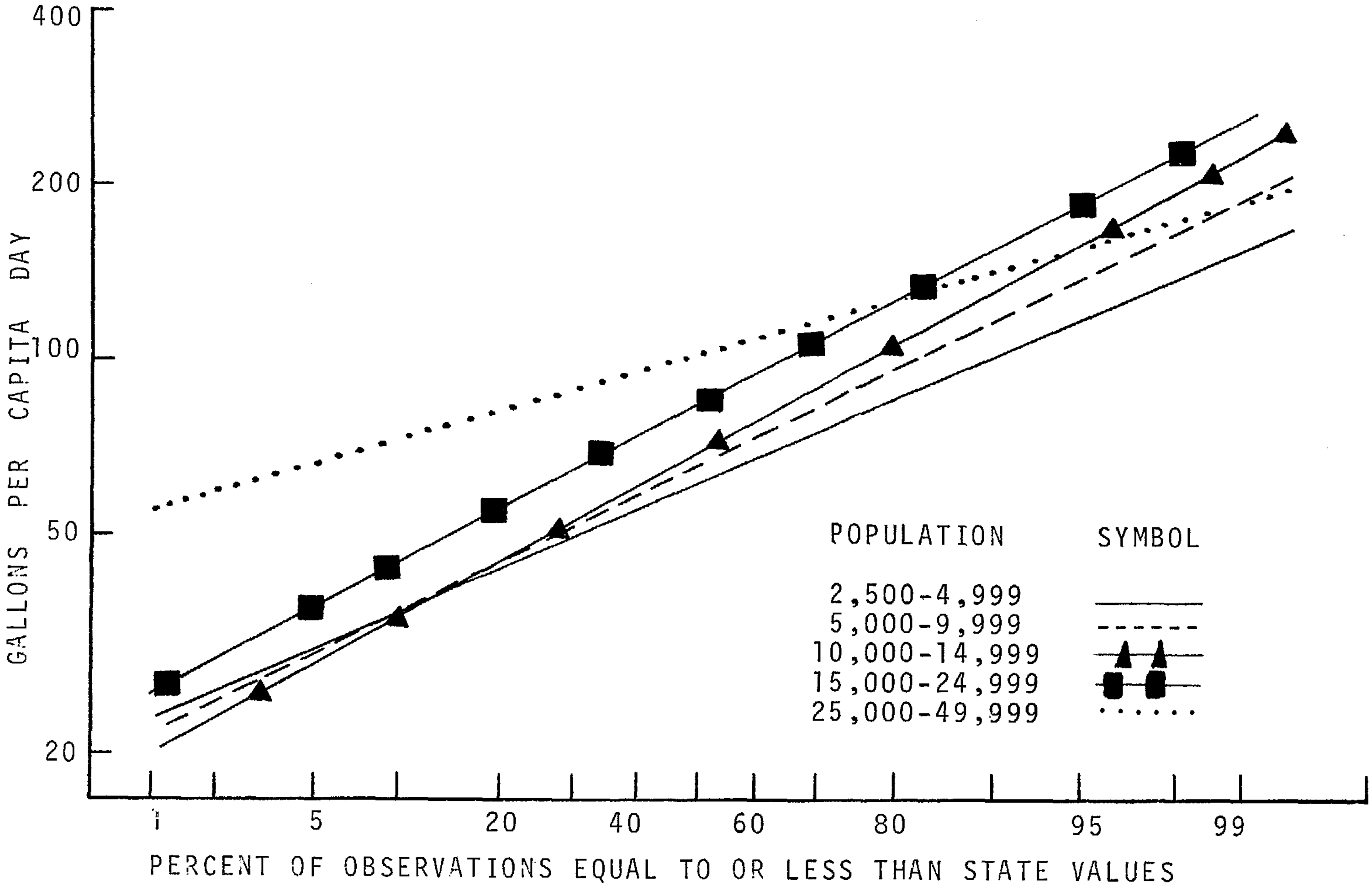


FIG. A-6;

PROBABILITY ANALYSIS OF WASTEWATER FLOW DATA

FROM: WILLIAMSON, 1971

However, rainfall which percolates into the ground also can enter the separate sanitary sewer system by infiltration and significantly increases the flow going to the treatment plant.

Characteristics of typical municipal wastewater are summarized in Table A-2. Industrial wastewater collected in the municipal system can alter the composition of the wastewater. The water use and the infiltration of rainfall into the collection system also effect the characteristics of the wastewater. The average contribution of 5-day BOD and suspended solids for people in Texas are 0.16 pounds and 0.21 pounds per capita per day respectively. These values are considerably lower than the national averages which are 135 gallons of wastewater, 0.20 pounds of 5-day BOD, and 0.23 pounds of suspended solids per capita per day, respectively.

INDUSTRIAL WASTEWATERS

The quantity and characteristics of industrial wastewaters are as varied as the type of industry producing the wastes. The composition of wastewaters from different industries are presented for illustrative purposes in Tables A-3 and A-4.

WASTEWATER TREATMENT AND RENOVATION

All municipal and most industrial wastewater and return flows require some type of treatment to minimize the effects on the uses of the estuaries and bays. Current technology of wastewater treatment and renovation is such that the removal of almost all non-desirable constituents of wastewater is possible, although it must be noted that the cost of removing some substances makes these processes somewhat prohibitive.

Municipal

Treatment or renovation of municipal wastewater is usually classified as primary, secondary, or tertiary. Primary treatment included numerous processes required for the removal and disposal of a portion of the suspended solids in the wastewater. Biological (secondary) treatment involves the removal of a portion of the dissolved organic material in the wastewater by means of microbiological oxidation. These processes are usually aerobic and vary in the way in which the bacteria are utilized. Waste stabilization ponds contain algae which provide the oxygen for use by bacteria in oxidizing the organic material. The effluent BOD is a function of the detention time and temperature. The effluent suspended solids concentration is between 50 and 100 mg/L. Trickling filters are treatment units in which bacteria which oxidize the organic matter grow in the form of slime attached to the surface of a rock or suitable support. These bacteria oxidize the organic matter with which they come in contact as the wastewater passes over the slime covered medium.

TABLE A-1

Weight of Basic Materials Production in the United States plus New Imports, 1963-65

(10^6 tons)

Material	1963	1964	1965
Agricultural (incl. fishery and wildlife and forest) products:			
Food and fiber:			
Crops	350	358	364
Livestock and dairy	23	24	23.5
Fishery	2	2	2
Forestry products (85% dry wt. basis):			
Sawlogs	107	116	120
Pulpwood	53	55	56
Other	41	41	42
Total	576	596	607.5
Mineral fuels	1,337	1,399	1,448
Other minerals:			
Iron ore	204	237	245
Other metal ores	161	171	191
Other nonmetals	125	133	149
Total	490	541	585
Grand total[a]	2,261	2,392	2,492

SOURCE: R. U. Ayres and A. V. Kneese, "Environmental Pollution," in *Federal Programs for the Development of Human Resources*, a compendium of papers submitted to the Subcommittee on Economic Progress of the Joint Economic Committee, Congress of the United States, Vol. 2 (U. S. Government Printing Office, 1968).

[a] *Excluding construction materials, stone, sand, gravel, and other minerals used for structural purposes, ballast, fillers, insulation, etc. Gangue and mine tailings are also excluded from this total. These materials account for enormous tonnages but undergo essentially no chemical change. Hence, their use is more or less tantamount to physically moving them from one location to another. If this were to be included, there is no logical reason to exclude material shifted in highway cut and fill operations.*

TABLE A-2

*Characteristics of Typical Municipal Wastewater**

Characteristic	Maximum	Average	Minimum
PH Units	7.5	7.2	6.8
BOD (mg/l)**	276	147	75
COD (mg/l)	436	288	159
Settleable Solids (mg/l)	6.1	3.3	1.8
Total Solids (mg/l)	640	453	322
Suspended Solids (mg/l)	258	145	83

**Hunter, J. V., and H. Huekelekian - "The Composition of Domestic Sewage Fractions," Journal Water Pollution Control Federation, 37, 1142 (1965)*

***mg/l = milligrams per liter = parts per million*

TABLE A-3

Industrial Wastewater Characteristics

Industry	Flow (gal)	BOD (lb)	SS (lb)	Other
Brewery	370			
per barrel		1.9	1.03	
Cannery	75			
per case		0.7	0.8	Total Dissolved Solids
Dairy				
per 100 lb				
Creamery butter	410-1350	0.34-1.68	---	
Cheese	1290-2310	0.45-3.0	---	
Condensed and evaporated milk	310-420	0.37-0.62	---	
Ice Cream	620-1200	0	---	
Milk	200-500	0.05-0.26	---	
Meat Packing per 100 live wt. killed				
old technology	2112	20.2	---	
typical technology	1294	14.4	---	
advanced technology	1116	11.3	---	
Poultry Processing				
per 1000 birds				
old technology	4000	31.7	---	
typical technology	10400	26.2	---	
new technology	7300	26.0	---	
Petrochemical Plants				Phenol Sulfide
Petroleum Refining				
per barrel				
old technology	250	0.4	---	0.03 0.01
typical technology	100	0.1	---	0.01 0.003
newer technology	50	0.05	---	0.005 0.003
Pulp & Paper				
per ton				
Bleached Kraft				
old technology	110,000	200	200	
prevalent technology	45,000	120	170	
new technology	25,000	90	90	
Bleached Sulfite				
old technology	95,000	500	120	
prevalent technology	55,000	330	100	
new technology	30,000	100	50	
Steel Mill				
per ingot ton				
old technology	9,860	---	103	Phenols, cyanides
prevalent technology	10,000	---	125	
new technology	13,750	---	184	Fluorides, ammonia, oil, acids, emulsions, soluble metals
Tannery				
per 100 lb	660	6.2	13.0	
Textile				
per pound of cloth				
Wool	63	0.30	---	
Cotton	38	0.16	0.07	
Synthetic				
Rayon	3-7	0.02-0.04	0.02-0.09	
Acetate	7-11	0.04-0.05	0.02-0.06	
Nylon	12-18	0.04-0.06	0.02-0.04	
Acrylic	21-29	0.10-0.15	0.03-0.15	
Polyester	8-16	0.12-0.25	0.03-0.16	

The Cost of Clean Water, Volume III, Industrial Waste Profiles, Federal Water Pollution Control Administration, U. S. Department of the Interior, Washington, D. C., (1968).

No. 1 Blast Furnaces and Steel Mills
No. 3 Pulp and Paper
No. 4 Textile Products
No. 5 Petroleum Refineries
No. 6 Canneries
No. 7 Leather Tanning and Finishing
No. 8 Meat Products
No. 9 Dairies

TABLE A-4

Petro-Chemical Wastewater Characteristics

From Gloyna, 1970.

Chemical Product	Flow (gal/ton)	BOD (mg/l)	COD (mg/l)	Other Characteristics
Primary Petrochemicals:				
Ethylene	50-1,500	100-1,000	500-3,000	phenol, pH, oil
Propylene	100-2,000	100-1,000	500-3,000	phenol, pH
Primary Intermediates:				
Toluene	300-3,000	300-2,500	1,000-5,000	
Xylene	200-3,000	500-4,000	1,000-8,000	
Ammonia	300-3,000	25- 100	50- 250	oil, nitrogen, pH
Methanol	300-3,000	300-1,000	500-2,000	oil
Ethanol	300-4,000	300-3,000	1,000-4,000	oil, solids
Butanol	200-2,000	500-4,000	1,000-8,000	heavy metals
Ethyl Benzene	300-3,000	500-3,000	1,000-7,000	heavy metals
Chlorinated Hydrocarbons	50-1,000	50- 150	100- 500	pH, oil, solids
Secondary Intermediates:				
Phenol, Cumene	500-2,500	1,200-10,000	2,000-15,000	phenol, solids
Acetone	500-1,500	1,000-5,000	2,000-10,000	
Glycerin, Glycols	1,000-5,000	500-3,500	1,000-7,000	
Urea	100-2,000	50- 300	100- 500	
Acetic Anhydride	1,000-8,000	300-5,000	500-8,000	pH
Terephthalic Acid	1,000-3,000	1,000-3,000	2,000-4,000	heavy metals
Acrylates	1,000-3,000	500-5,000	2,000-15,000	solids, color, cyanide
Acrylonitrile	1,000-10,000	200- 700	500-1,500	color, cyanide, pH
Butadiene	100-2,000	25- 200	100- 400	oil, solids
Styrene	1,000-10,000	300-3,000	1,000-6,000	
Vinyl Chloride	10- 200	200-2,000	500-5,000	
Primary Polymers:				
Polyethylene	400-1,600		200-4,000	solids
Polypropylene	400-1,600		200-4,000	deashing solvents
Polystyrene	500-1,000		1,000-3,000	solids
Polyvinyl Chloride	1,500-3,000	50- 500	1,000-2,000	
Cellulose Acetate	10- 200	500-2,000	1,000-5,000	
Butyl Rubber	2,000-6,000	800-2,000	2,500-5,000	
Dyes and Pigments:	50,000-250,000	200- 400	500-2,000	heavy metals, color, solids, pH
Miscellaneous Organics:				
Isocyanate	5,000-10,000	1,000-2,500	4,000-8,000	nitrogen
Phenyl Glycine	5,000-10,000	1,000-2,500	4,000-8,000	phenol
Parathion	3,000-8,000	1,500-3,500	3,000-6,000	solids, pH
Tributyl Phosphate	1,000-4,000	500-2,000	1,000-3,000	phosphorus

Activated sludge is the general name applied to a number of similar processes which involve the introduction of oxygen into a system containing a mixture of suspended bacterial growth (activated sludge) and the dissolved organic material in the wastewater. The effluent of trickling filter and activated sludge plants contains between 12 and 45 mg/L of 5-day BOD and generally less than 20 mg/L of suspended solids.

The destruction of disease causing bacteria remaining after primary and/or secondary treatment is generally accomplished by adding chlorine to the plant effluent. The chlorine also reacts with organic material and no free chlorine is found in the effluent entering the receiving stream.

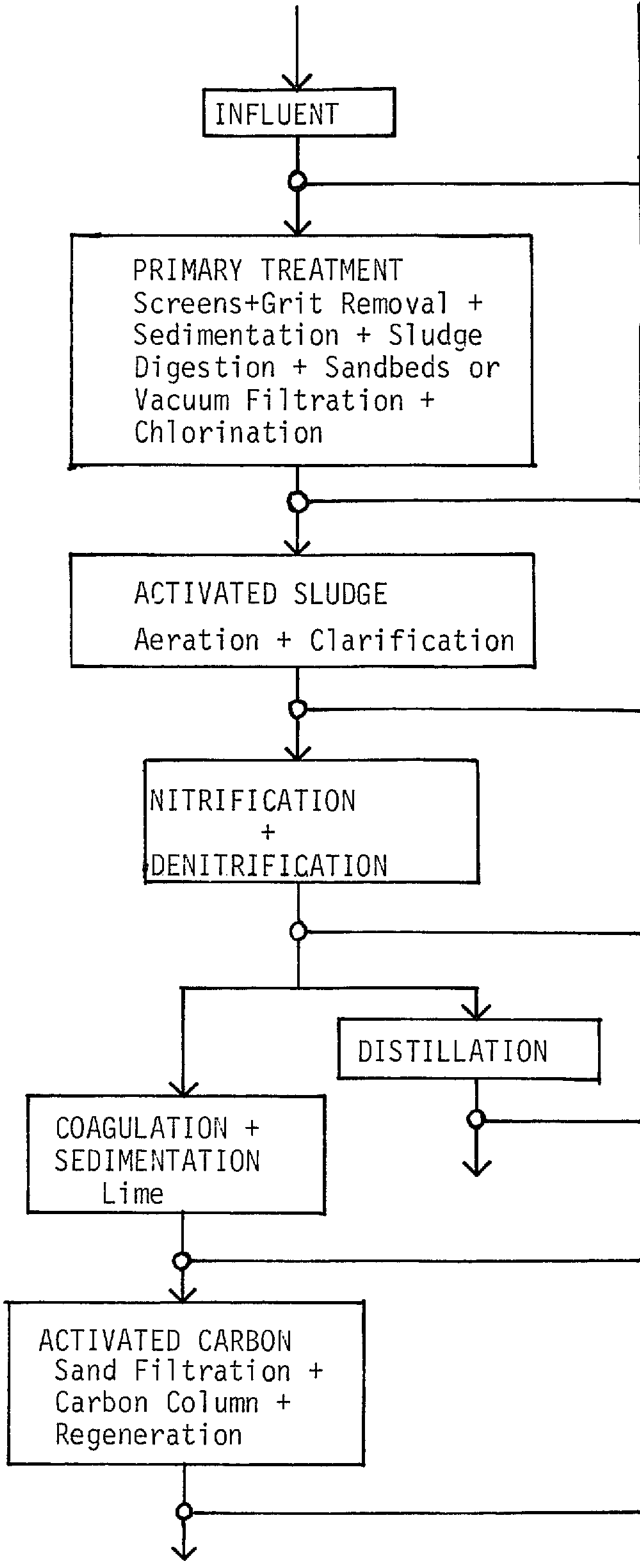
Tertiary treatment or water renovation systems include processes which will remove those substances which persists after primary and biological treatment. The typical persistent materials and methods of removal of the refractory materials are:

- Suspended solids which may be removed by filtration through sand or diatomaceous earth or other granular media or by microstraining;
- Dissolved organic materials which may be removed by adsorption on activated carbon,
- Inorganic substances measured as total dissolved solids (TDS) which may be removed by ion exchange, and
- Nutrients such as phosphorous which may be removed by chemical precipitation and nitrogen which may be eliminated biologically or by air stripping.

A typical sequence of processes for the treatment of municipal wastewater is illustrated schematically in Figure A-7. The quality of the effluent of the various unit processes is also included in the illustration.

Industrial

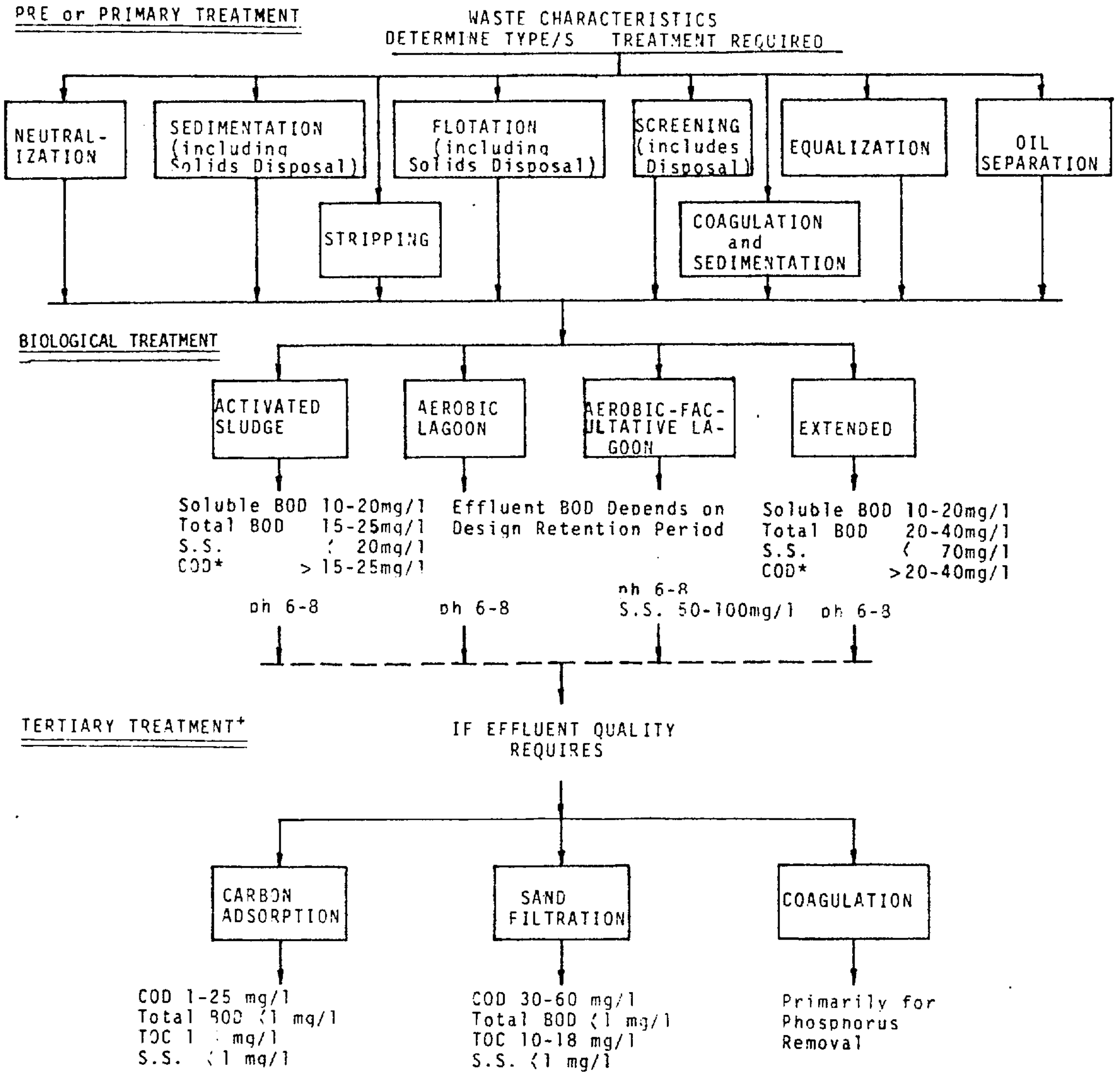
The sequence of processes and alternatives which may be used for the treatment of industrial wastewaters are shown in Figure A-8. The possible effluent quality of each process is also included. The efficiencies of the individual processes and combinations used in practice for the treatment of specific wastewaters are summarized in Table A-5.



BOD mg/L	SS mg/L	PO$_4$ mg/L as PO$_4$	NH$_3$ mg/L as N	ORG mg/L as N	TDS mg/L	COD mg/L
200	250	40	30	20	620	550
132	103	40	30	16	620	275
12	<20	26	20	5	435	100
12	<20	26	<1	<4	435	100
<2	0	<1	<1	<1	50	<5
10	5	<1	<1	<4	---	40
<1	0	<1	<1	<4	---	12

FIG. A-7: UNIT PROCESS FLOW DIAGRAM AND EFFLUENT COMPOSITION FOR MUNICIPAL WASTE WATER TREATMENT

FROM: MALINA AND ECKENFELDER, 1967.



* The COD, which includes the non-biodegradable fraction, can assume any value above the total BOD value.

\+ The effluent qualities given are for domestic sewage.

FIGURE A-8

FROM: ECKENFELDER, 1967

TABLE A-5

Reported Wastewater Treatment Process Efficiencies

From Eckenfelder, 1967.

INDUSTRY	TYPE OF TREATMENT	REMOVAL EFFICIENCIES - %		
		SS	BOD	OTHER- as indicated
Pulp & Paper	Primary Clarifier	65-90	15-40	
	Secondary**			
	Activated Sludge*	75-90	81-96	
	Aerated Lagoon	79-91	65-90	
	Trickling Filter	-	57-90	
Chemical	Primary (Includes Clarification, Neutralization, Floatation, Coagulation, etc.)	90-100	4-50	
	Secondary**			
	Activated Sludge	-	51-99	
	Extended Aeration	83-93	80-99	
	Aerated Lagoon	-	61-71	
	Activated Sludge*			
	Trickling Filters	-	72-99	
Meat Packing	Primary			
	Anaerobic Lagoon	67-98	65-95	
	Anaerobic Contact	90	92	
	Screening	32	27	
	Secondary**			
	Anaerobic Treatment* Facultative or Aerobic Ponds	81-98	93-99	
Petroleum	Primary (API Separator, Clarification, Coagulation, Floatation, etc.)	63-75	-	27-23 COD
	Secondary**			
	Aerated Lagoons	-	-	50-80 COD
	Trickling Filter	-	-	20-92 COD 46-96 Phenol
	Activated Sludge	-	-	60-70 COD 85-100 Phenol
	Extended Aeration	-	-	50 COD
Dairy	Secondary			
	Extended Aeration	neg. -81	90	
	Aerated Lagoons	-	75	
	Trickling Filter	32-91	60-71	

**Includes contact stabilization*

***Includes primary treatment when used*

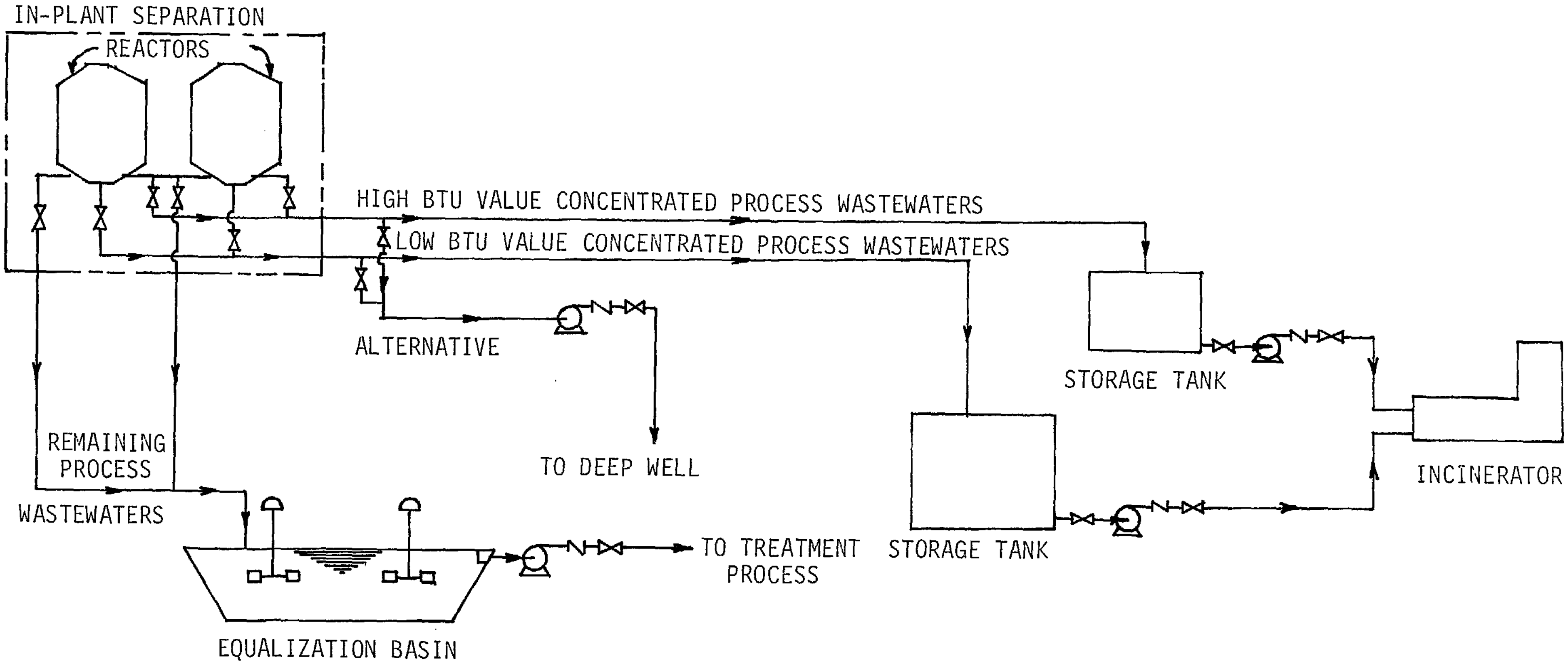
Petrochemical plants comprise one of the major sources of industrial wastewaters in the Coastal Zone; therefore, a generalized treatment scheme for these wastewaters is presented in Figures A-9 and A-10. Industrial plants generally provide biological treatment in the form of activated or aerated lagoons or a combination of anaerobic and aerobic processes depending on the required effluent quality. At the present time filtration, adsorption and ion exchange (processes 8, 9 and 10 in Figure A-10) are considered tertiary treatment and very few, if any, industrial plants include these processes for the treatment of process wastewaters. Cooling water and boiler water blowdowns at petrochemical plants are generally considered clean water effluents. The composition of and source of these waters are summarized in Table A-6. These clean effluents may be treated with the process waters, treated separately in some cases or discharged directly into the receiving stream. In the case of cooling water, some artificial means such as once-through ponds, towers etc., generally is used.

Some industrial wastewaters are difficult to treat and treatment to meet regulatory standards is considered to be economically unfeasible. These industrial wastewaters are injected into subsurface porous strata, sealed by impervious strata, and isolated from useable underground water supplies or minimal resources. Such unfractured sedimentary formations generally can store large volumes of wastes. This group includes sandstones, limestones, and dolomites. Unconsolidated sands also are generally excellent disposal formations. Fractured strata should be avoided since vertical fissure may exist and the injected waste may travel vertically towards useable water supplies. Disposal walls vary in depth from a few hundred feet to about 15,000 feet. The capacity of various wells ranges from less than 10 to more than 2,000 gallons per minute. Waste disposed of in injection wells includes streams containing acids, alkalies, chlorides, chromium, cyanides, high BOD wastes, nitrates, phosphates, radioactive wastes, and others which are difficult or more expensive to dispose of by other methods. The disposal system consists of a well and surface equipment such as pumps and pretreatment equipment which are necessary to remove constituents of the waste which may interfere with subsurface disposal.

Some of the brines from the exploration for natural gas and oil are injected into the ground in water flood operations. However, the discharge of these brines into surface waters and into the ground water by seepage from unlined pits and lagoons can cause potential problems.

FIGURE A-9: FLOW OF WASTEWATER TREATMENT FACILITIES

FROM: FEDERAL WATER POLLUTION CONTROL ADMINISTRATION, 1968 (B).



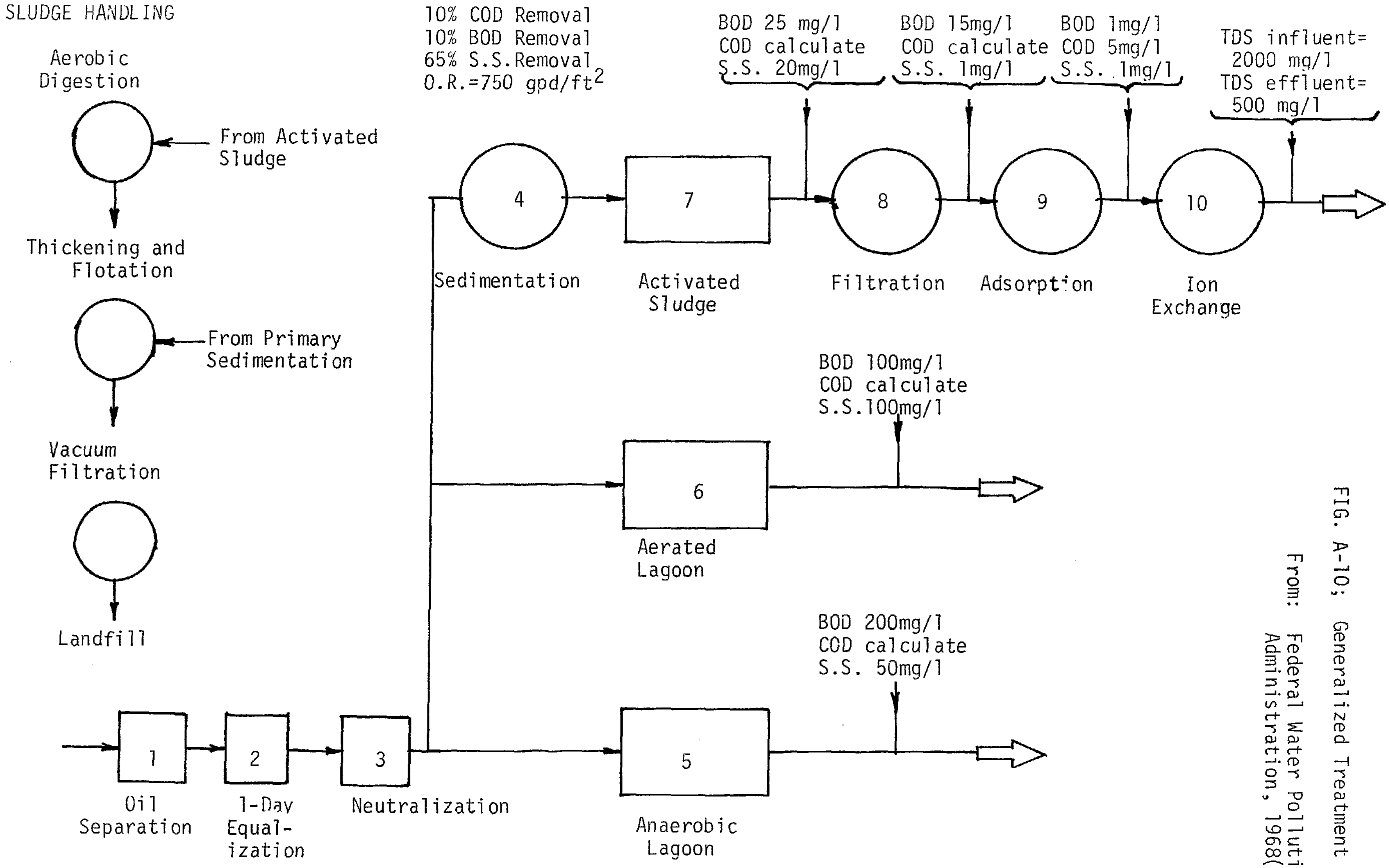


FIG. A-10; Generalized Treatment Processes

From: Federal Water Pollution Control Administration, 1968(a)

TABLE A-6

Composition of Typical Clean Water Effluent

Water Sources	% of Total Waste Water	Flow Range (GPM)	Potential Pollutants		Concentration Range (ppm)
			Sources	Type	
Cooling Water (excluding sea water)	40-80	100-10,000 (500-200,000 gal. water ton product)	Process leaks: Bearings, exchangers, etc.	Extractables	1-1,000
				Mercaptans	
				Sulfides	
				Phenols	0-1,000, but usually less than 1 ppm
				Cyanide	
				Mics. N. compounds	
				Acids	
			Water treatment	Chromate	0-60
				Phosphate	0-60
				Heavy Metals	0-30
				Fluoride	0-30
				Sulfate	100-10,000
				Biocides, algacides	0-50
				Misc. organics	0-100
			Scrubbed from air through tower	Hydrogen sulfide	
				Sulfur dioxide	0-1,000
				Oxides of nitrogen	
				Ammonia	
				Particulates	0-300
			Make-up Water	Total dissolved solids	100-5,000
				Particulates	0-100
				Phosphates	0-5
				Fluoride	0-2
Steam Equipment	10	50-1,000	Boiler Blowdown	Total dissolved solids	500-10,000
				Particulates	5-300
				Extractables	0-10
				Phosphate	1-50
				Sulfite	0-50
				Sulfide	0-5
				Misc. organic compounds	0-200
				Misc. N. compounds	1-100
				Heavy metals	0-10
				Alkalinity	50-400
			Waste Condensate	Extractables	0-100
				Ammonia	0-10

Source: Freedman, A. J., et. al., *National Petroleum Refiners Association, Tech. GC-67-19, 1967*

Summary

The municipal and industrial wastewater load to the environment can be determined from the data presented in Tables A-2 through A-6 and in Figures A-5 and A-10. The quality of the effluent from municipal and industrial wastewater treatment plants is affected by the characteristics of the influent wastewater, by the operation of the plant and the adequacy of the facility to handle the present wastewater flows as well as the daily fluctuations of the influent wastewater.

SOLID WASTES

Solid wastes include a broad spectrum of materials which are no longer useful to man or for industrial purposes in their present form. A general classification of solid wastes which may be generated in a municipality is presented in Table A-7. Most municipalities collect and dispose of "ordinary refuse", "bulky waste," and in many cases "abandoned vehicles." The extent to which municipal service is provided to small businesses, restaurants, commercial establishments and industry is determined by the policy established by individual municipality or local government.

Municipal Refuse

The composition of ordinary municipal refuse is presented in Table A-8. It is interesting to note that paper and paper products constitute more than 40 percent of the weight of the refuse and that garbage constitutes only ten percent of the weight. The use of household disposal units will reduce the quantity of garbage that enters the refuse collection system but will increase the load of suspended solids and BOD which must be handled at the municipal wastewater treatment plant. The relative percentage of glass, paper, metals, and plastics will depend on the packaging industry, although an increase in the quantity of paper and paper products can be expected. The average refuse production rate in the coastal zone is 5.12 lb/capita/day (Malina, 1970) which compares well with the national average of 5.0 lb/capita/day.

Abandoned automobiles pose serious problems. The results of a 1966 study of Solid Waste Production in Selected Texas Cities indicate that 1.6 passenger vehicles were abandoned for each 1,000 people (Malina and Smith, 1968).

A. *Ordinary Refuse*

1. Garbage includes animal and vegetable residue resulting from the preparation, cooking and eating of food. This material is readily decomposed and is generally the cause of the foul odors associated with domestic solid wastes.
2. Rubbish or trash includes all other materials which are generally discarded by a homeowner, resident, small business, commercial establishment or restaurant. A portion of this material is burnable.
3. Yard trimmings include debris from cutting lawns, pruning, etc., but excludes branches longer than 3 feet in length and tree stumps.
4. Small dead animals includes dogs, cats, squirrels, etc., which are accidentally killed on public streets or roads.
5. Street refuse - litter from receptacles.

B. *Bulky or Oversized Wastes*

Discarded stoves, refrigerators or other large appliances and sofa, stuffed chairs or other large pieces of furniture, as well as large branches, fallen trees, and tree stumps.

C. *Abandoned Vehicles*

D. *Industrial Wastes*

E. *Demolition Wastes*

F. *Construction Wastes*

G. *Hospital Wastes*

H. *Hazardous Wastes*

Includes explosive toxic or radioactive liquids and solids

I. *Water and Wastewater Treatment Plant Sludges*

TABLE A-7

Classification of Solid Wastes

Component	Dry Weight Percent
Paper & Paper Products	40-65
Garbage & Putrescibles	8-12
Yard Trimmings	6-15
Plastics	1- 4
Other Combustibles (textiles, leather goods, rubber, etc.)	2- 5
Non-Combustibles (ferrous & non-ferrous metals, glass & ceramics, ashes, etc.)	15-30

From Malina and Makela, 1971.

TABLE A-8

Composition of Municipal Refuse

Acceptable methods of refuse disposal include sanitary landfill, incineration, composting, and sorting followed by disposal of the unrecyclable material usually in a sanitary landfill. The majority of solid wastes are disposed of on the land; therefore, a brief description of this method is presented.

A sanitary landfill includes the placement of the refuse on the ground or in a prepared trench and compacted with a caterpillar bulldozer or similar equipment. The compacted refuse is covered at the end of each operating day with about six inches of compacted soil. No burning of the refuse is permitted at the landfill site and proper drainage of the site is provided.

The pollution of ground water can take place only if the following conditions exist:

- The sanitary landfill is in a permeable formation directly above or adjacent to an aquifer,
- The refuse in the sanitary landfill becomes supersaturated because of percolation of rainfall, pooling of surface water, or flow of ground water, and
- Leached fluids are produced and the leachate enters the aquifer.

The geology, topography and subsurface and surface water resources at the proposed site should be carefully evaluated. The site which provides the least potential for water pollution should have prime consideration.

Open burning of refuse at dumps, although it is controlled by the Air Control Board, often contributes to the particulate and gaseous emissions to the atmosphere which constitute air pollution. The organic material in the refuse provides a good breeding place for flies. In the warm summer months, the time for flies to develop from the egg stage to adult is about 5 to 7 days. Although flies have not been directly incriminated with the transmission of diseases from refuse to humans, the flies are a nuisance. The garbage in the refuse also provides a source of food for rats. Therefore, an open dump is generally infested with rats which in turn can migrate from the dump to adjacent housing. Water that accumulates in discarded containers provides a breeding place for mosquitoes which in turn are vectors for the transmission of diseases such as encephalitis, malaria, and yellow fever. Of these diseases, encephalitis is probably the most common and of most concern in the Coastal Zone.

Incineration of refuse includes the destruction of the combustible portion of the refuse at a temperature in excess of 1400°F. Effective combustion requires sufficient time, oxygen, turbulence and temperature. The residue is usually quenched in water and in time the flyash in the gas stream is also removed from the exhaust gas in a water system. An air pollution problem can develop if adequate gas cleaning is not provided and discharge of the quench and scrubber waters into water courses without treatment and cooling could cause water pollution problems.

Composting on the other hand, is a biological process in which the putrescible and biodegradable fraction of the solid waste is converted to a stable innocuous soil conditioner through microbial action. A market for the finished compost must exist if this process is employed; otherwise, the solid wastes are merely converted to another form for residual disposal. Sorting of paper, ferrous and non-ferrous metals and glass which can be recycled and the non-degradable plastics should precede composting. Therefore, the amount of material to be composted based on the data in Table A-8 would be about 35 percent of the incoming refuse at a maximum and probably less than 20 percent. A market for the reclaimed paper metals and glass must exist if sorting and recycle is practiced.

Industrial Solid Wastes

The characteristics of industrial solid wastes are as varied as the industries. A very limited amount of information regarding the characteristics of industrial solid waste is available. These residues frequently include packaging materials such as wood and paper. Solid wastes from processing usually include plastics, metals, wood, and other wastes. The remainder of industrial solid wastes result from the treatment of water and liquid wastes. Most industrial plant sites will store the sludges from water and wastewater treatment in lagoons on the plant site, if land is available. Otherwise, these residues and other semi-solid residues are hauled off for disposal by private collections. Most of the combustible residues in solid wastes in industrial plant sites are incinerated at the plant site or collected by a private collection agency for disposal at some other site.

Water and Wastewater Sludges

Sludge and residues resulting from the treatment of water for municipal and industrial supplies and from the treatment of municipal and industrial wastewaters also present a solid waste disposal problem. The quantity of sludge produced during treatment of water is affected by the quality of the raw water supply, the chemicals added, the degree of treatment required to make the water suitable for municipal water supply, or for the specific industrial purpose. The water treatment sludges generally contain chemical precipates and the sludges are difficult to concentrate and contain sufficient quantities of putrescible organic material which produces offensive odors.

The characteristics of the wastewaters and the degree of treatment will determine the quantity of sludges from municipal and industrial wastewater treatment. These sludges generally contain putrescible organic material which readily decompose resulting in obnoxious odors. Characteristics of sewage sludges are summarized in Table A-9. These sludges require some type of treatment and disposal. Sludge handling, concentration, treatment and disposal processes used in practice are presented schematically in Figure A-11. The residual solids may be buried or placed on the land as a soil conditioning agent. The disposal of the solid residue and sludges from the treatment of wastewaters may result in pollution of ground and surface waters if improperly disposed of on land and air pollution if proper air cleaning is not furnished during incineration.

Animal Waste

The production of animals such as beef cattle, milk cows, hogs, sheeps and lambs, chickens, and turkeys present a solid waste management problem and can be a source of water pollution. The characteristics of animal waste are presented in Table A-10. The information in this table shows that for beef cattle, each animal produces wastes which have the same strength of the waste produced by 3.5 humans based on the total pounds of Biochemical Oxygen Demand (BOD) produced. The potential for pollution of surface and ground waters as the result of runoff from rainfall from these areas where animals have grown in high concentration is quite evident.

The effective handling, treatment and disposal of these concentrated wastes must be included in any animal waste management program. The disposal methods represent additional costs; therefore, a wide variety of systems are employed. The degree of treatment ranges from almost no treatment to extensive waste processing similar to that presented for liquid industrial wastes.

AIR POLLUTION

Atmospheric emissions constitute a major waste input in the Coastal Zone. The removal of gases and particulate material from these effluents, using air control devices using liquid as an adsorbent or absorbent, could result in a liquid waste or a residue that requires disposal. The industrial gaseous emissions into the atmosphere include nitrogen oxides, sulfur oxides, hydrocarbons, carbon

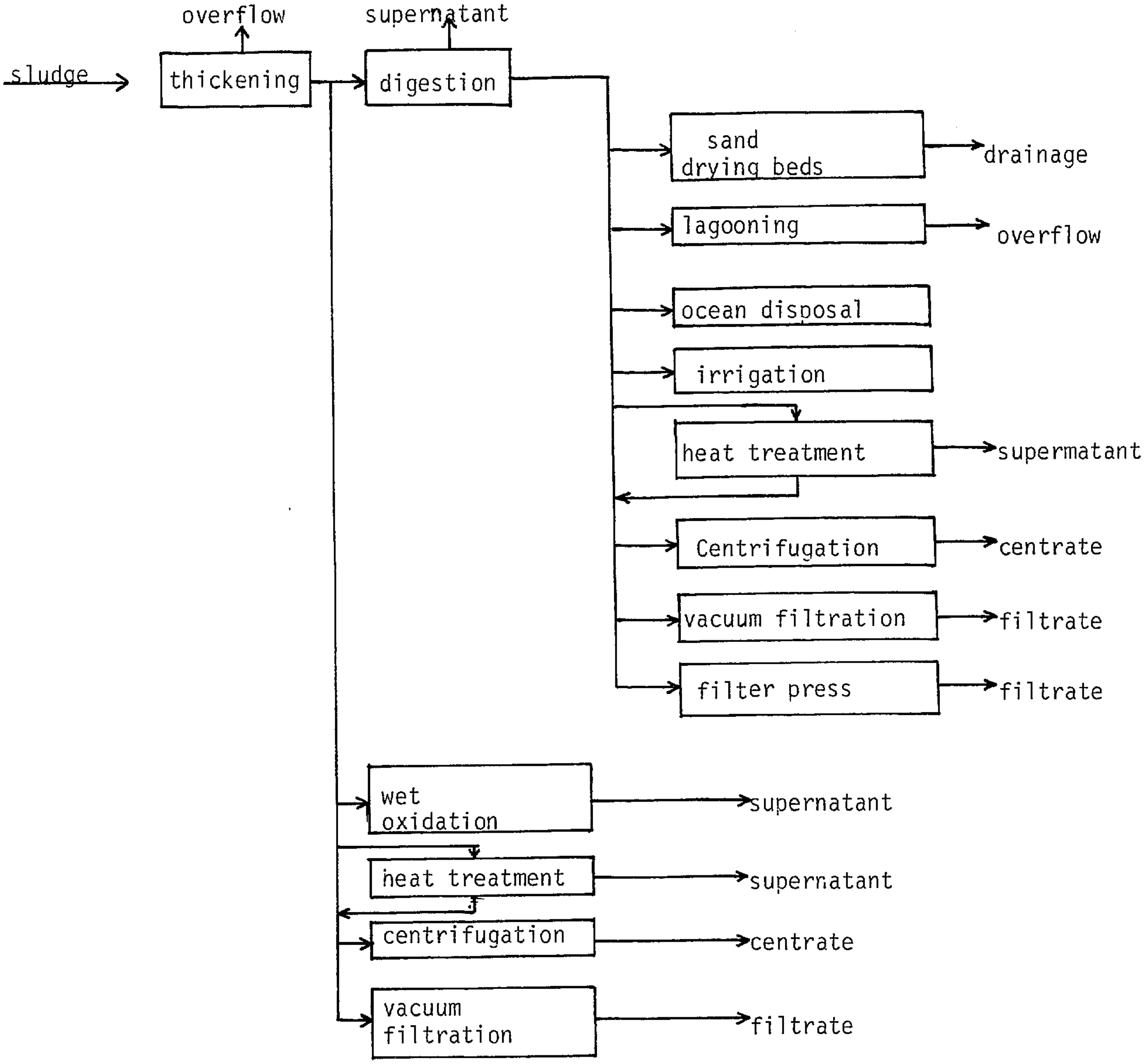


FIG. A-11; SLUDGE HANDLING TECHNIQUES... From: Malina and DiFilippo, 1971.

TABLE A-9

Average Chemical Constituents of Sewage Solids and Sludges, Per Cent on Dry Weight Basis

From Malina and DiFilippo, 1971. Hunter and Heukelekian, 1965.

	Fresh	Activated	Digested
Organic	60-80	65-75	45-60
Total Ash	20-40	25-38	40-55
Insoluble Ash	17-35	22-30	35-50
Grease and Fat (Ether)	7-35	5-12	3.5-17
Nitrogen (N)	4.50	6.20	2.25
Phosphoric (P_2O_5)	2.25	2.50	1.50
Iron (Fe_2O_3)	3.20	7.20	6.00
Chlorides (Cl)	0.50	0.50	0.50
Moisture Content prior to drying (per cent)	94-97	99	88-94

TABLE A-10

*Characteristics of Animal Wastes**

	Beef Cattle	Dairy Cattle	Swine	Sheep	Poultry
Animal Weight (lb)	950	1400	200	100	5
Manure Produced (lb/day)	60.0	80.6	17.4	7.2	0.4
Dry Solids (lb/day)	10.0	10.6	0.9	1.7	0.1
BOD (lb/animal/day)	1.0	1.0	0.3	-----	0.02
Total Nitrogen (lb/animal/day)	0.3	0.4	0.05	-----	0.003
Population Equivalent**	3.5	-----	0.90	0.31	-----

**Livestock Industries in Texas as Related to Water Quality, Preliminary Report, Texas Water Quality Board, June, 1970.*

***Population Equivalent is the number of humans required to produce the same amount of BOD produced by one animal. These numbers are based on the contribution to the BOD of municipal wastewater attributable to the organic material in human excrement.*

monoxide, hydrogen sulfide, sulfuric acid, flourides, and other compounds. Water vapor is also gaseous but is considered relatively harmless and not an air pollutant in the same sense as chemical compounds.

Each industry has characteristic emissions which are unique to an industrial category or classification. Some typical emissions for industrial and agricultural activities are summarized in Table A-11. The quantity and quality of gaseous and particulate emissions is related to the rate and type of raw material used, the process applied and the effectiveness of the air pollution control equipment which is installed, if, in fact, any air cleaning devices are used.

The industrial emissions have the most direct effect on the environment immediately adjacent to the source of the emissions. In many cases the industrial emissions to the atmosphere are manifested by visible plumes at plant sites. This dramatic emission of colored plumes, particulate materials and chemical mists, etc., may travel some distance and affect the health and property of individuals at relatively remote locations. Odors may be the principle indicator of industrial emissions when no plume is obvious.

RESEARCH NEEDS

A more accurate appraisal of the quantities and characteristics of the waste inputs in the Coastal Zone is required. The costs of eliminating or reducing the waste inputs to levels prescribed by regulatory agencies must be developed. The impact on the economy of the Coastal Zone and on the quality of the bays and estuaries can then be evaluated.

TABLE A-11

Classification of Industrial Emissions

From Malina, 1970.

Type of Industry	Emissions
Chemical Industry	
Ammonia Plant	Ammonia fumes, carbon monoxide
Chlorine Plant	Chlorine, gas, liquid chlorine, mercury
Nitric Acid Plant	Nitric oxide, nitrogen dioxide, acid mist
Paint and Varnish Manufacturing	Fumes, aldehydes, ketones Phenols, terpenes, particulates
Phosphoric Acid Plants	P_2O_5 Acid mist, nitrogen oxides
Phosphoric Acid	Gaseous fluorides
Fertilizer Plant	Silicon Tetrafluoride, hydrogen fluoride
Sulfuric Acid Plant	Sulfur dioxide, acid mist
Food and Fiber Industry	
Cotton Ginning	Particulates, dust
Coffee Roasting	Particulates, smoke, odors
Feed and Grain Mills	Dust
Metallurgical Industry	
Aluminum Ore Reduction	Particulate alumina, carbon and fluorides, gaseous fluorine
Copper Smelters	Carbon monoxide, sulfur oxides, nitrogen oxides and fine particulate fumes
Iron and Steel Mills	Particulates, fumes, smoke, particulate lead fumes
Lead Smelters	Lead fumes, sulfur dioxide
Zinc Smelters	Particulates, fumes, sulfur dioxide
Secondary Metals Industry	
Ferrous Metals	Particulates
Aluminum	Fine particulates, gaseous chlorine and fluorine
Brass and Bronze Smelting	Particulates, zinc oxide fumes
Gray Iron foundary	Particulates
Lead Smelting	Particulates, sulfur compounds
Magnesium Melting	Particulates
Zinc Processes galvanizing, calcining smelting and sweating	Particulates
Mineral Products Industry	
Asphalt Roofing	Particulates, oil mist
Asphaltic Concrete Plant	Particulates
Calcium Carbide Plant	Acetylene, sulfur dioxide, sulfur trioxide, particulates
Cement Plant	Dust
Concrete Batch Plant	Particulates
Frit Manufacturing Plant	Particulates, condensed metallic fumes, fluorides
Glass Manufacturing Plant	Particulates, fluorides
Lime Manufacturing Plant	Particulates
Insulation Manufacturing Plants	Asbestos fiber, rock wool fibers
Petroleum Refinery	Hydrocarbons, particulates, nitrogen dioxide, carbon monoxide, aldehydes, ammonia
Plastics	Ethylene, methacrylate
Petrochemical Plants	Losses of intermediate and final product
Pulp and Paper Industry	Particulates, hydrogen sulfide, methyl mercaptan, dimethyl sulfur
Dry Cleaning Plants	Chlorinated hydrocarbons, tetrachloroethylene, petroleum solvents, hydrocarbon vapors
Metal Scrap Yards	Smoke, soot
Rendering Plant	Organic vapors, odors
Agricultural Activities	
Crop spraying and dusting	Organic phosphates, chlorinated hydrocarbons, arsenic and lead
Field Burning	Smoke, flyash, soot
Refuse Incineration	Particulates, flyash
Open Dump Refuse Burning	Particulates, odors, hydrocarbons, smoke

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APPENDIX B

CRITERIA FOR BAY AND ESTUARINE USES

In this appendix, the coastal zone activities will be limited to those that are dependent on the water and sediments of the bays and estuaries. The physical, chemical and biological qualities of bay and estuarine water and sediment vary widely in nature. Such quality conditions are a product of changes that occur from the moment of entering the environment by any process from the land, open sea, or air, each of which reflect a multitude of possible combinations. Thus, the most difficult task in defining use criteria is the evaluation of quality along baseline or natural conditions. Furthermore, even the term quality is relative because it is often dependent on the use to be assigned.

CRITERIA FOR TEXAS BAYS AND ESTUARIES

During the past many months, state and federal agencies have been active in developing water quality criteria and control programs to meet the requirements of the Water Quality Act of 1965 (National Academy of Sciences 1966). Figure B-1 illustrates a concept proposed by this 1965 committee on pollution.

The Water Quality Act specifies that water quality criteria and a plan of implementation be adopted by each state on their interstate waters, and approved by the Secretary of the Interior. Such criteria and plan then shall be used to promulgate the water quality. Criteria are defined as the scientific requirements on which a decision or judgment may be based concerning the suitability of water quality to support designated use. A standard is a plan that is established by governmental authority as a program for water-pollution prevention and abatement as specified in the report of the National Technical Advisory Committee on Water Quality Criteria (Federal Water Pollution Control Administration, 1968).

It is immediately obvious, when one scientifically considers the complexity of an environment, especially that of Texas, the criteria will in all probability never be equivocally defined. The physical, chemical and biological parameters of the water and sediments are so

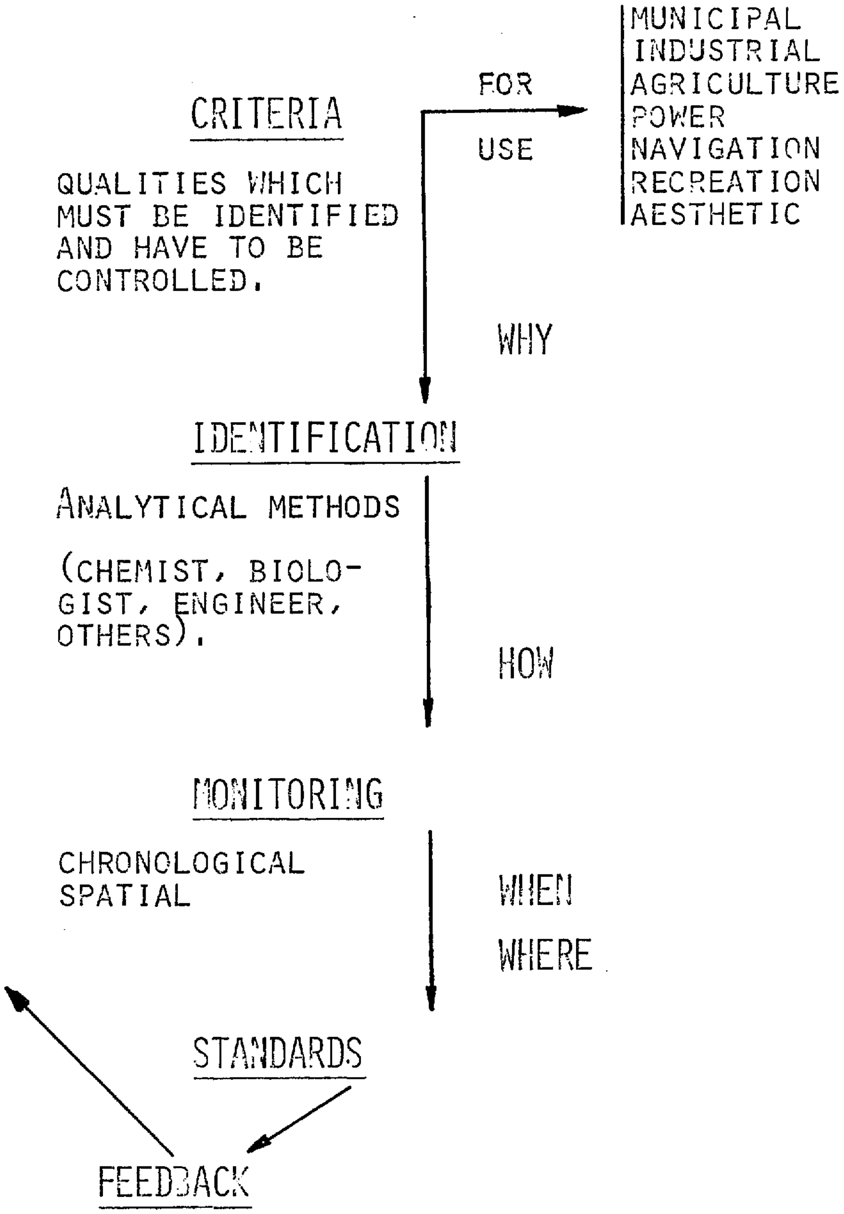

FIG. B-1: PROCESS FOR DEVELOPING WATER QUALITY STANDARDS interrelated and complex as to be analytically indescribable at the present state of science and technology. Therefore, any criteria or standard as defined above can only be relative to the obvious parameters and dictated by esthetic aspects, economic importance and specific use.

Water quality standards for the State of Texas have been developed and water uses assigned as a result of 30 public hearings and the best judgment of the Texas Water Quality Board staff; these standards were subsequently approved by the Federal Government. These water quality criteria are not as comprehensive as they conceivably might be and will probably be upgraded in the future as more information regarding the quality of the bays and estuaries becomes available.

For identification the waters of the State of Texas are divided into inland and tidal waters. The tidal waters include the waters of the Gulf of Mexico within the jurisdiction of the State of Texas, bays, estuaries, and those portions of the river system which are subject to ebb and flow of tides and the intrusion of marine waters. The salinity of tidal waters restricts their use to the following:

- Contact recreation,
- Non-contact recreation,
- Propagation of fish and wildlife,
- Fishing,
- Aesthetics,
- Navigation,
- Industrial cooling water, and
- Mining and recovery of minerals.

Some portions of the tidal waters have more limited use allocated to them in the standards. Exceptions to the water uses indicated above for tidal waters include:

> The Neches River tidal portion designated as Taylor Bayou below the barrier which may be used only for non-contact recreation, fishing, aesthetics, navigation, and industrial cooling water;

> The Houston Ship Channel from the San Jacinto Monument to the Turning Basin be limited to non-contact recreation, aesthetics, navigation and industrial cooling water;
>
> The Houston Ship Channel in the Turning Basin area, the Corpus Christi Ship Channel and Brownsville Ship Channel be limited to use for aesthetics, navigation and industrial cooling.

The water quality criteria for tidal waters, includes chlorides, sulfates, total dissolved solids, (TDS), biochemical oxygen demand (BOD), dissolved oxygen (DO), pH, most probably number of coliform organisms (MPN), temperature, toxic materials, free or floating oil, foaming or frothing materials, radioactive materials, and other materials. Quantitative data for the chlorides, sulfates, TDS, BOD, DO, pH and coliform concentration are listed for the various tidal waters. The maximum increase in temperature during the fall, winter, and spring is set at 4°F and that for the summer months is 1.5°F over ambient water temperature.

The control of other substances not included in the criteria must be guided by the U. S. Public Health Service manual, Sanitation of Shellfish Growing Areas, 1965 revision. In those waters which are not considered shellfish growing areas there is a requirement that the water entering or contiguous to a shellfish growing area not interfere with the shellfish growing area.

Toxicity and toxicants which may cause acute or chronic toxicity which will impair the use of the water should not be present in the bays and estuaries. The water should also be substantially free of floating oils and no foaming or frothing materials of a persistent nature should be present in the water. The water should contain no taste and odors that will taint fish, including shellfish.

More specific details regarding the water uses permitted and the water quality criteria are included in Water Quality Standard Summary, prepared by Texas Water Quality Board and the U.S. Department of the Interior, Federal Water Pollution Control Administration, September, 1969.

PRESENT USES OF TEXAS BAYS AND ESTUARIES

A review of the uses of bays and estuaries indicates major categories such as sustenance of living systems, recreational enjoyment, transportation, human habitats, water supply, waste disposal, mineral resources and specific definable uses. These categories are discussed in general.

Sustenance of Living Systems

Although it is difficult to categorize the habitats of estuarine organisms (particularly the highly mobile fishes) in relation to a single environmental factor, it is reasonable to provide the following related general classification based on salinity:

Freshwater forms that occasionally enter brackish water.

True estuarine species that are confined to the estuary waters and sediments.

Anadromous (species that go up the estuaries and rivers to spawn) and catadromous (species that go down the river and out to sea to spawn).

Marine species that seasonally enter estuaries, usually as adults.

Marine species that utilize the estuary as a nursery.

Occasional marine visitors with apparently no estuarine environment.

All but the first, freshwater species, and the last category are estuarine dependent in that they utilize the estuary at some stage in their life history. Most of the Texas fishery is based upon estuarine-dependent species. Examples are menhadden *(Brevoortia)* and shrimp *(Penaeus)* and crabs *(Calinectes)*.

Pelagic species tend to inhabit the upper portions of the water column, whereas demersal forms live on or near the bottom. Estuarine fishes are extremely varied in size and mode of life which range from gobies which mature when they are less than one inch long to sharks and the fearsome, but harmless, manta rays. Phytoplankton and zooplankton are plants and animals usually microscopic, that live in the water and sediments.

Numerous species of dolphins (porpoises) are permanent or semi-permanent residents. The bottlenose dolphin *(Tursiops)* is seen quite often in the Texas estuaries. While they are of no commercial value, they are of great aesthetic value because their clowning behavior brings great joy to signtseers.

Although some species spend their entire lives in estuaries, most species are estuarine-dependent at some stage but not restricted to the estuary throughout life. Many of the dominant estuarine-dependent species of the Gulf of Mexico, such as the croaker *(Micropogon)*, and mullet *(Mugil)* exhibit a rythmic, seasonally correlated, estuary-offshore migratory pattern.

Crustaceans are a conspicious segment of the estuarine fauna. Shrimp and crabs support extensive Texas fisheries. They occupy all segments of the estuarine environment from the bottom sediments where minute cumaceous and mudshrimps *(Callianassa)* burrow, to the shore where one encounters the fiddler crab *(Uca)* and the ghost crab *(Cardisomci)*.

Microorganisms including protozoa, algae, fungi and bacteria are very active as primary producers and mineralizers and as the bottom of the food chain for filter feeding fishes, crustaceans, and invertebrates.

Extensive grass and benthic algae assemblages are in the waters and intertidal areas. Blue green algal mats stabilize salt flats where evaporation brings salt from the exposed sediments by capillary action.

Other wildlife that live in the estuarine habitat along the shores include the racoon *(Procyon)* and the legendary coyote *(Canis latrans)*, the brown pelican *(Pelecanus occidentalis)*, egrets, storks, cranes, and herons. The dependence of waterfowl on the estuarine zone is both complex and not completely understood. The primary sport species of game waterfowl such as mallards and canvasbacks, have been successfully adapted to manmade changes in their environment, particularly those which do not affect the nesting sites. In some cases, the construction of roads, drainage canals, and other works have enhanced nesting areas by stabilizing water levels, providing protection from floods and drought-proof rearing ponds. Many sea ducks feed upon small crustaceans, fish, and aquatic insects that are estuarine dependent. Other species, such as Canadian geese and mallards have demonstrated great adaptability, many remaining the entire winter in the freshwater lakes of the Midwest.

Recreation

The demand for outdoor recreation has greatly increased over the past decade. Higher personal income levels and shorter work weeks have provided more surplus capital and leisure time, making it possible for greater numbers of Texans and neighbors from other states to seek new outlets for enjoyment. New highways and improved air travel facilities have made it possible for large numbers of persons to visit the nearby coastal estuaries for a variety of recreational purposes.

Clusters of recreational activities that require similar environmental conditions, but differ in environmental quality needs, can be grouped as follows:

Swimming, water skiing, surfing and related water contact activities;

Sports fishing from the shore, jetties, small boats, or commercial charter boats;

Boating and related activities such as fishing, cruising and sail and power boat racing;

Associated shore activities such as hunting, picnicking, camping and exploring; and

Aesthetic appreciation of the total environment.

Transportation

The Texas estuary system provides the physical, social, and economic conditions required for an effective system of water terminals serving international trade and coastal shipping. All Texas seaports are estuarine-dependent. Waterborne transportation in the estuaries has required large capital investments to support and maintain this activity. Adequate channels must be provided to carry oceanic ship traffic. This requires considerable dollar outlay for maintenance dredging to provide sufficient water depth to float deep draft vessels. The trend toward more economical "supervessels" will accentuate dredging operations and/or bring about the use of offshore ports. Commodity flow networks linking these terminals with shore cross through the estuarine areas. In addition, the Intracoastal Waterway System crosses all ship channels and passes through or along all major estuarine complexes in Texas. Large capital outlays have been made for loading, unloading and storing cargo, particularly petroleum and petro-chemical stores.

Besides the basic access and docking facilities needed, there are certain environmental considerations. There must be adequate water depth to keep the vessels afloat. Dock facilities and berthing space are expensive and cannot be assigned to single ships for long periods of time. Accordingly, there must be anchorage areas where ships can await their turns at piers. These anchorages must provide safe harbor in times of severe weather.

Transportation in estuaries is not limited to waterborne traffic. Complementary water-air transportation networks will require extensive engineering talent and capital investment to preclude irreversible ecological damage. Tradeoff mechanisms must be formulated. Heavy ship traffic interferes with pleasure boating and related activities. Maintenance of ship channels will bear heavy ecological ramifications.

Use as a Human Habitat

Included are the uses that inevitably occur whenever people live and work in civilized communities. They represent uses not unique to the coastal areas of Texas, but the estuarine zone places certain restrictions on some uses and offers advantages in other activities. Chapter IV, treating land and water use capabilities, expands upon this topic in great detail. Competitive needs from homes, apartments, hotels, and condominiums will intensify as the coastal zone is developed. Guidelines for desirable and undesirable land uses for human habitations will of necessity have to be developed and intelligently implemented in the near future.

Utilities

Estuarine water can serve as a source of both domestic and industrial water supply, but its utilization for domestic purposes has not yet been developed along the Texas coast. Normally the brackish water, ranging in salinity from 5 ppt to 40 ppt is unpotable and treatment costs to render it potable are extremely high and infeasible at this time. However, where the upstream freshwater inflow is sufficient to repel salinity intrusion from portions of the tidal area, the water could be used for municipal and agricultural purposes. Presently, the Texas watershed and its underground aquifer system are the only sources of potable water. Brackish estuarine water is a poor source for industrial process water because high purity is normally required in the process water and the cost of removing the dissolved salts is prohibitive.

Texas estuarine water is being used extensively as an industrial coolant and this use will grow substantially. For this purpose, the most important considerations are ambient temperature and volume. In many ways the estuaries of the Texas coast are globally unique. From an engineering viewpoint, each estuary presents a special set of considerations. Strong user competition between industrial and conservation factions will continue. Fortunately, constructive dialogue between industrial cooling specialists and ecologists are being pursued. It is imperative that management guidelines be established to prevent open user conflict.

Waste Disposal

A waste is discharged into a body of water because a city, industry, or individual wishes to eliminate a useless and somewhat noxious mess from the environment. However, such action is a necessary part of our present existence. At this time, technology and economics being what they are, such actions are necessary. One of the main uses of estuaries has been to be impressed as "sewers of civilization" to carry personal, municipal, and industrial wastes out to sea. Virtually all of the cities and industries in the Coastal Zone dispose of wastes either directly or indirectly into the estuarine system. Liquid waste discharges include domestic waste products, industrial waste materials of all degrees of chemical complexity and sophistication, spent cooling water with its attendant thermal load, and the often ignored, but highly significant, urban and agricultural runoff. These can affect the estuarine environment in different ways and can sharply restrict or entirely eliminate other beneficial uses. Two problems are generally involved. First, since most liquid wastes are dilute solutions in fresh water, they tend to be less dense than the saline water into which they are discharged. Therefore, resistance to mixing of waste with receiving water (the estuary water) may be considerable unless discharge is carried out through a carefully engineered diffuser. Secondly, current patterns of the receiving body will dictate whether the discharged material will be carried to sea or returned to other estuarine areas to create a nuisance. Reliable hydrographic information concerning the hydrodynamic characteristics and transport patterns is of cardinal importance whenever discharge of liquid wastes into an estuary is contemplated.*

Another use of the estuarine zone for waste disposal includes the prevalent use of the shoreline for refuse dumps and land fills. In addition to considerable debris getting into the water, leachates from these dumps pose a very serious threat to estuarine biota.

**This subject is considered sufficiently important to rank a separate appendix (C - Estuary Modeling Techniques).*

In the context of estuarine uses it is important to recognize, however, that waste disposal is a highly significant and universal use of the estuarine resource and that it is likely to remain so. Along with the many other socio-economic uses of the estuarine environment, it must be managed so that it does not impair the biophysical environment, to the extent that other beneficial uses are precluded.

Mineral Resources

Minerals within the water, on the bottom, and beneath the bottom are the backbone of the Texas economy. Sub-bottom mining operations include the recovery of sulphur, petroleum, and natural gas. Recovery of minerals from submerged estuarine zone bottoms by surface mining (dredging) is primarily directed toward sand, gravel, and oyster shell production. Most sand and gravel dredging operations supply nearby users; therefore, they tend to be distributed in relationship to production and population. Oyster shell production is of major importance since the major oyster shell deposits in the United States are in shallow embayments such as Galveston Bay and Mobile Bay, Alabama. Recently considerable argument has developed about the rate at which these deposits are being depleted. Most of the magnesium produced in the U. S. is taken from the waters off Freeport, Texas.

Special Purpose Uses: Deliberate Alteration and Modification

As land use capabilities for the estuarine zone are developed, it will be necessary to deliberately alter it to suit domestic and residential needs. Other alterations related to public welfare and protection such as the construction of hurricane abatement structures and public utilities will of necessity have to be made. Industrial growth will augment the list of manmade changes. Effective guidelines for future resources development will require formulation and adoption by various development and regulatory agencies.

REGULATORY AGENCIES

Numerous federal and state agencies have various responsibilities as regards setting and enforcing water quality criteria.

Federal Agencies

Congress has been aware of our declining water quality for many years, but provided little emphasis on control as our nation rapidly became industrialized. In fact, our nation would not have made such progress today if stringent controls such as implied in the Rivers and Harbor Act of 1899 were rigidly enforced. Technology was not available at that time to handle the effluents of man's activities because of the extreme diversity of by-products.

The first legal basis for water quality control was the Rivers Pollution Prevention Act of England in 1867. This Act formed the basis of all legal action on water quality up to 1955 and led to the Rivers and Harbors Act of 1899 in the U.S. Although this latter Act was solely for the prevention of restriction of navigable rights, it contains some of the ingredients for modern day control through its lack of specificity. The Public Health Service Act of 1912 authorized investigation of water pollution related to disease. In 1924 the Oil Pollution Act was passed for the specific control of oil discharges in coastal waters.

While the water quality bills before 1965 had sufficient wording for appropriate control, the Federal government did not act until the Water Pollution Control Act and this as a result of popular opinion. That Act provided for the development of specific control measures in cooperation with the states and set guidelines for such control. On the basis of this Act, first the Federal Water Pollution Control Administration, then the Federal Water Quality Administration, and presently the *Environmental Protection Agency* have clearly emerged as having the federal role of coordination of the development of water quality standards. They also have the responsibility for enforcement of quality standards and to establish methodology and criteria at the Federal level.

The *U. S. Bureau of Reclamation* is responsible for studies and plans for water resource development. The primary concern in bays and estuaries of the Bureau is with the inflow of fresh water. It does not establish water quality criteria or guidelines.

The *U. S. Geological Survey* does not engage in water quality criteria development or preparation of guidelines. The primary role is in collection of data and the preparation of environmental impact statements. The U. S. Geological Survey has been actively engaged in data collection programs in cooperation with the Texas Water Development and the Water Quality Boards. Most of the data are for inland waters and activity in the bays and estuaries has only become significant quite recently. Data collected include sampling location, date, flow, silica, calcium, magnesium, sodium, potassium, bicarbonate, sulfate, chlorides, flourides, nitrates, heavy metals, dissolved solids, hardness, noncarbonate hardness, specific conductance, pH, and temperature. Although very few of these sampling stations are directly located in bays and estuaries, this information can be helpful in evaluating the quality of the fresh-water inflows.

The *U. S. Corps of Engineers* do not issue criteria, standards or guidelines in regard to coastal construction; however, the guidelines developed by the Water Quality Office of the Environmental Protection Agency are used. The responsibility for the enforcement of the Refuse Act of 1899 has put the Corps in a position of evaluating and granting applications for permits to discharge waste into navigable waters. The Corps of Engineers has been collecting samples and data for the Environmental Protection Agency, who are responsible for most of the analyses. The Corps will be responsible for granting permits, evaluating the status of the permit, and listing the type of permits in the coastal zone, using the guidance of EPA and other data collecting agencies.

The Corps also is responsible for spoil disposal and waste disposal. An application for discharge in navigable waters will require the following information: the type of activity, quantity of water use, treatment processes, point of discharge, waste abatement practices, flow, pH and temperature of the intake and discharge waters, and color, turbidity, radioactivity, hardness, solids, ammonia, organic nitrogen, nitrates, nitrites, phosphorous, BOD, COD, total dissolved solids, total suspended solids, total volatile solids, among others for municipal and industrial discharges. The Corps of Engineers can have a marked effect on the development of water quality criteria, water use patterns, and general management of estuaries and bays. The main objective of the Corps prior to the resurrection of the Refuse Act of 1899 was the development of navigation resources, water resources, flood protection, hurricane protection, large coastal construction, and the regulation of navigable waters which are either actively used or have a potential for use. However, with the expanded role of the Corps in the area of control in coastal construction, dredging, shell mining, land reclamation and pollution control, development of a set of water quality criteria must include the activities and inputs of the Corps of Engineers.

The *Bureau of Sport Fisheries and Wildlife* have been evaluating Texas bays and estuaries but do not establish any criteria, guidelines, or standards. They are responsible for reviewing the projects of the Corps of Engineers and the permit applications mostly in terms of the biological effects.

The *National Marine Fisheries Service* do not evaluate water quality criteria nor issue guidelines or standards. They are engaged in the collection and analysis of water data and the review and comment on any application for permits for waste disposal or coastal construction.

State Agencies

Various Texas State Agencies are involved in the collection of water quality information but only the *Texas Water Quality Board* has the responsibility and authority to establish any water quality criteria and subsequently enforce compliance with these criteria.

The Texas Water Quality Board developed, adopted and issued water quality criteria because the development of such standards is a statutory responsibility. Such standards were adopted and issued only after extensive review by other agencies, both State and Federal, as well as after extensive public hearings.*

The Galveston Bay Project, sponsored by the Texas Water Quality Board is currently collecting data in an attempt to establish the existing quality of the Galveston Bay. Eventually these data could be used to establish more realistic criteria for bays and estuaries.

The *Texas Water Development Board* has not actively been engaged in establishing water quality criteria, standards or guidelines. The main role of this group is the development of the water resources of the State and to plan for the orderly development of these resources. The Texas Water Development Board, in cooperation with the U. S. Geological Survey, monitors water quality, but most of the sampling stations are on inland waters. These stations are part of the network of hydrological stations. A complementary ground water data program is also carried on. The Water Development Board is quite interested in determining the required fresh water inputs to the bays and estuaries so that this vital use may be incorporated into their long-range planning.

The *Texas Railroad Commission* is primarily concerned with the regulation and the disposal of oil field brines and subsurface water injection. The Railroad Commission does not have any criteria, guidelines or standards relating to the disposal of brines in tidal waters. However, recently permit holders have been required to provide certain information on the effluents.

Data for effluents of gasoline plants include pH, total residue, chlorides, sulfates, total suspended solids, volatile suspended solids, settleable material, BOD, COD, oil and grease, temperature, color, chromium, zinc, sulfides, free or floating oil and debris. The quality data for oil field brine include pH, sodium, calcium, magnesium, iron, zinc, chlorides, sulfates, carbonates, total dissolved solids, and chromium.

The *Texas Parks and Wildlife Department* does not issue any criteria, guidelines or standards. However, discharge permit applications are submitted to the Parks and Wildlife Department for review and comment. This procedure is also followed with the other agencies represented on the Texas Water Quality Board. The Parks and Wildlife Department are primarily interested in the water quality criteria as related to the propagation of fish and wildlife. This biologic use of water and quality criteria applicable to this use will be discussed later and will not be included in this section.

**The Texas Water Quality Board is made up of four executive heads of State agencies and three citizen members who are appointed by the Governor to serve staggered six-year terms.*

The *Texas State Department of Health* does not issue any water quality data criteria. However, this agency is actively engaged in sanitary surveys of the bays and estuaries directed at regulating the harvesting of shellfish and oysters. The data include pH, wind direction and velocity, ambient and water temperature, sulfates, chlorides, total solids, dissolved solids, suspended solids, DO, BOD, and coliform as most probable number.

The *Texas Water Rights Commission* is not actively engaged in developing criteria, guidelines and standards, but is more interested in control of water use from a legal viewpoint. The Water Rights Commission is interested in permitting water diversions. In the coastal zone permits have been granted to the Freeport and Mansfield desalting plants. Specific information for which the Water Rights Commission has responsibility include the permits of appropriations of water, acres of irrigation, industrial diversion, and domestic water supply uses.

A comprehensive evaluation of the water quality for various uses of the bays and estuaries must include the more subtle waste inputs such as gaseous and particulate emissions to the atmosphere and the leachates from solid waste disposal sites. The interrelationships between the air, water, and land must be considered when developing the use criteria for bays and estuaries. In Texas, the Air Quality Board establishes the permissable levels of gaseous and particulate emissions. These standards are based on guidelines and criteria developed by the Environmental Protection Agency. The Air Quality Board has the authority to prosecute pollutors and levee penalties from $50 to $1000 per day for non-compliance with the standards. Several air monitoring stations are located in the coastal zone, primarily for evaluation of particulate emissions. Industrial discharges to the atmosphere are sampled and those cases which indicate that the standards are not being met. The Texas State Department of Health is responsible for the refuse disposal programs in the State. No permits are required for refuse disposal; however, the State Health Department attempts to evaluate the disposal methods used and provide technical assistance in developing and locating acceptable refuse disposal.

An attempt at coordinating the activities of the various State agencies and providing a communication device among the various agencies has been accomplished through the formation of the *Interagency Natural Resources Council*. The Council includes the representatives of Texas Parks and Wildlife Department, Texas Water Development Board, Texas Water Quality Board, Texas Water Rights Commission, Railroad Commission, Texas Highway Department, Air Control Board, Texas Industrial Commission, Office of the Governor, General Land Office, Department of Agriculture, and Soil and Water Conservation Board, with the University of Texas at Austin and Texas A & M University as ex-officio members. Staffing is provided by the Division of Planning Coordination within the Office of the Governor. At the present time, the Interagency Natural Resources Council is actively engaged in the development of the Coastal Resources Management Program of Texas, the development of a Water-Oriented Data Bank, and the promotion of inter-agency cooperative projects.

CRITERIA FOR NON-BIOLOGICAL USES

The major non-biological uses of the bays and estuaries include the following:

- Contact and non-contact recreation,
- Navigation, and
- Industrial cooling water.

A summary of the characteristics of water that may be used for contact and non-contact recreation are summarized in Table B-1 and the quality of water which may be used for cooling purposes for industrial installations is summarized in Table B-2.

The Texas criteria for water-oriented recreation are somewhat more stringent than those listed above and require that the geometric mean of the number of fecal coliform bacteria be less than 200/100 ml and that not more than 10% of the samples in any 30 day period exceed 400 fecal coliform bacteria per 100 ml.

For comparison purposes the criteria of the State of California are listed below:

(a) The water must be aesthetically enjoyable and free from floating and suspended materials, objectionable color and foul odors.
(b) Free from toxicants which may be ingested or cause skin irritations.
(c) Free of toxigenic organisms and have a monthly mean mpn of 1,000 organisms per 100 milliliters, and
(d) Require less than .5 mg/l of alum.

The criteria for boating and aesthetic enjoyment include:

(a) No floating and suspended materials
(b) No settleable solids from sewage and garbage

TABLE B-1

Water Quality Criteria for Recreation and Aesthetics

Quality	Contact		Non-Contact	
	Noticeable** Threshold	Limiting Threshold	Noticeable Threshold	Limiting Threshold
MPN/100	1000	(2)		
Visible solids or sewage effluent	None	None	None	None
ABS mg/l	1*	2	1*	5
SS	20*	100	20*	100
Floatable oil & grease*	0	5	0	10
Emulsified oil & grease	10*	20	20*	50
Turbidity (SIO_2)	10*	50	20*	--
Color	15*	100	15*	100
Odor (number)	32*	256	32*	256
pH	6.5 - 9.0	6.0 - 10.0	6.5 - 9.0	6.0 - 10.0
Temperature, ^{o}c	30	50	30	50
Transparency (Secchidisk)	--	--	20* feet	--

***Noticeable threshold, level at which people begin to notice limiting threshold, level at which use is prohibited.*

**Not to be exceeded in threshold 80% of 20 consecutive samples, nor in any 3 consecutive samples.*

TABLE B-2

Cooling Water Quality Criteria

	Once Through Brackish[1]	*Makeup for Recycling Brackish*[1]
Silica (SiO_2)	25	25
Aluminum (Al)	(2)	0.1
Iron (Fe)	(2)	0.5
Manganese (Mn)	(2)	0.02
Calcium (Ca)	420	420
Magnesium (Mg)	(2)	(2)
Ammonia (NH_4)	(2)	(2)
Bicarbonate (HCO_3)	140	140
Sulfate (SO_4)	2,700	2,700
Chloride (Cl)	19,000	19,000
Dissolved Solids	35,000	35,000
Copper (Cu)	(2)	(2)
Zinc (Zn)	(2)	(2)
Hardness ($CaCO_3$)	6,250	6,250
Free Mineral Acidity ($CaCO_3$)	(3)	(3)
Alkalinity ($CaCO_3$)	500	115
pH units	6.0 - 8.3	(2)
Color, units	(2)	(2)
Organics:		
Methylene blue active substances	(2)	1
Carbon tetrachloride extract	(4)	2
Chemical oxygen demand (O_2)	75	75
Dissolved oxygen (O_2)	(2)	(2)
Temperature F	(2)	(2)
Suspended solids	2,500	100

[1]Brackish water--dissolved solids more than 1,000 mg/l by definition 1963 census of manufacturers. [2]Accepted as received (if meeting total solids or other limiting values); has never been a problem at concentrations encountered. [3]Zero, not detectable by text. [4]No floating oil. NOTE: Application of the above values should be based on Part 23, ASTM book of standards (1), or APHA Standard methods for the examination of water and wastewater (5).

From Federal Water Pollution Control Administration, 1968.

(c) No sludge banks
(d) No slime infestation
(e) No heavy growth of attached plants or animals
(f) No bloom or high concentration of plankton
(g) No discoloration or excessive turbidity from sewage, industrial waste or natural sources
(h) No evolution of dissolved gases, especially hydrogen sulfide
(i) No visible oil, grease or emulsions
(j) No excessive acidity or alkalinity
(k) No surfactants that might cause foam upon agitation
(l) No high temperature that might cause evaporation or cloudiness and coliform organisms which have a monthly average most probably number equal to or less than 5,000/100 ml.

The criteria established for the use of water for electric power and navigation include:

(a) No acids, alkali or salinity which will cause corrosion or cavitation
(b) No debris, silt, suspended solids which will block channels, intakes or settle as sludge banks
(c) No organic material which would cause odors or corrosive hydrogen sulfide
(d) No algae, fungi, worms or barnacles which may clog passageways, cling to vessels or cause corrosion
(e) No marine borers which would destroy wharfs and docks
(f) No oil or fire hazards.

CRITERIA FOR BIOLOGICAL USES

Many publications pertinent to water quality and biologic uses have emerged. For example, in 1960 a Conference on Physiological Aspects of Water Quality was published (Faber and Bryson 1960) and in 1962 Biological Problems in Water Pollution seminar was held by the U.S. Department of Health, Education and Welfare. Various publications on our shoreline such as the Pacific Coast Recreation Area Survey (U.S. Department of Interior, 1959), Our Vanishing Coastline (U.S . Department of Interior, 1955), the Seashore Recreation Area Survey of the Atlantic and Gulf Coast (U.S. Department of Interior, 1955) illustrate examples of prior concern.

More sweeping publications contain a more complete description of the dynamics and state of our coastal environments. Odum, et al. (1969) Coastal Ecological Systems of the United States, offers a comparison of various ecosystems. California and Use of the Ocean appeared as a publication of the University of California in 1965. Its 19 chapters cover most aspects of coastal use and identify problems. An interim report titled Coastal Wetlands of Virginia has been published by the Virginia Institute of Marine Science for the Governor of the State of Virginia (Wass & Wright, 1969).

A very comprehensive report was published in 1963 by McKee on Water Quality Criteria by the California State Water Quality Control Board. Listed are various chemicals and their effect on living organisms. Included is a comprehensive reference list which contains much of the literature on the subject up to the time of publication. Unfortunately, the data are specific to the organisms with little or no reference to translation to natural habitats. Pertinent to the subject, however, is the wide latitude of adverse effects of specific chemical materials to different species of fresh water and marine organisms. A revised version of this was published in 1971, which helps eliminate many of the earlier problems.

It is quite obvious that the pertinent literature as outlined shows the necessity of establishing guidelines for estuarine use that are related to specific localities or uses involved. This is especially true for the coast of Texas where a diversity of specific environments may not be related to other areas of the United States and where the intensity and type of development varies greatly between estuaries.

Water quality defined in terms of natural conditions and the introduction of adverse or favorable materials becomes most complex, especially in the Texas region where high intensity rainfall may flush a bay system, increase turbidity and change sediment distribution. The high wind action and alternation of direction during Northers also causes mixing, increases in turbidity, and amplifies tidal changes beyond lunal tides; this latter factor has a very major impact on the extensive mud and salt flats. The sunlight during summer conditions will cause a rapid diurnal change, especially during high winds, which are normal in that season. The combined effects of respiration and mixing create a high productivity and oxygen demand in the water and sediments. The fine sediments are generally anaerobic during the warm summer months and during quiet periods deeper basins will become anaerobic with the production of hydrogen sulfide. High evaporation rates coupled with a lack of fresh water inflow can produce hypersaline conditions that can be contrasted with moderate salinity bays which experience less evaporative losses and receive substantial fresh water inflows. The geographic features of the barrier island with infrequent passes for circulation and flushing further complicate the ecological situation.

The normal estuarine condition in Texas is one of instability and the living systems are of two types; indigenous organisms that will withstand and survive seasonal variations in the bays, such as the blue crabs, and the migratory organisms such as white shrimp that has a rather narrow temperature and salinity pattern (Copeland and Bechtel, 1971). Species of organisms responding and adapting to their environment comprise the biological components of any ecosystem. The complexity of geological, chemical, physical and biological combinations renders it nearly impossible to identify the environmental limits of each species. One can, however, approximate the range of major environmental factors by accurate observations of the behavior, growth and reproduction of populations.

Estuaries are among the most productive systems in nature. In addition, estuarine systems have fewer species than do either of the more stable fresh water or marine systems since only a few species have adapted to the widely varying physical-chemical conditions. The few species that are able to survive, however, do so in large numbers.

Species Diversity

All living organisms within an estuarine system use the environment for communication, to establish territories for food and for specific habitats. The water quality will affect the distribution of species and the number of individuals within a species in the environment.

The species diversity can be used as a measure of change in water quality and as a consequence, the biological use of the environment will change. This may result, for example, in a loss of a species such as shrimp or other specific fishes pertinent to man, eutrophication, etc.

Fishing

This activity is a direct response of man to extract from the environment, fishes and shellfish of edible desirability and during such practices, trashfish and organisms that are caught as a part of the activity. The water and environmental quality in some way allows areas to become more desirable than others for different fish. Migratory habits of the shrimp and flounder provide for a variation of habitats at different seasons.

To the complexity of selective environments and migratory patterns must be imposed man-made changes. The variability of the natural environment both seasonally and annually will change the habits of the fishes. Fishing effort will also change the habitat. Dredging for oyster shell will alter the bottom. Overfishing may produce momentary minima for certain populations.

Mariculture

For mariculture to be effective, it will necessarily supplant a body of water that would have had a normal distribution of living organisms with a more monogamous situation. A well-controlled shrimp marifarm would yield approximately 1000 pounds of shrimp per acre per year. Proper management of the farm will increase the density of a single species well beyond its natural concentration.

Mariculture thus will drastically affect the environment and the biological use. In most cases the area will be considerably changed from its original natural conditions although certain basic aspects such as circulation, salinity, oxygen, etc., must be controlled. This might be considered the ultimate of biological use of the coastal water environment.

Carbon Fixation (productivity)

The plants contributing to photosynthesis are of two types: planktonic or free floating and pelagic or attached. These plants have seasonal growth patterns and are directly influenced by the complexity of changes both natural and man-made. Certain areas are consistently more productive than others and for a given area the annual productivity remains somewhat constant unless an excess of growth factors become available or some adverse change in water quality occurs. Such biological use of the water results in the formation of protoplasm that is carried through the food chain, the basis for the total population, and a balancing effect on the oxygen content of the water and sediments.

When the natural balance of a community is changed, the number of species decreases, but usually the biomass remains the same. The ultimate effect can produce a body of water like the Houston Ship Channel which is relatively devoid of higher organisms, but microorganisms, continuing surface photosynthesis and decomposition are as abundant as a total community would be if the area were in balance. Such a condition can be natural such as in the Black Sea, Norwegian fjords, Walvis Bay and the areas off Peru during an El Nino, because of weather and circulation changes in the water.

DEVELOPMENT OF THRESHOLD LIMITS FOR BIOLOGICAL USES

Biological use then can be defined in terms of water quality when known inputs cause changes in the natural balance of living systems. Such water quality criteria are very difficult to estimate because of the diversity of a total community. However, there are common denominators that can be established at this time. Other criteria can be estimated in view of limited chemical data for certain estuaries and the open sea where the community structure appears not to be disturbed. It must be pointed out that estimates can only be used as a guideline for future criteria definition and may not be the ultimate working criteria. These guidelines also apply only to the Texas estuaries as adopted to the ecological description of enclosed bays with a varying amount of fresh water input and seasonal and annual weather patterns that affect materially the estuarine area.

Dilution (Fresh Water Input)

These values are given for the water system in general and input water characteristics must be established on an area basis. Because normal runoff and river flow bring elements and organic compounds from natural biological and chemical systems, from the land to the estuaries, one must realize that there will be a concentration gradient. Gradient allowances thus will be a part of any criteria to be established and must represent individual ecological situations.

Chemicals

The most difficult criteria for materials that affect biological use are those pertaining to chemicals. The number of inorganic and organic materials that result from man's activities are large and interactions that change toxicity are numerous. However, one can extrapolate from values available for natural environments to justify certain guidelines such as information on distribution of elements in seawater (Table B-3 and B-4) surface water criteria for public water supplies (Table B-5), nucleotide guidelines (Table B-6), and toxicity of various compounds including pesticide toxicity (Table B-7). Many other publications have discrete water quality criteria information such as the book Eutrophication (National Academy of Science, 1969).

TABLE B-3

Concentration and Amounts of Sixty of the Elements in Seawater

From Firth, 1969.

Element	Concentration (mg/liter)	Amount of Element in Seawater (tons/$mile^3$)	Total Amount in the Oceans (tons)
Chlorine	19,000.0	89.5×10^6	29.3×10^{15}
Sodium	10,500.0	49.5×10^6	16.3×10^{15}
Magnesium	1,350.0	6.4×10^6	2.1×10^{15}
Sulfur	885.0	4.2×10^6	1.4×10^{15}
Calcium	400.0	1.9×10^6	0.6×10^{15}
Potassium	380.0	1.8×10^6	0.6×10^{15}
Bromine	65.0	306,000	0.1×10^{15}
Carbon	28.0	132,000	0.04×10^{15}
Strontium	8.0	38,000	$12,000 \times 10^9$
Boron	4.6	23,000	$7,100 \times 10^9$
Silicon	3.0	14,000	$4,700 \times 10^9$
Fluorine	1.3	6,100	$2,000 \times 10^9$
Argon	0.6	2,800	930×10^9
Nitrogen	0.5	2,400	780×10^9
Lithium	0.17	800	260×10^9
Rubidium	0.12	570	190×10^9
Phosphorus	0.07	330	110×10^9
Iodine	0.06	280	93×10^9
Barium	0.03	140	47×10^9
Indium	$<$ 0.02	94	31×10^9
Zinc	0.01	47	16×10^9
Iron	0.01	47	16×10^9
Aluminum	0.01	47	16×10^9
Molybdenum	0.01	47	16×10^9
Selenium	0.004	19	6×10^9
Tin	0.003	14	5×10^9
Copper	0.003	14	5×10^9
Arsenic	0.003	14	5×10^9
Uranium	0.003	14	5×10^9
Nickel	0.002	9	3×10^9
Vanadium	0.002	9	3×10^9
Manganese	0.002	9	3×10^9
Titanium	0.001	5	1.5×10^9
Antimony	0.0005	2	0.8×10^9
Cobalt	0.0005	2	0.8×10^9
Cesium	0.0005	2	0.8×10^9
Cerium	0.0004	2	0.6×10^9
Yitrium	0.0003	1	5×10^8
Silver	0.0003	1	5×10^8
Lanthanum	0.0003	1	5×10^8
Krypton	0.0003	1	5×10^8
Neon	0.0001	0.5	150×10^6
Cadmium	0.0001	0.5	150×10^6
Tungsten	0.0001	0.5	150×10^6
Xenon	0.0001	0.5	150×10^6
Germanium	0.00007	0.3	110×10^6

TABLE B-3 (continued)

Element	Concentration (mg/liter)	Amount of Element in Seawater (tons/mile^3)	Total Amount in the Oceans (tons)
Chromium	0.00005	0.2	78×10^6
Thorium	0.00005	0.2	78×10^6
Scandium	0.00004	0.2	62×10^6
Lead	0.00003	0.1	46×10^6
Mercury	0.00003	0.1	46×10^6
Gallium	0.00003	0.1	46×10^6
Bismuth	0.00002	0.1	31×10^6
Niobium	0.00001	0.05	15×10^6
Thallium	<0.00001	0.05	15×10^6
Helium	0.000005	0.03	8×10^6
Gold	0.000004	0.02	6×10^6
Protactinium	2×10^{-9}	1×10^{-3}	3000
Radium	1×10^{-12}	5×10^{-7}	150
Radon	0.6×10^{-13}	3×10^{-12}	1×10^{-3}

TABLE B-4

Abundances of the Elements and Principal Dissolved Chemical Species of Seawater, Residence Times of the Elements

Element	Abundance (mg/l)	Principal species	Residence time (years)
O	857,000	H_2O; $O_2(g)$; SO_4^{2-} and other anions	
H	108,000	H_2O	
Cl	19,000	Cl^-	
Na	10,500	Na^+	2.6×10^3
Mg	1,350	Mg^{2+}; $MgSO_4$	4.5×10^7
S	885	SO_4^{2-}	
Ca	400	Ca^{2+}; $CaSO_4$	8.0×10^6
K	380	K^+	1.1×10^7
Br	65	Br^-	
C	28	HCO_3^-; H_2CO_3; CO_3^{2-}; organic compounds	
Sr	8	Sr^{2+}; $SrSO_4$	1.9×10^7
B	4.6	$B(OH)_3$; $B(OH)_2O^-$	
Si	3	$Si(OH)_4$; $Si(OH)_3O^-$	8.0×10^3
F	1.3	F^-; MgF^+	
A	0.6	$A(g)$	
N	0.5	NO_3^-; NO_2^-; NH_4^+; $N_2(g)$; organic compounds	
Li	0.17	Li^+	2.0×10^7
Rb	0.12	Rb^+	2.7×10^5
P	0.07	HPO_4^{2-}; $H_2PO_4^-$; PO_4^{3-}; H_3PO_4	
I	0.06	IO_3^-; I^-	
Ba	0.03	Ba^{2+}; $BaSO_4$	8.4×10^4

TABLE B-4 (continued)

Element	Abundance (mg/l)	Principal species	Residence time (years)
In	0.02		
Al	0.01	$Al(OH)_4^-$	1.0×10^2
Fe	0.01	$Fe(OH)_3(S)$	1.4×10^2
Zn	0.01	Zn^{2+}; $ZnSO_4$	1.8×10^5
Mo	0.01	MoO_4^{2-}	5.0×10^5
Se	0.004	SeO_4^{2-}	
Cu	0.003	Cu^{2+}; $CuSO_4$	5.0×10^4
Sn	0.003	(OH)?	5.0×10^5
U	0.003	$UO_2(CO_3)_3^{4-}$	5.0×10^5
As	0.003	$HAsO_4^{2-}$; $H_2AsO_4^-$; H_3AsO_4; H_3AsO_3	
Ni	0.002	Ni^{2+}; $NiSO_4$	1.8×10^4
Mn	0.002	Mn^{2+}; $MnSO_4$	1.4×10^3
V	0.002	$VO_2(OH)_3^{2-}$	1.0×10^4
Ti	0.001	$Ti(OH)_4$?	1.6×10^2
Sb	0.0005	$Sb(OH)_6^-$?	3.5×10^5
Co	0.0005	Co^{2+}; $CoSO_4$	1.8×10^4
Cs	0.0005	Cs^+	4.0×10^4
Ce	0.0004	Ce^{3+}	6.1×10^3
Kr	0.0003	Kr(g)	
Y	0.0003	(OH)?	7.5×10^3
Ag	0.0003	$AgCl_2^-$; $AgCl_3^{2-}$	2.1×10^6
La	0.0003	La^{3+}; $La(OH)^{2+}$?	1.1×10^4
Cd	0.00011	Cd^{2+}; $CdSO_4$	5.0×10^5
Ne	0.0001	Ne(g)	
Xe	0.0001	Xe(g)	
W	0.0001	WO_4^{2-}	1.0×10^3
Ge	0.00007	$Ge(OH)_4$; $Ge(OH)_3O^-$	7.0×10^3
Cr	0.00005	(OH)?	3.5×10^2
Th	0.00005	(OH)?	3.5×10^2
Sc	0.00004	(OH)?	5.6×10^3
Ga	0.00003	(OH)?	1.4×10^3
Hg	0.00003	$HgCl_3^-$; $HgCl_4^{3-}$	4.2×10^4
Pb	0.00003	Pb^{2+}; $PbSO_4$	2.0×10^3
Bi	0.00002		4.5×10^5
Nb	0.00001		3.0×10^2
Tl	0.00001	Tl^+	
He	0.000005	He(g)	
Au	0.000004	$AuCl_2^-$	5.6×10^3
Be	0.0000006	(OH)?	1.5×10^2
Pa	2.0×10^{-9}		
Ra	1.0×10^{-10}	Ra^{2+}: $RaSO_4$	
Rn	0.6×10^{-15}	Rn(g)	

TABLE B-5

Surface Water Criteria for Public Water Supplies

From Federal Water Pollution Control Administration, 1968.

Constituent or characteristics	Permissible criteria	Desirable criteria
Physical:		
Color (color units)	75	<10
Odor	Narrative	Virtually absent
Temperature*	do	Narrative
Turbidity	do	Virtually absent
Microbiological:		
Coliform organisms	10,000/100 ml[1]	<100/100 ml[1]
Fecal coliforms	2,000/100 ml[1]	<20/100 ml[1]
Inorganic chemicals:	(mg/l)	(mg/l)
Alkalinity	Narrative	Narrative
Ammonia	0.5 (as N)	<0.01
Arsenic*	0.05	Absent
Barium*	1.0	do
Boron*	1.0	do
Cadmium*	0.01	do
Chloride*	250	<25
Chromium,* hexavalent	0.05	Absent
Copper*	1.0	Virtually absent
Dissolved oxygen	≥4 (monthly mean) ≥3 (individual sample)	Near saturation
Fluoride*	Narrative	Narrative
Hardness*	do	do
Iron (filterable)	0.3	Virtually absent
Lead*	0.05	Absent
Manganese* (filterable)	0.05	do
Nitrates plus nitrites*	10 (as N)	Virtually absent
pH (range)	6.0-8.5	Narrative
Phosphorous*	Narrative	do
Selenium*	0.01	Absent
Silver*	0.05	do
Sulfate*	250	<50
Total dissolved solids* (filterable residue)	500	<200
Uranyl ion*	5	Absent
Zinc*	5	Virtually absent
Organic chemicals:		
Carbon chloroform extract* (CCE)	0.15	<0.04
Cyanide*	0.20	Absent
Methylene blue active substances*	0.5	Virtually absent
Oil and grease*	Virtually absent	Absent
Pesticides:		
Aldrin*	0.017	do
Chlorodane*	0.003	do
DDT*	0.042	do
Dieldrin*	0.017	do
Endrin*	0.001	do
Heptachlor*	0.018	do
Heptachlor epoxide*	0.018	do
Lindane*	0.056	do
Methoxychlor*	0.035	do
Organic phosphates plus carbamates*	0.01[2]	do
Toxaphene*	0.005	do
Herbicides:		
2,4-D plus 2,4,5-T, plus 2,4,5-TP*	0.1	do
Phenols*	0.001	do
Radioactivity:	(pc/l)	(pc/l)
Gross beta*	1,000	<100
Radium 226*	3	<1
Strontium 90*	10	<2

*The defined treatment process has little effect on this constituent.

[1] Microbiological limits are monthly arithmetic averages based upon an adequate number of samples. Total coliform limit may be relaxed if fecal coliform concentration does not exceed the specified limit.

[2] As parathion in cholinesterase inhibition. It may be necessary to resort to even lower concentrations for some compounds or mixtures. See par. 21.

TABLE B-6

Distributions of Radionuclides in the Marine Environment[a]

From Fairbridge, 1966.

Nuclide	Half-life (yr)	Concentration in Oceans (g/liter)	(dpm/liter)	Concentration in Sediments (g/kg dry sediment)	(dpm/kg dry sediment)
H^3	12.26	(6.7-33.3) x 10^{-16}[b]	14.4-71.9[b]		
Be^{10}	2.5 x 10^6	1.4 x 10^{-13}	4.4 x 10^{-3}	(0.3-3.0) x 10^{-10}	1-10
C^{14}	5570	(2-3) x 10^{-14}[b]	0.2-0.3[b]	(0.1-1.0) x 10^{-10}	(1-10) x 10^2
Al^{26}	7.4 x 10^5	--	--	(0.15-1.5) x 10^{-12}[c]	(0.6-6) x 10^{-2}[d]
Si^{32}	500	5 x 10^{-19}	2.7 x 10^{-5}		
K^{40}	1.3 x 10^9	4.6 x 10^{-5}	720	(0.44-11.9) x 10^{-3}	(0.7-18) x 10^4
Rb^{87}	4.7 x 10^{10}	3.4 x 10^{-5}	6.2	(2.3-5.7) x 10^{-3}	(0.4-1.1) x 10^3
Sr^{90}	28	(0.63-9.5) x 10^{-16}[b]	0.02-0.3[b]		
Cs^{137}	30	(0.52-2.6) x 10^{-1}	0.1-0.5[b]		
Ra^{226}	1620	(3-16) x 10^{-14}	(6.6-35) x 10^{-2}	(0.3-40) x 10^{-9}	(0.65-87) x 10^3
Th^{228}	1.91	1 x 10^{-18}	0.2 x 10^{-3}		
Th^{230}	75,200	9 x 10^{-15}	0.4 x 10^{-3}	(1-30) x 10^{-7}	(0.45-136) x 10^3
Th^{232}	1.41 x 10^{10}	(0.36-4.5) x 10^{-9}	(0.87-10.9) x 10^{-4}	(2-12) x 10^{-3}	(0.48-2.9) x 10^3
Pa^{231}	32,480	2 x 10^{-15}	0.2 x 10^{-3}	(5-150) x 10^{-9}	(0.53-16) x 10^3
U^{234}	2.48 x 10^5	(1.6-2.1) x 10^{-10}	2.3-2.9	(0.024-4.9) x 10^{-6}	(0.34-67) x 10^3
U^{235}	7.13 x 10^8	(1.9-2.5) x 10^{-8}	0.092-0.17	(0.028-5.8) x 10^{-4}	(0.13-27) x 10^2
U^{238}	4.51 x 10^9	(2.7-3.4) x 10^{-6}	2.0-2.5	(0.4-80) x 10^{-3}	(0.30-59) x 10^3

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[a] *Concentration of the more important radionuclides found in the oceans and deep-sea sediments. The values given for sediments are those measured in surface sediments.*

[b] *Surface water only.*

TABLE B-6 (continued)

Decay Characteristics of Radionuclides Found in the Marine Environment[a]

Nuclide	Half-life (yr)[b]	Modes of Decay	Particle Energies (McV)	Particle Intensities (%)	Gamma-ray Energies (McV)	Gamma-ray Intensities
H^3	12.26	β^-	0.0181	100	None	
Be^7	53.6 days	EC	None		0.4773	10.32
Be^{10}	2.5 x 10^6	β^-	0.56	100	None	
C^{14}	5570	β^-	0.156	100	None	
Al^{26}	7.4 x 10^5	β^+ EC	β^+ 1.16 EC	85 15	1.11 1.83 2.95 Ann. Rad.	3.7 99.3 0.3
Si^{32}	500	β^-	0.1	100	None	
K^{40}	1.3 x 10^9	β^- EC	β^- 1.32 EC	89 11	1.46	11
Rb^{87}	4.7 x 10^{10}	β^-	0.27	100	None	
Sr^{90}	28	β^-	0.54	100	None	
Cs^{137}	30	β^-	0.52 1.18	92 8	0.662	92
Ra^{226}	1620	α	4.78 4.59	95 4	0.187 0.260	4 0.001
Ra^{228}	5.7	β^-	0.055	100	0.03	Very weak
Th^{228}	1.91	α	5.421 5.338	71 28	0.085 0.214	1.6 0.27
Th^{230}	75,200	α	4.682 4.615	76 24	0.0677 0.144	0.59 0.77

TABLE B-6 (continued)

Decay Characteristics of Radionuclides Found in the Marine Environment[a]

Nuclide	Half-life (yr)[b]	Modes of Decay	Particle Energies (McV)	Particle Intensities (%)	Gamma-ray Energies (McV)	Gamma-ray Intensities
Th^{232}	1.41×10^{10}	α	4.007	76	0.059	24
Pa^{231}	32,480	α	5.001	24	0.29	All weak
			5.017	23	>10 y's	
			5.046	10	0.027-0.356	
			4.938	22		
U^{234}	2.48×10^{5}	α	4.768	72	0.053	All weak
			4.717	28	0.118	
U^{235}	7.13×10^{8}	α	4.559	6.7	0.094	9
			4.370	25	0.1096	5
			4.354	35	0.144	12
			4.333	14	0.165	>4
			4.318	8	0.185	55
			4.117	5.8		
U^{238}	4.51×10^{9}		4.195	77	0.048	23
			4.14	23		

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[a] *The decay characteristics of the more important radionuclides found in the oceans and deep-sea sediments. Alpha, beta and electron capture decay are denoted by α, β and EC, respectively. Particle and gamma-ray intensities are given as the % of decays which result in the observed radiation. Only the more abundant modes of decay and transitions are noted. The presence of annihilation radiation (511-keV photons) is indicated by the abbreviation Ann. Rad.*

[b] *Units in years unless otherwise indicated.*

TABLE B-7

Effect of Alkyl-Aryl Sulfonate, Including ABS, on Aquatic Organisms

From Firth, 1969.

Organisms	Concentration (mg/l)	Time	Effect	References
Trout	5.0	26 to 30 hours	Death	Wurtz Arlet, 1960.
	3.7	24 hours	TL_m	
	5.0		Gill pathology	Schmid and Mann, 1961.
Bluegills	4.2	24 hours	TL_m	Turnbull, et. al., 1954.
	3.7	48 hours	TL_m	
	0.86		Safe	
	16.0	30 days	TL_m	Lemke and Mount, 1963.
	5.6	90 days	Gill damage	Cairns and Scheier, 1963.
	17.0	96 hours	TL_m	
Fathead minnows	2.3		Reduced spawning	Pickering, 1966.
	13.0	96 hours	TL_m	Henderson, et. al., 1959
	11.3	96 hours	TL_m	Thatcher, 1966.
Fathead minnow fry	3.1	7 days	TL_m	Pickering, 1966.
Pumpkinseed sunfish	9.8	3 months	Gill damage	Cairns and Scheier, 1964.
Salmon	5.6	3 days	Mortality	Holland, et. al., 1960.
Yellow bullheads	1.0	10 days	Histopathology	Bardach, et. al., 1965.
Emerald shiner	7.4	96 hours	TL_m	Thatcher, 1966.
Bluntnose minnow	7.7	96 hours	TL_m	Thatcher, 1966
Stoneroller	8.9	96 hours	TL_m	Thatcher, 1966.
Silver jaw	9.2	96 hours	TL_m	Thatcher, 1966.
Rosefin	9.5	96 hours	TL_m	Thatcher, 1966.
Common shiner	17.0	96 hours	TL_m	Thatcher, 1966.
Carp	18.0	96 hours	TL_m	Thatcher, 1966.
Black bullhead	22.0	96 hours	TL_m	Thatcher, 1966.
"Fish"	6.5		Min. lethality	Leclerc and Deviaminck, 1952.
Trout sperm	10.0		Damage	Mann and Schmid, 1961.
Daphnia	5.0	96 hours	TL_m	Sierp and Thile, 1954.
	20.0	24 hours	TL_m	Godzch, 1961.
	7.5	96 hours	TL_m	Godzch, 1961.

TABLE B-7 (continued)

Effect of Alkyl-Aryl Sulfonate, Including ABS, on Aquatic Organisms

Organisms	Concentration (mg/l)	Time	Effect	References
Lirceus fontinalis	10.0	14 days	6.7 percent survival. (hard water)	Surber and Thatcher, 1963.
Crangonyx setodactylus[1]	10.0	14 days	0 percent survival (hard water)	Surber and Thatcher, 1963.
Stenonema ares	8.0	10 days	20-23 percent survival	Surber and Thatcher, 1963.
	16.0	10 days	0 percent survival	Surber and Thatcher, 1963.
Stenonema heterotarsale	8.0	10 days	40 percent survival	Surber and Thatcher, 1963.
	16.0	10 days	0 percent survival	Surber and Thatcher, 1963.
Isonychia bicolor	8.0	9 days	0 percent survival	Surber and Thatcher, 1963.
Hydropsychidae (mostly cheumatopsyche).	16.0	12 days	37-43 percent	Surber and Thatcher, 1963.
	32.0	12 days	20 percent survival	Surber and Thatcher, 1963.
Orconectes rusticus	16.0	9 days	100 percent survival	Surber and Thatcher, 1963.
	32.0	9 days	0 percent survival	Surber and Thatcher, 1963.
Goniobasis livescens	16.0	12 days	40-80 percent survival	Surber and Thatcher, 1963.
	32.0	12 days	0 percent survival	Surber and Thatcher, 1963.
Snail	18.0	96 hours	TL_m	Cairns and Scheier, 1964.
	24.0	96 hours	TL_m	Cairns and Scheier, 1964.
Chlorella	3.6		Slight growth reduction	Maloney, 1966.
Nitzchia linearis	5.8		50 percent reduction in growth in soft water	Cairns, et. al., 1964.
Navicula seminulum	23.0		50 percent reduction in growth in soft water	Cairns, et. al., 1964.

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[1] *Misidentified originally as Synurella.*

Pesticides & Insecticides

(48 hour TL_m values from static bioassay, in micrograms per liter. Exceptions are noted.)

Pesticide	Stream invertebrate[1]		Cladocerans[2]		Fish[3]		Gammarus lacustris,[4]
	Species	TL_m	Species	TL_m	Species	TL_m	TL_m
Abate	Pteronarcys californica	100			Brook trout	1,500	640
Aldrin[5]	P. californica	8	Daphnia pulex	28	Rainbow trout	3	12,000
Allethrin	P. californica	28	D. pulex	21	do	19	20
Azodrin					do	7,000	
Aramite			D. magna	345	Bluegill	35	100
Baygon[5]	P. californica	110			Fathead	25	50
Baytex[5]	P. californica	130	Simoncephalus serrulatus	3.1	Brown t.	80	70
Benzene hexachloride (lindane)	P. californica	8	D. pulex	460	Rainbow t.	18	88
Bidrin	P. californica	1,900	D. pulex	600	do	8,000	790
Carbaryl (sevin)	P. californica	1.3	D. pulex	6.4	Brown t.	1,500	22
Carbophenothion (trithion)			D. magna	0.009	Bluegill	225	28
Chlordane[5]	P. californica	55	S. serrulatus	20	Rainbow t.	10	80
Chlorobenzilate			S. serrulatus	550	do	710	
Chlorthion			D. magna	4.5			
Coumaphos			D. magna	1			0.14
Cryolite			D. pulex	5,000	Rainbow t.	47,000	

TABLE B-7 (continued)

Pesticides & Insecticides

Pesticide	Stream invertebrate[1] Species	TLm	Cladocerans[2] Species	TLm	Fish[3] Species	TLm	Gammarus lacustris,[4] TLm
Cyclethrin			D. magna	55			
DDD (TDE)[5]	P. californica	1,100	D. pulex	3.2	Rainbow t.	9	1.8
DDT[5]	P. californica	19	D. pulex	0.36	Bass	2.1	2.1
Delnav (dioxathion)					Bluegill	14	690
Delmeton (systex)				14	do	81	
Diazinon[5]	P. californica	60	D. pulex	0.9	do	30	500
Dibrom (naled)	P. californica	16	D. pulex	3.5	Brook t.	78	160
Dieldrin[5]	P. californica	1.3	D. pulex	240	Bluegill	3.4	1,000
Dilan			D. magna	21	do	16	600
Dimethoate (cygon)	P. californica	140	D. magna	2,500	do	9,600	400
Dimethrin					Rainbow t.	700	
Dichlorvos[5] (DDVP)	P. californica	10	D. pulex	0.07	Bluegill	700	1
Disulfoten (di-syston)	P. californica	18			do	40	70
Dursban	Peteronareella badia	1.8			Rainbow t.	20	0.4
Endosulfan (thiodan)	P. californica	5.6	D. magna	240	do	1.2	64
Endrin[5]	P. californica	0.8	D. pulex	20	Bluegill	0.2	4.7
EPH			D. magna	0.1	do	17	36
Ethion	P. californica	14	D. magna	0.01	do	230	3.2
Ethyl guthion[5]			D. pulex		Rainbow t.		
Fenthion	P. californica	39	D. pulex	4			
Guthion[5]	P. californica	8	D. magna	0.2	Rainbow t.	10	0.3
Heptachlor[5]	P. badia	4	D. pulex	42	do	9	100
Kelthane (dicofel)	P. californica	3,000	D. magna	390	do	100	
Kepone					do	37.5	
Malathion[5]	P. badia	6	D. pulex	1.8	Brook t.	19.5	1.8
Methoxychlor[5]	P. californica	8	D. pulex	0.8	Rainbow t.	7.2	1.3
Methyl parathion[5]			D. magna	4.8	Bluegill	8,000	
Morestan	P. californica	40			do	96	
Ovex	P. californica	1,500			do	700	
Paradichlorobenzene					Rainbow t.	880	
Parathion[5]	P. californica	11	D. pulex	0.4	Bluegill	47	6
Perthane			D. magna	9.4	Rainbow t.	7	
Phosdrin[5]	P. californica	9	D. pulex	0.16	do	17	310
Phosphamidon	P. californica	460	D. magna	4	do	8,000	3.8
Pyrethrins	P. californica	64	D. pulex	25	do	54	18
Rotenone	P. californica	900	D. pulex	10	Bluegill	22	350
Strobane[5]	P. californica	7			Rainbow t.	2.5	
Tetradifon (tedion)					Bluegill	1,100	140
TEPP[5]					Fathead	390	52
Thanite			D. magna	450			
Thimet					Bluegill	5.5	70
Toxaphene[5]	P. californica	7	D. pulex	15	Rainbow t.	2.8	70
Trichlorofon (dipterex)[5]	P. badie	22	D. magna	8.1	do	160	60
Zectran	P. californica	16	D. pulex	10	do	8,000	76

From Federal Water Pollution Control Administration, 1968.

Chemical compounds important to estuaries can be divided into several sections such as nutrients, inorganic, and organic. Nutrients are defined as carbon, nitrogen, and phosphorous although there are many other elements and compounds both inorganic and organic that are utilized as nutrients or growth factors. Nitrogen and phosphorous may enter into the estuary from sewage outfalls, runoff from agricultural land and natural vegetation. (Carbon as defined as alkalinity is rarely if ever limiting or in excess in the marine environment.) All living organisms have a ratio of approximately 100 parts carbon, 16 parts nitrogen, and 1 part phosphorous, with approximately 80 percent water. Nitrogen can also accumulate from electrical storms, natural biological fixation such as bluegreen algae, from residue of burned fuel, etc. Nitrogen and phosphorous are generally considered the cause of eutrophication but complete control of these materials in effluents may depress the natural environment Mackenthum and Taft, 1965). This is due to the fact that natural water input to estuaries has through geological time brought these fertilizers into the communities and thus accounts for the great productivity of our shore area. The balance is quite critical and man has yet to understand all the ramifications of control. Therefore, guidelines must be established relative to the natural conditions and ratios of the materials.

Inorganic materials include the elements and ions such as sulfate, etc. The salinity (referred to as conductivity or total dissolved solids) includes all the natural occurring elements as a result of geological weathering and other activities. For example, lead produced from internal combustion and mercury have increased normal open sea levels manyfold and are expected to increase further. These materials are normally in a chemical balance but are continually being altered by living systems. All elements are concentrated by living organisms. Vanadium, for example can be concentrated up to 3% of some tissues in the sea squirt or tunicate. Copper is concentrated in shell fish, strontium and calcium are concentrated in bone and carbonate shells, titanium is concentrated up to 2000 times the background concentration. As biochemical studies proceed, more indications of element requirements in living systems are uncovered. Cobalt, manganese, magnesium, iron, selenium, copper, zinc, vanadium and others have known requirements for man, cultivated animals, plants and in general biological species. Thus, all organisms do not have the same requirements or normal concentration for specific elements.

Concentration criteria then for the inorganic materials can only be an arbitrary unit because it will be impossible to determine the value for each community. As more information becomes available, more appropriate values can be assigned. In the interim, it will be necessary to estimate the criteria from natural occurrence in the marine environment and those values for public water quality control.

The number of organic materials in waters and sediments of normal environments are probably equal to the known natural occurring compounds in living organisms. In addition, man formulated materials such as oils, detergents, pesticides, herbicides, freons, and by-products from chemical manufacturing are introduced in large amounts through effluents, rivers and general runoff and from the atmosphere. Generally, the naturally occurring organic materials are present in low concentrations that are not toxic; however, at times materials such as phytoplankton toxins are produced that cause occurrences such as the so-called red tide fish kills.

Some organic materials will have a protective effect as they combine with heavy metals and reduce the toxicity.

Threshold Limits for Biological Use

The following list of threshold units and parameters for water quality in Texas estuaries have been assembled over a two month period using as a guideline criteria from EPA, Public Health criteria, field data and various publications. The available literature review indicates that no absolute criteria can be established without more specific field research to determine the chemistry and biological use off the Texas coast at varying distances from land and at different seasons to compare with current data being collected in the bays. The published values for the elements in seawater are a summary and generally represent the open ocean. Data for inshore chemistry, other than nutrients, is lacking.

However, guidelines must be established and interim values will be useful in establishing management control. It must be emphasized that the following are only estimates and must be continuously reviewed as current information becomes available.

The ultimate form of the criteria should be based on a percentage of the natural variation for specific localities. However such baseline data for our Texas estuaries are only available for salinity, temperature, oxygen and a very few other parameters. Practically nothing has been published on average baselines for organic and inorganic elements and molecules. There is much to be accomplished.

The following list in Table B-8 is not considered complete, but only to be used as a planning tool. A two year program has been requested to continue these efforts.

TABLE B-8

Biological Use Criteria

	Threshold Limits
Salinity	±10% of maximum and minimum over 5 year average
Sulfates	10% above maximum average for total 5 years
Dissolved solids	±10% of maximum and minimum over 5 year average
BOD-organic carbon	One order of magnitude above primary product carbon over 5 years
O_2	2.5 ppm
pH	6.5 - 8.5
Coliforms	10,000/100 ml.
Temperature	4° - September - May 1.5° - June - August less than above ambient
Toxicants	(See specific compounds)
Solids & Turbidity	5000 mg/l.
Radio nuclides:	
Strontium	10 pc/l.
Gross Beta	1000 pc/l.
Radium 226	3 pc/l.
Color	No restriction except due to chemical composition
Taste & Odor	Organoliptical absent *in situ*
Phenols	1.0 mg/l
Alkyl-Aryl Sulfonates	1.0 mg/l
Pesticides	10 ug/l
Oil	No visible sheen
Detergents, cationic	1 ug/l

Trace elements:	mg/l*	mg/l**
Mercury	.00003	.01
Copper	.003	.01
Lead	.00003	.05
Nickel	.0054	.05
Zinc	.01	5.00
Chromium	.00005	1.00
Cadmium	.08	.10
Arsenic	.003	1.00
Silver	.0003	.01
Variadium	.002	1.00
Fluorine	1.30	10.00
Cyanide	--	.02
Manganese	.002	.10
Cobalt	.0005	.01
H_2S	variable	.50
Beryllium	.0000006	.001
Selenium	.004	.01
Ytrium	.0003	.01
Antimony	.0005	.01
Boron	4.6	10.00

**mg/l - normal oceanic seawater*

***mg/l - threshold limits*

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APPENDIX C

MODELING OF ESTUARINE TRANSPORT PROCESSES

When all of the factors influencing the use and environmental protection of estuarine waters are considered together in detail, it becomes obvious that a separate, detailed evaluation of each of the physical, chemical, and biological actions and interactions is essentially impossible. Additionally, it is uneconomical and unproductive to attempt to measure every action and interaction which occurs in real time in the estuarine system. These requirements have forced scientists and engineers to attempt to develop models which represent the prototype estuarine environment on a reduced scale and which can be used to simulate various conditions and provide reliable information for decision making.

The objective of this section is to describe the present-day use of models as planning tools in the management of bays and estuaries with emphasis on the state of the art in Texas.* The types of hydrodynamic and transport, water quality and sedimentation problems amenable to modeling are delineated. The basic methodology used in model development, verification and predictive use is described along with data limitations.

ESTUARINE PROBLEMS AMENABLE TO MODELING

The following are complex problems which result from man's activities in and adjacent to the estuaries which must be addressed and can be considered by decision-makers in terms of long-term management programs using modeling techniques.

Hydrodynamic and Transport Processes

Numerous projects that would drastically alter the inflow, circulation, and interchange patterns existing in Texas estuaries have been proposed. Studies need to be made to evaluate both the benefits and detriments to the estuaries that might accompany the following natural and man-made activities:

**A detailed technical review of estuarine modeling has been prepared by Ward and Espey (1971).*

- Effects of hurricanes on water levels in coastal areas and the efficiency of various types of protection structures; and
- The effects of tidal passes, ship channels, reefs, jetties, spoil banks and other type structures on the flow and velocity regimes.

Both physical and mathematical models have been used successfully for such planning in the Texas estuaries.

Water Quality

The transport of conservative materials in an estuary is the simplest water quality modeling problem. Chloride or salinity is an excellent example of such a conservative water quality constituent. One of the most pressing management problems is the prediction of salinity changes in estuaries due to reduced fresh water inflow and possible increased number of fish passes through the barrier islands. Such salinity models should be used subsequently to determine the effects of salinity changes on the organisms which use the estuaries during various stages of their life cycle. Both physical and mathematical models for salinity have been developed and verified for various Texas estuaries.

Other water quality constituents such as biochemical oxygen demand, dissolved oxygen, temperature, nutrients and inhibitory materials generally are considered non-conservative. The pressing management problems concern the degree of treatment of these water quality characteristics required to maintain the water quality necessary in the estuary itself to preserve mans' desired uses of the estuaries. Physical models are of little use in such cases.

Mathematical modeling of heated cooling-water discharges from fossil fueled power plants are quite adequate in terms of development and substantial verification work has been conducted in two Texas estuaries. The most work from a development point of view has been in terms of a BOD/DO model with particular emphasis on the Houston Ship Channel. Verification of such models in other parts of Galveston Bay and other estuaries has been limited. Little if any model development of nutrient cycling has been accomplished in Texas estuaries. The effect of inhibitory or toxic materials on estuarine organisms thus far has been limited to a preliminary stage of development for the Galveston Bay system.

Sedimentation

One of the most pressing management problems is shoaling of navigation channels and tidal passes. Physical models have been utilized exclusively in the Texas estuaries in the solution of this complex three dimensional problem. Little (if any in Texas) work has been accomplished on estuarine sediments serving as a vehicular mechanism for the transport of entrained materials throughout the estuary. Such materials include refractory organics, nutrients, pesticides and heavy metals. Ultimately it will aid in selecting alternative sites for dredge sediment deposition in order to avoid detrimental sediment deposition in key spawning, nursery and unique habitat areas.

MODEL CONCEPTS

A model is a technique or device which can be used to simulate the chemical or biological processes and/or reactions which occur in the prototype which the model is intended to represent. A model may be physical or mathematical.

The importance of the data utilized for model development verification and prediction of anticipated future conditions cannot be over-emphasized. The model is developed from data collected from the prototype system for one set of environmental conditions; e.g. low flow conditions in late summer. The model then is adjusted (mathematically or physically depending upon the model type) to reproduce precisely these measured data. Subsequently, data are collected from the prototype under a number of other environmental conditions; e.g. winter, spring, early summer, fall. If the model is capable of reproducing these different environmental conditions without further adjustment, it is considered verified. Likewise, the use of poor input data for prediction purposes (even though the model may provide an accurate simulation of the present prototype system) will result in equally unacceptable results. Thus, the reader must be constantly aware that the capabilities of the simulation tools discussed in this chapter are no better than the information and data used. Model development is simple and economical compared with the effort and cost required to provide the information needed to make them useful tools.

Moreover, a verified simulation model does not necessarily infer that the model will accurately predict future conditions. In addition to the reliability of the input information, predictive capability is a function of the stability of features of the future prototype which are not accurately represented by the present model and the degree of accuracy and confidence required by the decision-maker. In the final analysis, only the management personnel can determine the predictive adequacy of a given model.

Physical Models

A physical model as applied to an estuarine system is an actual structural representation of the prototype on a reduced and a distorted scale with a mechanical wave generator to furnish the tidal excitation.

Justification for the use of a physical model is usually based on the inability to obtain a direct analytical mathematical solution to a specific problem. This often may be the case in estuarine systems because of their highly complex nature. Physical models also have the added advantage of being able to illustrate to an uninitiated observer the phenomena which the models are simulating.

The analytical basis for the reproduction of natural phenomena in a physical hydraulic model can be found in the laws of dynamic similitude.

Once a physical model has been scaled and built, it must be verified to behave as the prototype. Verification of a physical model is a tedious "trial and error" process involving the modification of bottom roughness in the model until the scale relationships for tidal velocities and elevations are in agreement with the prototype. This adjustment usually is made with metal strips which are embedded in the model and then twisted and bent until prototype conditions are satisfied. While the advective transport processes generally are simulated satisfactorily, this distorts the turbulent diffusion process even further from the real situation in the prototype.

Mathematical Models

A mathematical model is a functional formulation of the behavior of a system presented in a form amenable to solution by analytical or numerical techniques. In its simplest form the mathematical formulation of a process consists of a perturbation (input), a transfer function, and an output. The mathematics involved are the partial differential equation forms of the Equation of Motion and the Equation of Continuity in various dimensions.

Because of the non-linearities of these equations, analytical solutions in closed form can seldom be obtained for "real world" conditions unless many simplifying assumptions are made to linearize the system. Particularly, when boundary conditions required by the prototype behavior become excessive or complicated, it is convenient to resort to numerical methods which require discretizing the system in such a manner that the boundary conditions for each discrete element can be applied or defined. Thus, it becomes possible to evaluate the complex behavior of a total system by considering the "input-transfer function-output" interaction between individual elements satisfying common boundary conditions in succession.

If the phenomena to be studied are time dependent, also it is convenient to increment the solution temporally. Thus, if a sufficiently small time interval is considered, the system may be treated as being in static or dynamic equilibrium instead of being continuously variant. This makes it possible to obtain at successive levels of time a solution whose accuracy is dependent to some extent on the length of time interval selected and the rate of change of the phenomenon being investigated. The smaller the time step used, the more accurate the solution will be.

With the advent of the third generation high-speed, large core memory digital computer, it has been possible to solve numerically the mathematical equations reasonably well and within an economical cost range, at least for the one and two-dimensional problems. The solutions thus obtained may be refined to achieve some desirable optimum between the demands for accuracy and the burden of additional cost which is proportional to both the number of elements and the number of discrete time intervals required for a complete analysis of the system. Parallel to these dimensionality considerations in time and space are certain mathematical constraints within which a solution can be obtained that is mathematically stable, convergent, and compatible with the prototype system.

Development of a digital simulation model of the tidal hydrodynamics in an estuary is similar to the "trial and error" process previously described for the physical model. In the case of digital simulation models the process is essentially a "coefficient hunt." However, there is a rational analytical basis for the quantification of these coefficients which is not available in physical modeling. Also, with a digital simulation model it is much more obvious where coefficient adjustments are required than with the physical model.

BASIC MODELING ASSUMPTIONS

Modeling is the process whereby one constructs a simplified replica of a complex prototype. In achieving this goal, most (if not all) models use various simplifying assumptions to render the phenomenon they describe amenable to solution. Since the prototype systems are inevitably too large (or too small if one is a nuclear physicist) and too slow (or fast) to reproduce at their natural scale, simplifying assumptions must be made concerning the spatial and temporal characteristics of the prototype.

Spatial Dimensionality

The first major assumption involves the spatial dimensionality of the problem. Certainly, all effects, either water quality or otherwise, are three-dimensional in the estuary. A water quality model which uses a one-dimensional analysis assumes that concentration gradients are only important in one direction, that most frequently being the direction of the longest axis of the prototype estuary

(This is generally in the direction of fresh water flow.) These assumptions of vertical and lateral homogenity sometimes can be used effectively on long, narrow estuaries, particularly where mixing of saline and fresh waters precludes formation of a prominent saline water wedge.

Two dimensional models can be used to describe concentration gradients in either one vertical and one horizontal direction or in two horizontal directions. The type of model which uses two dimensions in the horizontal and assumes complete mixing in the vertical is particularly applicable to Texas bays. The shallow water in these estuaries is mixed readily by wind and tidal action and the degree of vertical density stratification is minimal. However, in deep channels and cuts this type of model cannot predict the salinity stratification which may occur. The two dimensional model which uses the vertical as one dimension has been proven extremely useful for describing the effects of the salt water wedge over which the fresh water entering the estuary flows.

Obviously, the ideal model for describing an estuary would be three dimensional since three-dimensional phenomena are being simulated. To date, no one has successfully developed a three-dimensional estuary model.

Temporal Dimensionality

The other major assumption generally made in modeling of estuaries relates to the time dependency of the phenomena. The "steady-state" assumption considers that the hydrodynamics and/or water quality characteristics of interest at a given location does not change with time.

Since most of the inputs to an estuarine system vary with time (e.g., fresh water inflow, temperature, wastewater discharges, chemical and biological reactions), the temporally-varying model permits a more detailed simulation of the estuary than does the steady-state analysis. However, time-variable mathematical models introduce another magnitude of resolution and difficulty into estuarine analysis. The verification of the time-varying model requires considerably more detailed prototype data than the steady-state model, and sufficient data usually are not available for proper verification of this type of model. It thus often becomes a question of sacrificing reliability of model results for increased temporal resolution of the estuarine phenomenon being modeled.

HYDRODYNAMIC AND TRANSPORT MODELS

The fundamental theory and development of the basic formulations for tidal hydrodynamics have been described extensively in the literature (Dronkers, 1964) and will not be repeated here. It is sufficient to say that the tidal hydrodynamics of an estuarine system can be described by the Equation of Motion and the Equation of Continuity for an incompressible fluid. The Equation of Motion includes the inertia, friction, gravity and pressure forces as well as the added effects of wind stress and the coriolis acceleration. The Equation of Continuity, which accounts for the conservation of mass, also includes rainfall and evaporation.

Physical Models

The U.S. Corps of Engineers Waterways Experiment Station at Vicksburg, Mississippi has three physical models of Galveston Bay complex and previously had one of Matagorda Bay.

These models were designed and developed with two major applications in mind. First, they are used to study navigation problems, principally the hydraulics of estuaries as related to the construction and maintenance of navigation facilities. Secondly, they are used in the investigation of hurricane surges and the design of hurricane protection works.

The model of the Houston Ship Channel has been the most used physical model of any part of the Texas coast. Good verification has been obtained for tidal amplitudes and velocities. While its conservative transport simulation (salinity) has been verified for areas near the channels, its applicability to the shallow portions of the bay has not been thoroughly demonstrated.

Mathematical Models

Urban (1966) developed and applied a modified tidal prism model to the Galveston Bay complex. It was used to describe the impact of river inflows on the bay system, including exchanges, total accumulation, and residence time. The prism concept also has been applied to the Neches River estuary (Hann, 1970) to determine physical exchange through successive segments of the system. Both of the above models preclude a precisely detailed study of the tidal hydrodynamics without expensive and lengthly field and/or model tests. Nevertheless these approaches were useful as preliminary planning tools.

Because of the complexity and variety of boundary conditions in the Texas gulf coast estuaries, one-dimensional models have very limited application unless the system is grossly simplified. However, a one-dimensional tidal hydrodynamic model originally developed for the San Francisco Bay-Delta Study (Water Resources Engineer, 1965) has received wide application as a pseudo-two-dimensional model and should be mentioned briefly. This model involved a numerical solution of the one-dimensional Equations of Motion and Continuity for a network of one-dimensional channels in any other horizontal direction. This model then, in a sense, does approximate a two-dimensional vertically mixed system. Although this model is truly descriptive of a network of interconnected channels there are strong possibilities of anomalous conditions when it is used to represent large expanses of water such as is characteristic of the Texas coast estuaries. An example of the network used in this type of model is shown in Figure C-1.

Both Masch, et al. (1970) and Tracor (1971) used a time dependent vertically-integrated two-dimensional model to investigate the tidal hydrodynamics of Galveston Bay. Typical results of the use of these models are shown in Figure C-2.

Models similar to the two Galveston Bay models are being used by the Texas Water Development Board (1971) to determine the tidal hydrodynamics of San Antonio Bay and Matagorda Bay under low, average and high fresh water inflow conditions. Presently these models also are being applied to Aransas Bay, Copano Bay, and Corpus Christi Bay by the Texas Water Development Board. That agency anticipates using the results from these model studies (plus additional inputs) in determining the future water requirements for the bays and estuaries.

WATER QUALITY MODELS

Obviously, all water quality models of estuarine waters must take into account tidal hydrodynamics. This can be done in one of several ways. In the physical model, the operation of the model automatically simulates the hydrodynamics of the estuary and the input water quality characteristics are simply added at the appropriate boundaries of the model. In the mathematical model one can either use a time history of instantaneous velocities and flows in each model segment as determined from a hydrodynamic model; or, the hydrodynamics can be time-averaged and placed directly in the continuity equation for the parameter being modeled. Dispersion is the predominant process needed for input to the quality models.

Conservative Materials

The transport of conservative materials such as chlorides, in an estuary is the simplest water quality modeling problem. Also, it is often convenient to consider certain water quality

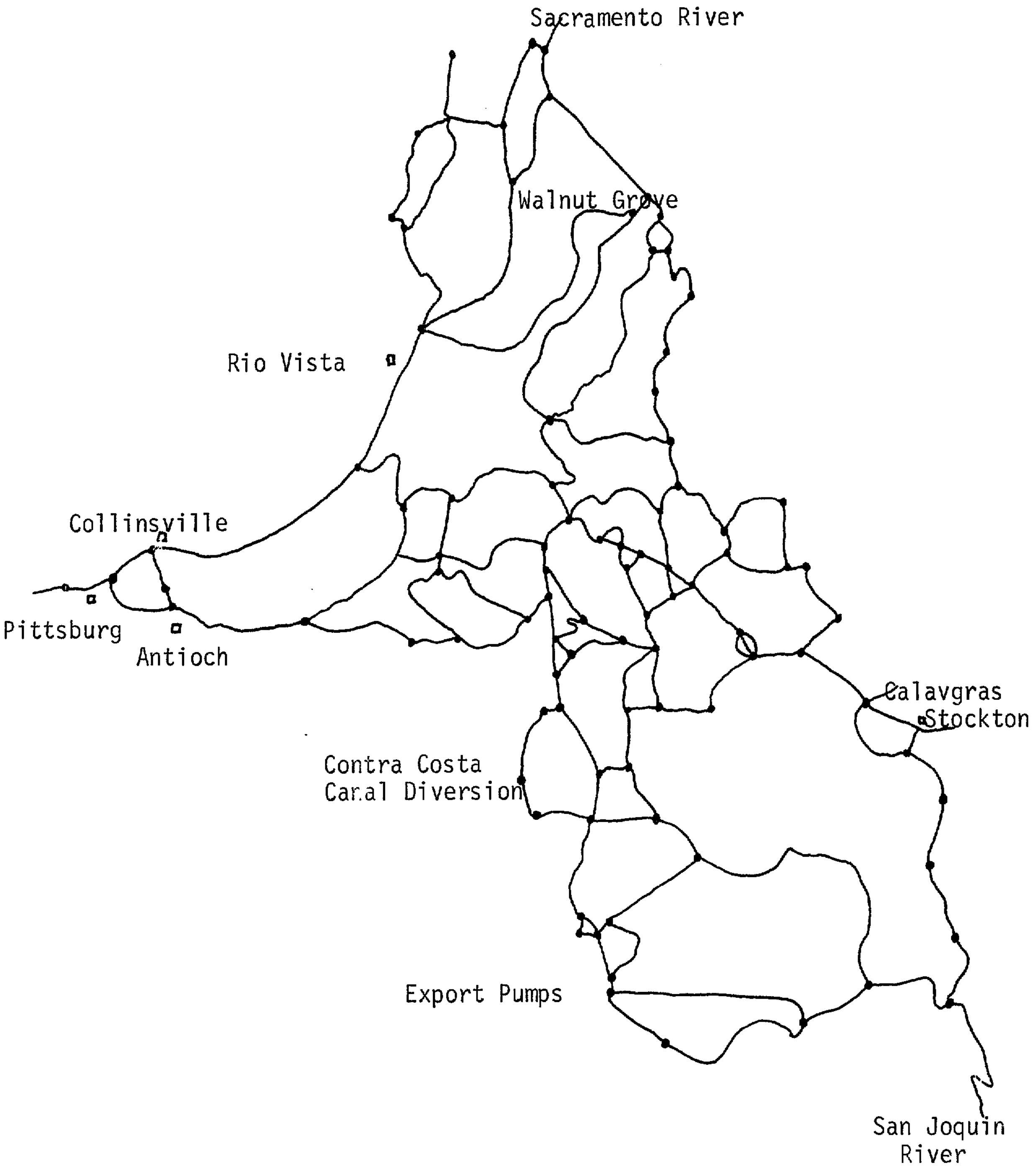


FIG. C-1; REDUCED DELTA NETWORK - STEADY STATE PROBLEM

From: Water Resources Engineers, Inc. 1965.

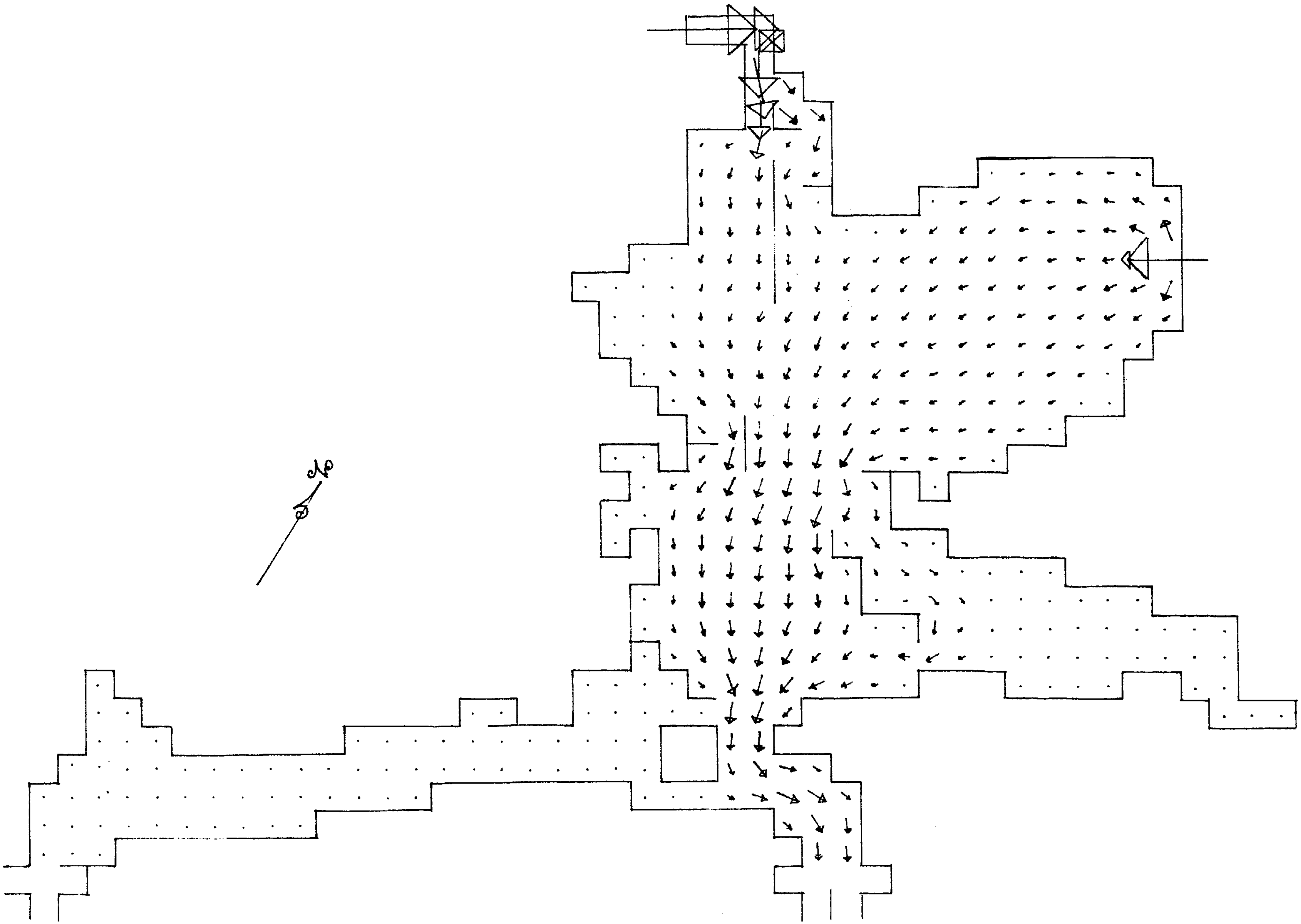


FIG. C-2; NET VELOCITY PATTERN FOR GALVESTON BAY --- From: Tracor, 1971. (High flow conditions) constituents as conservative materials even though they are not totally chemically and biologically inert. Typical examples of these are conductivity, total dissolved solids, sulfates, total nitrogen, and total phosphorous. A decision to consider an active substance as a conservative material must take into account the following:

- Degree of accuracy required in the answer,
- Availability of good data revealing its reaction rates,
- Amount of resources (dollars) available for modeling, and
- Severity of the error introduced by the assumption.

As with hydrodynamic modeling,either physical or mathematical models may be used to simulate the behavior of conservative water quality substances.

One can expect *physical models* to perform an acceptable simulation of conservative water quality constituents under most conditions. Salinity is the most commonly modeled conservative parameter for estuaries. This is achieved simply by introducing the substance into the hydrodynamic model in the desired amounts at the specific locations and times.

Modeling the salt wedge phenomenon involves preserving in the model the density ratio which exists in the prototype and achieving momentum similitude in the hydrodynamic regime. In general, physical models have been shown to be quite adequate for simulating the salinity gradients in estuarine systems, principally because salinity intrusion is a gravity-dominated transport process (e.g., density and momentum).

However, when one is interested in mass transfer of a conservative constituent in regions of somewhat uniform concentrations where diffusion-dispersion rather than advection becomes the prominent feature, the adequacy of the physical model is less certain. Many investigators have pointed out that physical models do not necessarily produce the appropriate scaling of the diffusion-dispersion mass transport effects between model and prototype. Although physical models have been used to study the transport of various dyes and tracers, there has been insufficient verification of the models for this type of constituent to consider them sufficiently reliable. In addition, many of the dyes used are affected by adsorption on the surfaces of the model. Such surface phenomena requires that correction factors be applied to verify the results using prototype data and which introduces another degree of uncertainty to the final model results.

The use of physical models to describe mass transport in Texas bays has been limited to salinity intrusion. The Corps of Engineers model of Matagorda Bay was operated with a mixture of fresh and salt water to determine the effects of the deep-draft ship channel on the salinity regime in the Bay (Ippen, 1966). The Galveston Bay physical model is under study to evaluate the effects of proposed hurricane barriers on the salinity distributions of Galveston Bay. Also, in the later model dye studies have been used to determine time-of-travel between certain waste discharges on the Houston Ship Channel and selected locations in Galveston Bay.

The verification of physical models for the conservative mass transport problem consists of comparing the concentration distributions generated by the model with those measured in the estuary under similar conditions. This requires a substantial effort, both in the laboratory and the field.

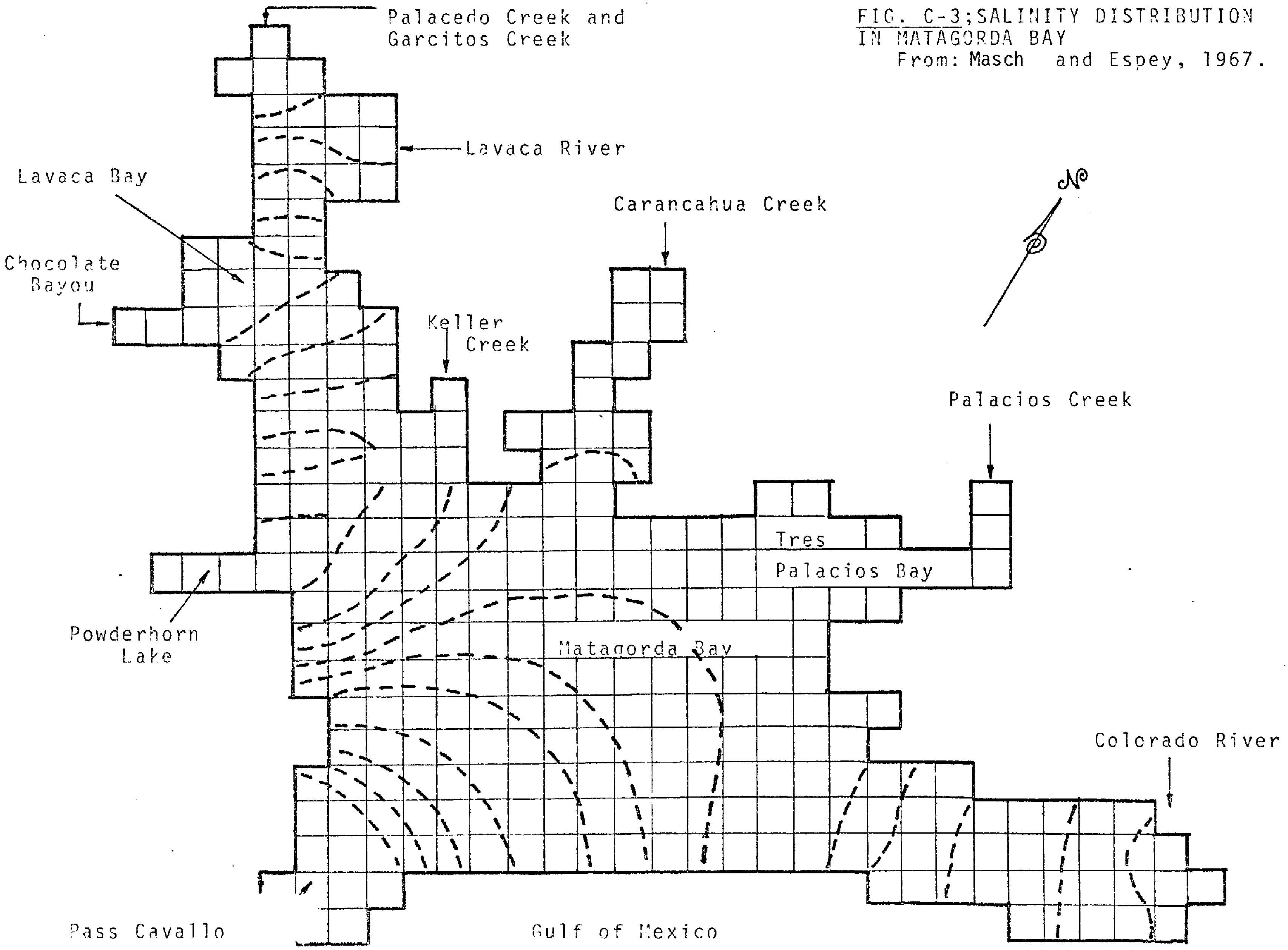
The mathematical model for transport of a conservative substance in an estuary is relatively simple and consists of performing a mass balance on each segment of the model estuary.* The mass continuity equation contains no temporally-varying sink terms and can be solved quite satisfactorily by finite difference or analytical techniques, depending upon the type of problem involved. Solutions for both the one and two-dimensional cases in terms of the steady-state and time varying conditions are available and have been extensively verified and used.

The Galveston Bay Study (Tracor, 1971) has used a two-dimensional (in the horizontal), steady-state digital model to predict salinity distributions under varying quantities of fresh water inflow. No rainfall or evaporation effects presently are considered in this model. Field verification based on mean annual chloride measurements for June 1968-July 1969 and low inflow conditions for July 1968-December 1968 has been obtained.

Masch, _et al_. (1970) at The University of Texas has used a similar mathematical model to predict the influence of various tidal inlets on the salinity regimes of Galveston and Matagorda Bay. Figure C-3 illustrates the grid system of the Matagorda salinity model and shows the salinity distribution for the model calibration run. A comparison of the salinities predicted by the numerical model at various stations in Matagorda Bay with prototype salinities and with salinities predicted by the Corps of Engineers physical model are shown in Figure C-4 (Shankar and Masch, 1970).

**However, the hydrodynamic behavior of the system must first be simulated and this can become a rather non-trivial endeavor.*

FIG. C-3; SALINITY DISTRIBUTION IN MATAGORDA BAY
From: Masch and Espey, 1967.



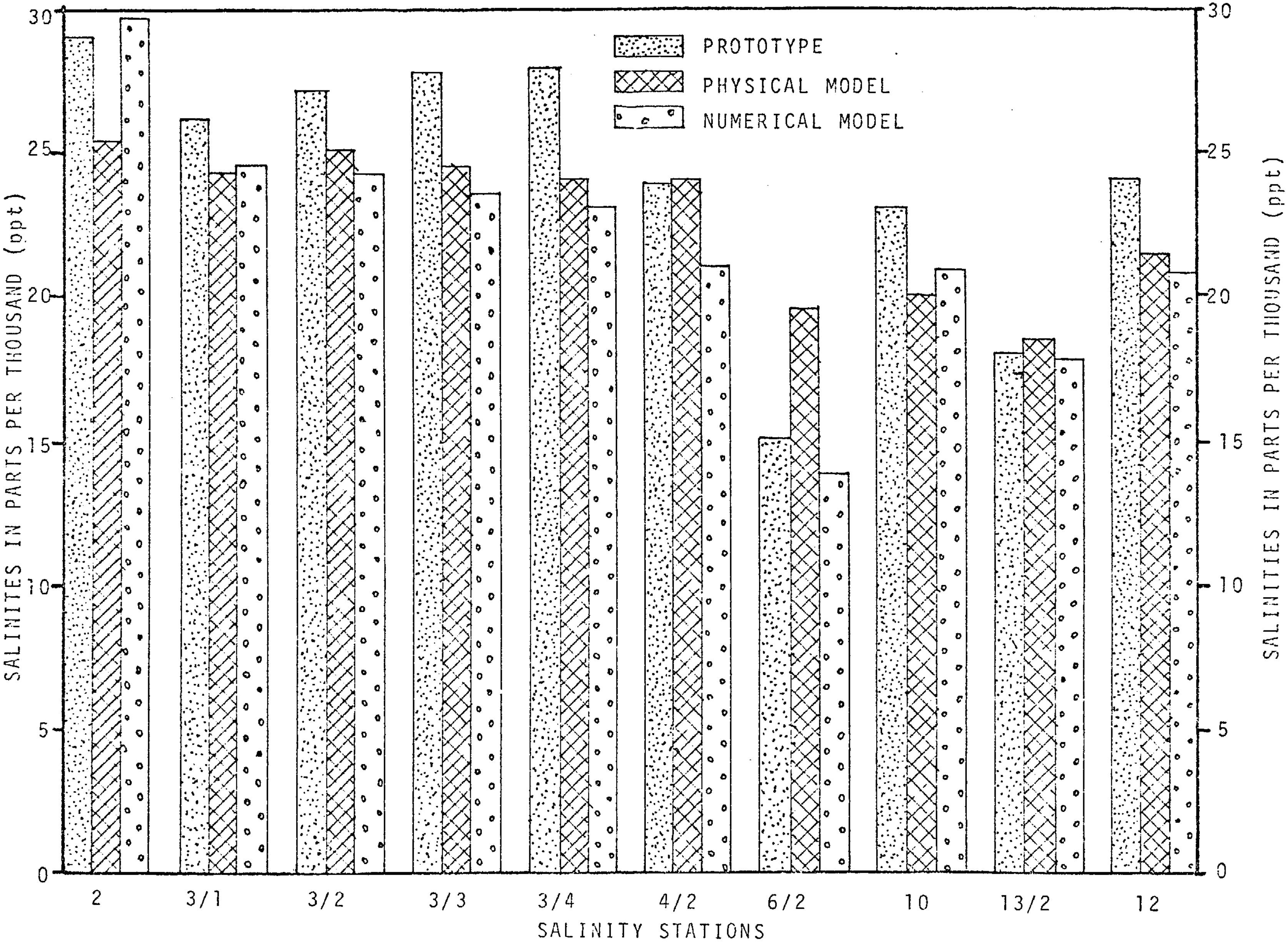


FIG. C-4; SALINITY MODEL VERIFICATION -- MATAGORDA BAY FROM: MASCH AND ESPEY, 1967

Similar models are being used by the Texas Water Development Board (TWDB, 1971) to determine the effects of various quantities of fresh water inflow on both the Matagorda and San Antonio Bay systems, and models of the Copano-Aransas and Corpus Christi Bay systems are being developed.

A one-dimensional steady-state model has been applied to estimate the distribution of a conservative substance in the Neches River estuary (Hann, 1970). The analysis was performed for six different rates of fresh water inflow using a constant tidal amplitude. However, extensive field data have not been published on the verification of the conservative model.

Temperature

Temperature, although not a concentration in the sense that salinity is, can be considered as a measure of the heat stored in a unit volume of water. And, temperature is non-conservative because of the heat fluxes external to those caused by the convective and dispersional processes. These heat fluxes enter and leave a water body primarily across the air-water interface and to a much lesser degree through the sides and bottom of the system. Thus, the simulation of temperature requires that a "source/sink" term be added to the mass continuity equation. The heat fluxes at the air-water interface are net solar radiation, atmospheric radiation, back radiation, conduction, and evaporation. In some situations where convective and dispersive transport are dominant, for example in the mixing zone of a power plant discharge, it may be possible to disregard all of the external heat fluxes. However, in real time temperature simulation, the diurnal cooling and heating effect at the air-water interface must be considered.

The limitations of physical models have precluded their use for rigorous simulation of the thermal behavior of estuarine systems. In some instances such as the power plant discharge mixing zone problem, dye studies in physical models have been used synonomously with temperature. However, the dangers involved in making such an extrapolation should be apparent.

Tracor (1971), assuming complete vertical mixing, developed a two-dimensional space and time dependent mathematical model of thermal behavior to investigate Houston Lighting and Power Company's P.H. Robinson Generating Station on Galveston Bay and Central Power and Light Company's Nueces Bay Generating Station. The results of both of these modeling efforts indicated that mathematical models are capable of describing quantitatively the thermal distribution resulting from a heated discharge into a shallow embayment. Field data collected during these investigations showed that although vertical thermal stratification occurred, it was short-lived and infrequent, thus qualifying the basic assumption of complete vertical mixing. Figure C-5 is an example of the output from this model.

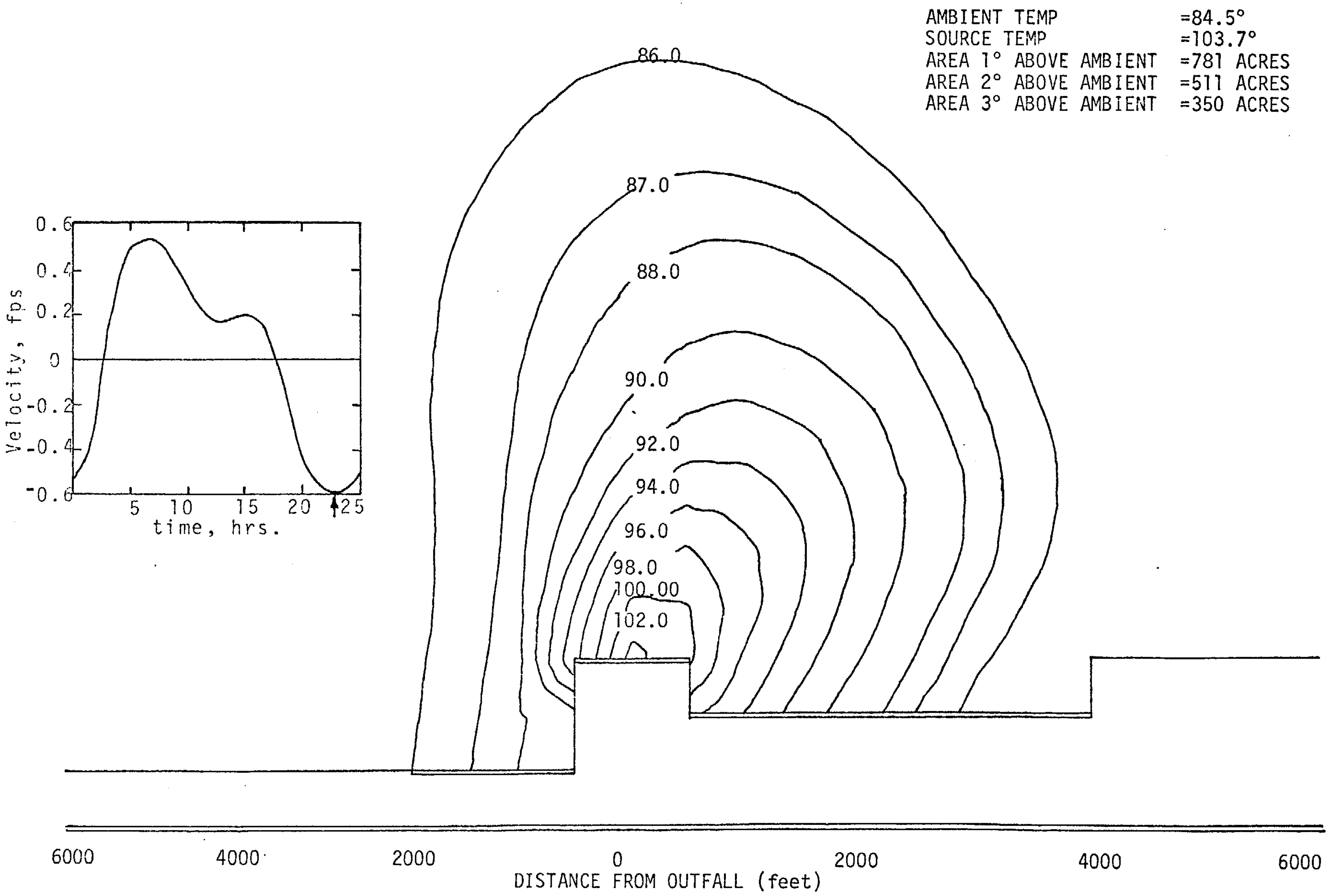


FIGURE C-5; TEMPERATURE CONTOURS - P.H. ROBINSON PLANT MAX. EBB TIDE, NO WIND - 23:00
FROM: TRACOR, 1971.

Biochemical Oxygen Demand/Dissolved Oxygen

The breakdown of organic materials by biochemical process and its impact on the dissolved oxygen resources--the BOD/DO reaction--has long been a standard parameter for assessing the impact of waste discharges on bodies of water.

A waste, upon being discharged into a water body, immediately undergoes a reduction in its BOD due to dilution/dispersion/diffusion. Also, as the biochemical reactions start, actual decomposition of the organics begins. Thus the mass continuity equation must consider two phenomena. First the output of the hydrodynamic model is needed to describe the physical interactions, and secondly the mass continuity equation must contain an additional "sink" term which represents the rate of the biological reaction which removes BOD from the system.

It is usually convenient to approximate the rate of this reaction by assuming first order kinetics, i.e., the rate of reaction is directly proportional to the concentration of BOD remaining. The BOD reaction rate coefficient is either estimated from prototype BOD data or from experience with similar aquatic systems and wastes. The BOD reaction itself is a combination of two principal categories of reactants, carbonaceous and nitrogenous materials. These can either be aggregated into one overall BOD concentration with a single reaction rate coefficient or can be treated separately using two rate coefficients. As a rule sufficient data are lacking to permit use of the latter approach for simulation modeling.

Generally, dissolved oxygen concentration gradients in an estuary are determined concurrently with the BOD simulation. This involves solving a second mass continuity equation to obtain the desired dissolved oxygen distributions. The BOD is a biological reaction which acts as a sink in the dissolved oxygen continuity equation. The primary source of oxygen is the atmospheric reaeration which occurs due to the depression of the dissolved oxygen concentration below saturation concentration for the existing temperature,and barometric pressure. This phenomena can be represented as a first order reaction with respect to the dissolved oxygen concentration deficit; computationally, it is included as an additional term in the general decay equation. The reaeration rate coefficient can be estimated from various empirical relationships or from prototype data. Furthermore, during the daylight hours green plants produce oxygen which is an additional source in the continuity equation, while during darkness they utilize oxygen which serves as an additional sink. Another dissolved oxygen sink is benthal oxygen demand, which is the result of biological action on the bottom sediments.

Because of all the complexities that arise because of temporal and spatial similitude,physical models simply can not be used to describe the BOD/DO interactions in an estuarine system.

In regards to spatial dimensionality and temporal solution techniques, the BOD/DO mathematical models are identical to other simulation models of mass transport phenomena. One and two-dimensional models can be solved for the steady-state and time varying cases. The time varying case (e.g., real time model) may be particularly applicable to dissolved oxygen modeling, since the diurnal variation of this water quality characteristic due to the photosynthesis-respiration cycle may be quite pronounced. However, to date, most dissolved oxygen modeling activities have incorporated the steady-state analysis.

A one-dimensional, steady state model of the Neches Estuary has been prepared for the Texas Water Quality Board (Hann, 1970). The model uses hydrodynamics estimated from an assumed sinusoidal tide to provide the necessary excitation for the mass transport model. The estuary is divided into 37 segments in the model, and the reaeration rate coefficient is empirical. An averaging technique is used to account for the effects of the saline wedge in this narrow estuary. The model was used to simulate the dissolved oxygen concentrations in the estuary under 5 alternative waste loading conditions for each of six fresh water inflow rates. Only one set of data was available for model verification. A similar model was developed for the Houston Ship Channel by the same investigator (Hann, 1969).

Two-dimensional modeling of BOD/DO is still in its infancy, both in Texas and elsewhere. Tracor (1971) has developed a two-dimensional model (in the horizontal) of the Galveston Bay System which simulates the spatial distribution of biochemical oxygen demand/dissolved oxygen under various waste discharge conditions. This model does not simulate the Houston Ship Channel but does consider it as a BOD loading on the system. The model has provision for either considering nitrogenous and carbonaceous demands separately or aggregated if insufficient data are available for estimates of the separate rate coefficients. Reaeration rates are calculated from one of the standard empirical methods. Consideration is being given to adding wind effects to the reaeration rate coefficient. An empirical relationship is used to estimate the benthic oxygen demand on the system. If appropriate data are available, the model can also simulate the effects of plant photosynthesis and respiration. All reaction coefficients in the Galveston Bay Model provide for temperature corrections to the rates, which can either be estimates of post/probable conditions or the output from a temperature model of the same estuary.

The two-dimensional Galveston Bay BOD/DO model has never been verified due to a lack of prototype data. However, the BOD portion of the model was used to examine alternative disposal methods for the wastewater from the Clear Lake area and to estimate their potential effects on Galveston Bay. Various model runs were made using projected growth conditions and alternative waste treatment schemes to estimate the BOD gradients in Galveston Bay. It was concluded from the simulation investigations that secondary effluent from the Clear Lake area could be discharged to Galveston Bay, even under projected 2020 conditions, without a significant increase in estuarine BOD values.

Several BOD/DO models of the Houston Ship Channel have been developed. The earliest was probably the Texas A & M University completely mixed model (Kramer, et al. 1970) which breaks the channel into two vertical segments and does a simple mass balance on each segment. The model assumes complete mixing within each of the segments in both the horizontal and vertical directions. An empirical equation was used to estimate the reaeration coefficient for each segment and the coefficient was corrected for temperature and salinity. The BOD reaction rate coefficient was estimated from the literature. The model was used to estimate the allowable BOD loading on the channel to meet specified dissolved oxygen criteria under various rates of fresh water inflow. Unfortunately, this model was never verified.

The Galveston Bay Study (Tracor, 1971) has developed two One-dimensional steady-state models of the Houston Ship Channel. The major difference between the two models involves the handling of the BOD reaction rate in regions with a zero dissolved oxygen concentration. The newer "anaerobic" model permits use of a lower BOD reaction rate when the dissolved oxygen concentration reaches zero while the earlier model uses the same rate for all dissolved oxygen concentrations.

Both models have been verified for several different conditions for which prototype data exists. The "anaerobic" model is felt to give more reasonable results. Presently the models are being used to estimate treatment requirements and the effects of flow augmentation.

Nutrients

The plant nutrients, particularly nitrogen and phosphorous, and their occurrence in estuarine waters have been the subject of several modeling attempts. Nitrogen and its various chemical species (ammonia, organic nitrogen, nitrite, nitrate) have been the subjects of most of these investigations. Modeling of the biologically mediated consecutive reactions in the nitrogen cycle involves solving a set of four mass continuity equations to determine the concentrations of each of the chemical species within a specific time (for the time-varying equation). Because two of the reactions act as dissolved oxygen sinks, and since some reactions are also oxygen concentration-dependent, it is necessary to simultaneously calculate the dissolved oxygen concentration in the estuary along with the nitrogen modeling. The greatest problem is the determination of the reaction rate coefficients for the various reactions affecting the nutrient being modeled. Additionally, prototype nutrient data are extremely rare, thus precluding adequate verification of most models.

A nitrogen cycle model of the Delaware Estuary has been developed and applied (Thomann, 1970). This was a one-dimensional, steady-state model which was solved analytically to estimate a continuous spatial distribution of the various nitrogen species in the estuary. Verification was performed using nitrogen data which had been collected in the estuary during several different seasons.

A steady state model simulating the feedback of algal nitrogen into the system due to organism death and decay has been developed for the Potomac Estuary (Thoman, 1970). Essentially, this is a multi-stage nitrogen model which follows the nitrogen flow in the estuary through four stages (organic nitrogen, ammonia, nitrate, algal nitrogen). The investigators empirically relate the algal nitrogen concentrations to chlorophyll-A concentrations and use the latter characteristic as a predictor of algae concentrations. The model has been used with data collected over a two-month period in the prototype estuary and thus far good correlation have been obtained between observed and predicted nitrogen and chlorophyll spatial distributions.

The mass transport models discussed previously all dealt with the simulation of physical and chemical water quality characteristics and treat the biological processes which affect these characteristics as a "reaction site" by using empirical reaction rate coefficients. No attempt is made in these types of models to simulate the actions of the biological organism(s) which actually drive the reaction. However, other nutrient models have been attempted with markedly good success considering the complexity of the situation--which attempted to describe the complex phenomena from a mechanistic viewpoint.

One such model (DiToro, et al. 1970) simulates the dynamic activities of the lower members of the food chain. This includes the phytoplankton and zooplankton and attempts to trace the basic processes of nutrient uptake and nutrient recycle.

A schematic of this interaction is shown in Figure C-6. The phytoplankton concentration is measured by its chlorophyll concentration, the zooplankton by its carbon concentration and the

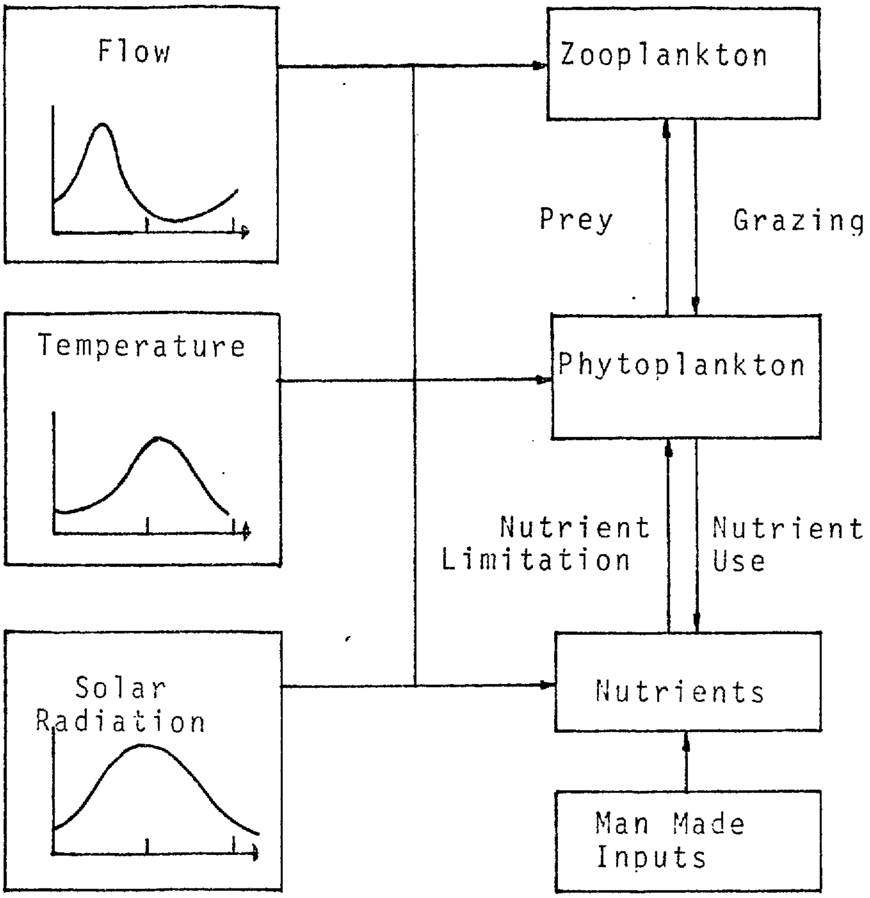


FIG. C-6; Interactions: environmental variables and the phytoplankton, zooplankton, and nutrient systems.

From: Ward and Espey, 1971.

nutrient requirements were assumed to be limited by total inorganic nitrogen alone. The model, as presently structured, assumes a completely mixed regime and no spatial variation of any of the characteristics is permitted. Included in the model as external stimuli such as: solar radiation, temperature, flow and input of nitrogen from land runoff or waste sources. Growth and death rates for the organisms in the two trophic levels are included as source and sink terms for the total inorganic nitrogen.

This model was applied to the phytoplankton and zooplankton populations measured at a location on the San Joaquin River in California for a two-year period. The results of these simulations are shown in Figures C-7 and C-8. The circles in the figures represent measured data and the continuous line is the model output. Good agreement between model output and observed population fluctuations was obtained. Of particular interest is the effect of the 1967 flood on the phytoplankton population.

Presently, work is underway to develop an ecosystem model applicable to either estuaries or fresh water bodies (Water Resources Engineers, 1969). This model would include organisms in the trophic level above phytoplankton. It would require as inputs the results from hydrodynamic temperature, and BOD/DO models. As output it theoretically should provide a complete description of the eutrophication process for any given water body under alternative conditions of waste inputs, circulation inhibition, inflows, etc. Presently, the availability of reliable data that is sufficiently accurate for model application/verification presents the biggest obstacle to the development of such complex nutrient-analysis procedures.

Toxicity

Toxic effects can arise in either of two forms: direct toxicity refers to substances which outright kill off a community whereas indirect toxicity means a modification of the aquatic environment which significantly disrupts its normal functioning.

Few studies have attempted to model the transport of toxicity throughout an estuary. In the San Francisco Bay Study (Armstrong, et al., 1969) acute toxicity to a common species of fish was measured at the various major waste outfalls. Subsequently in the transport model, the toxic material was assumed to be conservative and the same dispersion coefficients were used for salinity. No toxicity measurements were made at the sampling stations in San Francisco Bay to

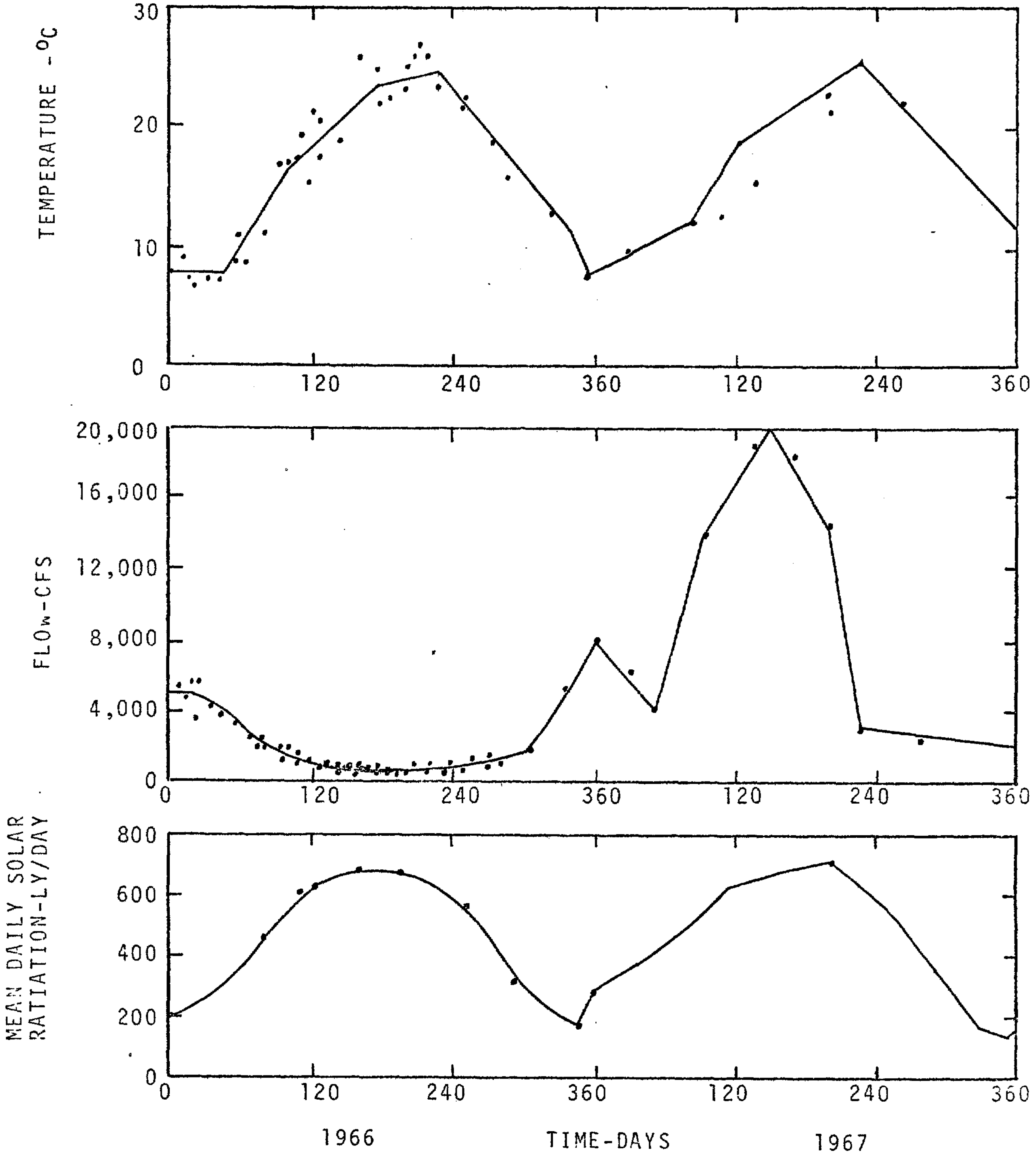


FIG. C-7; Temperature, flow and mean daily solar radiation
From: DiToro, et al, 1970.

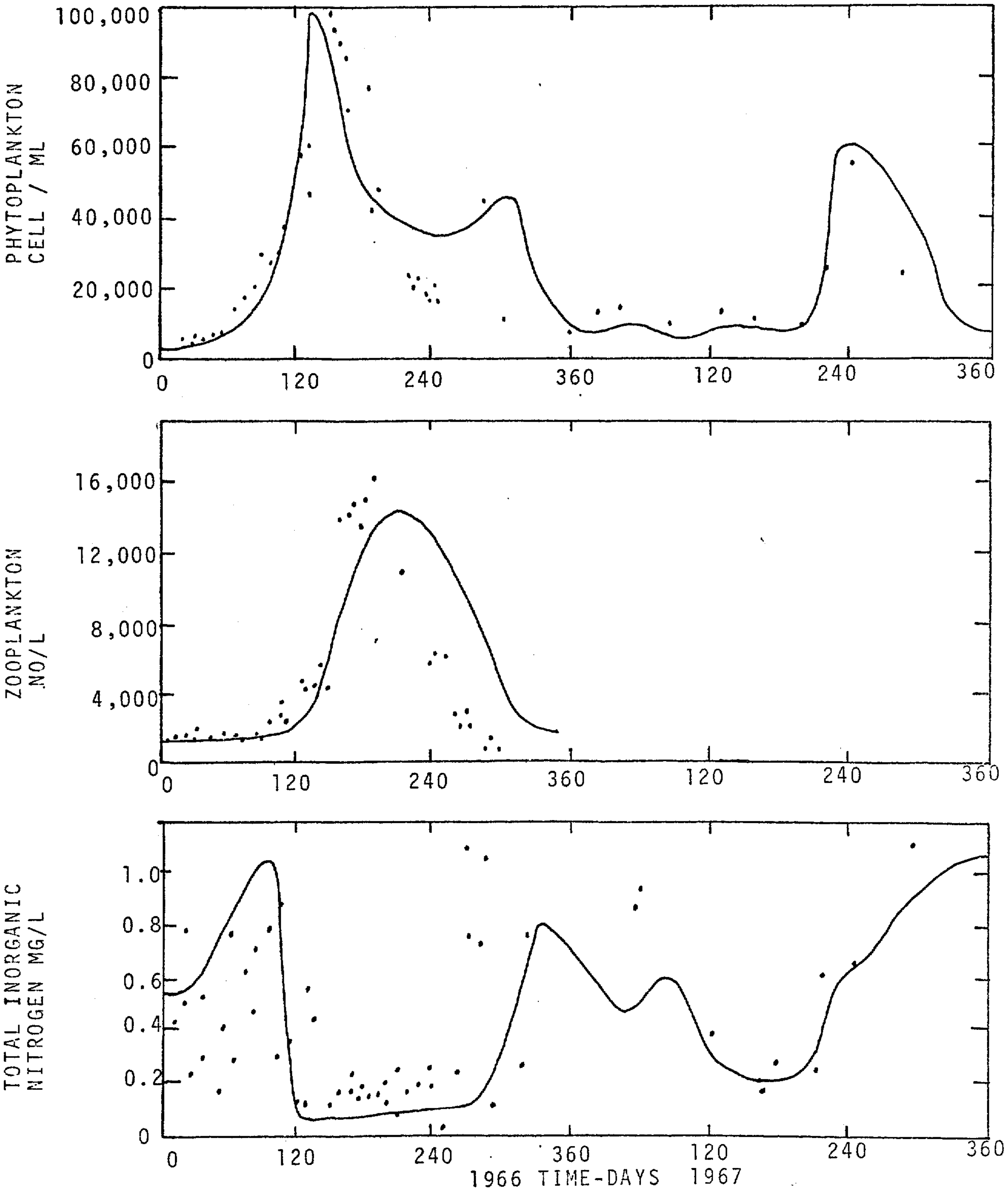


FIG. C-8; Phytoplankton, zooplankton, and total inorganic nitrogen. Comparison of theoretical calculations and observed data.
From: DiToro, et al, 1970.

verify the model; nevertheless, an indirect verification was achieved. Based on detailed biological data, a base line benthic animal diversity value was established for the Bay under "normal circumstances" (for communities not directly influenced by waste discharges, but yet affected by them to a slight degree.) In estuarine areas where major wastewater discharges were occurring, the benthic diversity was lower than the computed base line. This decrease in diversity subsequently was successfully correlated with the toxicity values computed from the transport model.

A similar approach has been utilized in studies conducted on Galveston Bay (Copeland and Fruh, 1970). A bioassay analysis utilizing phytoplankton was devised. Samples from all major water inputs (Buffalo Bayou, Trinity River, and the Gulf) were tested for toxicity by determining the depression of the phytoplankton growth rate K from the optimal rate of 2.0. Experimental modeling runs were made by Tracor (1971) to predict the distribution of the toxicity indicator (growth rate K) throughout Galveston Bay. K was assumed to be a conservative parameter with dispersion coefficients the same as found previously for salinity. Verification of the transport was made by comparing the predicted K model value to the actual observed K rate obtained at three sampling stations within the estuary. Results were as follows:

Averaging Period		*Dickinson Bay*	*Hannah's Reef*	*Texas City Dike*
March-October	*Pred.*	*1.33*	*1.20*	*1.65*
	Obs.	*1.51*	*1.40*	*1.59*
July-October	*Pred.*	*1.33*	*1.20*	*1.65*
	Obs.	*1.35*	*1.47*	*1.61*
August-October	*Pred.*	*1.34*	*1.21*	*1.66*
	Obs.	*1.45*	*1.35*	*1.70*

Based on these results, the transport model was judged adequate only during the August to October period when reasonable low inflow steady-state conditions prevailed. Subsequently the computed K model values for various stations throughout the estuary were correlated with the phytoplankton diversity indices found at those stations. Furthermore, for all trophic levels there was an obvious trend toward higher diversity indices with increase in computed K values (decrease in toxicity). Thus, the results of the above two studies indicate, that while some problems do exist with the modeling of toxicity, it does hold promise for the future.

SEDIMENTATION PROCESSES

To those familiar with the complexities of sediment transport by fresh water streams even under controlled laboratory conditions, sedimentation problems in an estuarine environment are clearly more difficult by another order of magnitude. In an estuary, river flows pass through a transition from nearly steady uni-directional fresh water flow to quasi-periodic and littoral movements as they mix with salt water. Because of these complex and changing currents as well as changing chemistry in an estuary, sediment transport is unlike that encountered in fresh waters.

The coarser sediments, entering an estuary as bed load, encounter reduced transporting capacities of flow as velocities decrease, and usually accumulate near the landward end of the estuarial region. Meanwhile, the finer clay and silt particles that are efficiently transported in suspension in river flows are readily deposited in the estuary as a result of the changed hydraulic and chemical environment. The repulsive surface forces that prevent aggregation of minerals in the fresh river water are depressed by the saline environment of the estuary and the particles form flocs as particle contacts occur, thus promoting more rapid settling.

These changes in physical characteristics may trigger hindered settling conditions, which in turn are apt to provide conditions favorable for the formation of sediment density currents, which subsequently produce another driving force for sediment transport. These sediment density currents are gravity dominated phenomena, and although they are directly influenced by tidal currents, they can move against the direction of flow. The key to the stability of the sediment density currents is the shear strength of the flocculated layer which determines whether or not the flocs can be torn apart and resuspended by shear stresses associated with the tidal velocities or by the turbulence from wave action in shallow water. Characteristically, sediment density currents behave as a non-Newtonian fluid, i.e., the shear strength of the flocculated layer is time dependent. As the shear strength increases to the point where the flocculated particles can not be resuspended by the turbulence in the tidal currents and waves, consolidation takes place on the floor of the estuary.

Because of the complexities of sedimentation processes in estuaries, mathematical models have received rather limited application. On the other hand, physical models at the present time, have the ability to more nearly represent a complex three-dimensional system. Physical models for sedimentation studies may be either of the fixed-bed or the movable-bed type, depending primarily on the properties of the sediment material involved and the forces which affect transportation and deposition of this material.

Moveable-bed models are normally used if the sediment material is sand and its transportation and deposition are affected by wave action as well as by tidal and density forces. Verification is accomplished when the model reproduces, within acceptable limits, the changes in bed scour and fill which are shown by prototype surveys and dredging data to have occurred in the period selected for verification purposes.

The Galveston Bay Entrance Model is an example of a moveable-bed model, although it can also be used as a fixed-bed model. This model was constructed for studies related to the relocation of the entrance channel and rehabilitation of the jetties.

The fixed-bed model is the same model that is used to simulate the tidal hydrodynamics of an estuarine system and requires the same type of data for verification purposes as the moveable-bed model. The fixed-bed model as opposed to the moveable-bed model uses verification tests to select a model sediment which will move and deposit under the influence of the model forces in the same manner in which the prototype sediments move and deposit under the influence of prototype forces. The model sediments such as coal particles or crushed and grade gibsonite are injected into the model through the fresh water inflows and allowed to be distributed by the model currents. Verification is attained when the distribution of model sediments conforms to known shoaling patterns in the prototype.

The Houston Ship Channel Model and the Matagorda Bay model previously described in this chapter are examples of fixed-bed models which have been used to investigate estuarine sedimentation along the Texas coast. These models have been used to study sedimentation in ship channels and related maintenance dredging.

Masch and Espey (1967) undertook detailed field and laboratory studies to determine the movement of sediments resuspended by shell dredging operations in a localized area of Galveston Bay. The study was carried out from an engineering standpoint only and was restricted to the effects that the physical characteristics existing within the Galveston Bay system (and in particular the twenty square miles between Redfish Island and Eagle Point) had on the dynamic behavior of the sediments. Controlled laboratory tests in semi-physical models (flume tanks) provided data on the conditions under which a sediment density layer would form, the effects of water currents and bottom slopes, and the likely behavior of sediment density layers at abrupt changes in bottom topography. However, the majority of the study shows the need for field studies and vividly reveals the complexity of the problem which in essence limits any physical or mathematical modeling.

SUMMARY

The modeling of Texas bays and estuaries is probably as advanced as anywhere else in the world. This is essentially true for both physical and mathematical modeling, in particular for both the hydrodynamic and water quality cases. Although certain investigators in locations outside of Texas might be somewhat more advanced in some aspects of modeling, the estuarine natural phenomena, it is not a quantum magnitude of difference but rather a narrow gap in sophistication which could be closed rapidly. The problem is that the capability to model the environment has exceeded our knowledge of the fundamental relationships in the estuarine system, particularly in the case of the water quality and sedimentation models. Until more and better prototype data amenable to modeling use are collected and better information is obtained in regard to the nature of the numerous physical, chemical and biological interrelationships, additional modeling will be a mere exercise in mental gymnastics. However, models, even though they may be incompletely verified, can be extremely useful for determining what data should be obtained and at what locations samples should be collected. Thus, although continuing work is needed on the computational and simulation techniques of physical and mathematical models, a maximum amount of effort should be made on increasing our understanding of the estuarine environment.

Thus, the decision-maker has in his hands presently a tool by which preliminary planning steps can be undertaken. Within the forseeable future, the decision-maker should be able to utilize practical alternatives generated from modeling programs.

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APPENDIX D

ECONOMIC ASPECTS OF ENVIRONMENTAL PLANNING

This appendix theoretically examines certain market imperfections in a free enterprise system which may give rise to environmental problems. The basic criteria by which to correct those imperfections in an economically efficient manner are described. Ultimately, other considerations than economic are used in the decision-making process. Social and political considerations often transcend economic ones, especially as the role of government is broadened in preserving the environment and in interceeding with the firm on behalf of society. The problem of payment for environmental improvement is also discussed.

MARKET IMPERFECTIONS

Water and air are traditional examples of free goods in economics. In many places they have generally represented the least expensive (optimum) site for firms and households to dispose of unwanted residuals from extraction, production, and consumption. However, in developed economies, with their high levels of residuals and their very artificial environments, the capacity of waterways, land and the atmosphere to absorb, dilute, and chemically degrade wastes is taxed, with the result that water and air become valuable common property resources. Unfortunately, the market cannot be depended upon to allocate these now scarce resources.

Hardin (1968) has characterized market allocation of common property resources as the "tragedy of the commons." Each individual, seeking to maximize his profits, is led to intensively utilize "free" resources. The collective result of this individual action is that these resources are over-utilized and eventually destroyed. Referring to the case of the commons (jointly owned pastures) Hardin observes: "Each man is locked into a system that compels him to increase his herd without limit - in a world that is limited. Ruin is the destination toward which all men rush, each pursuing his own best interest in a society that believes in the freedom of the commons. Freedom in a commons brings ruin to all."

The "tragedy of the commons" is part of a more general set of problems, termed externalities, in which there exists a divergence between private costs and social costs (Buchanan and Stubblebine, 1962; Coase, 1960). This divergence arises whenever the actions of one party cause an adverse effect on other parties, but when this adverse effect is not reflected in the first party's costs. In this situation the costs that arise are borne not by those that cause them but by others that happen to be around but are outside of the process -- bystanders so to speak. For example, a firm that emits smoke in the process of production may cause damages to its neighbors. The damage, however, is a cost to society and is not reflected in the firm's costs. This results in a situation in which private costs diverge from the social costs. Consequently, production decisions by the firm will result in a misallocation of resources, for the producer will be faced with production costs that are lower than they would be if he also had to pay the bill for the external diseconomies - the unpleasantness, nuisance, or other aggravation caused by his actions but borne by his neighbors or the environment.

Economic theory has long recognized the existence of "common property" problems and the more general set of externalities. (It should be noted that externalities may be positive rather than negative. For example, a power plant may discharge heated water into a watercourse which results in "thermal enrichment" and a corresponding increase in fishing opportunities.) In general, these difficulties result in a misallocation of resources by the market. However, it has generally been assumed that this set of problems constituted only a minor abberation in the workings of the competitive economy. Only recently has it been recognized that the presence of externalities is extremely pervasive in highly developed economies.

One does not have to look far to find numerous examples of external diseconomies. There is disposal of municipal, industrial, and agricultural wastes into rivers and lakes and of pollutants into the air; there is disfiguartion of the landscape through mining activities, transmission lines, and other symbols of industrial progress; there is ugliness along our highways, be it beer bottles, junk yards, or billboards; interference with plant life and wildlife through the indiscriminate use of insecticides and pesticides, and disturbance of the atmosphere through vibration caused by supersonic planes. Taken together, problems of externalities constitute the main body of environmental problems facing our society.

Early treatment of the problem of externalities by economists assumes that the proper role for public policy was either to internalize the costs created by a party's actions (by taxing it or by making it liable for the damage it causes) or to prohibit it from locating in an area where its activities would cause harm to its neighbors.

In later more sophisticated treatments of the problem of externalities, the recipricol nature of the situation was recognized (Coase, 1960). If A caused damage to B by his actions, to compel A to pay for these damages or to cease his harmful activities would in turn cause damages to A. From an economic efficiency point of view, the problem was to avoid the more serious harm. Further, it was demonstrated that the assignment of legal rights by the courts would not affect the economic outcome of the problem, providing the parties involved could modify by transactions on the market the initial legal determination of rights.

For example, if a firm is not held liable for the damages caused by its activities, the outcome will be for those that are harmed to bargain with the offending firm, bribing it to cease or reduce its harmful activities. This approach assumes: 1. ability of the damaged to pay and 2. recognition by the damaged parties of the value of their losses. Of course, this would only be possible to the extent that the benefit to those that are damaged (the extent of the harmful effects) exceeds the cost of bribing the offending firm to curtail its activities (the value of lost output). If the firm is made legally liable for the external damages that it creates, the end result will be the same. The firm will continue its harmful activities, thus incurring damages, up to the point where the costs of these offending activities (the damages being paid to its neighbors) just equals the benefits gained from these activities (the value of the added output). Thus, regardless of the initial legal determination of rights, if market transactions were costless, rearrangements of rights could be undertaken which would result in the maximization of the value of production.

In situations where market transactions are not costless, the economic solution may not be identical regardless of the initial legal determination of rights. Once the costs of carrying out the market arrangement of rights will only take place when the increase in the value of production resulting from the rearrangement of rights exceeds the costs which would be involved in bringing it about. In such cases it would be desirable for the legal determination of rights to reflect the underlying economic determination of which assignment of rights would maximize the value of output; otherwise, the costs of reaching the same result by altering and combining rights through the market may be so great that this optimal (again from an economic viewpoint only) arrangement of rights and the greater value of production which it would bring, may never be achieved.

It is significant that most efforts at formalizing the treatment of externalities have relied extensively on a two-party formulation of the problem. Externalities are generally discussed in the context of a firm and its neighbor, relying on the traditional "nuisance" cases that are actionable in the courts. However, the cause-effect linkage is much more difficult to establish in most environmental problems for several reasons.

First, the external effect may be very mild either due to the low intensity of the effect or to the low degree of quality deterioration that takes place. Second, the external effect may be long delayed in appearing, or it may turn up in areas quite remote from the locus of emission. Third, external effects do not occur in isolation, but are intermingled with a variety of other factors and developments. Thus, it is often difficult to identify the offender or to asses his share in the total effect. Fourth, in stark contrast to the two-party examples used most frequently in discussions of externalities, more commonly there is a widely dispersed multiplicity of the offended. This raises the question of both efficiency and equity in remedial action, and may threaten the feasibility of starting any action at all. Finally, when the external effects are widely dispersed, there is a problem of motivation - each of the offended parties may be affected to such a small degree that no action may be taken by the individual to seek a remedy.

CONCEPTS OF BENEFIT-COST ANALYSIS

The economic criterion for deciding whether action should be taken in the case of an externality is quite simple: action should be taken in such a manner as to ensure that the present value of the monetary measure of all gains from this action minus the monetary measure of all losses from this action are maximized, i.e. action must be carried out to the point where the benefits from such action are <u>at the margin</u> just equal to the costs of such action (Turvey, 1963).

This criterion reflects the common practice in economic theory of making decisions on the basis of the marginal unit, in order to maximize the value from some action. The process is depicted in Figure D-1. In part (a) of Figure D-1, the total benefits and total costs from pollution abatement in a given system are shown. In part (b) of Figure D-1, the marginal benefits and marginal costs (i.e., the change in total benefits minus total costs) are depicted. In the example being used, net benefits are maximized when abatement is carried out to the level of 75 percent. The benefits of further abatement (in excess of 75 percent) are simply outweighed by the costs.

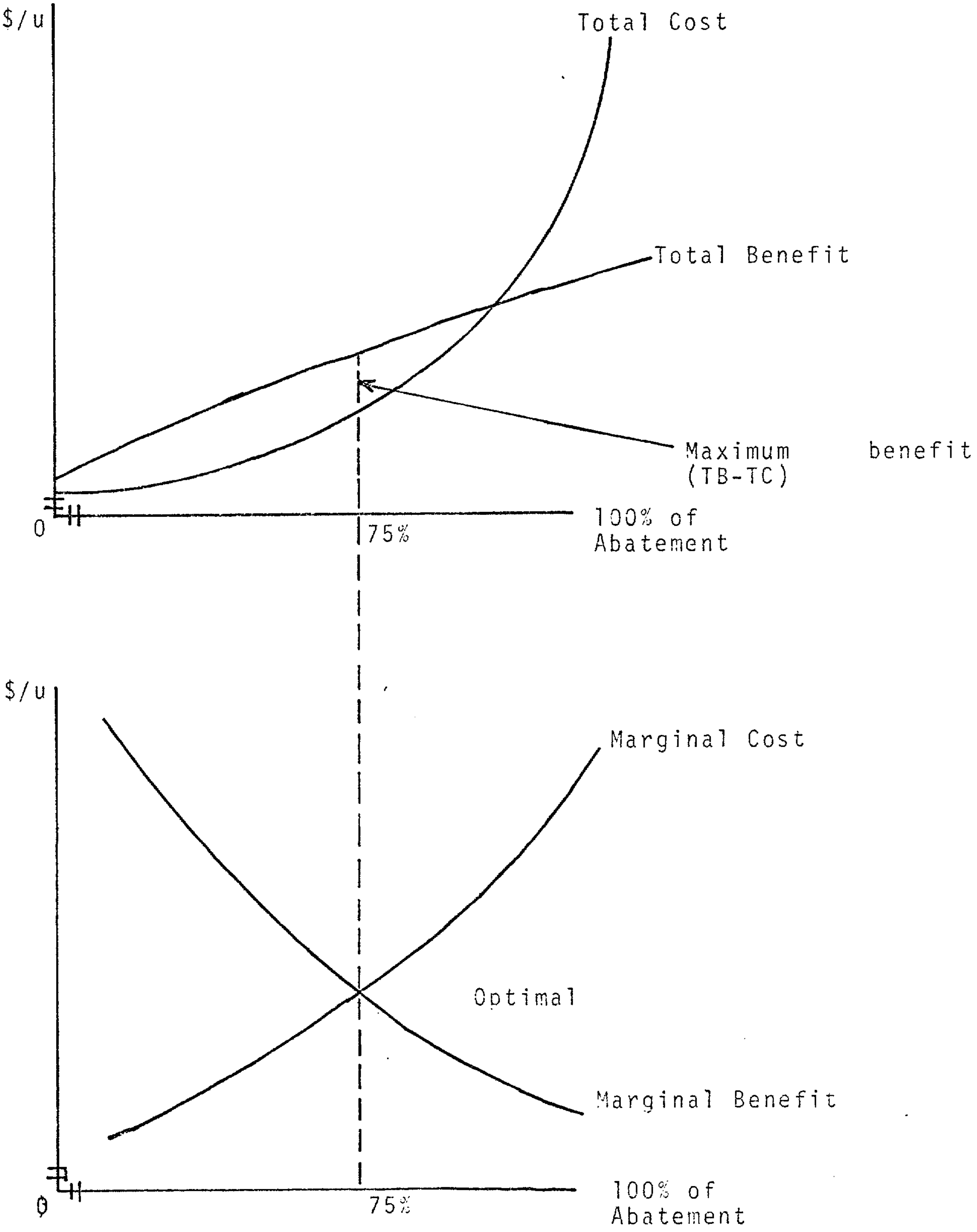
Figure D-2 presents a general picture of the steps involved in calculating costs and benefits. First, it must be determined if a given activity X affects other activities Yi (i = 1, ..., n). If there is no effect, no externality exists. If there is an effect, the next step is to determine whether the effect is complementary (indicating an external benefit) or not (indicating an external cost). If a benefit is derived to Y from activity X, then the value of this social benefit should be entered as an added gain from doing X.

Where the effect upon Y is not complementary, the next step is to determine whether the two activities are mutually exclusive, i.e. does activity X preclude the existence of activity Y? For example, flooding of the Nile River Valley by the Aswan Dam prevented further enjoyment and exploration of archaeological sites in the flooded area. In instances such as this, where the activities are determined to be mutually exclusive, then the problem is one of choosing between them. The cost of doing X is the loss of the opportunity to do Y. The decision is made on the basis of the loss from activity Y as compared with the benefit from activity X.

In general, where the activities are competitive, but not mutually exclusive, there will exist some degree of tradeoff between X and Y, i.e. trapping of sediments behind the Aswan Dam will reduce the fertility of the Nile Valley. These tradeoff terms should be computed for all the possible levels of X. The decision will again be based on a comparison of the costs of reducing activity Y with the benefits from doing activity X.

It should be recognized that there may exist a possibility of modifying the terms of tradeoff through some action of public policy. If this is possible, the costs of modification (and the effects of modification--i.e., changes in the tradeoff terms) should be determined. It also must be recognized that the modifications to be done are also activities which may have an effect on activities other than Y. If we assign the modification a Symbol Z, we then return to the beginning of our decision process and compute the social costs and benefits of doing activity Z (which is a modification of the terms of tradeoff between X and Y). The final decision will be made by

FIG. D-1; Cost Benefit Analysis



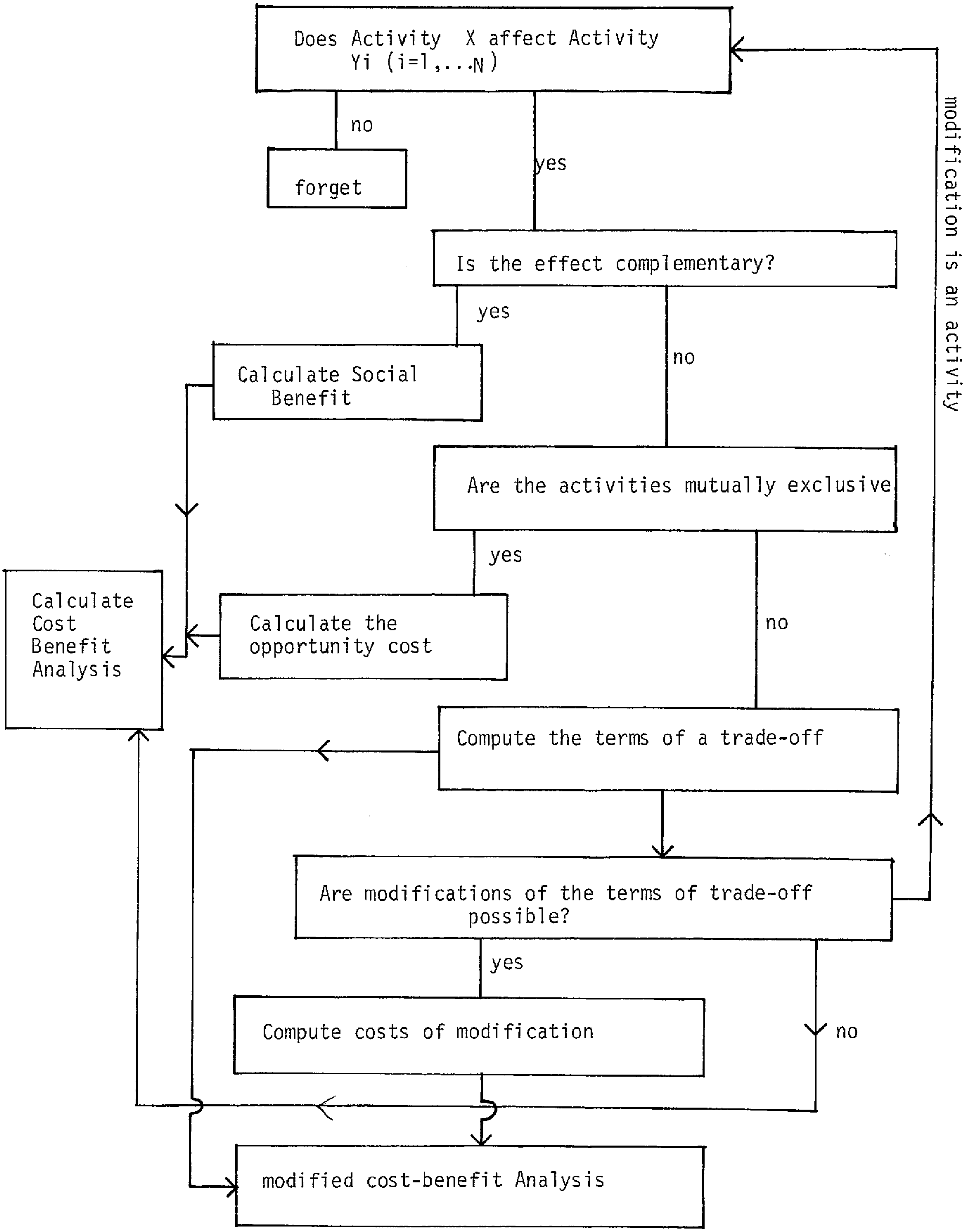


FIG. D-2; Flow chart for benefit-cost analysis.

comparing the costs of activity Z with the costs of activity X and with the benefits to be derived from the now possible new level of activity X.

The above description of benefit-cost analysis is based on the assumption that benefits and costs can be measured. It is frequently contended, particularly with regard to actions affecting the environment, that it is possible to calculate benefits and costs in dollar terms. This, of course, begs the question that the decision maker must compute costs and benefits in terms that are at least comparable if he is to make a decision, and even a failure to act represents a decision.

The costs of taking environmental actions are generally easier to calculate than the benefits. Costs may be defined as the additional expenditures which must be made by individuals and firms because of some action taken. They are generally capable of measurement, perhaps because there is a strong economic incentive on the part of those who must bear those costs to make them known.

On the other hand, the benefits from environmental actions are seldom easily quantified. In part, this is due to the fact that the benefits obtained by each individual probably represent a small portion of the total benefits derived from the action. In addition, the benefits are generally spread out over the entire population. Thus, individuals have little incentive to make known the benefits which they individually derive from environmental policy actions.

It is frequently asserted that the best way to calculate benefits is simply to ask people how much they would be willing to pay to achieve the results of the action. However, this procedure will not always work. Economic theory has long recognized that in the case of certain goods which must be consumed by the public at large, such as education, national defense, and clean air, individuals will not reveal their true preferences because they recognize that whether or not they pay for the action, they will share in the benefits. Thus, an individual will not reveal how much he would be willing to pay for clean air because he knows that if the air is cleaned up, he will get to breathe it regardless of how much he contributed to clean up costs. Many environmental actions fall in this category of collective or public goods.

It would appear that many of the benefits to be gained from environmental policies are quantifiable, but that the calculations are not easily made. In the case of amenities, for example, one can compare the value of land on the top of the hill that has a view with the same quantity of land without a view. The difference can be attributed, at least in part, to the difference in the environmental amenity.

One of the most difficult benefits to calculate is the benefit from saving life or preventing disease. It is frequently asserted that one cannot place a value on a human life. This contention neglects the fact that every time we build a highway or design a building, we build in a certain margin of safety, but we seldom incur the costs required to make that margin 100%. It also neglects the fact that our expenditures on public health are not sufficient to ensure that everyone obtains the medical care required for survival. If we were willing to increase our appropriations for public health, for example, to purchase more kidney machines, we could save many additional lives.

There are those who would calculate the benefit of a human life as they would that of a machine, simply computing the discounted value of its future earnings. Others, feeling that this underrepresents the value of life, would add in an amount for suffering of friends and relatives. Still others would calculate the value of human life by analyzing the investment decisions made by society, through the political process, that increase or reduce the number of deaths, thus, obtaining an implicit measure of the value of human life.

It has recently been suggested that an appropriate measure of the value of human life is to calculate the change in risk of death brought about by the action and then to determine what each member of the community is willing to pay or to receive for the estimated change of risk. (Mishan, 1971). The resulting composite can be usefully regarded as comprised of four types of risk: the voluntary risk that people assume when they consume (for example, the risk assumed when flying in an airplane); the involuntary risk imposed directly upon the individual (for example, if we build a nuclear power station and it is held to be responsible for an increase in the annual number of deaths); the indirect involuntary risk imposed upon the community due to the death of one of its members (for example, if your wealthy aunt dies and leaves you her estate, her death is an economic benefit to you); and the involuntary risk imposed upon the community of bereavement and other psychic costs from the death of a given individual. Voluntary risks can be ignored, since the benefit to each individual of the direct activity in question is already part of this calculation. The demand curve reflects the value of the risk associated with consumption. The three involuntary risks can be quantified in theory, by asking people to price them. However, this is probably very difficult to do.

Little has been done in attempting an evaluation of damage to the physical well being of man short of death. What social costs can be placed upon genetic mutations or the premature demise of the individual's productivity? Scientific as well as economic data are insufficient for meeting these analytical needs. Of course, similar approaches to the economic valuation of death could be calculated based upon loss of established productivity, but what of productivity foregone by stillborn babies? The moral and ethical considerations are still being discussed.

Benefit-cost analysis reveals whether taking action to removal or modify an externality will result in a net improvement in the value of output. It assumes that maximization of the net benefit is the objective to be achieved.

ALLOCATION OF COSTS

More disturbing from the standpoint of policy formulation than the failure or inadequacy of the market to handle many of the environmental externalities created by an industrial society is the lack of a basis for making judgments about who should bear the costs of solving these problems. Even if benefit-cost analysis can reveal what action should be taken, policy formulation will still involve a determination of how the costs are to be distributed. This determination requires a value judgment by society, acting through the political process, since there is no way to make a scientific judgment on the matter. The value judgment will be made in terms of the change in public welfare brought about by an action.

In designing public policies for the protection of the environment, we are concerned with the implications which these policies have for the social welfare. One cannot justify talking of one situation as an economic improvement compared with another without reference to the premises on which judgments of better or worse are to be based. We have traditionally believed that nothing is good for society unless it is held to be good by the individuals which form society. However, this still leaves open the matter of how we can determine what is good for society in the case where some people are made better off by an action and others are made worse off.

For example, if we are to impose an effluent surcharge on firms, those individuals which are harmed by the discharged are made better off. However, the firms, which now must pay for the use of a renewable resource, the air or water, which they previously used without charge, are made worse off by the action. The question arises, given that some parts of society are made better off by this public action and some are made worse off, does the action represent an improvement in the welfare of society as a whole?

This question represents one of the most difficult problems in economics because it requires comparing the welfare of individuals or groups. For example, to rank two configurations of the economy, A and B when individual 1 is better off (in his opinion) in A than B, and when 2 is better off (in his opinion) in B than in A, involves some judgment of the kind that the improvement in 1's welfare between A and B does or does not outweigh the worsening of 2's welfare for the same change. Such rankings involve interpersonal welfare judgments.

The problem with such judgments is that we have no way to measure the improvement in A's welfare or the decrease in B's welfare. In this case, welfare is a matter which can only be judged by an individual for himself. Each individual can select between A and B on the basis of what he perceives to be his own best interest. However, there is no way for society to select between A and B, if it relies solely on the concept of welfare maximization.

To avoid making such comparisons, economists have developed the following criterion: any change which makes at least one individual better off and none worse off is an improvement in welfare. However, most public policy actions of any significance involve a situation in which some people are made better off and some worse off.

Economists have attempted to strengthen the welfare criterion (called Pareto optimum after the economist who first enuciated the principle) by proposing: if a change makes some individuals better off and some worse off, it represents an improvement in social welfare only if winners can fully compensate the losers and still feel better off. However, the only way this can be determined is for the compensation actually to be made. It is the possibility of compensation that makes such a change economically efficient; however, it is the actual payment of compensation which makes the change optimal in the sense of ensuring an improvement in social welfare.

In most areas of public policy, no attempt is made to attain Pareto Optimality. Actions are taken through the legislative process under the tacit assumption that democratically elected representatives can make judgments about the common good. However, even in such instances, it becomes important that the actions taken reflect the underlying economic realities. Thus, society, acting through the legislative process, can determine that the firm must pay for the damages it causes. However, the economic criterion of benefit-cost analysis can help in determining how much the firm should pay.

A SOCIO-ECONOMIC PLANNING FRAMEWORK

Given the factors affecting the distribution of population and industry in the Texas Coastal Zone and given existing patterns of distribution, a model can be developed to project probable expansion of resource use. Such a model would estimate the impact of private decision on future land use. Use limitation of land classification categories because of engineering or other problems inherent in the properties of such lands would be considered in private location decisions to the extent that a private cost was incurred. These limitations would then be reflected in the projected pattern of land use.

Public policies for land resource management are necessary because private location decisions do not reflect social costs arising from environmental changes due to those private decisions. These costs would be of two types: first, location in and of itself may create social costs through such actions as filling of marsh land, dredging of channels, and devegetation of coastal areas - actions that alter the natural environment directly; second, location of firms and households also brings with it a specific pattern of waste discharges from production and consumption which may threaten the assimilative capacities of the environment.

Recognition of the existence of social costs stemming from the private location decisions of households and firms supports the need for public intervention to alter these decisions in such a way as to reduce the environmental damages. A planning model provides a useful vehicle for introducing environmental constraints of one type or another based on projected social costs and for simulating the resulting changes in the pattern of land use.

In this section, the modular compoments of a land use planning model are discussed, including the projection of socio-economic activity, the determinants of land use, and the requirements for land use control.

Projecting Socio-Economic Activity

Projections required for land use planning include population, economic and plant location. These projections are highly complex and impose a demanding task; yet they are essential to understanding the future of a region.

Population Projections--Perhaps the most commonly used method of projecting population is simply to extrapolate past growth rates or to assume some modification of the past growth rate and then extrapolate. A more sophisticated technique for population projection involves breaking population growth into its major components (birth, death, migration). Each component is then assigned an estimated rate of change which is age-specific. The rates for each component can then be multiplied by the base population, yielding an estimation of the number of births, deaths, and migrants that will occur during the forecast period. By adding or subtracting these components to the base population, adjusting for population aging, an estimate of the population at the end of the forecast period can be obtained.

The validity of the population estimates, of course, depends entirely on how successfully the estimator is able to anticipate future changes in mortality, fertility, and migration rates. Of these three components, the difficulty of estimation probably increases as we move from death rates to fertility rates to migration. This is particularly important for a regional population projections, since migration is the most important variable, overshadowing the other two components. In making estimates, the analyst can, of course, project on the basis of several alternative assumptions, perhaps providing a bracket (i.e., a high estimate, low estimate and "best guess" estimate) which will give guidance as to the likely range of population growth.

Economic Projections--A variety of econometric projection models has been developed but are still found wanting in the projection of specific subcomponents such as employment by industry. Three types of models for projecting regional economic activity are briefly discussed below.

Economic base models represent a method of analyzing small regional areas. This approach divides the employment of a region or community into "jobs generated from exports" and "jobs generated from local expenditures." Such a division is frequently made on the basis of an analysis of each major industry with regard to its share of total regional output compared to the share of that industry across the nation. "Export" industries are those industries within the region which have a larger share of total regional employment or output than does the industry on the average have of the national employment or output. It should be noted that service activities, such as education, medical care, and insurance, as well as the traditional manufacturing activities may constitute export industries for a region.

Export employment is forecast into the future. The change in employment generated by local expenditures resulting from the increase in exports is estimated by multiplying the estimated change in employment in export industries by a multiplier (developed from the ratio of total employment to base employment for the region). The change in total employment is the sum of the changes in export employment plus the changes in local service employment.

Input-Output Analysis, one of the more useful developments in economic modeling, stemmed from the original work of Professor Wassily Leontief at Harvard. As Leontief (1966) described it, input-output analysis is "an attempt to apply the economic theory of general equilibrium...to an empirical study of interrelationships among the different parts of an economy." The input-output table of the American economy, for example, contains hundreds of industry accounts showing how the output of each industry is broken down into inputs into all other industries of the economy. The ultimate purpose of such a table is to show what happens when there are changes in the allocation of society's productive efforts - as, for example, an increased defense effort. The table enables one to trace through the total impact on all sectors of the economy, both direct and indirect, of such changes in the economy.

Input-output analysis has been developed not only for the national economy, but for various regional economies as well. The State of Texas has recently completed an input-output table, both for the state as a whole and for a number of sub-regions. Input-output models are useful for projection purposes, since assumed changes in the sectoral development of an economy can be traced through to determine their total impact on all sectors of the economy.

Intersectoral flow analysis represents a more sophisticated analysis of the small area economy than the export base analysis. The employment multipliers estimated from the model are more refined than those used in the economic base study and are developed for various industries. They take into account both the direct and the indirect effects of a change in employment in a given industry. The major advantage of this type of model is that it is fairly easy to develop from secondary sources of data. It thus represents an inexpensive alternative to the costly input-output analysis.

Industrial Location--The next step is concerned with the problem of determining the most profitable location for a firm. As developed by Losch (1954) and elaborated upon by Moses (1958), location theory for the firm begins by assuming that producers desire to locate in such a way as to maximize profits. Economies of scale and transport costs are the key determinants of firm location, although concentration of raw material resources, interindustry relationships, transportation networks, and other factors affecting inputs are also important. Competition among producers will lead to the development of a trading area for each producer differentiated on the basis of transport costs.

The theory of plant location provides a basis for the development of a theory of spatial structure for an economy. As developed by Christaller (1933) and Losch (1954) a honeycomb of trading areas will develop on a homogeneous plain for each product. Many economic activities will have the same size market areas, thus leading to the emergence of central places. Some central places will be the center of many different sized market areas, thus leading to a hierarchy of central places or a system of cities.

The task of determining land use patterns in the Texas Coastal Zone will involve an analysis of the spatial structure of the region (utilizing central place theory)including the location and relative size of central places and the relations between them. Once the spatial structure has been determined, the analysis could focus on the pattern of land use in the areas surrounding central places, the areas most likely to be affected by changes in socio-economic activity in the region.

Determining Land Use Patterns

Once a projection model has been developed to forecast future changes in population and in the nature and level of economic activity in the Coastal Zone, it is necessary to determine the resulting changes in land use patterns. One problem with most regional econometric projection models is despite their level of detail and sophistication, they tend to concentrate on the determination of population and of output and employment by sector and to ignore the spatial distribution of such activity. On the other hand, the land use models that have been developed for dealing with urban problems tend to treat the determination of socio-economic activity as being exogenous to the model. Moreover, the level of detail involved in these urban models severely limits their application to a well defined and relatively confined area. Extension of these models to a large diverse region, such as the Texas Coastal Zone, presents significant problems in terms of both data requirements and computational difficulty.

It is significant, however, that land use models, almost without exception, have been based on the theory of land use originated by Thunen (1826) and developed by Alonso (1964). This theory attempts to determine the most profitable use to which a given piece of land can be put as a function of its distance from the market. Prices at the market, freight rates, and the prices of inputs other than land are assumed to be given. The problem then becomes one of allocating resources in such a manner as to maximize the value of output for the firm and the level of utility for the consumer subject to the normal restrictions of economic theory. The solution yields the now familiar Thunen rings with uses having the highest rent being located closest to the center. While the theory was developed to explain the patterns of land use on a homogeneous plain, it has been extended to include the modification or distortions of the pattern of land use due to the development of transportation networks and to topography.

Requirements for Land Use Control

The projection of socio-economic activities in the Coastal Zone and the resulting changes in land use, provide a foundation for efforts on the part of the public to institute controls designed to alter the location decisions of households and firms in order to reduce the level of environmental damages. The first step in this process is to identify the nature and extent of environmental effects expected to occur through the private location decisions of firms and households.

Next, an evaluation must be made of the impact of these effects on the biosphere (man and biota). Finally, the costs of altering location or restricting land use must be compared with the benefits (elimination of damaging effects in the biosphere), the tradeoffs between location and costs must be identified, and on the basis of this analysis and evaluation, guidelines for a land resource management program can be developed.

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APPENDIX E

A LISTING OF DATA
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APPENDIX F

THE TEXAS WETLANDS--

A LITERATURE REVIEW

In Chapter IV the coastal wetlands as well as thirty-three other coastal units were described in terms of their exhibited basic factors or properties which limit or restrict their prime capability or uses. Undesirable land uses were delineated based on these factors. The objective of this Appendix is to determine if the degree of what was termed an undesirable land use could be quantitatively related to environmental impact from data available in the literature.

Coastal wetlands were chosen as an appropriate ecological sub-unit and emphasized because man is altering the Texas marshes and wetlands significantly and no comprehensive guidelines exist upon which to develop management policy.

The scope of this study was to:

Indicate from the literature the effects (beneficial and detrimental) of certain of man's activities in the marsh;

Present data from the two major marsh studies conducted in Texas;

Indicate and discuss the program that another State has initiated for marsh management; and

Delineate the research required for management of Texas marshes.

BACKGROUND

The Texas marshes are located primarily between the Texas-Louisiana Gulf border and the southern end of Matagorda Bay. South of Matagorda Bay on to Mexico grassflats predominate and serve as feeding grounds and resting areas for many marsh related organisms. See Figure F-1 and Table F-1 for an indication of the location and extent of marshes in the Texas Coastal Zone.

Marsh Definition

Marshes are synonymous to wetlands which support vegetation and are periodically exposed to air and then covered by water. Although marshes primarily contain brackish waters of the intertidal zone, they may contain mostly fresh waters or mostly saline waters, thus tying the cycles of mineral nutrients of the land and sea together. The lower marshes of Texas border the estuaries and lagoons while the upper marshes extend into the freshwater swamps and agricultural and ranch land.

Marshes can be classified by salinity types, elevation, productivities and types of vegetation present. The University of Texas Bureau of Economic Geology (in press) defines various areas of the marsh land as follows:

- *Salt Marsh:* Areas frequently inundated by astronomical or wind tides along back sides of barrier islands, tidal creeks, broad areas along mainland side of bays, and distal parts of bayhead deltas; sand, muddy sand to mud. Water table a few inches below to a few inches above sediment surface; relatively high to low physical energy. Common plants are *Spartina alterniflora* (cordgrass), *Salicornis perennis, Salicornia bigelovii* (glass wort), *Suaeda* (Seepweed), *Batis maritima* (maritime saltwort) and *Borrichis frutescnes* (sea-oxeye).

- *Brackish to Fresh Marsh:* Occurs within tidal creeks and interconnected or isolated lakes on mainland sides of bays and on some bayhead deltas; sand, muddy sand, and mud. Grades seaward into salt marsh. Water table at or few inches below surface. Physical energy low; storm-surge floods frequently inundate marshes and storm berms may be constructed. Characteristic plants are *Spartina spartinae* (coastal sachuista), *S. Cynisuroides* (big cordgrass), some *S. Alterniflora* at waterline of brackish lakes, *Scirpus* (bullrush), *Typha* (cattail) and *Juncus* (rushes).

- *Brackish Marsh (closed):* Occurs between barrier islands and mainland representing ultimate bay fill; topographically low and perenially wet. Salt water inundation from runoff from adjacent higher lands. Vegetation consists of *Spartina patens, S. cynosuroides, Distichlis spicata* (saltgrass) and *Juncus* (rushes).

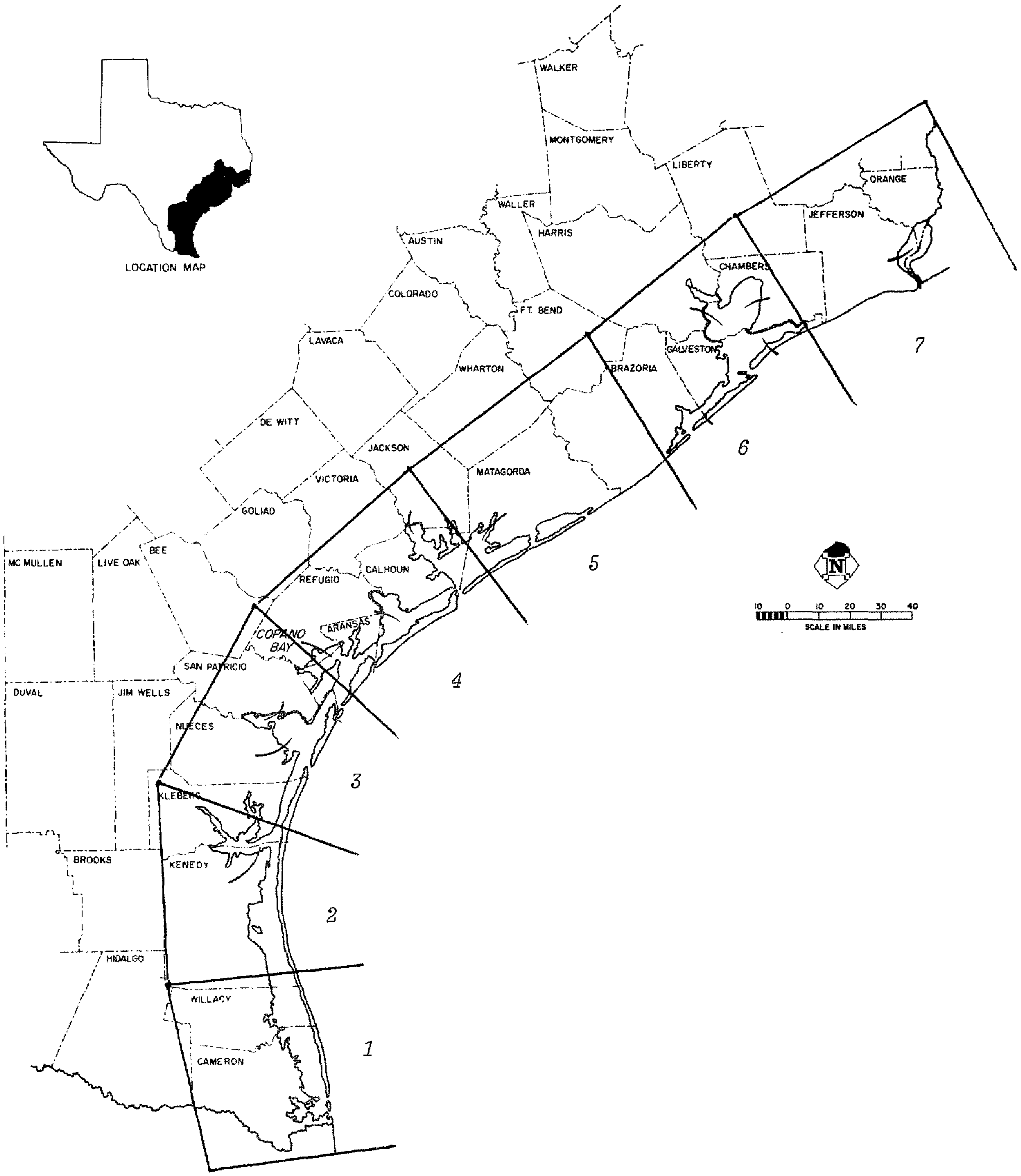


Fig. F-1; Areal Coverage--Bureau of Economic Geology Mapping Program

(Tables F-1 through F-6 follow page F-25)

- *Inland Fresh Marsh:* Flood plains of some large streams, abandoned channels and cut-offs, and inland parts of of larger bayhead deltas; abandoned channels and cut-offs chiefly near sediment surface. Vegetation consists of *Juncus* (rushes), *Scirpus* (bullrush), *Typha* (cattail) and *Spartina pectinata* (sloughgrass).

Marsh-Estuary Interaction

Marsh-estuary interactions and their effects on coastal ecology are many and varied. Physical, chemical and biological systems interact in complex fashions, many of which are poorly understood. The vegetation of the marsh plays a key role in many of these processes. By converting sunlight and nutrients (carbon, nitrogen, phosphorus, etc.) transported by the rivers and the tides, marsh vegetation is produced. The plant tissue is of prime importance as an energy transfer mechanism to consumer ogranisms in the marsh and estuary. Particularly important to the estuarine ecosystem is the transformation of complex molecules of cellulose by bacteria and other decomposers into other carbon compounds digestable by animals and the conversion of nitrogenous wastes of animals into compounds available to plants and/or lower animals. If this mechanism were not removing some of the nutrients in the marsh, more frequent blooms of undesirable algal numbers might occur in the estuary. Furthermore, the marsh vegetation slows flood waters and helps to stabilize channels, banks and water levels. At the same time that nutrients are being converted into vegetation, sediment and suspended materials are being mechanically and chemically removed from the water and deposited in the marsh. Were the sediment not partially removed, more of it would come to rest on shell fish beds and also in navigation channels.

With high river inflows and tides, large amounts of dead vegetation and animal materials (detritus) are transported from the marshes to the adjoining water. Some of this material becomes water-logged and sinks, and although not yet fine enough to be ingested by suspension feeders, it is a main food for various amphipods which become a major food item for juvenile fish. Although many organisms cannot utilize the carbohydrates present in detrital materials (especially cellulose) they can utilize the micro-inhabitants of the detritus which are capable of converting the cellulose to digestable animal protoplasm. Hence, many organisms are abundant in estuarine areas distant from the marshes because of the food web that begins in the marsh.

Also, the seeds of several of the brackish and freshwater marsh plants and the leaves and roots of submerged aquatic plants are prime duck foods. Many kinds of birds and animals could not survive without marsh-dependent food.

Small (and often subtle) changes in a given aspect of this complex web are often magnified exponentially as they are transmitted through the system. The resultant effect is often far removed in space and much greater in magnitude than one would casually suppose.

Effect of Man's Activities on the Marsh

The various functions of the Texas marshes are being altered and sometimes destroyed by man's activities both in and near the marsh. These activities usually stem from land pressures exerted on the marsh in the form of agricultural, housing and industrial development. The problem at hand is devising operational guidelines for multiple use of the marsh area without destroying the ability of the marsh to serve its natural functions.

*CHANNELIZATION AND SPOILING**

Channels are constructed to navigate ships, to obtain fill material to form new land in a bay, to raise the level of adjacent marshes, to drain wetlands, to accommodate pipelines, to provide for waste disposal, to transport water, to create waterfront property, to obtain minerals or buried shell, to improve sport fishing, and for many other reasons. Regardless of why a channel is dug, two basic alterations to the estuarine environment are evident:

- Channels deepen a portion of the estuary; and
- Spoil tends to reduce the remaining water depths.

The two basic methods of channel dredging are mechanical and hydraulic; modifications permit varying degrees of control over resulting spoil materials. Mechanical dredging by bucket dredge or dragline is used for construction and maintenance of small channels. Spoil can be relatively well controlled in a small area. Control of spoil is necessary from a fish and wildlife standpoint, particularly when spoil is to be placed in shallow bays and brackish marshes instead of on adjacent uplands. Hydraulic dredging is usually employed for construction of the larger channels, through deeper open-water areas, and for large maintenance operations. Spoil areas are necessarily large and proper control of spoil requires use of enclosed ponding areas. Ponding areas, however, usually are not practical in open, deeper water; thus, spoil is dispersed widely over the shallow water bottoms with serious ecological ramifications.

**Summary of contribution No. 246 from Bureau of Commercial Fisheries Biological Laboratory, Galveston, Texas, by Charles Chapman: Presented at Marsh and Estuary Management Symposium, 1967.*

Loss of Habitat

Recently, gross measurements (U. S. Fish and Wildlife Service, 1967) revealed that dredging and filling have destroyed more than 200,000 acres of shallow bay nursery areas (not including coastal wetlands) in Gulf and South Atlantic estuaries over the past 20 years. Schmidt (1966) reported that 45,000 acres of tidal marshes were destroyed between Maine and Delaware from 1954 to 1965. Spoil from dredging navigation channels and boat harbors accounted for 34 percent of this loss. Rounsefell (1964) reported that a single project in Louisiana, the Mississippi River-Gulf Outlet Channel, destroyed 23,606 acres of marsh and shallow-water nursery areas (17,058 acres by spoil deposition and 6,548 acres by deepening). About 20 percent of the total surface area of Boca Ciega Bay, Florida, has been buried under waterfront lots (Bureau of Commercial Fisheries Biological Laboratory, 1967) and in San Francisco Bay, 192,000 acres of formerly important estuarine habitat have been reduced to 37,000 acres, mostly by filling. (Delisle, 1966.)

Recent reports and maps (U. S. Army, Corps of Engineers, 1966a and 1966b) show that about 700 miles of federal navigation channels in Texas have modified more than 13,000 acres of shallow bay estuarine nursery areas and destroyed almost 7,000 acres of marsh by deepening. Spoil from excavation of these channels was placed on an additional 23,000 acres of marsh and more than 55,000 acres of shallow bay areas (Table F-2). Texas has approximately 1.3 million acres of inland waters that are affected by tidal influence, e.g., estuarine. Apparently approximately 10% of Texas' estuarine zone has been destroyed or severely damaged already. The private destruction of vital bay and marsh nursery areas in Texas from dredging of non-public channels for navigation and from other projects is not known, but is probably significant.

The Galveston Bay estuarine system is the largest and most important in Texas; it contains some 430,000 acres of surface water and brackish marsh. To date, about 67,000 acres (about 15% of the total acreage) of this valuable estuary have been rearranged or isolated, severely damaged or physically destroyed. Channels and resulting spoil have accounted for 56 percent of this damage (U. S. Fish and Wildlife Service, in press).

Changes in Transport

Cary (1966) reported that the many canals being dredged in Louisiana coastal marshes were allowing vast amounts of fresh water to enter the coastal bays during freshets, causing salinity reduction to levels dangerous to oysters. Numerous examples of increased salt water intrusion via deep channels also have been studied or reported (McConnell, 1952a and 1952b; St. Amant, et al., 1956, St. Amant, Friedrichs and Hadju, 1958).

One of the more striking examples of saltwater intrusion is that caused by the Mississippi River-Gulf Outlet Channel in Louisiana. This channel has permitted normal marine salinity waters from the Gulf of Mexico to penetrate and disperse throughout thousands of acres of marsh and shallow bays and has caused salinities in the 640-square mile Lake Pontchatrain to increase manyfold. The problem of saltwater intrusion via the Mississippi River-Gulf Outlet Channel first was predicted from a hydraulic model study (U. S. Fish and Wildlife Service, 1962; Talland and Simmons, 1963), was discussed by Rounsefell (1964), and confirmed by subsequent field sampling (Corps of Engineers and U. S. Fish and Wildlife Service, personal communication).

Segmentation of associated bays and estuaries by channels and spoil banks also can cause serious derangements. Large areas of shallow water and brackish marsh frequently are isolated to be as effectively lost for nursery areas as if they were physically destroyed. Kutkuhn (1966) noted that deposition of spoil from channel dredging may subdivide a bay in such a way that subsequent changes will render the segmented portions shallower and less useful as nursery areas. Shoaling has become so serious in Lake Grand Ecaille and Bay Long, Louisiana, because of severe silting caused by bay segmentation, that boats can no longer operate out of marked channels (Waldo, 1958).

Benefits from Channelization and Spoil

Channel construction in a shallow bay or brackish marsh frequently can benefit the fishery resources even though relatively small amounts of habitat may be destroyed by spoil. Channels can and do connect isolated waters and marsh areas with the estuary proper to enlarge the estuarine/nursery area. Much of the coastal marsh between Sabine Lake and Galveston Bay, Texas, was formerly isolated and not available to estuarine animals. Dredging of the Gulf Intracoastal Waterway across 40 miles of this marsh opened thousands of acres of nursery area to estuarine shrimp, crabs, and fish. Recently, some of this marsh since has been re-isolated to prevent saltwater intrusion into nearby rice growing areas.

Severe winter storms locally called "northers," have caused massive fish kills in the marsh dependent shallow Texas bays (Gunter, 1941; Gunter and Hildebrand, 1951). The deeper waters in channels do not chill as fast as shallow bay waters and thus provide fish with a refuge. The 30-foot-deep Offatts Bayou in Galveston Bay is noted for its excellent sport fishing during and following winter storms.

The Gulf Intracoastal Waterway through the Laguna Madre of Texas now provides an avenue of escape for fish from both winter cold and the hypersaline conditions that develop in summer from high evaporation (Simmons, 1957). The Gulf Intracoastal Waterway reportedly (Breuer, 1962) improved water circulation in the Laguna Madre and thus has lessened excessive hypersalinity. Salinity greater than 100 parts per thousand was reported by Collier and Hedgpeth (1950) before construction of the Gulf Intracoastal Waterway, but since has not exceeded 80 parts per thousand (Simmons, 1957; Breuer, 1962).

Although Gunter (1957) recognized that the deleterious effects from spoil are real, but localized, he hypothesized that the release of nutrients may more than offset the damage done. However, concentrated toxicants could also be released.

MARSH BURNING (DEVEGETATION)

Certain procedures and guidelines exist for marsh burning (Hoffpauer, 1967) which enable the most productive grass plants to become the dominant species. (See Table F-3.) Since some marsh grasses grow faster than others the type of burning is extremely important. Therefore, burning which destroys only grass shoots may be more beneficial to one species than others. Other factors such as the occurrence of tidal action and height of the water table influence the burning technique used.

Marsh burning also has been used for insect control. The fires are mainly directed against greenhead flies rather than mosquitoes. However, the burning destroys wildlife habitat and other animals in addition to insect eggs and larvae. Much of the marsh grass that would supply food to marine animals thus is lost from burning.

Marsh burning could, of course, generate air pollution; however, Regulation II of the Texas Air Control Board governs procedures related to open burning.

EFFECTS OF DECREASED RIVER FLOW ON MARSH ECOLOGY (DRAINAGE)

The increasing use of water upstream and ever-increasing number of reservoirs constructed on watersheds have created profound and varied effects on the biota of the marsh ecosystem. Reservoir construction has become a common practice throughout Texas' watersheds. However, the short and long range effects on the various aquatic species in the marshes downstream from the reservoir often are overlooked.

River water inflow is the most important factor for maintaining adequate salinity variations for marsh production. Proper management of reservoirs should include periodic releases for marsh flooding; however, too much fresh water inflow may make the entire estuary fresh or near-fresh water, as has occurred in Sabine Lake in east Texas (Copeland, 1966).

Another problem which stems from reservoir construction and its effect on water release is the removal in the reservoir of essential nutrients. Many of the suspended solids and associated nutrients settle out on the bottom of the reservoirs. Lake Livingston, Trinity River, Texas, showed a decrease in nutrient concentration as the water was impounded in the lake. As a result, the water released from this reservoir contains relatively fewer nutrients needed downstream for a productive marsh. However, due to stratification, various levels of the lake contained greater nutrient concentrations than in other levels. Perhaps selective withdrawal at different lake levels could assure nutrient transport to the estuaries (Fruh, 1969).

A study (Parker, et. al., 1971) of a marsh area in West Galveston Bay between Hayes Ridge and the Intracoastal Canal spoil banks resulted in three conclusions concerning salinity concentrations in a marsh.

- As a result of frequent tidal floods, saline conditions generally prevailed within the marsh. Freshwater floods resulting from local rainfall were common, but salt leached from the bottom sediments readily reestablished saline conditions.
- Durine freshwater floods, only the stable macro-fauna *(Cyprinodon variegatus, Fundulus grandis, Poecilia latipinna, Mugil cephalus, Menidia beryllina, Palaemonetes sp.,* and *Callinertes sapidus)* were found. Marine species were presumably either forced out into the bay or died as a result of the rapid salinity decline which typically occurred.
- Drought conditions occurred to varying degrees during the summer months, producing abnormally high water temperatures and hypersalinities. The stable macrofauna were more tolerant to these conditions than other species, but during severe droughts all aquatic macro-fauna perished.

*THE EFFECTS OF BIOCIDES**

The use of various insecticides has become an ever increasing problem. Insecticides are effective in extremely minute amounts and are not obviously apparent except by death effects. Some are very stable compounds that are very slowly broken down by biochemical activity. Some insecticides enter the marshes from land runoff. Others are sprayed directly on the marshes.

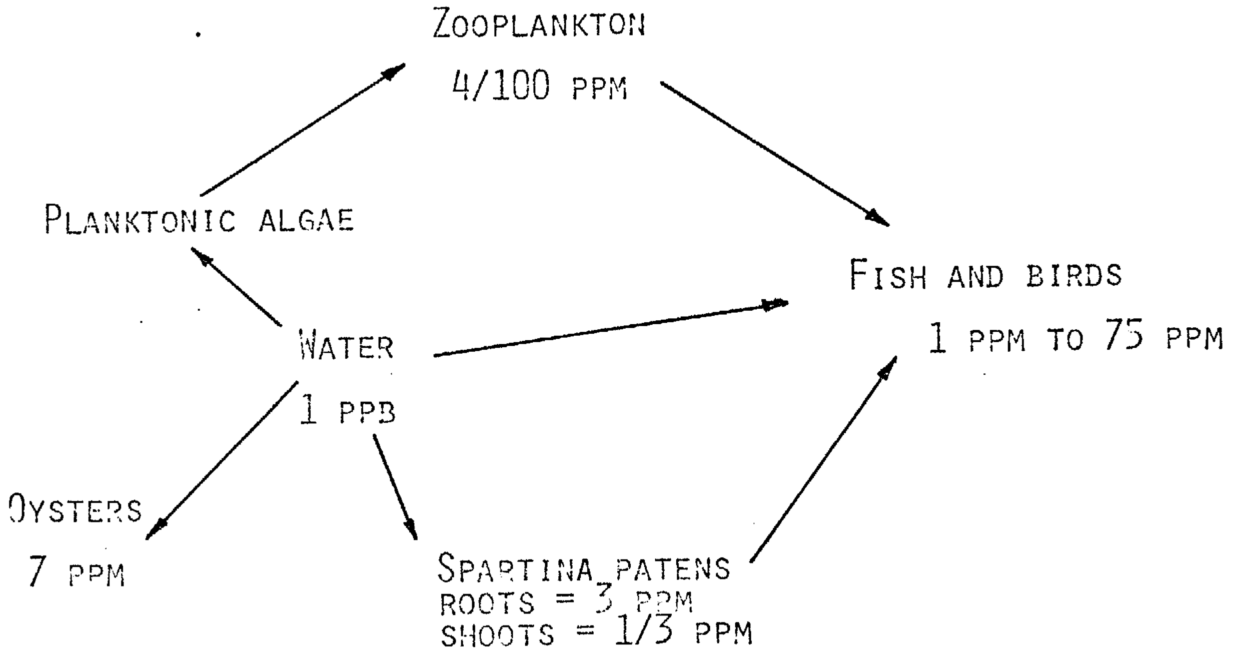
In studies of the biological concentration of DDT on a salt marsh estuarine system on Long Island, it was found that there was little DDT in the water although the marsh had been sprayed for twenty years. Only one part insecticide in one billion parts of water (one ppb) was recorded. A very different result was found for DDT in the soil, since this pesticide is nearly insoluble in water. The soil beneath *S. patens* marshes contained an average of thirteen pounds of DDT per acre and mud in the ditches contained nearly three pounds per acre. DDT in the soil serves as a reservoir from which the water can continually extract the poison. Water carries very little of the pesticide at any one time, but it continually leaches DDT from the soil and transports it to the organisms in the water that will concentrate it.

In the study of the Long Island marsh, no analysis of DDT concentrations were made in algae or detritus. The roots of *Spartina patens* contained three ppm (parts per million) DDT while the shoots contained one third ppm. Apparently the planktonic algae in the marsh contained appreciably less than the grass, for the grazing zooplankton contained only four hundredths ppm. Of the animals utilizing the zooplankton, several types of minnows were analyzed and found to contain about one ppm DDT, a concentration of twenty-five times over their food supply. In the higher levels of the food web in fish and birds, a little more than one ppm to over seventy-five ppm were found. The highest value was found in a young ring-billed gull. Fish eating birds, such as herons and terns, were reported to have about four ppm, a fourfold concentration of DDT over their food. Birds such as gulls are scavengers and exist on a higher level in the food chain. Birds that eat birds are on a higher level yet and probably contain five to ten times more DDT concentration. The amounts in the most contaminated birds in the study were at the lethal level. (See Figure F-2.)

**Summary is from Life and Death of the Salt Marsh by John and Mildred Teal, 1969.*

FIG. F-2: DDT CONCENTRATION IN FOOD CHAIN OF TIDAL MARSH

FROM: TEAL AND TEAL, 1969.



PPM = PARTS PER MILLION

PPB = PARTS PER BILLION

(NO INFORMATION AVAILABLE FOR DDT CONCENTRATIONS IN DETRITUS)

WEIRS AND POTHOLES FOR MARSH MANAGEMENT

The estuarine habitat might be enhanced for some wildlife and fish species by placement of structures (weirs) in the tidal marsh channels to partially stabilize water levels and hence, salinity gradients.

Waterfowl Management

The use of weirs and their effects on waterfowl in regularly flooded salt marshes, irregularly flooded salt marshes, and salt meadows and salt flats have been documented by Baldwin (1967). Some plants important as food for waterfowl grow particularly well at specific salinities. Therefore, these plants can become dominant species in various marsh types by use of weirs for salinity control. For instance, a marsh having a bottom relatively free of silt and detritus and containing only sparse growth of *Juncus roemerianus* (a plant not attractive to feeding waterfowl or muskrats) could be transformed into a highly productive feeding ground for waterfowl. This could be accomplished by planting widgeongrass (an important food for waterfowl), which grows best in marshes relatively free of silt and detritus, can tolerate a wide range of salinities, and grows best in about 18-24 inches of brackish water (Baldwin, 1967).

*Nursery Use and Fishery Management**

The use of weirs or potholes (small open ponds dug in marsh areas) also can be used for fishery management. Regulation of water levels and salinity gradients can be obtained by setting the crest of the weir about six inches below average marsh water surface level. This allows water to flow over the weir on most incoming tides and flow back out when the tide drops until it reaches the crest level. The water remaining behind the crest is impounded. Since flow in both directions is possible a good portion of the time, the area behind the weir is termed a "semi-impounded marsh."

Seven major species and eighteen minor species were analyzed in a study of semi-impounded Louisiana marshes. (See Tables F-4 and F-5). The study indicated that juvenile fishes and shrimps respond by immigration and emigration to the interaction of seemingly minor changes in environmental factors, although Herke (1971)

**This section is a summary of the work reported by Herke (1971).*

emphasized salinity. Almost all juvenile organisms associated with the bottom undergo a delay in immigrating into the semi-impounded area. This tendancy was not observed for species often associated with the surface.

The growth rates of the major commercially important species in the marshes were reported as much higher than the rates reported by other investigators for open estuarine areas. However, more studies should be undertaken, since problems exist for measuring growth rates of *Penaeus aztecus*, *Penaeus setiferus*, and *Anchoa mitchilli* in semi-impounded marshes. These species are so mobile and grow so fast, it is difficult to determine accurately their growth rates. Moreover, it must be noted that semi-impoundment stimulates growth of rooted aquatic plants. Hence, the long range effect of impoundment will probably benefit *Micropogan undulatus*, *Penaeus aztecus*, and possibly *Leiostomus xanthurus* by supplying food. It will probably result in decreased production of *Brevoortia patronus*, *Anchoa mitchilli*, and possibly *Penaeus setiferus*.

It was found that the minor species judged to have benefited from semi-impoundment in this study were either freshwater or tiny brackish water organisms.

SUMMARY OF TEXAS STUDIES

Most research conducted in the Texas coastal zone has centered around the bays and estuaries or the Gulf of Mexico. Few studies of Texas marshes have been sufficient to obtain an understanding of the biological, chemical and physical constraints placed on the marshes by man's activities. Only two comprehensive marsh studies have been found in the literature.

One of the Texas studies presents short term before and after data on a marsh altered by a waterfront housing development at Jamaica Beach on Galveston Island. The other Texas studies have been composited in this review because they all relate to the utilization of the Trinity River marsh as a nursery area for organisms. Part of this marsh will be inundated shortly by the backwaters of a reservoir.

*Waterfront Housing Development in West Bay**

Many of the shallow bays and marshes along the Texas coastline are being dredged, bulkheaded, and filled for waterfront

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**Summary of study of Waterfront Housing Developments - Their Effect on the Ecology of A Texas Estuarine Area, W. L. Trent, E. J. Pullen, and D. Moore, (1970), National Marine Fisheries Service Biological Laboratory, Galveston, Texas.*

housing sites. Such shoreline development changes the environment for marine organisms in the following manner:

- Reduction in acreage of natural shore zone and marsh vegetation;
- Changes in marsh drainage patterns and nutrient inputs; and
- Changes in water depth and sediments.

The effects of these types of environmental changes on marine organisms are poorly understood.

In order to acquire more knowledge about such effects, the Bureau of Commercial Fisheries (National Marine Fisheries Service Biological Laboratory, Galveston, Texas) investigated the natural and altered areas with respect to:

- Sediments and water quality;
- Phytoplankton productivity;
- Relative abundance of benthic micro-invertebrates, fishes, and crustaceans; and
- The setting, growth and mortality ratios of the American oyster (*Crassostrea virginica)*.

The study area, located in West Bay, Texas, included a natural marsh, an open bay area, and a canal area that was similar to the natural marsh before it was altered by channelization, bulkheading, and filling (Figure F-3). The developed area, which included about 45 hectares of emergent marsh vegetation, intertidal mud flats, and subtidal water area prior to alteration, was reduced to about 32 hectares of subtidal water area by dredging and filling. The water volume (mean low tide level) was increased from about 184,000m^3 to about 394,000m^3.

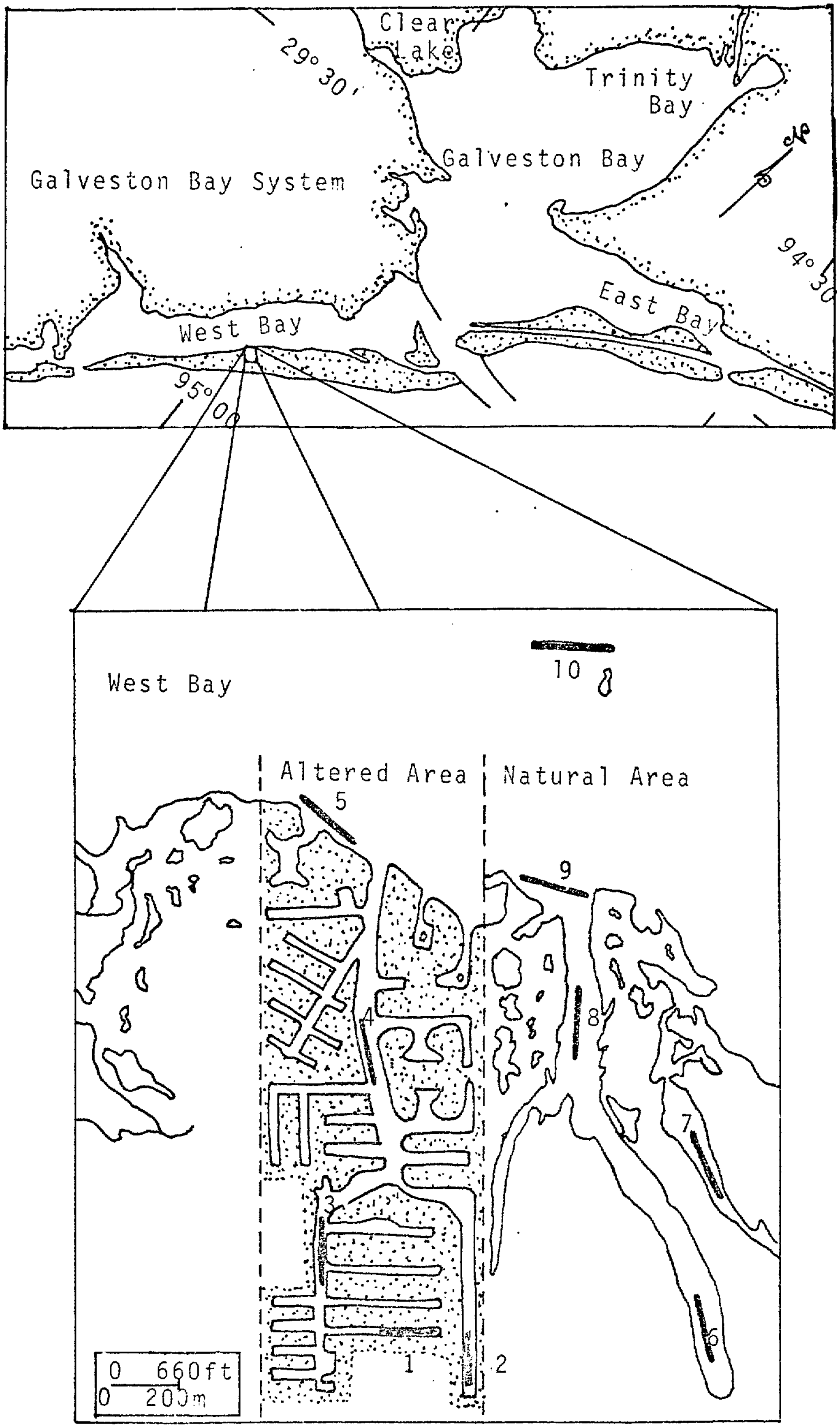

Fig. F-3; The Galveston Bay System showing the study area and station locations in West Bay, Texas.
From: Trent et al, 1969.

Physical and Chemical Properties--The canals, marsh, and bay were composed of distinctly different sediments. Higher percents of silt and clay were found in the canals (41%) than in the marsh (31%) or the undredged bay area (17%). The total carbon in the sediments was highest in the canals and lowest in the bay; however, the difference did not appear significant. The marsh contained almost twice as much detrital vegetation on and in the sediment than the canals. The bay's sediments contained very little detritus.

The average temperature, salinity, total alkalinity, and pH differed only slightly between the three areas.

The dissolved organic nitrogen contents were highest in the marsh. It was indicated that a major part of the nitrogen in the marsh may have originated from cattle that graze adjacent to this area. The average total phosphorus was the same in the three areas, although occasionally higher concentrations were found in the canal area. The source of phosphorus possibly could be seepage from septic tanks adjacent to the canals and runoff from fertilized lawns. The study was too short in time to determine if an algae species change due to increased nutrients did occur and would be significant in terms of metabolism through the food chain.

Average turbidity readings of surface water samples were highest in the marsh and bay, although the highest turbidity reading of bottom waters was measured in the canals. The lower turbidities of surface water in the canals enhances light penetration needed for phytoplankton production.

The dissolved oxygen concentration on an average basis was highest in the bay, intermediate in the marsh, and lowest in the canals. During the summer, the dissolved oxygen dropped to levels critical to marine organisms at stations (1, 2, and 3) in the canal and on four occasions to 0 mg/l at night during phytoplankton blooms. This appeared to reduce the abundance of fishes and invertebrates in the canals during the summer.

> *"Probably poor oyster growth, high mortality, and low to mid standing crops of benthic organisms, fishes, and crustaceans during June-September were directly or indirectly caused by low oxygen levels at station 1. Furthermore, stations 2 and 3 in the area of the development furthest from the bay had low oxygen levels during the summer and a smaller than average standing crop of fishes and crustaceans." (Trent, Pullen, Moore, 1970).*

Phytoplankton--The primary productivity of phytoplankton was determined twice each month at five stations (1, 2, 6, 7, and 10) in June, July, and August. The productivity of phytoplankton was measured by the light-dark bottle technique in terms of gross photosynthesis and respiration. One milligram of oxygen was assumed equivalent to three tenths of a milligram of carbon.

The average gross photosynthesis gauged from 1.17 mg C per liter per day in the bay to 2.25 in the canals. The average values at the canal stations (1 and 2) were almost identical to those at the marsh stations (6 and 7). The average photosynthesis in the canals was 8% higher than in the marsh and 49% higher than in the bay.

The investigators considered poor water circulation in parts of the development canals as a cause of favorable conditions for high populations of phytoplankton.

Benthic Macro-Invertebrates--The marsh contained a greater number and volume of benthic organisms than the canal. The crustaceans, mollusks, and nemerteans were particularly affected while polychaetes were not significantly changed. Both the marsh and canal had a greater productivity than the bay. The greatest production in volume was found in the marsh, probably because of more stable dissolved oxygen levels.

Oyster Spatfall, Growth and Mortality--The attachment of oyster spat to sampling plates was higher in the marsh than in the canal. Similarly, the oysters in the marsh grew faster (72%) in length than in the canal. The average mortality rates of the oysters was greater in the canals (91%) than in the marsh (52%). The high mortality rate for oysters in the canals could be directly or indirectly caused by low oxygen levels.

Fishes and Crustaceans--The marsh was the most productive area in terms of numbers of animals caught when all species were combined. Ten of the species caught represented 96% of the total number of specimens. Six of the most abundant species (89% of the total catch) consisted of brown shrimp, white shrimp, spot, large scale menhaden, Atlantic croaker, and bay anchovy. It is significant that the first three specimens were most abundant in the marsh and the last three were most abundant in the canals.

The brown shrimp, the most valuable commercial fishery species, were more abundant in the marsh probably because of bottom type and food availability. Brown shrimp feed on benthic organisms and detrital material. Benthic organisms and detrital vegetation were more abundant in the marsh than in the canals and least abundant in the bays.

White shrimp were more abundant in the marsh because they have even more distinct preference than do brown shrimp for shallow water habitats characterized by muddy or peaty bottoms high in organic detritus and an abundance of marsh grasses (Weymouth, Linder, and Anderson, 1933, Williams, 1955; Loasch, 1965; Moak, 1967).

Juvenile spot feed predominantly on planktonic and benthic microcrustaceans (Gunter, 1945; Dannell, 1958.) Phytoplankton productivity in the canal and the marsh were similar. Thus, the juvenile spot were probably more abundant in the marsh because of the higher abundance of crustaceans in the marsh area.

The largescale menhaden and bay anchovy are plankton feeders during their juvenile stages. The abundance of these fishes in the three areas was probably related to phytoplankton productivity which was greatest in the canals.

The Atlantic croakers were most abundant in the canals. This is difficult to explain since juvenile croakers prefer soft substrates where they can obtain much of their food by digging for subsurface invertebrates and organic debris (Roelofs, 1954; Reid, 1955). This type of substrate was more abundant in the marsh than either the canal or the bay.

Discussion--Trent et al. (1970) reported that the total biological productivity was highest in the marsh, intermediate in the canals of the altered area, and lowest in the open bay. The productivity of the canals probably would have increased if dissolved oxygen levels had been higher in all canals of the altered area during the summer. Wastewater treatment other than septic tanks appears in order.

Because there still was a great abundance of benthic organisms, fishes, and crustaceasn in the altered area, the National Marine Fisheries Service are planning studies to determine whether the altered area is self-supporting in terms of phytoplankton productivity or if the altered area derives much of the vegetative detritus from the natural marsh through tidal action. Primary production solely from phytoplankton could place constraints on some species of organisms in the food chain. If detrital vegetation is present in a sufficient quantity to maintain those species which feed mainly on detritus, a large biological community could be sustained. However, if the altered area is not self-supporting, and if developers continue to use the marsh in a manner similar to the present, then the biological productivity of the estuaries will be altered in relation to the acres of marsh developed.

TRINITY RIVER MARSH

The objective of this section is to present the results of various investigators on the extent of utilization of the Trinity River delta by migratory early life-history stages of estuarine and marine aniamls. In addition, comments will be presented concerning the hypotheses advanced by various state and federal agencies on the potential effects of the Wallisville Dam.

Water Quality--Bauldauf et al., 1970, obtained water quality measurements at most stations from March, 1966, through May, 1968. (This is before impoundment of the Trinity River upstream at Lake Livingston.) Comparison of river flow and salinity values during low freshwater inflows indicated that salt water intrusion occurred in some marsh areas but not in others. Temperatures were found to be approximately the same at each station on any one date. Kjeldahl nitrogen tests indicated a considerable variation in dissolved organic nitrogen and and ammonia nitrogen levels between sampling stations although the water in the Trinity River channel had lower levels of Kjeldahl nitrogen than did other parts of the study area. No measurements were made for nitrite or nitrate nitrogen. Total phosphorous levels were reported highest in the main channel of the Trinity River, with peak levels occurring during times of reduced river discharge. Phosphorous values throughout the marsh were related with the extent to which the Trinity River water influenced the hydrology of the marsh. No dissolved oxygen measurements were made.

Trinity River Marsh Utilization by Important Estuarine and Marine Organisms--This section is a review of various studies. Some were not based on data obtained directly in the marsh, but their conclusions are based on sampling of migratory routes of organisms in the estuaries.

Chapman (1966) reported that the upper area of Trinity Bay is the most heavily utilized blue crab nursery of the Galveston Bay System (see Figure F-4). Bauldauf et al. (1970) reported that these organisms were present throughout the Trinity River marsh during all months. The relative abundance varied greatly from station to station and from trip to trip, but the investigators found no discernible pattern for this phenomena. Small crabs were reportedly affected by salinity variations.

Parker (1970) reported on the density distribution of juvenile brown shrimp in the Galveston Bay System by time in 1963 and 1964. (See Figure F-5). Chapman (1966) showed the importance of the marsh as a habitat for brown shrimp. (See Figure F-6). Bauldauf, et al. (1970) reported a similar recruitment of brown shrimp in the Trinity River marsh in 1967. However, the brown shrimp recruitment was much lower in 1966, evidently because of freshwater flooding in the spring.

The recruitment of white shrimp in Galveston Bay and the Trinity River marsh is similar to that of the brown shrimp except for season of migration. Also, Baldauf et al. (1970) reported that the flooding effects in spring 1966 did not have a major effect on summer and fall immigration of the white shrimp.

The nursery utilization of the Trinity River marsh has been diagrammed by Parker (1971) as shown in Figures F-7 and F-8. Although data are presented for only 1964, Parker's report includes 1963 and 1965 data which shows that the pattern was the same. The Trinity River marsh was the most highly utilized croaker nursery in Galveston Bay. The area also is important for spot.

Baldauf et al. (1970) indicated the importance of the marsh as a nursery for Gulf menhaden (*Brenvoortia patronus*). In general, the movement, growth, and other factors of the biology of the Gulf menhaden in the study area duplicated those recorded factors for this species in other areas of the Gulf coast.

Management Difficulties--The U.S. Fish and Wildlife Service in coordination with the Texas Parks and Wildlife Department in March 1966 commented on the preconstruction plan for the Wallisville Reservoir. They ascribed substantial benefits to freshwater sport fishing with essentially an offsetting decrease in estuarine sport fishing, a small gain to the freshwater commercial fishery, and an extremely large net loss to the commercial fishery through elimination of marsh habitat and a reduction in flow of nutrients to the bay.

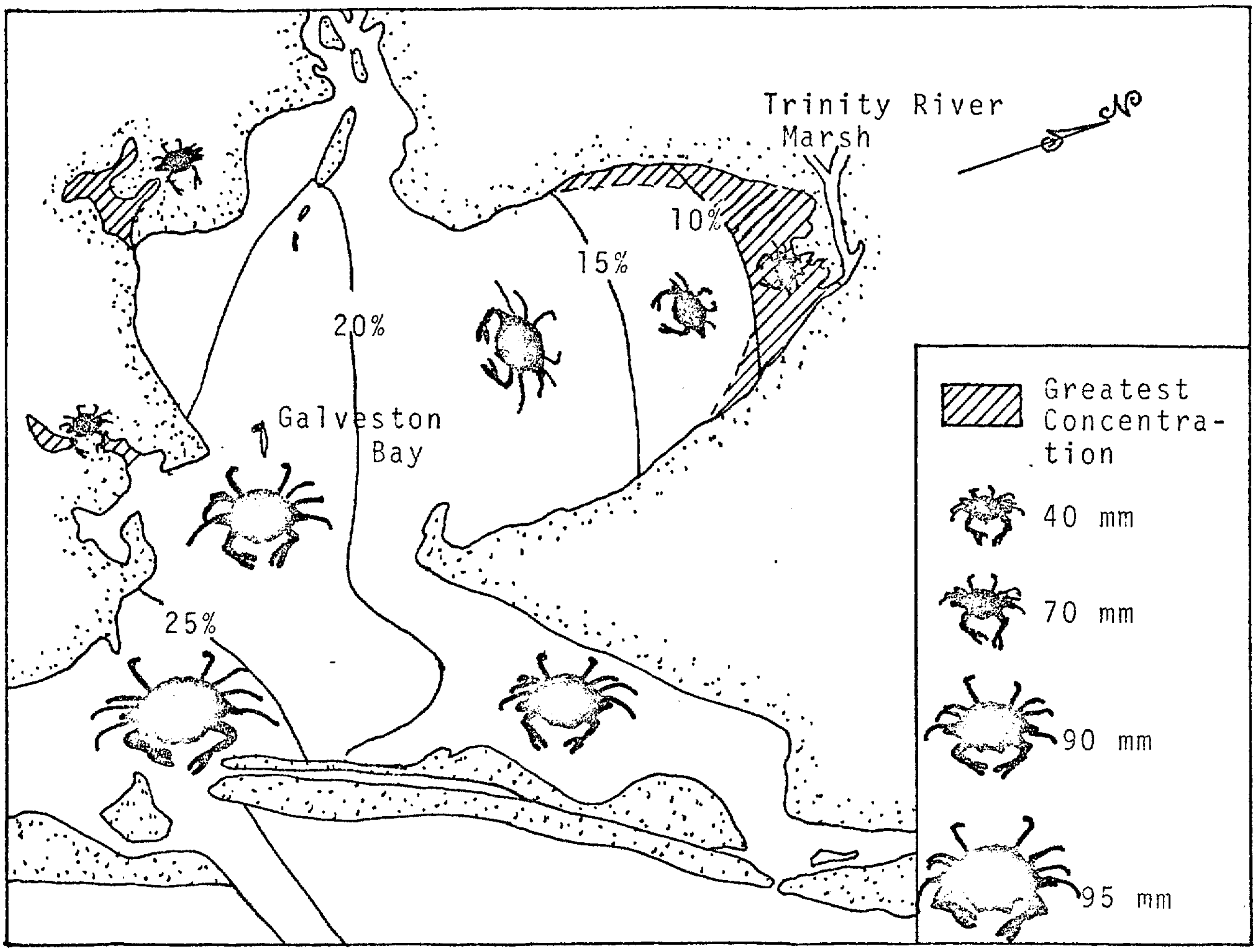

FIG. F-4; Average carapace width of blue crabs in relation to salinity in the Galveston Estuary; with areas of greatest concentration indicated.
From: Chapman, 1966.

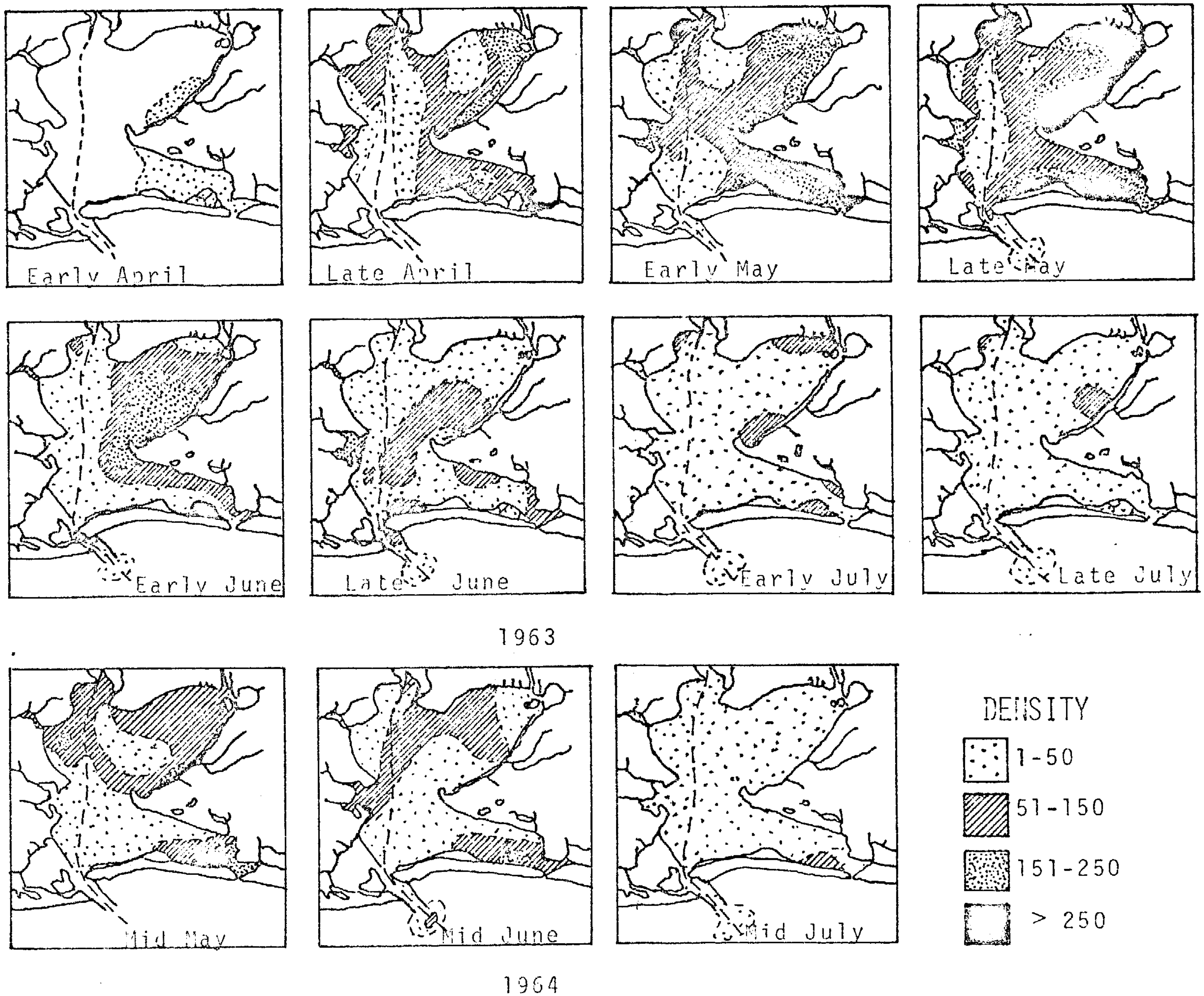

FIG. F-5; Density distribution of juvenile brown shrimp in the Galveston Bay System by time in 1963 and 1964.
From: Parker, 1970

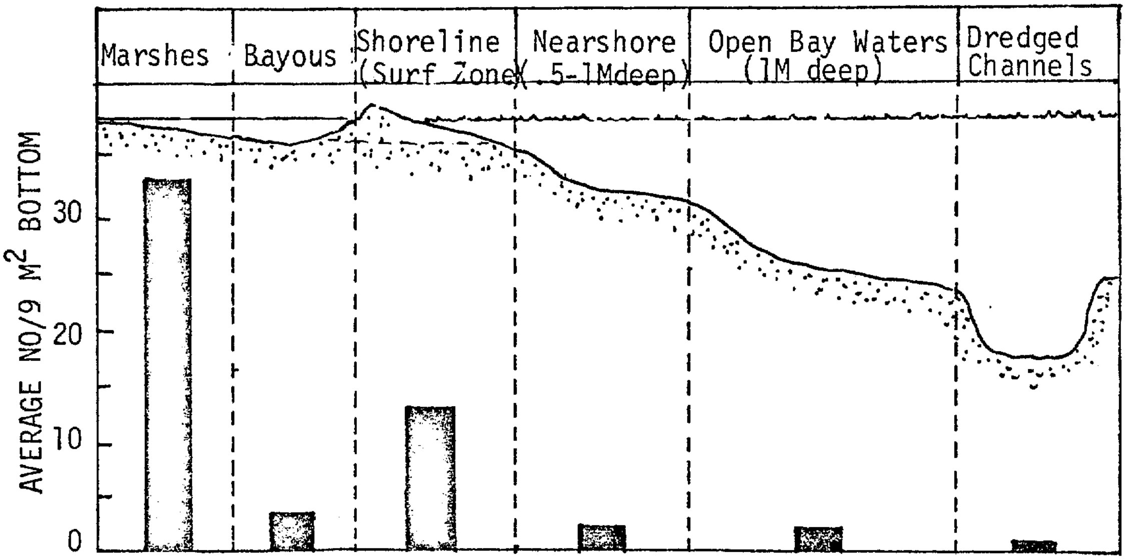

FIG. F-6; Relative importance of different types of habitat in the Galveston estuary as nursery areas for juvenile brown shrimp.

From: Chapman, 1966.

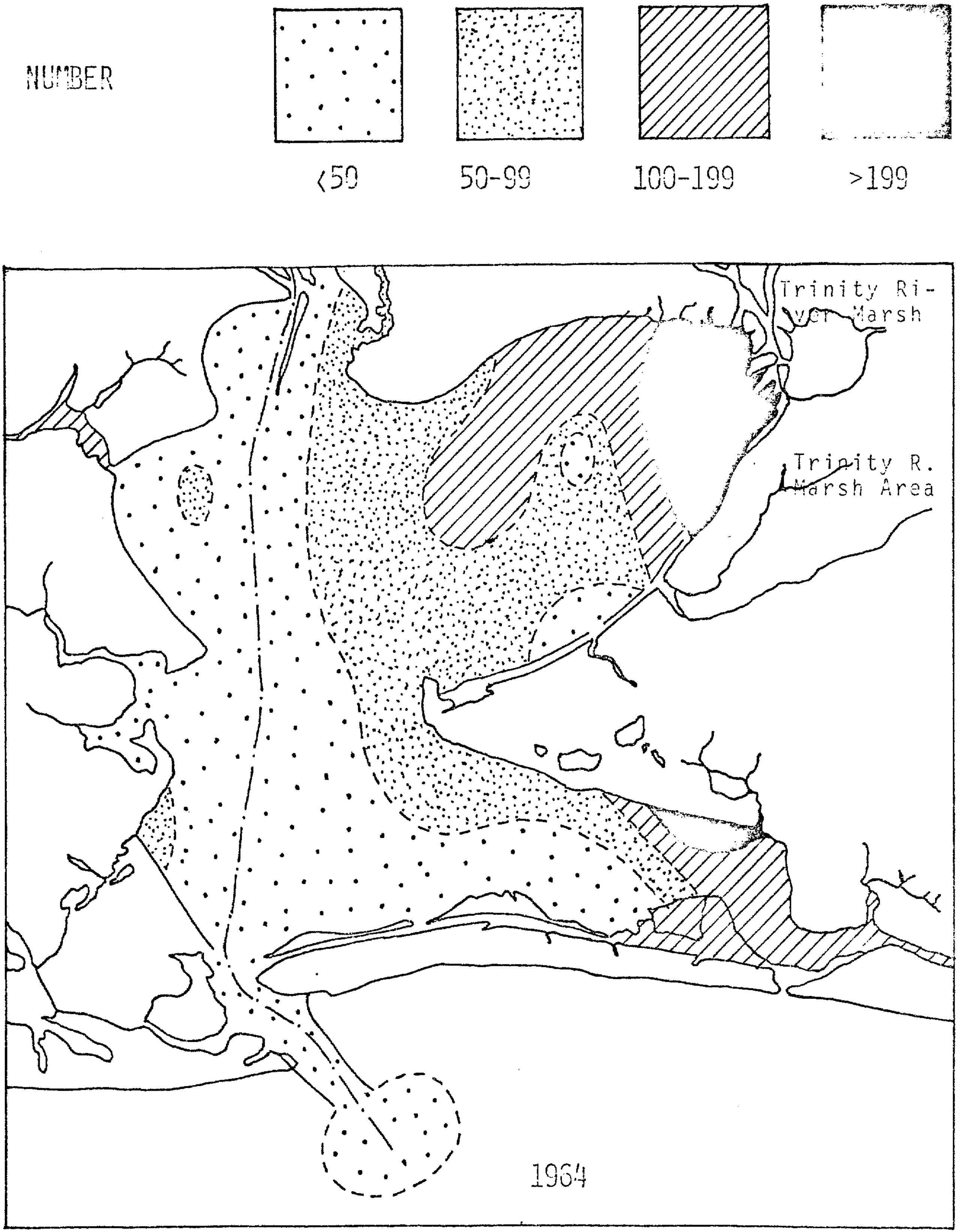

FIG. F-7; Distribution of croakers in Galveston Bay during 1964. From: Parker, manuscript.

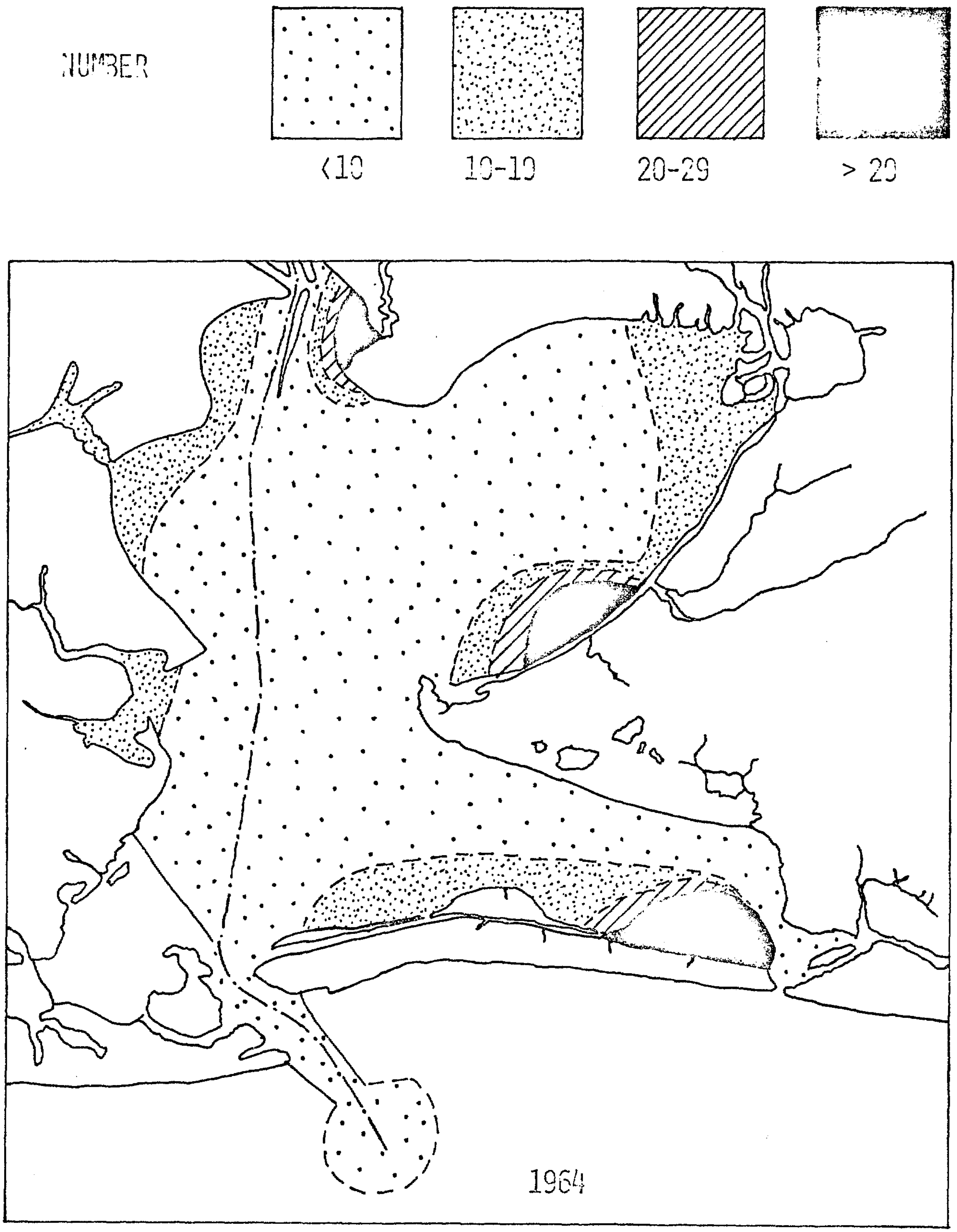

FIG. F-8; Distribution of spot in Galveston Bay during 1964.
Numbers indicate average per trawl.
From: Parker, manuscript.

In 1966, the Corps of Engineers, seeking to verify the findings of these agencies obtained an independent evaluation from a recognized consultant, Dr. Gordon Gunter, who concluded:

> 1. *The Galveston Bay system is being over-fertilized now and this over-fertilization will increase. Any dimunition of the nutrient salts flowing into the system might be beneficial.*
>
> 2. *The Wallisville Reservoir will divert less than three percent of the water which will be diverted from the Trinity River, and this effect will be negligible.*
>
> 3. *The submerged area of the marsh within the reservoir area is rather small and its production of marine animals is spotty over the years. Estimates of the marine production of this area are quite difficult to make and probably impossible with present data, and they seem to have been highly overrated by the Fish and Wildlife Service reports to the Corps of Engineers. It is possible that with a high influx of freshwater the production of upper Trinity Bay would be just as high as it would be with a low inflow and movement of young marine organisms into the marsh.*
>
> 4. *For the above reasons, it may be concluded that the Wallisville Reservoir is going to have a minor effect upon the marine fisheries of the Galveston Bay system.*

The conflict between the agencies was not resolved in 1966. The Corps of Engineers Environmental Impact Statement (1971) states:

> *"The differing evaluations of the Fish and Wildlife Service and the consultant's report were presented* in toto *in the general design memorandum; the project was approved for initiation of construction and land acquisition and initial phases of construction were started in 1966."*

Baldauf et al. (1970) study subsequently was initiated, and their results were reported herein in the previous section. Although Baldauf et al. (1970) only evaluated pre-impoundment conditions, they also made a number of predictions about post-impoundment conditions:

1. *The Trinity River marsh area serves as nursery ground for menhaden, blue crab, and brown and white shrimp.*

2. *The construction of the proposed Wallisville Lake will destroy about 12,500 acres of nursery ground located behind the proposed dam-saltwater barrier. Changes in the nursery below the dam site also are likely.*

3. *Placing of the dam-saltwater barrier from 4.5 to 5 or more miles farther upstream would have saved much prime nursery area from direct destruction.*

4. *Wallisville Lake will isolate brown and white shrimp, blue crabs, and Gulf menhaden from nursery areas and will cause permanent declines in the numbers of these species.*

The Corps of Engineers, in its Environmental Impact Statement (1971), concluded from the conflicting evaluations

> *"that damages to the marine fishery will occur from the project's isolation of an area of estuarine habitat but that quantification is probably not possible and that there is no apparent way to reconcile the conflicting opinions."*

However, this statement recently has been challenged by a number of federal and state agencies. In particular, one federal agency points out that only the Corps consultant believed that the dam's impact would be minimal as opposed to those evaluators who either deferred judgement pending more information or concluced that the area was a major nursery ground for marine fishes and crustaceans, and the dam construction would impair such use. Furthermore, the Corps consultant provided no data in his report and actually only indicated one sampling test. Another point of major conflict involves the effect of vegetative growth in the proposed reservoir on freshwater sports fisheries.

It is of major importance to understand that many federal and state agencies reserved comment on the effects of the proposed reservoir or the use of the marsh as a nursery area by estuarine organisms until only recently when the Baldauf et. al. (1970) report was made available. It was recognized by these agencies in 1966 that sufficient information was not available to make a sound scientific judgement on the project. However, since 1966, the construction of the reservoir has been implemented.

There are times when decisions must be made. For this reason, it is essential to develop management criteria and operating guidelines in order to adequately analyze problems which will confront the state.

WETLANDS MANAGEMENT IN VIRGINIA

Several other states have undertaken management studies for their bays, estuaries, and wetlands. The only significant published scientific report found in the literature was on the Virginia Wetlands Study (Wass and Wright, 1969).

The State of Virginia recognized the value of their wetlands even though they only comprised one percent of the total area of the state. The Virginia Institute of Marine Science was directed by House Joint Resolution No. 69, 1968, "to make a study and report on all marsh lands and wetlands in the State for the purpose of assessing their relative importance, respectively, to the marine resources of the State."

Environmental Evaluation

An evaluation of the ecology of the Virginia wetlands was undertaken because of the recognized importance of these areas to the fishery industry. Numerous environmental studies obtained from the literature were analyzed and evaluated. Much of the data presented was developed specifically for Virginia wetlands and in some instances field data were obtained for evaluation.

Mapping and Identification

As might be expected, the Virginia Study devotes a considerable effort to the definition and identification of wetlands. Delineation of types of wetlands was obtained from an areal survey by use of topographic maps. Considerable effort was expended in calculation of numbers of acres of various types of wetlands. In addition, the number of miles of tidal shoreline was determined and its usage was delineated in its harbors and ports, recreation, residential, industrial, conservation, military, NASA, and no present use. The type of ownership also was noted with use criteria.

Biological, Chemical and Physical Data

Considerable effort was spent in analyzing the various biological, chemical, and physical interactions in which the wetlands were involved. These interactions because of their detail and yet simplicity of description are presented *in totem* as a supplement to this appendix.

The second major contribution was the estimation of the productivity of eight different marsh grasses in tons per acre as shown in Figure F-9. However, in addition to productivity, the rate of decay of the various grasses is significant in determining the importance of a particular marsh as a food source.

Food webs were discussed for brackish, fresh, and salt water wetlands. In particular, the types and preference of foods of ten different finfish were delineated as shown in Table A-6. This contribution points out a weakness of past marsh and estuarine studies which focus on the commercially important finfish and crustaceans but ignore the food sources.

Economic Evaluation

The Virginia Wetlands Study includes an attempt to evaluate the economic benefits derived from preservation of the wetlands. Two alternative approaches are examined, the "user fee" and the "total user expenditure" approach.

In the total expenditure method, secondary multipliers for employment and income are calculated and used to approximate the total income generated in the whole state economy due to wetlands. This approach has the value of trapping all secondary benefits attributible to wetland productivity, but this value would not indicate the true social cost of destruction of the wetlands, as most of the income and employment would be generated in other sectors of the economy if wetlands were destroyed. To by-pass this problem the user-fee method was used, in which only the primary benefits which would accrue to a private owner of the wetlands are counted. This method produced a value of $78.00 annual income per acre of wetland.

In a comprehensive coastal management program, neither of these approaches would adequately reflect the social benefits of the wetlands, as both ignore the possibilities for substitution in demand and production in the differing sectorial growth rates.

Management and Public Financing

Wass and Wright (1969) recommended that steps be taken at once to halt, by any means possible, uncontrolled or unnecessary alteration of wetlands. Adoption of a legal definition of the Virginia wetlands as well as a series of guidelines for zoning of wetlands, shorelines, and shallows were recommended. The Marine Resources Commission was suggested as the statutory authority to regulate any activity which affects the ecology of coastal wetlands

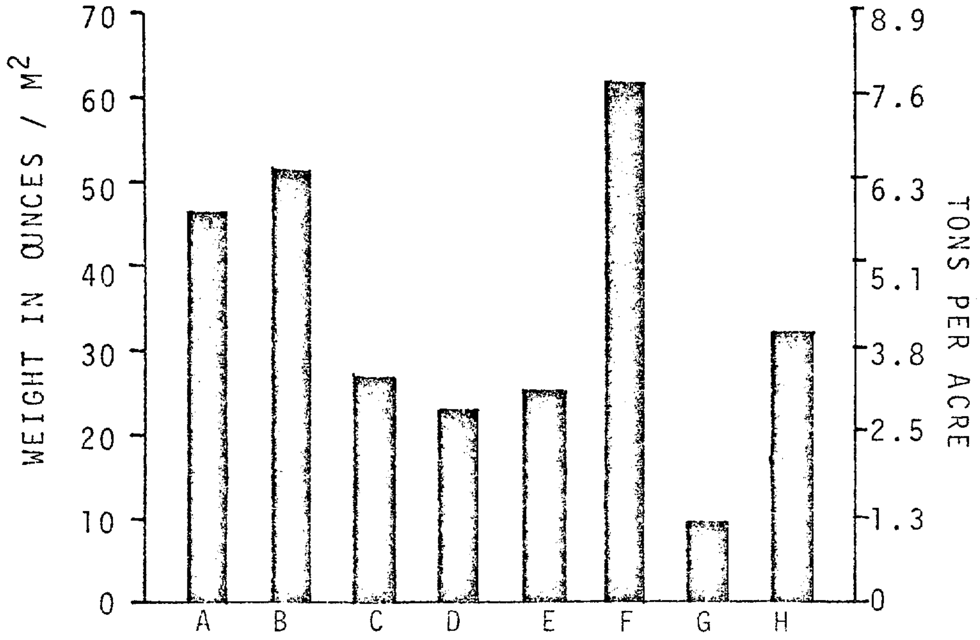

FIG. F-9; Marsh Grass data. (A-Spartina Alterniflora; B-*Spartina cynosuroides*; C-*Spartina patens*, *Distichlis spicata*, *Borrichia frutescens* mixture; D-*Juncus roemerianus*; E-*Scirpus olneyi*, *Zizania aquatica*, *Zizaniopsis*, *Phragmites*; F-*Leersia oryzoides*; G-*Nuphar advena*; H-*Typha angustfolia*).
From: Wass and Wright, 1969.

or the estuarine flora and fauna associated with coastal wetlands. A determination of the ownership and boundaries of wetlands and acquisition of wetlands as rapidly as possible by the State were prime recommendations. One method of State acquisition suggested was that tax-delinquent coastal wetlands should revert to the people (State) upon the satisfaction of tax liens by the people (State) to the municipalities. An immediate moratorium should be placed upon disposition of all wetlands currently in the hands of the State government or the courts. It also was recommended that new land created by nature which does not accrete to riparian land should be retained in the possession of the State. A fund for purchase of coastal wetlands was recommended to be financed by the following:

- General Fund appropriation;
- Bonds;
- Increased commercial user fees;
- Recreational user fees (salt water angling licenses, boat registration fees, etc.)
- Unrefunded taxes on fuel used in motor boats;
- Gifts;
- Specific appropriations; and
- Joint State and Federal programs for land acquisition and management.

Certain shallow areas immediately adjacent to coastal wetlands were reported to be as highly productive as the adjacent wetlands. It was recommended that these areas should not be leased by the people for any purpose that would reduce their productivity.

CONCLUSIONS

This literature review reveals that there is an acute absence of primary data on marshes. Hence, even qualitative assessments of the effects of man's activities on the marshes are difficult to make.

Two general research needs must be satisfied before marsh management can be understood and socially and politically implemented:

1. the environmental impact of various man-related activities on the marsh; and
2. the socio-economic impact of these same activities.

Environmental Analysis

Once all the possible alternative activities of man in a particular marsh have been delineated, the next step involves the determination of the environmental impact of each alternative. Most studies reported in this review drew their conclusions from a minimum amount of primary data.

Basic research needs include the following:

1. A better understanding of erosion and accretion processes in order to determine the role of sediments and associated nutrients in marsh processes;
2. Spatial and temporal (seasonal) identification and quantification of marsh flora and fauna for all significant wetland areas, including the chemical and physical factors associated with them;
3. A detailed knowledge of the energy flow nutrient transport processes would greatly enlighten our understanding of marsh productivity mechanisms.
4. Studies of food chains and food webs within each estuary and its associated marshes with emphasis on the percent composition of the food of species important in the commercial and sports fisheries industries; and
5. A determination of the transient and long-term effects of stresses such as decreased freshwater inflow, liquid waste input, etc., on biological communities, particularly the primary producers.

Socio-Economic Evaluations

An economic evaluation is needed to determine the importance of the marsh for maintenance of the fishing industry, recreation, aesthetics, etc. Also required is a determination of the contribution of all marsh associated activities to the marine economic sector as well as to the state's entire economy.

Unfortunately, it is not (nor will it ever be) a straightforward numerical procedure to evaluate entities such as marshes which possess so many subtle, non-quantifiable features. The economic analysis of an ecological subunit such as wetlands is extremely difficult since it must involve social trends and value estimates of an aesthetic base. Difficulties arise basically because of the doctrines of tastes. "The beauty is in the eye of the beholder"--one individual might perceive beauty in thousands of acres of natural productive marshes another might consider thousands of acres of productive rice fields to be more beautiful. The nature lover, fisherman, and hunter often view alteration of wetlands as non-beneficial unless it can produce more waterfowl fish and shrimp or preserve the natural quality of the area. Another individual might view alteration as beneficial if it will produce employment and pay taxes.

On the surface, it would appear that wetlands which have a high value would be less vulnerable to alteration than those of low value. However, this is dependent upon those factors which enter into the value estimation of a particular marsh.

Before wetlands are destroyed or altered all pertinent values must be examined and the decision to destroy a wetland area must be based on the impact of alteration to the public as a whole.

Since Texas wetlands, marsh and grass flat acreage, constitute less than 0.4% of the total state acreage, the destruction or detrimental alteration of each acre of Texas' wetlands is an ecological risk whose ramifications could impact society many years later. If the marginal wetlands are destroyed before the resulting impact is determined, it must be justified over the use of marginal uplands that are present in far greater quantity.

A few acres of marsh in a populated area may have a low productivity value, yet be considered extremely valuable by the residents of the area. This same marsh might represent a greater value to the developer who desires to fill it. A conflict immediately arises which is not easily resolved. As an area becomes more densely populated, the value of land itself increases. Undeveloped land and open areas become increasingly vulnerable as the value they have if they were altered increases. As this type of environment decreases, it becomes more valuable to those who wish it to remain unchanged.

Society is not only dependent upon homes, roads, industries and all other amenities of a technological and affluent era, but is also dependent on open spaces and natural areas for its psychological well being and aesthetic doctrines.

Environmental-Socio-Economic Evaluation

A need exists for analyses not only of man's impact on the environment, but also environmental impact on man's activities in order to develop a tool for social control of marshes. Since management decisions cannot be made logically with only an environmental or socio-economic evaluation, it is necessary to develop an understanding of an ecological subunit utilizing an interdisciplinary approach. It is recommended that the methodology established in the Chapter III, "Analytical Framework", of this report be utilized in order to develop a systematic approach for studying "ecological subunits" and developing guidelines for their management with the perspective that the ecological subunit is an inter-acting component of the entire Coastal Zone.

SUMMARY

A literature search was presented of the qualitative data available in the literature on the environmental impact of man's activities on the marshes. Relatively little quantitative data are available for Texas marshes to ascertain the degree of the effect from the undesirable land uses of the marsh cited in Chapter IV. Thus present-day management of Texas coastal wetlands for multi-purpose use is not possible. The research recommendations presented herein are essential for the development of a practical marsh management program but the results will not be available for a number of years. Thus, guidelines based on the analysis presented in Chapter IV will have to be utilized presently by Texas' decision-makers.

TABLE F-1

Texas Coast Marsh Areas

From Bureau of Economic Geology, personal communication.

	Salt Marsh	Fresh to Brackish	Brackish (Closed System)	Inland Fresh (swamp)	Grass Flats**
Sheet 1*	-	-	-	-	131,840 acres
Sheet 2	-	-	-	-	20,992 acres
Sheet 3	5,120 acres	6,400	-	-	43,776 acres
Sheet 4	10,240 acres	5,120	-	-	2,560 acres
Sheet 5	22,528 acres	45,568	-	-	2,048 acres
Sheet 6	50,048 acres	44,032	7,040	17,920***	3,840 acres
Sheet 7	11,392 acres	125,888	46,592	-	-

**See Figure A-1*

***Included because the Texas Coast south of Matagorda Bay contains large amounts of productive grassflats.*

****Only freshwater marsh figures available at this time.*

TABLE F-2

Estimated Area of Estuarine Zone in Texas Destroyed or Severely Damaged by Excavation and Spoil

From Federal Navigation Channels

(After Chapman, 1967)

Type of Habitat	Length (miles)	Area (acres)	Spoil Area (Acres)	Total Area (Acres)
Open bay waters	282	7,590	30,320	37,910
Bay shoreline zone	178	5,690	21,310	27,000
Tidal flats	36	920*	3,920	3,920
Marshes	193	6,980	23,000	29,980
TOTAL	689	20,260	78,550	98,810

**Not included in totals*

TABLE F-3

Average Daily Growth (Inches) of Plants After Burning

(After Hoffpauer, 1967)

Plant	45 Days	100 Days
Pharagmites	0.62	0.65
Scirpus sibustus	0.57	0.36
Scirpus olneyi	0.55	0.48
Spartina patens	0.35	0.28

TABLE F-4

Some Effects of Semi-Impoundment of Marshes on Seven Major Species

(Data from Herke, 1971)

Juvenile	Delays Immigration Into Semi-Impounded Area	Delays Emigration From Semi-Impounded Area*	Growth Rates in Semi-Impounded Area Increased-Decreased **See Text	
1. Atlantic Croaker *Micropogon undulatus*	+	+	+	0
2. Manhaden *Brevoortia patronus*	0	+	+	0
3. Striped mullet *Mugil cephalus*	0	Insufficient Data	Insufficient Data	Insufficient Data
4. Brown shrimp *Penaeus aztecus*	+	+	+	0
5. White shrimp *Penaeus setiferus*	+	+	+	0
6. Spot *Leiostomus xanthurus*	+	+	+	0
7. Bay anchovy *Anchoa mitchilli*	Insufficient Data	Insufficient Data	+	0

*Not as severe for larger mature organisms

TABLE F-5

Apparent Overall Semi-Impoundment Effect on Use of the Marsh as a Nursery by Some of the Minor Species

(After Herke, 1971)

	Increased		Decreased	
	With Vegetation	Without Vegetation	With Vegetation	Without Vegetation
Bagre marinus			X	X
Bairdiella chrysura			?	?
Cynoscion arenarius			X	XX
C. nebulosus			?	?
Galeichthys felis			X	X
Lagodon rhomboides	?			X
Membras martinica			X	X
Paralichthys lethostigma			?	?
Sphoeroides parvus			X	X
Symphurus plagiusa				?
Lepomis macrochirus	XX	X		
L. microlophus	XX	X		
L. punctatus	XX	X		
Menidia beryllina	XX	X		
Microgobius gulosus	XX	X		
Palaemonetes paludosus	X			
P. pugio	X			X
Trinectes maculatus	no apparent effect			

TABLE F-6

Foods of Some Adult and Juvenile Fish by Percentage of Volume

(Data from Van Engel and Josepn, 1968)

Species	No. Stomachs	Food				Principal Food Items
		Epifauna	Infauna	Plankton	Fish	
White perch*	187	18.0	64.0	12.0	9.0	*Gammarus* (amphipod) and *Crangon* (sand shrimp) (54%)
Spot	162	2.8	76.5	13.0	1.0	Polychaete worms and amphipods (49%)
Croaker	102	0.0	56.0	42.0	0.0	Amphipods and mysids (83%)
Weakfish	268	1.5	18.0	25.0	60.0	Anchovies, gobies, and mysids
Silver perch	116	0.0	26.0	60.0	14.0	Mysids (60%)
Black drum	32	10.0	89.0	0.3	0.7	Small clams (73.5%)
Southern kingfish	35	0.0	94.0	4.0	1.0	*Crangon, Neomysis, Ogyrides*
White catfish*	86	21.0	51.0	27.0	0.0	Mysids, small clams, amphipods, and cumaceans
Hogchoker*						Polychaete worms
Striped bass**	297					Fish (50%), decapods, mysids, polychaete worms, insects, amphipods (mysids absent in James River bass)

*All sizes

**Juvenile only; data from Markle and Grant (in press).

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The diagram illustrating the interactions between physical and biotic interactions (Figure F-10) is drawn with the factors most involved on the left-hand side. The following commentray will begin with major interactions and proceed clockwise around the diagram.

1. *Marsh Plants.* Affected by:

    a) Tidal range causes a greater luxuriance where daily inundation occurs.
    b) Water chemistry determines the species of plants present and their productivity to a great extent.
    c) Turbid water during a high tide coats photosynthesizing surfaces and affects production of organic compounds.
    d) Pollutants--Organic pollution often enhances plant growth; thermal pollution increases growth in some plants, decreases it in others.
    e) Water temperature, especially where tides cover the soil, affectes growth and seed germination.
    f) Homiotherms affect marsh plants in several ways--Building of nests by birds has little effect, grubbing for roots by Muskrats and Snow Geese has long-lasting results; grazing by Nutria may deprive aquatic animals of food but increases photoplankton production since feces would be swept into the water; Blackbirds and waterfowl may eat most of the seed produced by some marsh plants but ducks are known to carry seeds to new areas; Marsh Wrens and Yellow-throats eat grasshoppers and other insects which feed on marsh plants; finally, man benefits physically and aesthetically from marsh plants in many ways and has eminent domain over their survival.
    g) Marsh poikilotherms are here intended to include Fiddlers, Crayfish, insects, frogs, snakes, turtles and those fish which live in close proximity to the marsh. Square-backed Fiddlers eat considerable of the total grass production and leaf hoppers such the juices of plants, Carp erode away the soil from plant roots.
    h) Wind is needed to pollinate plants but strong winds may cause some plants to lodge.
    i) Without solar energy, green plants could not grow.
    j) Plants also require nutrients and may grow better next to channels because certain minerals are more available there; plants also release stored nutrients as microbes degrade dead tissue.

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*(*From Wass & Wright, 1969*)

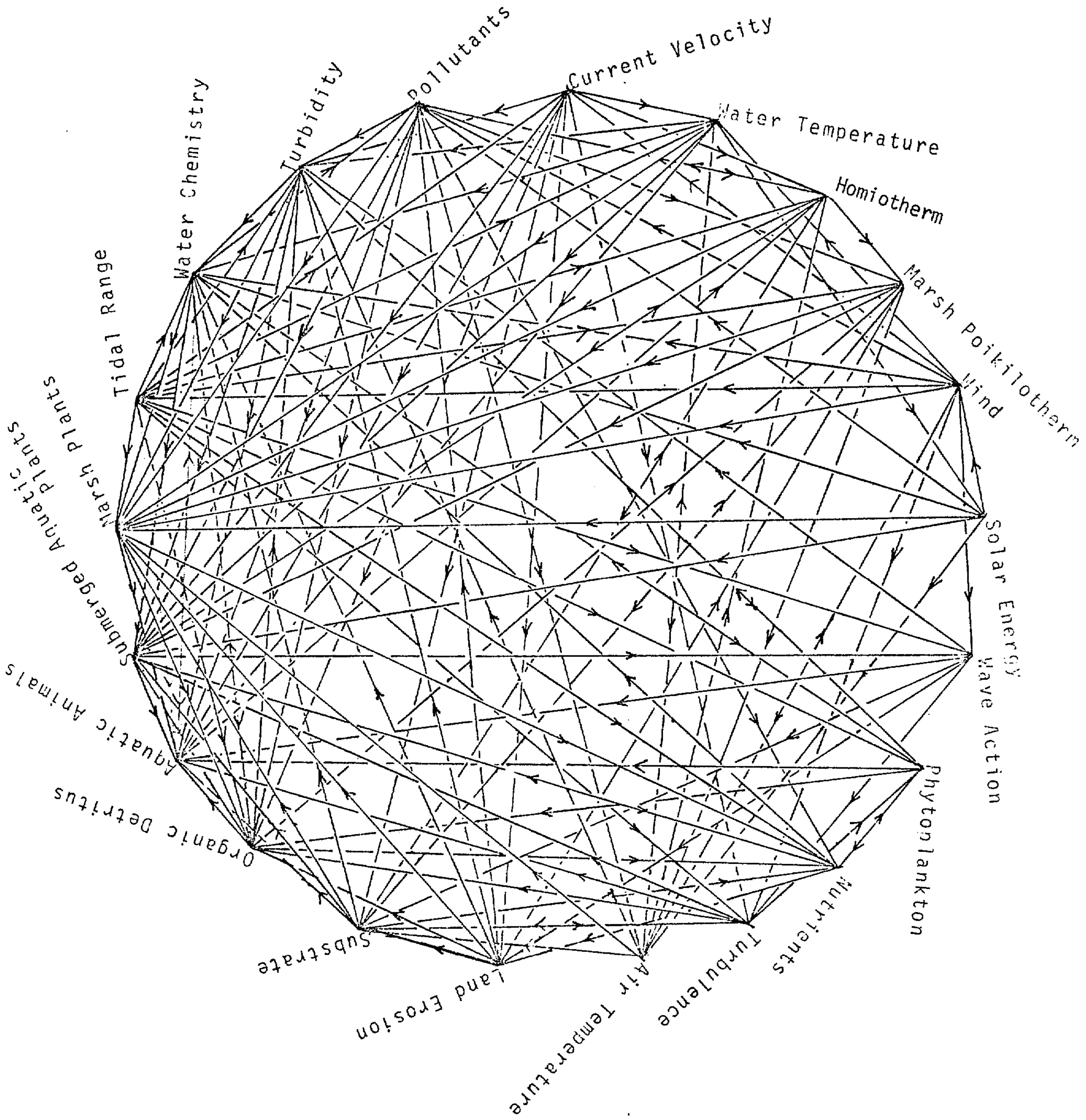

FIG. F-10: Diagrammatic flow of biotic and physical effects, both unidirectional and reciprocal, in a marsh-bordered estuary. See appendix for explanation of interactions.
From: Wass and Wright, 1969.

k) Some perennial marsh plants grow a little during the winter but warm air temperatures are needed for fast growth.

l) Land erosion affects plants by depositing more silt in marshes--usually this accumulates more in creeks and results in destruction of productive marsh; type of soil substrate, if clay or sand, seems minor in affecting type of plant growth, but a tough peat base is much more erosion resistant.

m) Plants provide abundant detritus to the estuary if tidal range or floods are effective.

n) Smaller aquatic animals feed on detritus supplied by plants.

2. *Tidal Range* is highly important to an estuary. Its greater height in the brackish to fresh zones and on seaside makes those areas more productive. Higher tides have many effects:

a) They provide for greater exchange of nutrients and waste products.
b) Turbidity is increased.
c) Current velocity is heightened on the ebb tide and dampened (in rivers) on the flood.
d) Water temperatures are moderated over the wetlands by being cooled in summer and warmed in winter.
e) Homiotherms are able to feed in marshes and flats when the tide is out, except for ducks which usually find food more available at high tide. Birds and mammals which breed in the marsh must elevate their nest structures above the highest tide levels.
f) Likewise, Fiddler Crabs must enter their burrows and snails must climb up the grasses to escape predation by fish as the tide comes in. On the Eastern Shore, some species of fish lays its eggs in the shell cavity of a dead Ribbed Mussel at high tide, and live Mussels and marsh Oysters can feed only when the tide is in. Insects may stay above the tide, but the Greenhead Fly and Salt-marsh Mosquito (*Aedes solicitans*) evidently deposit their eggs when the tide is out. The Striped Killifish "adheres to the very shore's edge" (22) on a flood tide and other small fish probably do the same, ranging into the marsh on the highest tides.
g) High winds greatly amplify tides, piling water into the Bay with sustained northeast wind and blowing it out with prolonged northwest wind in winter. In the latter situation, gulls have an opportunity to carry off shellfish on very low tides. Killifish burrow in the mud to escape death, but some invertebrates may die when frozen during low tide.

h) Wave action obviously affects more area during high tides.
i) Phytoplankton composition would be quite different in marsh pools and guts if tides did not provide an exchange of water. Since plankton productivity is higher in marsh pools than in the river, tides carry this living material to the estuary.
j) Nutrient exchange requires tidal transport.
k) Turbulence is more dependent on wind than on tides, but tides along have an effect.
l) Organic detritus would not be supplied to the water in significant amounts without good tidal exchange.
m) Aquatic animals benefit from wetlands through the agency of tides.
n) Submerged plants may benefit from nutrients released from marshes but they also are prevented from growing on mudflats bared at low tide.

3. *Water Chemistry*. Oxygen, salinity, phosphorus, nitrogen and in freshwater, alkalinity are particularly involved. Water chemistry is affected by many factors and, in turn, affects many others.

a) Turbid waters become clearer in the estuary due to the flocculating effect of saline water.
b) Pollutants affect water by their biological oxygen demand (BOD). Marshes help aerate the water during high tide and they release the least organic matter in summer when oxygen is naturally low. Pollution, either organic, toxic, or thermal, exerts the greatest influence in the summer. Saline water coagulates fine particles and causes them to sediment out, resulting in a diminution of organic pollution to safer levels.
c) Water temperature strongly affects chemical reactions, which tend to double with each 10°C rise.
d) Wind affects water chemistry mainly by oxygenating the water but also by producing high tides which flush detritus and nutrients from the marsh.
e) Solar energy causes photo-oxidation of some chemicals and otherwise affects chemistry by providing energy for storms.
f) Phytoplankton requires nutrients and also produces oxygen by day and uses it by night.
g) Nutrients produced elsewhere become part of the total water chemistry.
h) Land erosion brings clay, organic material and toxic wastes which affect normal water chemistry.

i) Substrates have a lesser effect on the overall chemistry, but the myriad stems of marsh plants are instrumental in accumulating clay particles at least temporarily.
j) Water chemistry and organic detritus interact--saline water precipitating fine organics while organics supply nutrients.
k) Aquatic animals require ample oxygen, especially the more active organisms, but they produce carbon dioxide which affects pH and reduces the rate of oxidation of organic debris.
l) Submerged aquatic plants release large amounts of oxygen, some of which they need for respiration at night. Nutrients and salt concentrations which cause one plant species to luxuriate may be deleterious to another.

4. Turbidity, the condition of having varying amounts of suspended materials in water, is particularly evident in tidal freshwater.

a) Pollutants increase turbidity.
b) Strong currents increase turbidity, as evidenced by the Hurricane Camille floods.
c) Water temperature is affected by turbidity--dark water absorbs more heat.
d) Wave action also increases turbidity.
e) Turbidity affects phytoplankton by decreasing the compensation point depth but phytoplankton by their abundance may affect turbidity.
f) Air temperature secondarily affects turbidity simply by heating the upper layers of water, thereby promoting stratification.
g) Land erosion is the source of most clay particles which produce turbidity.
h) Organic detritus increases turbidity, thus affecting phytoplankton production but at the same time nurturing a great amount of animal biomass.
i) Aquatic animals may be benefited or harmed by by turbidity, depending on the nature and amount of the suspended materials.
j) Submerged aquatic plants are adversely affected by turbidity. Silt-laden rivers support little aquatic vegetation.

5. Pollutants have both direct and indirect effects which may often be complex and occur far from the sources of pollution.

a) Warm-blodded animals are particularly affected by toxic pollutants such as chlorinated hydrocarbons. The Bald Eagle has become rare in Virginia in less than a decade because of DDT.

b) Cold-blooded animals of the marsh, such as Fiddler Crabs and Mosquitoes, are directly affected by pesticide pollutants.
c) Some pollutants--dust, aerial sprays and smoke--are carried by wind.
d) Sunlight is effective in decomposing many pollutants.
e) Warm air aids dispersal of dust and smoke.
f) Land erosion has historically affected the upper tidal reaches of rivers and creeks more than any other pollutant.
g) Organic detritus from sewage and manure often cuases noxious pollution.
h) Aquatic animals, such as bivalve moluscs, may be adversely affected by silt and clay pollution. Pesticides particularly magnify in organisms as they enter a food chain via the detritus pathway and end up in tertiary carnivores such as the Osprey and humans.
i) Aquatic plants are adversely affected by excessive sewage wastes and severe siltation.

6. Current velocity varies with rain, tides, wind, and coresection of a river.

a) It affects water temperature by making it more uniform.
b) Strong currents make feeding more difficult for ducks and grebes, as well as for swimming mammals.
c) Currents and turbulence are directly proportional to each other.
d) Land erosion products are carried distances proportional to the current velocity.
e) The same condition as in (d) applies to organic detritus.
f) Aquatic animals, especially smaller ones, are particularly affected by strong currents.
g) Submerged aquatic plants are seemingly less affected by currents.

7. Water temperatures may vary up to 60°F. The activities of the biota are much influenced by temperature.

a) Wind usually moderates water temperatures, but it also promotes mixing and thus general warming.
b) Temperature of the water ultimately depends on the Sun's warmth.
c) Temperature of water and air together modify climates of wetlands.

d) Aquatic animals being cold-blooded have their activities dependent on water temperature; some cease feeding in winter.
e) Submerged aquatic plants typically regress in winter.

8. *Homiotherms* (warm-blooded animals) are less important to man than their aquatic relatives but scarcely less interesting.

a) Racoons seem to feed in marshes mainly on Fiddler Crabs and Crayfish most of the year, although we did find one scat composed of only *Macoma balthica* shells. Wrens feed on insects and Rails on a variety of small animals.
b) While less affected by temperature than poikilotherms are, homiotherms must still adapt to the rigors of summer's heat and winter's chill.
c) Muskrats prefer marsh peat substrates for their houses. The Belted Kingfisher requires vertical clay banks for nest sites. Ground-nesting birds need dry sites, except for Rails, Coots, Gallinules and Willets which may use rather damp nest sites. These animals have adepted to marsh living but many others only come to marshes and swamps for food.
d) Many homiotherms, especially birds, feed on aquatic animals such as frogs and small fish.
e) Some ducks, such as the now scarce Canvasback and Redhead, eat rooted aquatic plants as most of their diet.

9. *Marsh poikilothers* are mainly Fiddler Crabs, Killifishes, turtles, insects and a surprising number of spiders.

a) All of these creatures are able to retreat to shady or watery places when air temperatures become severe.
b) They are affected mildly by land erosion if silt fills their burrows, clouds the water and coast the vegetation.
c) Fiddlers feed on detritus somewhat and create more, as do most of the animals.

10. *Wind* is most effective in conjunction with high tides and its influence is particularly felt in seaside and bayside areas.

a) Solar energy is largely responsible for wind.
b) Wind, in turn, produces waves.

c) Wind, through waves, is largely responsible for turbulence in shallow waters.
d) Wind and air temperatures have a reciprocal relationship.

11. *Solar energy* may be blocked by cloud cover and its effect altered by the sun's angle to the earth, but it is otherwise independent of earthly phenomena.

a) Air temperature is most affected by the sun's heat.
b) Submerged aquatic plants depend as much on the sun, and thus also on clean water, as do the marsh plants.

12. *Wave action* depends highly on direction fetch and tide levels, thus its effect on wetlands varies greatly.

a) Waves are directly responsible for most turbulence.
b) Bank erosion results in exposed areas if the land is unprotected by grass, gentle slope, or artifices.
c) Beach and marsh substrates are altered if waves carry away finer materials and deposit them in quieter waters.
d) Aquatic animals must be able to cope with strong waves or retreat from them.
e) Aquatic plants, such as Eelgrass, are torn loose and deposited on beaches by waves.

13. *Phytoplankton* consists of one-celled plants, particularly diatoms and dinoflagellates.

a) Phytoplankton change inorganic nutrients into organic compounds capable of being digested by certain crustaceans and fishes.
b) Turbulence may supply nutrients to phytoplankters but may also make the water turbid and thus reduce the light supply.
c) Organic detritus is partially produced by phytoplankton, especially in summer.
d) Many aquatic animals feed directly on plankton.

14. *Nutrients* include inorganic and organic compounds.

a) Erosion of the land produces certain nutrients but may also tie up others on clay particles.
b) As with phytoplankton, rooted aquatics utilize simple coumpounds to produce complex food substances.

15. *Turbulence* refers particularly to the vertical mixing of water.

a) Substrates may be eroded by turbulent water.
b) Organic detritus is kept in suspension by turbulence.
c) Aquatic animals, particularly filter feeders, require some turbulence.
d) Submerged rooted plants probably thrive better where turbulence is only moderate.

16. *Air temperature* varies daily and seasonally and affects the activities of all organisms in shallow water, flats and marshes.

17. *Land erosion* produces only minor amounts of beneficial organic detritus. Erosion of high ground is largely detrimental.

18. *Substrate* type often determines the kinds of benthic animals present.

19. *Organic detritus* is essential to many aquatic animals. Submerged aquatic plants may contribute considerable detritus in some water.

20. Relatively few aquatic animals feed directly on rooted aquatic plants.

GLOSSARY

Acclimation--The process of adjusting to a change in an environment.

Adaptation--A change in the structure, form, or habit of an organism resulting from a change in its environment.

Aerobic--Requiring dissolved oxygen.

Algae (Alga)--Simple plants, many microscopic, containing chlorophyll. Most algae are aquatic and may produce a nuisance when conditions are suitable for prolific growth.

Algicide--A specific chemical highly toxic to algae. Algicides are often applied to water to control nuisance algal blooms.

Amphipoda--Large order of laterally compressed crustaceans with the first thoracic segment fused with the head and lacking a true carapace.

Amphipods--(see Scuds).

Anadromous Fishes--Fishes that spend a part of their life in the sea or lakes, but ascend rivers at more or less regular intervals to spawn. Examples are sturgeon, shad, salmon, trout, and striped bass.

Anaerobic--Requiring, or not destroyed by the absence of air or free "elemental" oxygen.

Annelids--Segmented worms, as distinguished from the nonsegmented roundworms and flatworms. Most are marine; however, many live in soil or fresh water. Aquatic forms may establish dense populations in the presence of rich organic deposits. Common examples of segmented worms are earthworms, sludgeworms, and leaches.

Aquifer--A geologic formation in which a water supply is found; permeable material through which ground water moves.

Assimilation--The transformation of absorbed nutrients into body substances.

Autotrophy--A type of nutrition in which complicated organic molecules are synthesized from carbon dioxide and water, using light or reduced chemicals for energy.

Benthic Region--The sediments and associated habitats of a body of water.

Benthos--Aquatic bottom-dwelling organisms. These include: (1) Sessile animals, such as the sponges, barnacles, mussels, oysters, some of the worms, and many attached algae; (2) creeping forms, such as insects, snails, and certain clams; and (3) burrowing forms, which include most clams and worms.

Bioassay--A measurement of the concentration of a given material by the determination of the quantity necessary to affect a test animal under stated laboratory conditions.

Biogenic--Resulting from the activity of living organisms.

Biochemical oxygen demand (BOD, abbreviation for biochemical oxygen demand)--The quantity of oxygen used in the biochemical oxidation of organic matter in a specified time, at a specified temperature, and under specified conditions. A standard test used in assessing wastewater strength.

Biomass--The weight of all life in a specified unit of environment or an expression of the total mass or weight of a given population, both plant and animal.

Bloom--A readily visible concentrated growth or aggregation of phytoplankton.

Blow-outs--An area of active wind deflation.

Blue-Green Algae--A group of algae with a blue pigment, in addition to the green chlorophyll.

Borrow pits--Excavations from which fill material was removed.

Brackish--Pertaining to the waters of bays and estuaries, salty but of lower salinity than sea water.

Buffers--Any of a number of combinations of chemicals which stabilize the pH against acid or base additions.

Caliche--Impure calcium carbonate.

Catadromous Fishes--Fishes that feed and grow in fresh water, but return to the sea to spawn. The best known example is the American eel.

Climax vegetation--The theoretical ultimate stage of plant succession under a given set of environmental conditions; a stabilized condition of the dominant vegetation of a region.

Coarse or Rough Fish--Those species of fish considered to be of poor fighting quality when taken on tackle and of poor food quality. These fish may be undesirable in a given situation, but at times may be classified differently, depending upon their usefulness.

Chemical Oxygen Demand (COD)--A measure of the oxygen required for complete reduction of the impurities in water using an oxydizing agent, under special conditions of temperature and time.

Coelenterate--A group of aquatic animals that have gelatinous bodies, tentacles, and stinging cells. These animals occur in great variety and abundance in the sea and are represented in fresh water by a few types. Examples are hydra, corrals, sea anemones, and jellyfish.

Cold-Blooded Animals (Poikolothermic Animals)--Animals that lack a temperature regulating mechanism that offsets external temperature changes. Their temperature fluctuates to a large degree with that of their environment. Examples are fish, shellfish, and aquatic insects.

Compensation Point--The light intensity at which the release of photosynthetic oxygen equals the utilization of respiration oxygen.

Conservative--Not changed by biological and chemical processes;

Consumers--Those organisms in an ecosystem which feed upon other organisms; often divided into primary consumers (plant eaters), secondary consumers (carnivores which eat primary consumers), etc.

Crustacea--Mostly aquatic animals with rigid outer coverings, jointed appendages and gills. Examples are crayfish, crabs, barnacles, water fleas, and sow bugs.

Degradation--A process by means of which various parts of the surface of the earth are worn down and carried away and their general level is lowered, by the action of wind and water; the breakdown of substances by biological action.

Demersal--Occurring on or near the bottom.

Denitrification--The reduction of nitrates in solution by biochemical action.

Detritus--Fine particulate debris of organic or inorganic origin.

Diatoms--Unicellular, microscopic aquatic organisms with a structure consisting principally of silica.

Dinoflaggellates--A great diversity of mostly pigmented and mobile unicellular organisms having two flagella. Brown pigments predominate, although chlorophyll is present.

Dissolved oxygen (DO)--The quantity of gaseous oxygen dissolved in water at a given temperature.

Ebb tide--The outgoing water (tide).

Ecosystem--All organisms in a community plus the associated environmental factors.

Ecotone--Transition area between two adjacent communities.

Eh--Oxidation-reduction potential.

El Nino--An aberrant southward flow usually near Christmas time, of the Equatorial Countercurrent which has disasterous effects upon the biota in the coastal zone near Peru.

Emergent Aquatic Plants--Plants that are rooted at the bottom but project above the water surface. Examples are cattails and bullrushes.

Epifauna--Sessile or sedentary benthic organisms living on the bottom.

Eulittoral Zone--The lighted region that extends vertically from the water surface to the level at which photosynthesis fails to occur because of ineffective light penetration.

Euphotic Zone--The lighted region that extends vertically from the water surface to the level at which photosynthesis fails to occur because of ineffective light penetration.

Eurytopic Organisms--Organisms with a wide range of tolerance to a particular environmental factor. Examples are sludgeworms and bloodworms.

Eutrophication--The intentional or unintentional enrichment of water by nutrients.

Eutrophic Waters--Waters with a good supply of nutrients. These waters may support high organic production resulting in algal blooms.

Facultative Aerobe--An organism fundamentally an anaerobe that can grow in the presence of free oxygen.

Fauna--The entire animal life of a region.

Fetch--The uninterrupted distance travelled by wind over water.

Flagellates--Microscopic protozoans and algae which use flagella (long whip-like structures) for locomotion.

Flood tide--The incoming water (tide).

Flora--The entire plant life of a region

Flotsam--Materials found floating on the water

Fry (Sac Fry)--The stage in the life of a fish between the hatching of the egg and the absorption of the yolk sac.

Fungi (Fungus)--Simple or complex organisms without chlorophyll The simpler forms are one-celled; the higher forms have branched filaments and complicated life cycles. Examples of fungi are molds, yeasts, and mushrooms.

Game Fish--Those species of fish considered to possess fighting quality when taken on fishing tackle and of good food quality.

Green Algae--Algae that have pigments similar in color to those of higher green plants.

Hammock--A woodland surrounded by marsh.

Heterotrophy--Type of nutrition characteristic of animals and some bacteria and true fungi which depend on organic matter from other plants and animals for food.

Higher Aquatic Plants--Flowering aquatic plants. (These are separately categorized herein as Emergent, Floating and Submerged Aquatic Plants.)

Hydrography--The science of the measurement, description and mapping of the surface waters of the earth.

Infauna--Benthic organisms which burrow into the bottom.

Insecticide--Substance or a mixture of substances intended to prevent, kill or repel insects.-Cidal suffix meaning to kill, or that can kill; is used with word to which suffix applies; i.e., fungicide, herbicide, etc.

Intertidal--Area on a beach between mean high water and mean low water.

Isopoda--Large order of dorso-ventrally compressed crustaceans with the thoracic segment fused with the head, abdomen short, and some or all segments fused.

Life Cycle--The series of stages in the form and mode of life of an organism: i.e., the stages between successive recurrences of a certain primary stage such as the spore, fertilized egg, seed or resting cell.

Littoral Zone--The shoreward region of a body of water.

Longshore currents--The flow of water parallel to a beach caused by waves approaching the beach at an angle.

Macro-organisms--Plants, animals, or fungal organisms visible to the unaided eye.

Meroplankton--Organisms in the plankton for only part of their life cycle.

Microbiota--Microscopic plants and animals of a habitat or region.

Mollusk (Mollusca)--A large animal group including those forms popularly called shellfish (but not including crustaceans). All have a soft unsegmented body protected in most instances by a calcareous shell. Examples are snails, mussels, clams, and oysters.

MPN--That number of organisms per unit volume that, in accordance with statistical theory, would be more likely than any other number to yield the observed test result with the greatest frequency. Expressed as density of organisms per 100 mg. Results are computed from the number of positive findings of coliform-group organisms resulting from multiple-portion decimal-dilution platings.

Mycology--The study of fungi.

Nekton--Minute swimming organisms able to navigate at will near the surface of the sea.

Nematoda--Unsegmented roundworms or threadworms. Some are free living in soil, fresh water, and salt water, some are found living in plant tissue; others live in animal tissue as parasites.

Neuston--Organisms resting or swimming on the surface film of the water.

Non-conservative--Materials that are changed by biological and chemical processes in estuaries.

Nutrient transformation--The biotic cycling or nutrients from inorganic to organic compounds.

Offshore--From the mean high tide line seaward or bayward.

Osmole--The standard unit for expressing osmotic pressure. One osmole is the osmotic pressure exerted by a one-molar solution of an ideal solute.

Oligotrophic Waters--Waters with a small supply of nutrients; thus, they support little organic production.

Parasite--An organism that lives on or in a host organism from which it obtains nourishment at the expense of the latter during all or part of its existence.

Pathogens--Disease-producing organisms

Pelagic Zone--The free-water region of a sea. (Pelagic refers to the sea, limnetic refers to bodies of fresh water.)

Periphyton--The association of aquatic organisms attached or clinging to stems and leaves of rooted plants or other surfaces projecting above the bottom.

pH--A measure of the hydrogen ion concentration or the relative acidity or alkalinity of a solution; a pH of 7 is neutral, greater than 7 alkaline and less than 7 acid.

Photosynthesis--The process by which simple sugars and starches are produced from carbon dioxide and water by living plant cells, with the aid of chlorophyll and in the presence of light.

Phytoplankton--Microscopic organisms

Plankton (Plankter)--Organisms of relatively small size mostly microscopic, that have either relatively feeble powers of locomotion or that drift in that water with waves, currents, and other water motion.

Poikilothermic Animals--(see Cold-Blooded Animals).

Pool Zone--The deep-water area of a stream, where the velocity of current is reduced. The reduced velocity provides a favorable habitat for plankton. Silt and other loose materials that settle to the bottom of this zone are favorable for burrowing forms of benthos.

Porifers--(see Sponges).

Potamology--The study of the physical, chemical, geological, and biological aspects of rivers.

Producers--Plant organisms that synthesize their own organic substance from inorganic substances.

Productivity--The rate of increase in number or size of organisms.

Protozoa--Organisms consisting either of a single cell or of aggregates of cells, each of which performs all the essential functions in life. They are mostly microscopic in size and largely aquatic.

Primary Productivity--Total quantity of carbon fixed by photosynthesis per unit time. It is usually approximated by measuring dissolved oxygen evolved, amount of a radioactive C^{14} label taken up, or the change in standing crop of chlorophyll in a sample of phytoplankton.

Red Tide--A visible red-to-orange coloration of an area of the sea caused by the presence of a bloom of certain "armored" flagellates.

Reducers--Organisms that digest food outside the cell wall by means of enzymes secreted for this purpose. Soluble food is then absorbed into the cell and reduced to a mineral condition. Examples are fungi, bacteria, protozoa, and nonpigmented algae.

Respiration--The process by which a living organism or cell takes in oxygen from the air or water, distributes and utilizes it in oxidation, and gives off products of oxidation, especially carbon dioxide.

Rheotropism--Movement in response to the stimulus of a current gradient in water.

Rhizome--A root-like subterranean stem, commonly horizontal in position, which usually produces roots below and sends up shoots progressively from the upper surface.

Salinity Gradient--A decrease in salinity with distance away from the sea.

Scuds (Amphipods)--Macroscopic aquatic crustaceans that are laterally compressed. Most are marine and estuarine. Dense populations are associated with aquatic vegetation. Great numbers are consumed by fish.

Secchi Disc--A device used to measure visibility depths in water. The upper surface of a circular metal plate, 20 centimeters in diameter, is divided into four quadrants and so painted that two quadrants directly opposite each other are black and the intervening ones white. When suspended to various depths of water by means of a graduated line, its point of disappearance indicates the limit of visibility.

Seiche--A form of periodic current system, described as a standing wave, in which some stratus of the water in a basin oscillates about one or more nodes.

Sessile Organisms--Organisms that sit directly on a base without support, attached or merely resting unattached on a substrate.

Sinusoidal (tide)--A periodic tide conforming to shape of a sine wave.

Solids--1. Suspended (SS)--those that will remain in a standard glass fiber filter and dry to constant weight at 103-105^{o}C. 2. Dissolved (DS)--those capable of passing a standard glass fiber filter and dry to a constant weight at 180^{o}C. 3. Volatile solids (VS)--the amount of solids that are combustible at 550^{o}C. 4. Total solids (TS)--the sum of the dissolved and suspended solids.

Species (Both singular and plural)--A natural popularion or group of populations that transmit specific characteristics from parent to offspring. They are reproductively isolated from other populations with which they might breed. Populations usually exhibit a loss of fertility when hybridizing.

Sponges (Porifera)--One of the sessile animals that fasten to piers, pilings, shells, rocks, etc. Most live in the sea.

Standing crop--The total weight of organisms present at any one time, usually expressed as dry weight.

Stenotopic Organisms--Organisms with a narrow range of tolerance for a particular environmental factor. Examples are trout, stonefly nymphs, etc.

Sublittoral Zone--The part of the shore from the lowest water level to the lower boundary of plant growth.

Sump--A tank or pit that receives drainage and stores it temporarily and from which the drainage is pumped or ejected.

Surfactant--A substance that will cause a change in the surface properties of a liquid.

Swale--A low wet place.

Symbiosis--Two organisms of different species living together, one or both of which may benefit and neither is harmed.

Synergism--The cooperative action of two or more discrete agents such that the total effect is greater than the sum of the two effects taken independently.

Tidal prism--The volume of water between high and low tide.

Total Organic Carbon (TOC)--A measure of the amount of carbon present in the water or waste that is in the form of an organic compound.

Total Oxygen Demand (TOD)--The amount of oxygen required to oxidize all the impurities in water or waste to carbon dioxide and water.

Toxic Substance--Material which is lethal to organisms or inhibits reproduction.

Transpiration--The escape of water vapor from plants.

Treatment--Wastewater treatment, either industrial or municipal: 1. primary--includes screening, sedimentation and grit removal--may include sludge treatment. 2. secondary--includes a form of biological process (activated sludge, etc.) to remove dissolved organics from the waste--may include sludge treatment. 3. tertiary--a physical-chemical process to completely remove all impurities from the waste, such as ion exchange or activated carbon adsorption.

Trophic level--One of several successive levels of nourishment in a food chain; plant producers constitute the first (lowest) trophic level and dominant carnivores constitute the last (highest) trophic level.

Turbid plumes--Discharging water ladened with sediment.

Tychopelagic--A benthic organism which enters the water column.

Zooglea--Bacteria embedded in a jellylike matrix formed as the result of metabolic activities.

Zooplankton--Microscopic animal organisms.

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THE FRONT COVER

The logo symbolizing the Coastal Resources Management Program represents the objectives of responsible coastal resource management. The circle is the perfect geometric design within which the dark land mass is balanced against the white water mass. The balance between light and dark, land and water, is also symbolic of a balance between man and nature leading to a balance between preservation and development. The live oak and olive branches surrounding the circle are from the State Seal and represent both strength and compassion, while the hands holding the circle represent management by man to meet the foregoing objectives.

The schematic drawing illustrates the most general classes of land and water resource capability units found in the Texas Coastal Zone. These are:

I. Bay, Lagoon and Estuary
II. Major River System
III. Coastal Wetland
IV. Coastal Plain
V. Made Land and Spoil
VI. Coastal Barrier

These constitute the basic framework from which 34 such detailed capability units are develo apter IV.