Segment No. 2491 • Laguna Madre

REPORT NO. WQS-14

WATER QUALITY SEGMENT REPORT
FOR
SEGMENT NO. 2491
LAGUNA MADRE

REPORT NO. WQS-14

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PREFACE

The water quality segment report is designed to describe prevailing water quality in a segment and to provide a basis for decision making in the continuing effort to maintain and improve the quality of Texas' surface waters. Periodic updating of the report offers a basis for evaluating the success of past and present programs concerning the segment.

INTRODUCTION

The Laguna Madre, Segment 2491, is the elongate bay lying between the lower third of Texas' Gulf coast and Padre Island (Fig. 1). It is part of an estuary, a partially enclosed body of water that has a free connection with the open sea and within which sea water mixes with fresh water derived from land drainage. Fresh water inflow is limited and is mainly via intermittent streams draining into Baffin Bay, and the Arroyo Colorado and Northern Floodway carrying overflow from the Rio Grande. Its permanent Gulf connections are also limited, being confined to communication via Corpus Christi Bay, a dredged channel opposite Port Mansfield, and the natural Brazos Santiago pass (now artificially maintained) at the southern tip of Padre Island.

A large semidry region, the "Middle Ground", essentially divides the Laguna into two parts. It is an extensive bar located about 35 miles south of Corpus Christi Bay and composed of sand transported naturally from Padre Island. It has been suggested (Simmons, 1957) that the bar resulted from a hurricane in 1919. Thus the upper and lower portions of the Laguna Madre were separate bodies of water until 1948-49, when the Gulf Intracoastal Waterway was dredged across the bar, connecting the two. This portion of the Waterway is known as the "Land-cut."

The natural depth of the Laguna Madre is shallow, less than four feet over most of its extent. The shore slopes very gradually, so that relatively small changes in tidal level result in the covering or uncovering of extensive areas ("flats") by water. Another factor contributing to the short-term variability of the shore/water boundary is wind, which generally blows from either the north or the southeast. Strong winds are capable of reversing the direction of tidal flow (Hildebrand and King, 1972-73).

In contrast to these short-term fluctuations, the average mainland shoreline in the upper Laguna Madre has remained essentially static since first mapped in 1877. Mapping studies by the U.S. Geological Survey (Hunter and Hill, 1973) show that during the period 1968-1973 even small details of shoreline topography have persisted. It may be that such features are actively shaped only by the extreme tides and flooding of tropical storms. The Padre Island shoreline, on the other hand, is very unstable; windblown sand from the island resulted in a westward movement of about 700 feet during the period 1948-1968. If it continues to fill with sand at this rate, the upper Laguna Madre will be eliminated in roughly 750 years.

One of the Laguna's most widely known characteristics is its high salanity. Values are generally well in excess of the salt content of sea water, i.e. greater than 35 parts per thousand. Together with the Laguna Madre del San Antonio (Laguna Tamaulipas) of northern Mexico, it constitutes the only hypersaline lagoonal area in North America, and one of only two or three in the world (Gunter, 1967). High evaporation rates, limited tidal exchange, and limited fresh water inflow contribute to this hypersalinity. Tropical storms also have a substantial influence on salinity; Hurricane Beulah, for instance, delivered 17-20 inches of rain to the lower Texas coast in September 1967, resulting in an enormous input of fresh water to the bay. Storms of comparable magnitude occurred in 1970 (Celia) and 1971 (Fern).

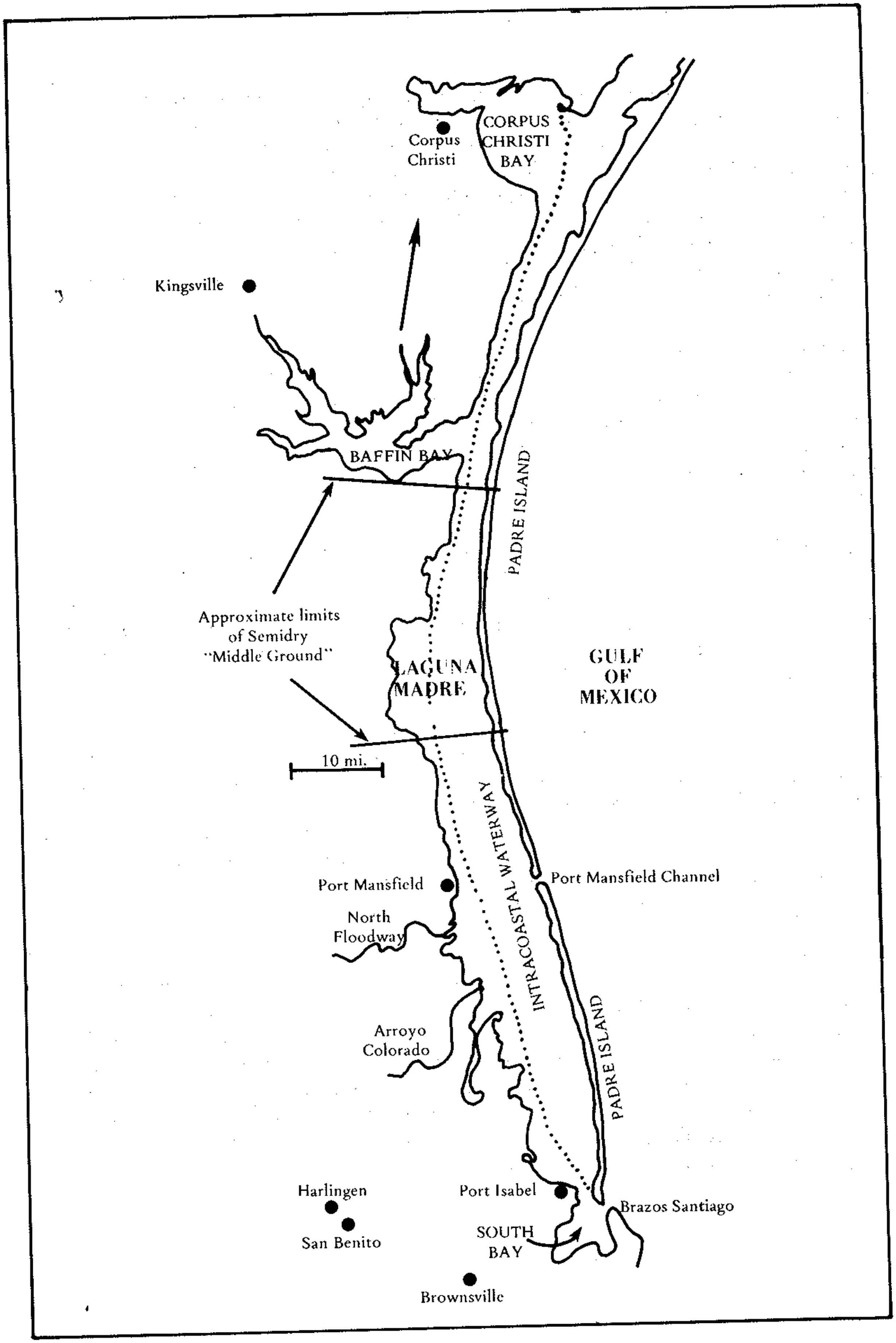

FIGURE 1

Location of Laguna Madre and principal features

While the Laguna Madre is probably the least influenced by man of all Texas' bays, there is nevertheless considerable evidence of human activity. The principal population center is Corpus Christi in Nueces County, with a 1973 estimated population of 215,000 (A.H. Belo, 1974-75). Other large communities include Brownsville (54,613), Harlingen (35,610), and San Benito (16,840), all in Cameron County. Kingsville (29,500) is the headquarters of King Ranch, which covers much of Kleberg and Kenedy Counties. Principal ports include Corpus Christi, Brownsville, Port Mansfield (731) in Willacy and Port Isabel (3,740) in Cameron Counties.

Most man-made features in the bay have been designed to improve transportation and/or to reduce salinity by increasing exchange with the Gulf. One conspicuous feature is the Gulf Intracoastal Waterway, or Intracoastal Canal. This is a dredged channel, 12 feet deep by 125 feet wide, paralleling the Gulf Coast from Brownsville, Texas to Florida. In shallow areas deposition of material removed during dredging of the Intracoastal Canal has produced a chain of emergent "spoil" islands that is quite extensive.

A second canal, the Port Mansfield Channel, is dredged across the Intracoastal and, together with a pass maintained across Padre Island, joins the turning basin at Port Mansfield to the Gulf. It is 12 feet deep and 100 feet wide. Other dredged channels include the Brownsville Ship Channel (36 feet deep, variable width); the Arroyo Coloardo (nine feet deep, 125 feet wide), which is extended across the bay and connects to the Intracoastal Waterway; and numerous access channels to oil well sites, many of which are no longer maintained.

Causeways have been built at either end of the Laguna Madre, connecting the mainland to Padre Island. At the upper end is the John F. Kennedy (Padre Island) Causeway, completed in 1950. It is a landfill structure, with three openings totaling 900 feet in width at mean low tide. Communication between the Laguna and Corpus Christi Bay is restricted to these openings. At the southern end is the Queen Isabella Causeway, which links Port Isabel to Padre Island.

Prior to completion of the Intracoastal Canal several attempts were made to cut passes through Padre Island to increase tidal exchange with the Gulf. In general the opening of such passes was followed closely by their closing due to natural deposition of sediment. Most notable of these was Yarborough Pass (Simmons, 1957) between Baffin Bay and the Middle Ground in the upper Laguna Madre. It was opened four times during the period April 1941 - December 1944, stayed partially open ten months, and was fully open for only six months. Relatively little penetration of Gulf water into the bay occurred during the open periods.

Construction of the Intracoastal has increased both circulation in the Laguna and exchange with the Gulf. The upper and lower portions of the bay, formerly isolated from one another except during extremely high tides, are now permanently connected. When winds are from the southeast, Gulf water enters through the Brazos Santiago; water flows from the lower Laguna to the upper via the Land-cut and to the Gulf via the Port Mansfield Channel. The direction of flow in the upper portion is through the openings at the causeway to Corpus Christi Bay. This is the prevailing pattern during much of the year. Winds are predominately from the north in the winter, however, and then the circulation pattern is reversed.

Principal commodities carried on the Intracoastal Waterway include crude petroleum, refined petroleum products, and unmanufactured shells. In 1971 these comprised, respectively, 30%, 25%, and 12% of the commercial traffic (A.H. Belo, 1974-75). Corpus Christi is the major seaport and manufacturing center along the Laguna Madre. Besides Corpus Christi, the economy of the area bordering the Laguna is based on agriculture, petroleum, fishing, and tourism. The availability of Rio Grande water has nurtured an intensive irrigated farming industry in Cameron and Willacy Counties, with Cameron being one of Texas' leading agricultural counties (A.H. Belo, 1974-75). Crops include cotton, sorghum, fruits, sugar cane, and vegetables. There is a substantial sport and commercial fishery out of Port Isabel and Port Mansfield, and seafood processing and tourism also constitute important sources of income. In Kleberg and Kenedy Counties to the north, on the other hand, the economy depends mainly on oil, gas, and ranching.

Conclusions

The Laguna Madre is a shallow, elongate bay, largely enclosed by the mainland on one side and a barrier island on the other. As a result of its shallow, enclosed nature, its shoreline is quite variable on a short-term basis, and salinity values are generally well above those of normal sea water. Hurricanes play a large part in changes occurring in the estuary. Major recent storms have been Beulah (1967), Celia (1970), and Fern (1971).

The Laguna Madre is actually two bays, connected by the dredged Gulf Intracoastal Waterway. The Land-cut portion of the Waterway increases water exchange both between the two bays and with the Gulf of Mexico. Dredging activities have resulted in a prominent chain of spoil islands that extend along much of the length of the bay. Thus, while the Laguna is probably less affected by the activities of man than other Texas bays, man-made features nevertheless are an important influence.

Population is concentrated mainly in Corpus Christi in Nueces County, and in Cameron County where the availability of Rio Grande water supports an intensive irrigated crop-farming industry. Commercial and sport fishing, seafood processing, refining and manufacturing (in Corpus Christi), and tourism are other important industries. In Kenedy and Kleberg Counties the economy is mainly of an oil/ranching type.

Shipping is also a major industry in the Laguna Madre area. The Intracoastal Waterway, which connects Brownsville to Gulf ports all the way to Florida, transports barge traffic with the major commodities being crude petroleum, refined petroleum products, and unmanufactured shells.

BAY QUALITY

Water quality standards for Segment 2491 are established in the Texas Water Quality Standards approved by the Texas Water Quality Board and the United States Environmental Protection Agency in 1973. They apply to measurements of water quality taken one foot below the surface. The parameters for which limits are set include temperature, pH, dissolved oxygen concentration (DO), and total coliform count. In addition to these, a number of other parameters measuring water quality are considered in this section.

Water quality is monitored by the Texas Water Quality Board at quarterly intervals at seven stations in the Laguna Madre. These are given, together with their locations, in Table 1 and Figure 2. The northernmost station is 2491.0050, at the boundary between the Laguna Madre and Corpus Christi Bay. Station 2491.0200 is located in a fairly narrow portion of the bay between Padre Island and the mainland. Approximately 12 miles south is Station 2491.0100, in the mouth of Baffin Bay. Stations successively farther south are 2491.0600, 2491.0500, 2491.0400, and 2491.0300, the latter of which lies between the southern tip of Padre Island and Port Isabel. The distance separating stations 2491.0050 and 2491.0300 is about 130 miles. The stations have been monitored for varying periods of time, as shown in the table. Water quality data collected at each station are given in the Appendix.

Table 1. Monitoring stations maintained by the Texas Water Quality Board in Segment 2491.

Station No.	Monitoring Began	Location
2491.0050	December 1971	Intersection Padre Island Causeway and Intracoastal Canal
2491.0100	February 1972	Marker 121, mouth of Baffin Bay
2491.0200	October 1973	Marker 59, Intracoastal Waterway
2491.0300	October 1971	Marker 129, east of Port Isabel
2491.0400	December 1971	Intersection of Arroyo Colorado and Intracoastal Waterway
2491.0500	October 1971	Intersection Port Mansfield Channel and Intracoastal Waterway
2491.0600	February 1972	Marker C-225A, north of Port Mansfield

Salinity

Salinity in the Laguna Madre generally exceeds 35 parts per thousand (0/00), the approximate salinity of normal sea water. During 1946-48 prior to construction of the Intracoastal Waterway, salinities frequently exceeded 70 0/00 and values as high as 114 0/00 were recorded (Gunter, 1967). Recent measurements on the other hand, seldom exceed 60 0/00, even in parts of the upper portion where circulation is most limited (Texas Parks and Wildlife Department, 1971-73).

Laguna Madre salinity values and patterns are the result of a complex interaction of factors including tidal activity, wind, evaporation, and fresh water inflow. In the first place, the bay is relatively isolated from the Gulf of Mexico; along most of its 130 miles they are separated by a

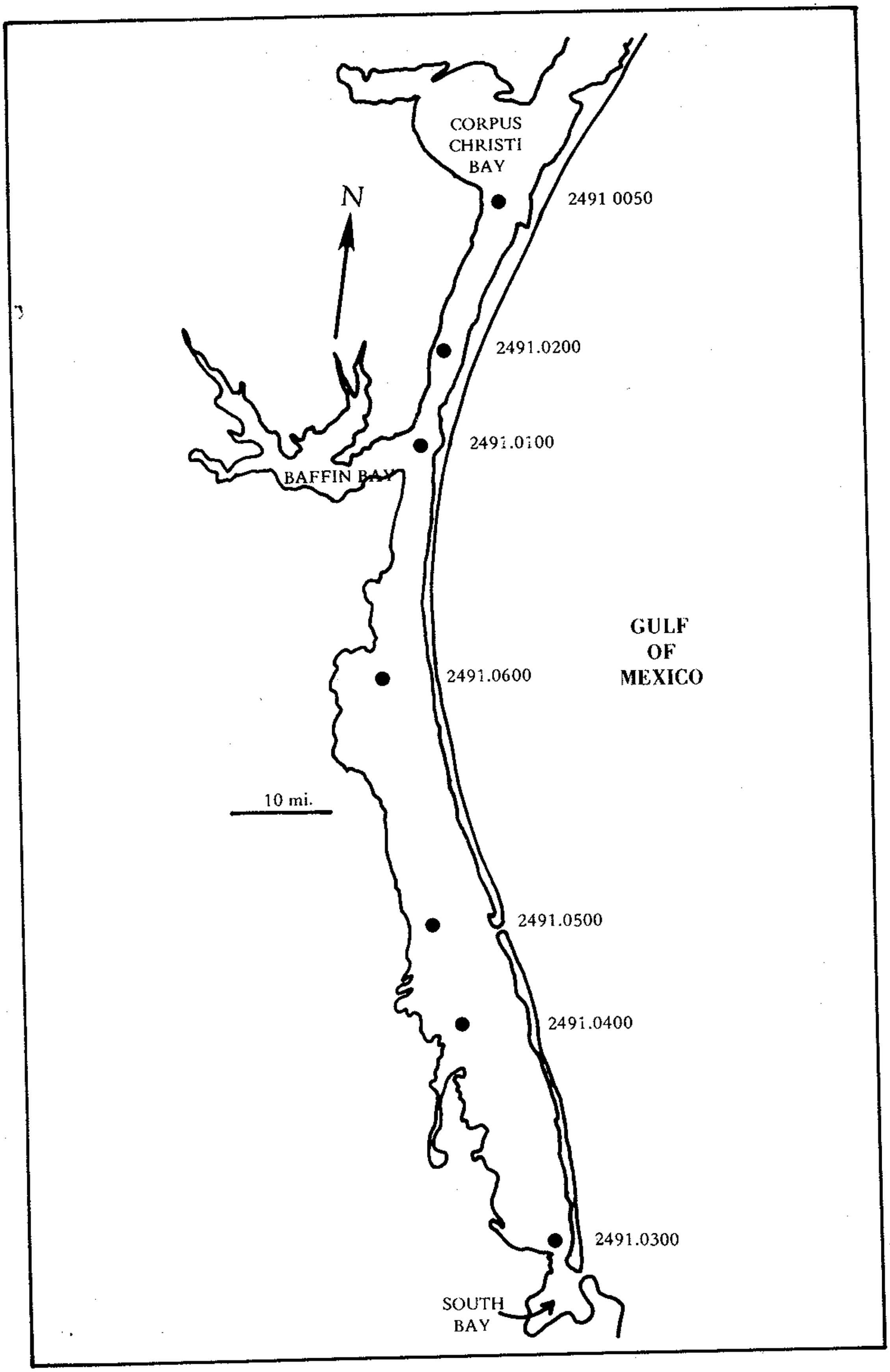

FIGURE 2

Location map of Laguna Madre showing locations of Texas Water Quality Board sampling stations.

continuous barrier island. Tidal influence is generally confined to communication via Corpus Christi Bay at the northern end, a tidal channel maintained at Port Mansfield, and the Brazos Santiago natural pass at the southern end. Additional tidal channels may be opened from time to time, particularly as a result of extremely high tides and fresh water inflow during hurricanes, but these are temporary.

Wind is apparently an important factor in the amount of water exchange taking place at the northern and southern ends (Texas Parks and Wildlife, 1969-70). Strong northerly winds in winter tend to pull less saline water in from Corpus Christi Bay, resulting in a decreasing gradient of salinity values from south to north in the upper Laguna Madre. Strong southerly or southeasterly winds have the reverse effect, causing values to increase in the upper portion south to north.

The hypersaline conditions are attributable in part to the relative isolation of the Laguna Madre from the Gulf, as well as its shallow depth (less than four feet throughout most of its extent). The shore slopes very gradually, such that the land/water boundary is poorly defined and broad areas are left uncovered by water at low tide or during strong winds. Evaporation from these windtide flats leaves extensive salt deposits, which may be redissolved at high tide or washed into the bay during rainy periods.

Fresh water inflow to the upper portion of the Laguna is by means of numerous intermittent streams that enter Baffin Bay; these streams are dry except during periods of precipitation (Hildebrand and King, 1972-73). In the lower portion fresh water input is mainly via channelized floodways that carry overflow from the Rio Grande. These include the North Floodway and the South Floodway drainage system, the latter of which is the Arroyo Colorado. Both systems also carry local runoff and agricultural drainage, and the Arroyo Colorado carries a substantial amount of treated sewage.

Figure 3 summarizes extensive salinity data, some of which are unpublished, that are provided by the Texas Parks and Wildlife Department (TPWD, 1961-73). The values covering Water Years 1962-74 are based on monthly measurements at approximately 30 monitoring stations in the Laguna Madre. Several features of the salinity regime are illustrated in the figure. Values in the upper portion tend to be considerably higher than those in the lower. Most of the exceptions to this pattern occur during periods following sharp declines that are attributable to flooding caused by tropical storms; Beulah in 1967 and Fern in 1971. The period of recovery following such a decline appears to be on the order of several years; following Beulah in 1967, salinities in the upper Laguna Madre did not reach pre-Beulah levels until 1971. Recovery following Fern in 1971 was clearly incomplete before 1973.

The effect of hurricane-caused flooding on salinity is further considered in Figure 4. The pattern along the length of the bay is similar prior to both Beulah (1967) and Fern (1971), with values being highest in the upper portion above Baffin Bay. Salinity declines southward, with a slight dip being evident in the region of tidal mixing at the Port Mansfield Channel and the North and South (Arroyo Colorado) Floodway inflows. The figure also shows the sharp decreases following each storm; values in the region above Baffin Bay are depressed, probably by fresh water input via the intermittent streams draining into Baffin Bay. Increases in the lower portion result in maximal readings near Port Isabel at the southern end, where moderation by tidal mixing reduces the effects of tropical storms upon salinity.

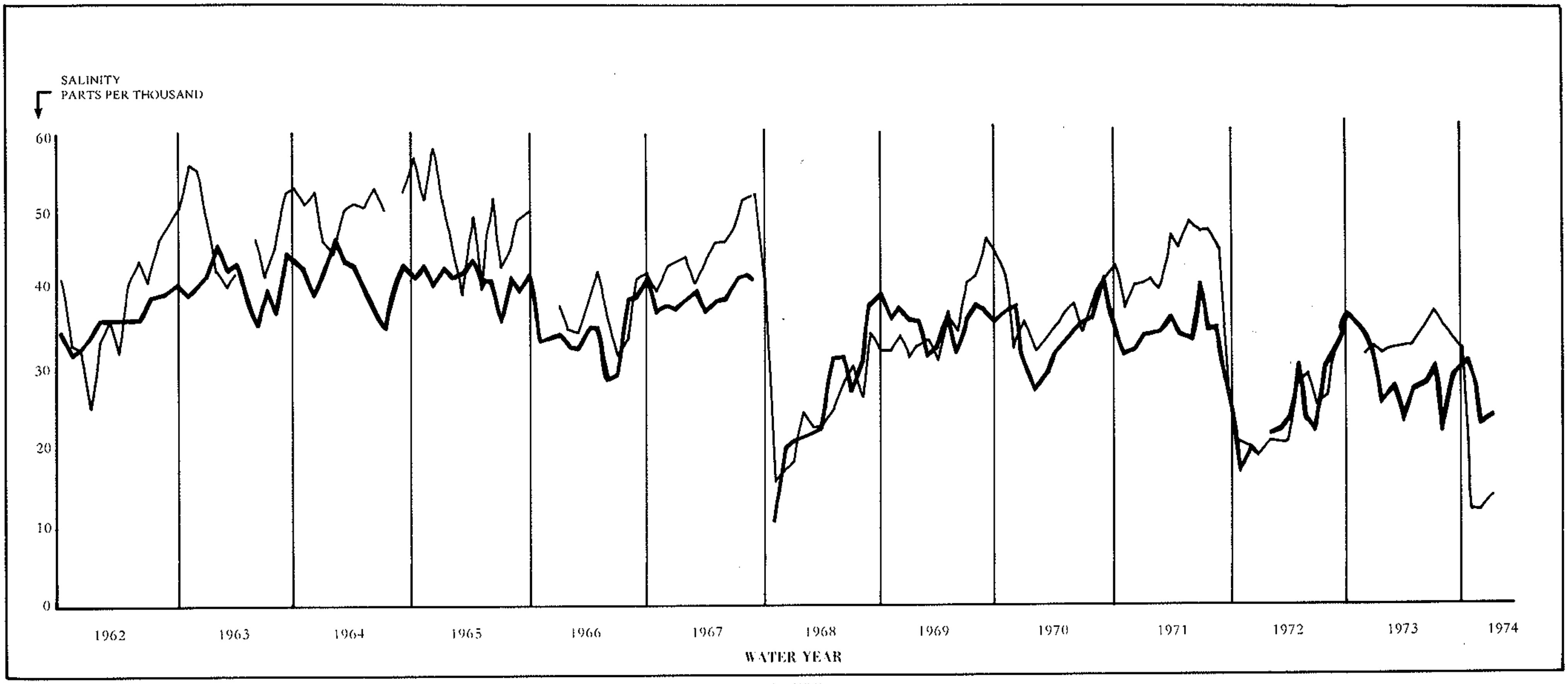

FIGURE 3

Bay quality: salinity in the upper (light line) and lower (heavy line) Laguna Madre. Each value is an average of measurements at 12-15 stations and is expressed as parts per thousand. Data from Texas Parks and Wildlife Department (1961-1973).

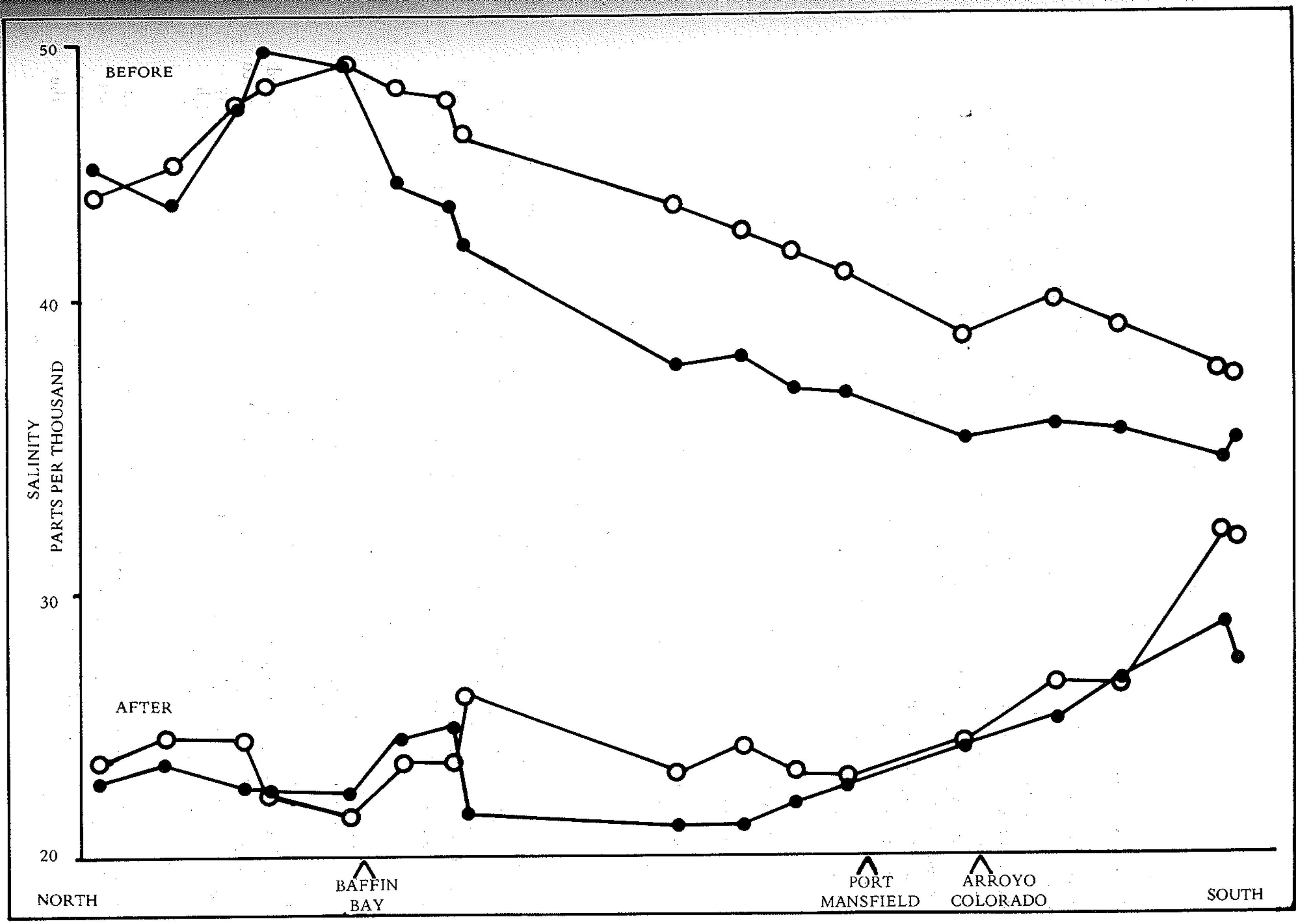

FIGURE 4

Bay quality: effects of Hurricane Beulah (open circles) and Fern (closed circles) on salinity in the Laguna Madre. The upper graphs are based on averages for the eight months preceding September 1967 (Beulah) and September 1971 (Fern). The lower graphs are based on averages for the period December-July following each storm. Data from Texas Parks and Wildlife Department (1967-68, 1971-72).

Temperature and pH

The Texas Water Quality Standards specify a maximum temperature of 95°F for the Laguna Madre. Values recorded in the Appendix range 52-89°F, well below the standard.

pH is limited by the Standards to a range of 7.0-9.0. Four of 92 determinations at the regular monitoring stations fall outside this range, as shown below. Intensive plant and algal growth can cause the pH to be high, due to changes in water chemistry associated with photosynthesis. Photosynthesis also results in the production of oxygen, so oxygen concentration can be used as an indicator of photosynthetic activity. The oxygen values given below and in the Appendix show that oxygen concentration is frequently above the 100% saturation value, the maximal concentration that can be dissolved in the water by physical processes. Thus, photosynthetic rates in the Laguna are probably also high, and the occasionally high pH values that have been observed may be caused in part by plant growth. Other factors such as salinity probably also influence pH. Most pH measurements fall within the allowed range of 7.0-9.0, with no seasonal pattern of variation indicated.

STATION	DATE	pH	OXYGEN (% Saturation)
2491.0050	07/07/72	9.2	168
	07/30/73	9.3	105
2491.0300	09/13/73	9.8	103
2491.0500	03/21/73	6.8	92

Dissolved Oxygen

The solubility of oxygen in water decreases with increasing temperature and salinity. Thus, the maximal amount of oxygen that can be dissolved in water by physical processes is determined by water temperature and salinity. For instance, fresh water at 60°F, when fully saturated with dissolved oxygen, contains 10.1 mg/l; whereas water at 85°F and 50% salinity contains only 3.8 mg/l when fully saturated. The latter conditions are realized in the upper Laguna Madre during some summers.

Approximately 40% of the oxygen measurements in the Appendix exceed the fully saturated concentration (100%) for the given temperature and salinity values. It is probably the case that these high values are due to photosynthesis by the rooted aquatic plants that are abundant throughout the Laguna. Photosynthesis by algae suspended in the water also probably contributes to these values. But data in the Appendix show no apparent correlation between oxygen concentration and chlorophyll "a" concentration, which is a measure of the abundance of suspended algae; and rooted aquatic plants are extremely abundant in the Laguna, forming lush submerged meadows in many areas. Thus, it is likely that rooted plants are the more important factor contributing to the high oxygen concentrations observed.

Dissolved oxygen concentration is required by the Texas Water Quality Standards to equal or exceed 4.0 mg/l. Most measurements are above this standard, as shown in the Appendix. There are several low values, however, recorded at 2491.0050. Of 30 determinations there, three during the summer of 1974 are below 4.0 mg/l. Circulation through this area is thought to be limited by the

Padre Island Causeway, a landfill structure that restricts exchange with Corpus Christi Bay. There are no known wastewater discharges of any magnitude. A special survey of this area is being planned by the Water Quality Board to determine the factors contributing to the low oxygen values.

Of 60 observations at the remaining stations, only two are below the standards. A value of 1.5 mg/l is recorded at 2491.0500 in September 1973, and 3.8 mg/l is reported at 2491.0400 in June 1974. Thus, of the five values falling below 4.0 mg/l in the Laguna Madre, all occur during the warmest months, i.e. June - September. This is the period of the year when the capacity of the water to hold oxygen is lowest and the oxygen demand of the biological community (e.g. bacteria, plants, fish) is highest due to the high ambient temperature. Studies by Hildebrand and King (1972-73) indicate that there is little stratification of oxygen values in the Laguna, so that these "surface" measurements probably reflect conditions throughout the water column.

Total Coliform Count

Coliform bacteria are considered to be a fairly reliable indicator of the suitability of shellfish for human consumption. For that reason, total coliform count continues to be the principal means of monitoring bacteriological quality of coastal and inland marine waters. The Texas Water Quality Standards require that the median of bacteriological observations not exceed 70/100 ml.

Bacteriological samples were collected at nine locations in the Laguna Madre by the Texas State Department of Health in March 1964. Analysis of each of these samples revealed less than two coliform bacteria per 100 ml. More recently, bacteriological quality has been monitored by the Texas Water Quality Board. As shown in Table 2, individual counts above the standard do occur, but all median values are well within 70/100 ml.

Table 2. Bay quality: total coliform count (No./100 ml) at stations in Laguna Madre. Values refer to all measurements made during WY 1972-74.

Station	No. Samples	Range	Median
2491.0200	4	0-10	< 2
2491.0100	10	0-92	< 2
2491.0600	3	<2-1300	< 2
2491.0500	3	0-94	< 2
2491.0400	3	0-240,000	< 2
2491.0300	3	0-220	20
Standard			70

Nutrients: Ammonia, Nitrate, and Phosphate

No standards have been established for ammonia (NH_3), nitrate (NO_3), or phosphate (PO_4) in Texas surface waters, but their importance in the productivity of the State's bays warrants their consideration. The concentration of ammonia has additional significance, in that high values are frequently indicative of recent sewage pollution. In addition, the oxidation of large amounts of ammonia by natural bacteria populations can deplete available oxygen.

Nutrient concentrations are considerably higher at Station 2491.0400, where the Arroyo Colorado intersects the Intra-coastal Waterway, than at other stations (Table 3). Whereas concentrations of ammonia and nitrate are generally below the respective detectable limits of 0.1 and 0.03 mg/l, median values at the Arroyo Colorado Station are 0.3 and 0.18 mg/l. Median phosphate concentration at 2491.0400 is 0.32 mg/l, approximately three times that at other stations. The phosphate values are similar to those recorded in 1955 by Simmons (1957). He gives averages of 0.10 and 0.24, respectively, for the upper and lower Laguna Madre. These suggest that nutrient concentrations have not been increasing over the past 15-20 years.

Table 3. Bay quality: median concentration of nutrients in Laguna Madre. Values are ammonia expressed as nitrogen (NH_3-N), nitrate expressed as nitrogen (NO_3-N), and total phosphorus converted to phosphate (T-PO_4). All are expressed as mg/l and based on data in Appendix.

Station	NH_3-N	NO_3-N	T-PO_4
2491.0050	< 0.1	< 0.03	0.08
2491.0200	< 0.1	< 0.03	0.10
2491.0100	< 0.1	< 0.03	0.11
2491.0600	< 0.1	< 0.03	0.07-0.10
2491.0500	< 0.1	< 0.03	0.08-0.09
2491.0400	0.3	0.18	0.32
2491.0300	< 0.1	< 0.03	0.10

Heavy Metals

The presence of heavy metals is monitored in aquatic systems due to their potential toxicity and to the tendency of organisms to accumulate them. Toxicity is considered to be of two types: chronic, which is long-lasting and usually produces less obvious effects; and acute, which yields more obvious effects and often includes death of the organism. Chronic toxicity occurs at a concentration above some tolerable maximum, and acute toxicity usually occurs at higher concentrations. The significance of certain metals in aquatic ecosystems is given in Table 4, together with levels proposed by the United States Environmental Protection Agency (1973) as being unacceptable in marine waters. It should be noted that these values are subject to revision in the final version of this document.

Because metals are usually present in water only in very small concentrations, the unit of measurement used is very small. This is a "microgram per liter" (mg/l), which is equal to 1/1000 of a "milligram per liter" (mg/l), or one part metal per billion parts water.

Table 4. Significance of certain heavy metals and selenium in marine ecosystems. Summarized from U.S. Environmental Protection Agency (1973). All values are micrograms/liter.

METAL	SIGNIFICANCE	UNACCEPTABLE LEVEL IN WATER (PROPOSED)
Arsenic (As)	Accumulated by shellfish. Cumulative poison with long-term chronic effects on aquatic organisms and mammals.	50
Barium (Ba)	Poisonous but generally present in low concentrations due to precipitation by sulfate and carbonate.	1000
Boron (B)	Uncertain	–
Cadmium (Cd)	Concentrated by marine organisms, particularly molluscs. Marked acute and chronic effects. Toxicity increases in the presence of zinc or copper.	10
Chromium (Cr)	Accumulated by marine organisms. Lower forms such as algae and zooplankton are especially sensitive.	100
Copper (Cu)	Essential in small amounts. Accumulated by marine organisms. Toxic in larger amounts, particularly to molluscs.	50
Iron (Fe)	Essential in small amounts. Toxicity not known.	–
Lead (Pb)	Concentrated by certain marine plants and animals. Toxicity not well studied.	50
Manganese (Mn)	Concentrated by some marine organisms. Toxicity not well studied.	100
Mercury (Hg)	Shows acute and chronic toxicity to many marine organisms. Organo-mercury compounds, which are formed from mercury salts in ecosystems, are more toxic than the salts themselves.	1
Nickel (Ni)	Not well studied, but known to be somewhat toxic, more so for plants than animals.	100
Selenium (Se)	Toxicity not known.	10
Silver (Ag)	Highly toxic to marine invertebrates and fishes. Accumulated by some forms.	0.5
Zinc (Zn)	Concentrated by marine animals, particularly shellfish. Long-term chronic toxicity probably more important than acute toxicity.	100

Table 5 shows the concentrations of certain heavy metals and selenium in water samples collected in the Laguna Madre during the period 1969-74. The upper levels proposed by the Environmental Protection Agency are also given for the purpose of comparison. Most values are below the EPA levels, and many are below the limits of detection used in the 1974 analyses. The mercury measurement in 1974 is unexpectedly high in view of the fact that very little mercury was detected in sediment samples collected at the same station, 2491.0200 (Table 6). It is possible that the 1974 mercury value is erroneous. In general, water quality in the Laguna Madre is very good with respect to metals concentrations.

Table 5. Bay quality: concentrations of heavy metals and selenium in water samples collected in the Laguna Madre during 1969-70 (Hahl and Ratzlaff; 1972, 1973) and in 1974 (present study, Station 2491.0200). Maximal acceptable levels proposed by the United States Environmental Protection Agency (1973) are also given. All values are micrograms/liter.

	September 1969	July 1970	July 1974	E.P.A. Levels (Proposed)
Arsenic	–	< 10	<5	50
Barium	–	–	< 500	1,000
Boron	920–6,300	5,500	6,500	–
Cadmium	0	0	<10	10
Chromium	0	0	<100	100
Copper	4–43	2	<50	50
Iron	0–20	80	500	–
Lead	0–7	0	<50	50
Manganese	0	40	120	100
Mercury	–	0.5	3.3	1.0
Nickel	–	–	200	100
Selenium	–	–	<1	10
Zinc	10–50	40	<100	100

Sediment

Bottom deposits are the result of sedimentation, the settling of particles from the water column, and of shoaling, the movement of deposits from some areas to others due to physical disturbance. The materials contained in the bottom deposits or sediment can exert an important influence upon the quality of the overlying water. Wind-induced water movements, ship traffic, and dredging activities are some physical processes that can cause mixing and transfer of materials from the sediment to the water. Chemical changes resulting from seasonal temperature fluctuations, photosynthesis, and respiration, can influence the rate of movement and distribution of dissolved substances between water and sediment. Certain materials, including heavy metals, tend to accumulate in the bottom deposits such that they may be detectable in sediment but not in water samples. The unit used in sediment analysis is "milligrams per kilogram" (mg/kg), which, like the "milligrams per liter" (mg/l) used in water analysis, is essentially equivalent to parts per million.

The parameters most often used to characterize sediment quality include Total Kjeldahl Nitrogen, chemical oxygen demand, volatile solids, oil and grease, and heavy metals. Total Kjeldahl Nitrogen (TKN) is the sum of ammonia and organic nitrogen present in the sample. Thus, it is a measure of the amount of reduced nitrogen, that which consumes oxygen if it is converted to more oxidized forms such as nitrate. Chemical oxygen demand (COD) is also a measure of potential depletion of oxygen, since it includes all of the substances that can be oxidized. Volatile solids (VS) is a measure of the amount of organic material present. Most often the occurrence of a substantial amount of oil and grease in a sample reflects the discharge of oil-contaminated waste from ships. The significance of the more common heavy metals in marine systems is given in Table 4. There are presently no standards for sediment quality in Texas waters.

The values given in Table 6 indicate that sediment quality in Laguna Madre is very good. This is expected, since there are no significant industrial discharges to the area, and barge traffic on the Intracoastal, while economically important, is not heavy. The small amounts of contaminants that are present probably represent background levels, as these values are at or below those (Withers et.al., 1973) given for Lake Corpus Christi and considered to be baseline levels for the Corpus Christi area.

Table 6. Sediment quality: concentrations of heavy metals and other constituents in sediment at Station 2491.0200 on October 23, 1973. All values are mg/kg dry weight except volatile solids, which is percent of dry weight.

	Observation (mg/kg)
Kjeldahl Nitrogen	760
Chemical Oxygen Demand (COD)	15,800
Volatile Solids (VS)	2.2
Oil and Grease	280
Arsenic	<1
Cadmium	0.2
Chromium	3.9
Copper	8.9
Lead	4.3
Manganese	52
Mercury	0.04
Silver	200
Zinc	14

Sediments in the Laguna Madre contain a relatively high proportion of sand and low proportion of clay, compared to sediments in other Texas bays (Shepard and Rusnak, 1957). The input of clay depends mainly on the inflow of freshwater carrying suspended material, and fresh inflows to the Laguna are limited. Bottom areas containing a large amount of clay are restricted to deltas at the mouths of the Floodways and to South Bay, which formerly received a large amount of silt from the Rio Grande. The sand deposits are derived from material washed and blown from Padre Island, where erosion is rapid. The sand on Padre Island is replenished in turn via transport along the coast in longshore currents.

Very little sampling for pesticides has been done in the Laguna Madre. Where they are found in sediment samples elsewhere in Texas, they are usually adsorbed to silt particles (Tidswell and McCasland, 1972). The results of a single sample collected by the Water Development Board (Hahl and Ratzlaff, 1972) are shown in Table 6a. The sampling location was the silty delta deposits near the mouth of the Arroyo Colorado. The only pesticide residue detected was DDE, a breakdown product of DDT.

Table 6a. Sediment quality: pesticide residues in the Laguna Madre near the mouth of the Arroyo Colorado (Hahl and Ratzlaff, 1972). Sample collected September, 1969.

Pesticides	Observation* (micrograms/kg)
Aldrin	0
DDD	0
DDE	0.84
DDT	0
Dieldrin	0
Endrin	0
Heptachlor	0
Heptachlor epoxide	0
Lindane	0

* A value of "0" indicates none of the material was detected. In such cases the material would have been present in an amount below the limit of detection.

Conclusions

While increased circulation and tidal exchange resulting from the influence of the Intracoastal Canal have significantly reduced Laguna salinity, it still generally exceeds the corresponding value for normal sea water. These hypersaline conditions are the result of a number of factors, including relative isolation from the Gulf, shallow depth, and low freshwater inflow. Tropical storms in 1967 and 1971 resulted in a large amount of fresh water's entering the bay, greatly reducing salinities. The period of recovery following such a sharp reduction appears to be about four years. With the exception of the periods immediately following hurricanes, salinity determinations are generally higher in the upper than in the lower Laguna Madre.

Water and sediment quality is generally very good. Oxygen concentration occasionally falls below the standard of 4.0 mg/l during the warmer months, especially at Station 2491.0050. Otherwise, almost all measurements are within requirements for temperature, pH, oxygen concentration, and total coliform count. It is not surprising that water quality standards would be occasionally exceeded in a system as naturally variable as the Laguna Madre.

Nutrient concentrations are low with the exception of the station near the Arroyo Colorado mouth in the lower portion. This stream carries a substantial amount of treated sewage which, together with local and agricultural runoff in the Floodway system, accounts for the elevated nutrient values. The concentrations of heavy metals and other contaminants are low in water and sediment, and probably constitute baseline levels for this part of the Texas coast.

WASTEWATER DISCHARGES

(November 1973 - October 1974)
Municipal

DISCHARGER Population served	TREATMENT	DISCHARGE RATE MGD	OXYGEN DEMAND LOADING lb/day	DISCHARGE POINT(S)
City of Donna Undetermined	Trickling filter	0.90	149	Drainage ditch to Main Floodway to Laguna Madre
City of Edinburgh 20,000	Trickling filter	2.1	275	Hidalgo County drainage ditch to North Floodway to Laguna Madre
City of Raymondville 8,000	Contact aeration	0.59	28	Drainage ditches to Hidalgo Willacy WCID No. 1 drain to Laguna Madre
City of Weslaco 14,600	Trickling filter	1.5	382	North Floodway to Laguna Madre

WASTEWATER DISCHARGES

(November 1973 - October 1974)
Industrial

DISCHARGER Products	COMPOSITION OF WASTE	DISCHARGE RATE MGD	OXYGEN DEMAND LOADING lb/day	DISCHARGE POINT(S)
Central Power and Light Steam electric generating plant	Mainly cooling water	0.44	38	Hidalgo County drainage ditch to Main Floodway to the Laguna Madre
Right-Away Foods Corporation Freeze-dried foods	Mainly cooling and process water	0.09	12	Ditch to Donna drain to North Floodway to the Laguna Madre
Willacy County Navigation District Shrimp processing plant	Process and washdown water, treated sewage from activated sludge plant	0.08	14	Port Mansfield harbor basin to the Laguna Madre

WATER QUALITY PROBLEMS

Water quality in the Laguna Madre is most reasonably defined on the basis of its suitability for the propagation of fish and wildlife. Given this definition, the principal water quality "problems" have been natural in origin. Extreme salinity levels, which exert osmotic stresses and reduce the oxygen-holding capacity of the water, have caused extensive die-offs of fish and invertebrates. Major kills also have occasionally resulted from temperature shock associated with severe winters. These conditions have been alleviated somewhat by the increased circulation and tidal exchange that have resulted from construction of the Gulf Intracoastal Waterway and associated channels and passes.

The only water quality problem revealed by the Water Quality Board's monitoring program is the low oxygen concentrations recorded near the Padre Island Causeway at the northern edge of the Laguna. There are several factors that are probably contributing to these values. Salinity tends to be highest in the upper Laguna (Fig. 3), thus reducing the amount of oxygen that can be dissolved in the water. It has also been suggested that circulation through this region is limited due to the reduced communication that resulted between the Laguna and Corpus Christi Bay when the Causeway was built. Although there are no known wastewater discharges of significance to this area, it does receive an unknown amount, probably small, of oxygen-demanding organic material from an adjacent sport fishing dock and fish cleaning area. An intensive survey is planned by the Water Quality Board to determine the importance of these or other factors in causing the low oxygen values.

Relatively few water quality problems are known to have resulted from the activities of man in the Laguna. Probably the most obvious are areas of increased siltation and turbidity that have resulted from dredging. These include limited areas at oil well sites in the upper Laguna (Simmons, 1957) and the entire South Bay region in the lower (Breuer, 1962). Rooted vegetation is choked out by silt deposition, and as a consequence the silt is more easily resuspended by water currents. This resulting turbidity is different in origin from a "discoloration" that is occasionally noted in Laguna water (Simmons, 1957); several natural factors, including dissolved iron compounds, decaying vegetation, and diatoms and dinoflagellate algae, have been suggested to account for the addition of color.

A potential problem related to dredging is alteration of circulation patterns due to the construction of emergent spoil islands. In the upper Laguna Madre one chain of islands extends with only small inter-island spaces for a distance of 13 miles, effectively dividing the bay in two. In the event that water movements through such an area are reduced and oxygen is depleted by, for instance, decaying vegetation, that area could become stagnant. Elsewhere in the Laguna some spoil islands have been placed on alternate sides of the Intracoastal Canal, increasing the inter-island distance. Besides this approach of "staggered" islands, circulation can be maintained by building levees to contain the spoil on the islands and prevent the closing of the small passes between them. The Water Quality Board is monitoring spoil disposal areas and water quality in the Laguna Madre. At present no instances of water quality degradation have been found to be attributable to reduced circulation caused by spoil deposition.

Another potential problem is water quality changes resulting from the recent development of suburban housing on parts of Padre Island. While much of the island is federally owned, comprising the Padre Island National Seashore, homes are constructed in privately-owned areas. At the southern end of the island is a cottage and condominium-type development, which is served solely by septic tank systems (TWQB, 1971). No degradation of water quality is indicated by monitoring data at Station 2491.0300; such degradation, if it did occur, would be short-lived due to the highly seasonal use of many of the dwellings. Recently the Cameron County Fresh-Water Supply District No. 1 has received funding to build two sewage treatment plants to serve the area. Completion of these plants, projected to be operational in 1½ - 2 years, will eliminate the need for septic tanks in the area.

The largest development eventually will be at the northern tip of the island, across the Laguna Madre from Corpus Christi. An extensive system of canals is being dredged to provide emergent land for construction and waterfront access for residents of the 50,000-person development. The area is being provided with a tertiary sewage treatment plant, so sewage discharges probably will not pose a threat to bay quality. But there is likely to be little tidal exchange between the canal system and the Laguna, with the possible result of stagnation and oxygen depletion in the canals. An extensive monitoring program will be maintained in the canal system, and the Watery Quality Board will take whatever measures are necessary to maintain water quality in the Laguna Madre.

Pesticides contributed to the estuary by the Arroyo Colorado have been identified as a water quality problem by the Texas Parks and Wildlife Department (TPWD, 1969-70; Bryan, 1971). A decline of spotted sea trout in the lower Laguna, as evidenced by decreased commercial catches and fewer juveniles in nursery areas, is attributed to the effects of DDT residues on reproduction. Evidence for this relationship includes a rough correlation between residue concentrations in trout and the timing of the decline. DDT concentrations found in trout ovaries and eggs are similar to those (3-5 ppm) that cause almost complete mortality in young lake trout, a related species (Bryan, 1971). It is also the case that the pesticides are widespread and fairly abundant in Arroyo Colorado sediments (Table 7), and that adult trout feed extensively on juvenile menhaden in the lower reach of this stream. Other factors, including the hurricanes of 1967 and 1971, may also have influenced trout survival and/or reproductive success.

Whereas the Arroyo Colorado is probably the principal source of pesticide contamination in the lower Laguna Madre, it is also an important source of nutrients. It receives runoff from the Rio Grande Valley, much of which is intensively fertilized. The Water Quality Board is currently conducting a year-long study of the Arroyo, in part to determine the magnitude of its contribution of nutrients to the estuary.

Table 7. Sediment quality: DDT and DDT-like residues at stations on the Arroyo Colorado during 1969-72. Stations are given in downstream order. For each station are given the percentage of samples in which a residue was detected and the average concentration (micrograms/kg) in those samples. Calculated from data in Tidswell and McCasland (1972).

Location	Pharr	Weslaco	La Villa	La Feria
DDD	55% (10.1)	82% (9.0)	60% (79.2)	73% (14.9)
DDE	64% (74.9)	91% (21.4)	60% (69.1)	73% (95.2)
DDT	55% (16.3)	73% (10.8)	50% (13.9)	55% (27.3)

BIOLOGICAL

The factors that are used to characterize water quality are chosen in part because of their importance in the ecology of aquatic organisms. Thus, water quality management decisions take into account possible effects upon aquatic plants and animals. In addition, certain management activities can have a significant impact upon terrestrial organisms, as in the case of loss of nesting and feeding habitat when an area is dredged or filled. The consideration of these effects is particularly important when populations of endangered (an endangered species is one threatened with extinction throughout all or a significant portion of its range) or economically important species are involved.

Endangered Species

The Texas Parks and Wildlife Department has classified several species occurring in or near the Laguna Madre as endangered. The Florida manatee Trichechus manatus, a large aquatic mammal that feeds on water plants, has become endangered due to hunting and silting of its major feeding grounds in Florida; it has previously been seen at various points from Nueces south to Cameron Counties, but there have been no recent reports of its occurrence in Texas. The ocelot Felis pardalis is a moderate-sized South American cat that has been reported from South Texas and the Gulf Coast. The brown pelican Pelecanus occidentalis has been observed nesting and/or resting on islands in the northernmost part of the Laguna. The American alligator Alligator mississippiensis occurs in much of East Texas and all along the Gulf Coast.

Several other species are given on a list of "Rare, Endangered, and Peripheral Fishes, Amphibians, and Reptiles of Texas," compiled by Gehlbach and Hubbs (personal communication). A rare species is one with a single small population that is not endangered, but is subject to some risk. A peripheral species is one endangered in the United States but not in its range as a whole. The Amazon molly Poecilia formosa is an all-female fresh-water species that reproduces asexually and has been the subject of considerable biological research. It is known from Cameron and Willacy Counties, and is classified as peripheral. The green turtle Chelonia mydas is an endangered marine species that has been reported from Kenedy County but does not nest in Texas. Another endangered ocean turtle, the Atlantic ridley Lepidochelys kempi has previously been reported from Kenedy County; the establishment of a breeding population on Padre Island is being attempted. Finally, the speckled racer Drymobius margariteriferus is a common snake in Latin America but known in the United States only from Cameron County (peripheral).

Rooted Vegetation

Several agencies are currently involved in mapping the bottom types and vegetation of the Laguna Madre. These include the U.S. Geological Survey, Texas Parks and Wildlife Department, the University of Texas Marine Science Institute, and Texas A & I University at Kingsville. The most complete data so far published are those of the Geological Survey, which has mapped approximately 10 miles of the upper portion (Hunter and Hill, 1973). They show a centrally located unvegetated trough, generally deeper than three feet and varying 0.5 - 1.2 miles in width. The Intracoastal Waterway lies mainly within this trough, as do the emergent and submerged spoil islands formed of dredged material.

On each side of the central trough are two vegetated zones, an inner more narrow one of mainly Halophila engelmannii, and a wider outer zone dominated by shoal grass Halodule beaudettei. This outer zone is generally less than three feet deep. The bottom type in these areas is fine-grained shelly sand and muddy shelly sand, whereas that of the trough is mostly fine-grained shelly sand. The spoil islands are composed of shelly, sandy, and muddy material, and those that are submerged are partially vegetated by Halophila, shoal grass, and widgeon grass Ruppia maritima. The vegetative coverage of the spoil islands varies between "wet" and "dry" periods; they were largely bare in 1968 shortly after the end of a drought, and were approximately 50% covered by 1973. Other zones identified in the study include the narrow zone of fine-grained sand washed and blown into the lagoon from Padre Island; and shallow shoals of sand and shell gravel irregularly arranged along mostly the mainland shore. The shoals are also partly vegetated, mainly by shoal grass.

These three seagrasses, together with manatee grass Syringodium filiforme and turtle grass Thalassia testudinum, are characteristic of the Laguna in depths of less than five feet (Hildebrand and King, 1972-73). Salt tolerant plants such as saltwort Salicornia sp. and salt cedar grass Monanthocloe littoralis are occasionally abundant on infrequently submerged flats.

Plankton

Plankton are small plants and animals that are suspended in the water. Both phytophankton (plants) and zooplankton (animals) in the northernmost part of the Laguna Madre are included in the study of Hildebrand and King (1972-73).

Due to the collection method employed, only the large phytoplankton were sampled. Even so, 62 species of diatoms and dinoflagellates are identified as occurring in the bay. Diatoms are the dominant group, comprising 100% of many of the samples. Major genera, in terms of numbers of individuals, are Chaetoceros, Thalassiothrix, Skeletonema, and Asterionella.

Approximately 226 species of zooplankton are enumerated in the study. Many of these are larval stages of groups that as adults are part of the benthos (living in or near the bottom) or nekton (freely swimming, larger than plankton). By far the most abundant species, however, is the copepod Acartia tonsa, which is planktonic in both immature and adult stages. Based on its abundance, Acartia is an important part of the food web of the upper Laguna Madre, consuming phytoplankton and, in turn, being eaten by larger invertebrates and larval fish. Another apparently important link in the food web is the chaetognaths, small fusiform invertebrates that are voracious predators on other zooplankton and are a mainstay in the diet of many fish species.

Other abundant zooplankton groups include the Cryptoniscidae, which is a family of isopod crustacea, and barnacle larvae. Many forms are highly seasonal in their occurrence, due in part to seasonal cycles of reproduction among the adults. Species diversity values, calculated as the $\bar{d}$ statistic of Wilhm (1970) average 2.0, with 34 of 41 values falling between 1.5 and 2.5. This is an unexpectedly small variability in view of the seasonal fluctuations in many of the species populations. It is also the case that these values fall well below the range (3.0 - 4.0) identified by Wilhm (1970) as being typical of fresh water benthic communities in clean streams. The environmental fluctuations that characterize an estuary probably act to depress diversity values by excluding certain forms; also, zooplankton diversities may be naturally lower than corresponding values for benthic communities.

Benthos

The diversity of a biological community is generally considered to reflect the effects of toxic substances, extreme environmental variations, and any other factors that place stress on the organisms present. Benthic animals, those living in close association with the bottom, are relatively immobile and require a substantial period of time to regenerate their populations following an episode of environmental stress. For these reasons, benthic animal diversity is a particularly appropriate indicator of quality in aquatic systems.

The Texas Water Quality Board monitors benthic diversity at Stations 2491.0100 and 2491.0200 in the upper Laguna Madre. The former station is located near the mouth of Baffin Bay, whereas the latter lies in a more protected area between Padre Island and the mainland (Figure 2). Diversity values for samples collected at these stations are given in Table 8. The number of taxa and diversity are generally much higher at the more protected station. Water quality at the two stations is similar, so it is likely that some other factor is depressing diversity at 2491.0100. One factor that may be involved is wind. Wind-generated wave action is considerably greater there, and this may be exerting added stress on the benthic community in the form of higher siltation rates, which exclude certain intolerant species.

Table 8. Benthic diversity values at Texas Water Quality Board monitoring stations in the Laguna Madre. Diversity expressed as the $\bar{d}$ statistic of Wilhm (1970).

Station	Date	No. of Taxa	No. of Individuals	Diversity $\bar{d}$
2491.0200	10/23/73	24	109	3.90
	01/17/74	9	135	0.88
	04/09/74	29	630	3.45
2491.0100	04/10/73	7	718	1.07
	07/03/73	4	44	1.13
	07/16/74	6	282	1.16

Table 9 is a list of the species of polychaete worms, molluscs, and peracarid crustaceans identified from upper Laguna Madre benthic samples. It is probably only a partial list of the species occurring in the bay.

Polychaetes appear to be the most diverse group, with 30 species identified thus far; molluscs (23) and peracarids (14) are also well represented. The overall diversity of benthic life, which exists in spite of the natural stresses of fluctuating salinity, turbidity, water level, etc., reflects the good quality of the water in the Laguna.

Table 9. Species list of polychaetes, molluscs, and peracarid crustaceans collected in the upper Laguna Madre by the Water Quality Board and by Hildebrand and King (1972-73, 1973-74).

	TWQB	HK
Polychaeta (Annelida)		
Sabella microphthalma	x	
Ceratonereis mirabilis	x	
Eteone heteropoda	x	
Prionospio pinnata	x	
Prionospio cirrifera	x	
Prionospio heterobranchia		x
Pectinaria gouldi	x	
Pectinaria cistenides		x
Melinna maculata	x	x
Chone duneri	x	x
Aricidea fragilis	x	
Glycera americana	x	
Magelona pettiboneae	x	
Glycinde solitaria	x	x
Heteromastus filiformis	x	x
Syllis cornuta	x	
Clymenella torquata calida	x	
Dexiospira spirillum	x	
Diopatra cuprea	x	x
Nereis occidentalis	x	
Nereis (Neanthes) succinea	x	x
Maldane sarsi	x	x
Branchioasychis americana	x	x
Capitella capitata	x	x
Eteone heteropoda	x	x
Scoloplos robustus		x
Streblospio benedicti		x
Mediomastus californiensis		x
Exogone dispar		x
Thelepus setosus		x
Mollusca		
Anachis avara semplicata	x	
Anomalocardia cuneimeris	x	x
Tellina (Angulus) texana	x	x
Tellina tampaensis		x
Amygdalum papyria	x	x
Mulinia lateralis	x	x
Ensis minor	x	x
Bittium (Bittium) varium	x	x

Table 9. (Cont.)

	TWQB	HK
Retusa canaliculata	x	x
Turbonilla sp.	x	x
Mercenaria campechiensis	x	
Crepidula convexa		x
Brachidontes exustus	x	x
Macoma mitchelli	x	x
Laevicardium mortoni	x	x
Nassarius vibex		x
Acteon punctostriatus		x
Cerithium variabile		x
Cyrtopleura costata		x
Neritina virginea		x
Haminoea antillarum		x
Mactra fragilis		x
Lyonsia hyalina		x
Peracarida (Crustacea)		
Oxyurostylis smithi	x	
Caprella sp.	x	
Corophium sp.	x	x
Cerapus tubularius	x	
Ampelisca vadorum	x	
Ampelisca abdita		x
Leptochelia rapax		x
Melita sp.		x
Amphithoe sp.		x
Paracaprella tenuis		x
Peracerceis sp.		x
Erichsonella attenuata		x
Gammarus mucronatus		x
Cymodoce faxoni		x

Nekton

The nekton are larger and stronger swimmers than the plankton. Included in this group are several commercially important species, including the penaeid shrimps and several fishes.

The shrimp populations of the lower Laguna Madre have been extensively studied by Texas Parks and Wildlife Department (1961-73). Much of this work is summarized and new information contributed in a recent paper by Stokes (1974). The shrimp of the upper Laguna Madre are considered in the study by Hildebrand and King (1972-73).

Three species of penaeid shrimp occur in the bay, the brown Penaeus aztecus, white P. setiferus, and pink P. duorarum. White shrimp comprised most of the Texas shrimp catch until 1947, whereas the brown shrimp has been the most important species since 1949 (Hildebrand, 1954). Adult shrimp move offshore in the Gulf to spawn; the larvae migrate to nursery areas in the bays and estuaries where they grow rapidly, then adult migration occurs again in the summer or fall. It should be pointed out that, while this is the general pattern, some shrimp are found in the bay throughout the year.

Brown shrimp are far more numerous than the other two species. They occur in substantial numbers throughout the year, but are most abundant in the spring. Water temperatures at this time are conducive to maximal growth, such that by May or early June the main brood of the year has reached the size (70-80 mm) of emigration to the Gulf. During the spring they are abundant throughout the bay.

The period of maximal abundance of white shrimp is variable, but a population peak of juveniles frequently occurs during June-July or September. They appear to favor areas of low salinity, as they are scarce in the upper Laguna Madre and are restricted mainly to the lower reaches of the Floodways and areas along the Intracoastal Waterway in the lower. Pink shrimp are the least numerous of the three species. They appear in small numbers in samples collected in moderately to heavily vegetated areas.

The Laguna Madre does not support a significant food shrimp industry (Table 10). There is an active live bait shrimp fishery, however, which is concentrated in the lower Laguna near Port Mansfield, Arroyo City, and Port Isabel. Brown shrimp dominate the catch from December to June, while both brown and white shrimp are abundant in the catch during the period July-November.

The Laguna Madre is a productive commercial fishery for finfish as indicated by the data in Table 10. Catches in the upper and lower portions together accounted for 59% of the total finfish catch in Texas's major bays during 1969-71. Principal game and commercial food fish include redfish or red drum Sciaenops ocellata, spotted sea trout Cynoscion nebulosus, and black drum Pogonias cromis. Spotted sea trout were most abundant from 1961, when the Parks and Wildlife sampling program began, until 1968, when redfish became most numerous in field samples. This pattern continued through 1973, with the total sampling catch of adult trout in the lower Laguna Madre averaging 72% by weight of the redfish catch. The change is also reflected in commercial landings; during the period 1970-73 the commercial yield of trout averaged approximately half that of redfish (TPWD, 1970-73).

The replacement of trout by redfish as the predominant game and food fish is attributable mainly to a decline in reproductive success of trout. Collection in formerly productive nursery areas of

Willacy and Kenedy Counties revealed few juvenile trout during 1967 and 1969 (TPWD, 1969-70). A possible factor in the trout decline is pesticide residues entering the Laguna Madre system via the Northern Floodway and Arroyo Colorado. The Willacy-Kenedy nursery area receives run-off from the agricultural areas of the Rio Grande Valley via the floodways. A Texas Parks and Wildlife study (1969-70) indicates that residues contributed by these streams enter the diet of juvenile menhaden, which are in turn consumed by adult trout feeding in the lower reaches of the streams. The chlorinated hydrocarbon-type residues accumulate in the reproductive organs and, the study suggests, may account for a substantial portion of the decline of the spotted sea trout nursery in the lower Laguna Madre. Habitat modification by Hurricane Beulah may also have been a factor in the decline.

Extensive collections of nektonic invertebrates and vertebrates were made by Hildebrand and King (1972-73). Results from their study are summarized here to give a picture of the characteristic fauna in the principal habitat types of the Laguna Madre. Their results are generally similar to those of earlier studies in both the upper (Simmons, 1957) and the lower (Breuer, 1962) Laguna Madre. Most species are estuarine and adapted to varying ranges of salinity (euryhaline), rather than being Gulf species, which have more narrow tolerance limits. As in the case of the zooplankton, a number of the nektonic species are seasonal in their occurrence in the bay, with spawning taking place in the open Gulf.

The windtide flats are shallow nearshore areas that are periodically uncovered by water due to wind and/or tidal action. In some areas they are covered by mats of blue-green algae. The sheepshead minnow Cyprinodon variegatus, which feeds on the algae, is numerous on these flats and is one of relatively few species occurring there. Groups are often stranded in tidal pools that are inundated when the tide rises again. It has been collected from ponds with salinities as high as 142 0/00, leading Gunter (1967) to conclude that it is "the toughest aquatic animal in North America." Other species found mainly in shallow areas, though not confined to the windtide flats, include the tidewater silverside Menidia beryllina, longnose killifish Fundulus similis, and Gulf killifish F. grandis.

A number of species are largely confined to the grassbeds or submerged meadows. One, the pinfish Lagodon rhomboides, was the most numerous nektonic species collected in the study. Others include the grass shrimps Palaemonetes spp., pink shrimp Penaeus duorarum, caridean shrimp Tozeuma carolinensis, xanthid crab Neopanope texana, silver perch Bairdiella chrysura, sheepshead Archosargus probatocephalus, and pigfish Orthopristis chrysoptera.

Some species were taken mainly in deeper water, especially the Intracoastal Canal. These include the Atlantic croaker Micropogon undulatus, menhaden Brevoortia patronus, blackcheek tongue sole Symphurus plagiusa, and sea catfish or hardhead Arius (Galeichthys) felis.

Several species occur in abundance in both the grassbeds and deeper areas. This group is composed of the bay anchovy Anchoa mitchilli, brown shrimp Penaeus aztecus, spot Leiostomus xanthurus, blue crab Callinectes sapidus, striped mullet Mugil cephalus, and Gulf toadfish Opsanus beta. Besides the blue crab and brown shrimp, a number of other commercially important species are fairly common in both habitats: the black drum Pogonias cromis, southern flounder Paralichthys lethostigma, spotted seatrout Cynoscion nebulosus, and redfish Sciaenops ocellata. As noted earlier, the white shrimp Penaeus setiferus is not abundant in the upper Laguna Madre, probably due mainly to its a avoidance of high salinity.

Table 10. Commercial landing data in pounds for areas along the Texas coast. Values from Texas Parks and Wildlife (1969-71).

Pounds of Finfish

Year	Galveston	Matagorda	Aransas	Corpus Christi	Upper Laguna	Lower Laguna
1969	556,700	415,400	728,200	91,700	723,500	967,600
1970	334,739	458,803	441,889	105,753	937,115	960,092
1971	228,592	275,703	564,484	169,078	1,269.865	1,361,572

Pounds of Shrimp

Year	Galveston	Matagorda	Aransas	Corpus Christi	Upper Laguna	Lower Laguna
1969	4,285,100	1,427,800	735,000	327,000	26,000	0
1970	3,021,985	1,292.105	814,424	220.680	0	0
1971	4,081,046	1,543,679	921,116	159,256	0	0

Pounds of Blue Crab

Year	Galveston	Matagorda	Aransas	Corpus Christi	Upper Laguna	Lower Laguna
1969	1,705,700	891,000	724,200	152,500	528,500	0
1970	2,561,014	269,609	289,628	0	4,720	0
1971	550,049	505,451	258,733	0	4,000	0

Conclusions

Environmental fluctuations in the Laguna Madre are extreme, perhaps more so than in any other Texas bay system. On a daily basis, broad areas change from aquatic to terrestrial habitats due to wind and tidal action. On a longer time scale, salinity values vary widely due to the opposing effects of evaporative concentration and fresh water inflow, particularly as a result of hurricanes.

The biota reflects the lack of stability in the environment. Most species are excluded from the least stable habitats, the windtide flats. In the other areas, many species are highly seasonal in their abundance or occurrence. The zooplankton and nekton are dominated by larval and juvenile forms, which adapt the populations for rapid recolonization of areas where the fauna is eliminated by sudden changes.

Longer-term changes are also evident in the biological community. Two obvious examples involve commercialy important species: the displacement of white by brown shrimp, which has occurred all along the Texas coast, and the more recent replacement of spotted seatrout by redfish as the dominant food and sport fish in the lower Laguna Madre.

Nevertheless, despite the instability, the community is diverse and includes most of the characteristic species of Texas' bays and estuaries. In the terminology of Holling (1973), it is an unstable but resilient system, able to withstand perturbations while preserving the occurrence, if not always the relative abundance, of its species. With the possible exception of pesticides and the spotted seatrout, there are no indications that bay or sediment quality is adversely affecting the biological community.

A HISTORICAL PERSPECTIVE ON CHANGES IN WATER QUALITY

Prior to 1935, most of the Laguna Madre was essentially primitive area. Almost all of the principal man-made features, including the Intracoastal Waterway, the Ports of Brownsville and Mansfield, the Brownsville and Mansfield Channels, and the Kennedy and Queen Isabella Causeways, have been built since that time. While the Laguna is probably the Texas bay least influenced by human activities, the changes made by man have had an important impact on water quality. By water quality is meant mainly the suitability of the bay for the propagation of fish and wildlife, including a number of commercially important species.

In its natural state the Laguna was a very unstable and occasionally harsh environment. Large kills attributable to hypersalinity were common in the 1930's and 1940's, with such kills known to have occurred in 1936, 1937, 1939, 1943, 1944, and 1945 (Simmons, 1957). Particularly severe die-offs occurred at "Dead Man's Hole", a large shallow basin in the Middle Ground. Huge numbers of fish were trapped in Dead Man's Hole by the combined effects of wind and evaporation and were killed by elevated salinities. Many fish surviving these die-offs were rendered blind by the salinity (Gunter, 1967). Major temperature kills also occurred during severe winters, including those of 1940, 1945, 1947, and 1951 (Simmons, 1957). The magnitude of both kinds of kills was due in part to the inability of fish and invertebrates to escape from the bay to more moderate waters when conditions became extreme.

Changes resulting from construction of the Intracoastal Waterway, completed in 1948-49, have improved conditions for wildlife. Communication between the upper and lower bays is maintained at the Land-cut, providing an avenue of escape from the more saline upper bay, and reducing temperature and salinity extremes by means of increased tidal exchange. An escape pass for fish is also maintained from Dead Man's Hole to the Intracoastal by Parks and Wildlife. The magnitude of salinity kills has been significantly reduced by these changes (Gunter, 1967).

Completion of the Waterway also provided incentive for the deepening of the Brownsville Ship Channel and widening of the natural Brazos Santiago pass; and for construction of the Port Mansfield Channel and pass at Padre Island (Breuer, 1962). Whereas previous attempts to maintain a pass across Padre Island had failed, the construction of jetties in the Gulf and increased tidal scouring have made the Port Mansfield pass more successful. Since its completion in 1957, the number of redfish in the Laguna Madre has increased, brown shrimp and flounder are caught in abundance much farther north, and the forage fish (i.e. those that serve as food for game and commercial species) such as pinperch and pigfish have increased. These changes are attributable in part to increased access to the Gulf and in part to moderation of physico-chemical conditions in the estuary.

Whereas there have been important ecological benefits of human modification of the Laguna, there have also been deleterious effects. Spoil resulting from dredging of the Intracoastal has been deposited in closely-spaced islands approximately 13 miles long in the upper Laguna Madre, effectively dividing that portion in two (Simmons, 1957). Beyond this area some banks are staggered and spacing is wider. But even these may inhibit circulation and tidal flushing, which are crucial especially in the upper portion.

In the lower Laguna Madre, the effects of dredging have been damaging to the ecosystem in South Bay (Breuer, 1962). Formerly an arm of the Rio Grande carrying considerable quantities of silt emptied into South Bay. Tidal exchange with the Gulf occurred mainly at Boca Chica pass at the south end of Brazos Island (Figure 5). When the Brownsville Ship Channel was dredged to a depth of 28 feet in 1938, much of the spoil was placed in a line along the north end of South Bay, all but severing communication with the rest of the Laguna. Boca Chica pass had been maintained by the scouring effect of Laguna waters during winter northers. By 1945 Boca Chica was silted in, and circulation through South Bay was virtually eliminated. Each subsequent re-dredging has reduced its depth, which has declined from an average of 4.0 to 1.5 feet. Siltation has virtually eliminated rooted vegetation, leaving a bottom of mostly soft mud. Commercial oystering and fishing have declined substantially.

Thus, the impact of man upon the Laguna Madre, while reduced in comparison to that in other Texas bays, has substantially influenced water quality, defined as the suitability of the environment for wildlife. The adjoining land is still largely unpopulated, being owned mostly by the King Ranch and the federal government (Atascosa National Wildlife Refuge and Padre Island National Seashore). Wastewater discharges, therefore, pose no present threat to the Laguna. The most significant man-made features, the Intracoastal Canal and associated channels and spoil islands, have been the source of important beneficial and detrimental effects.

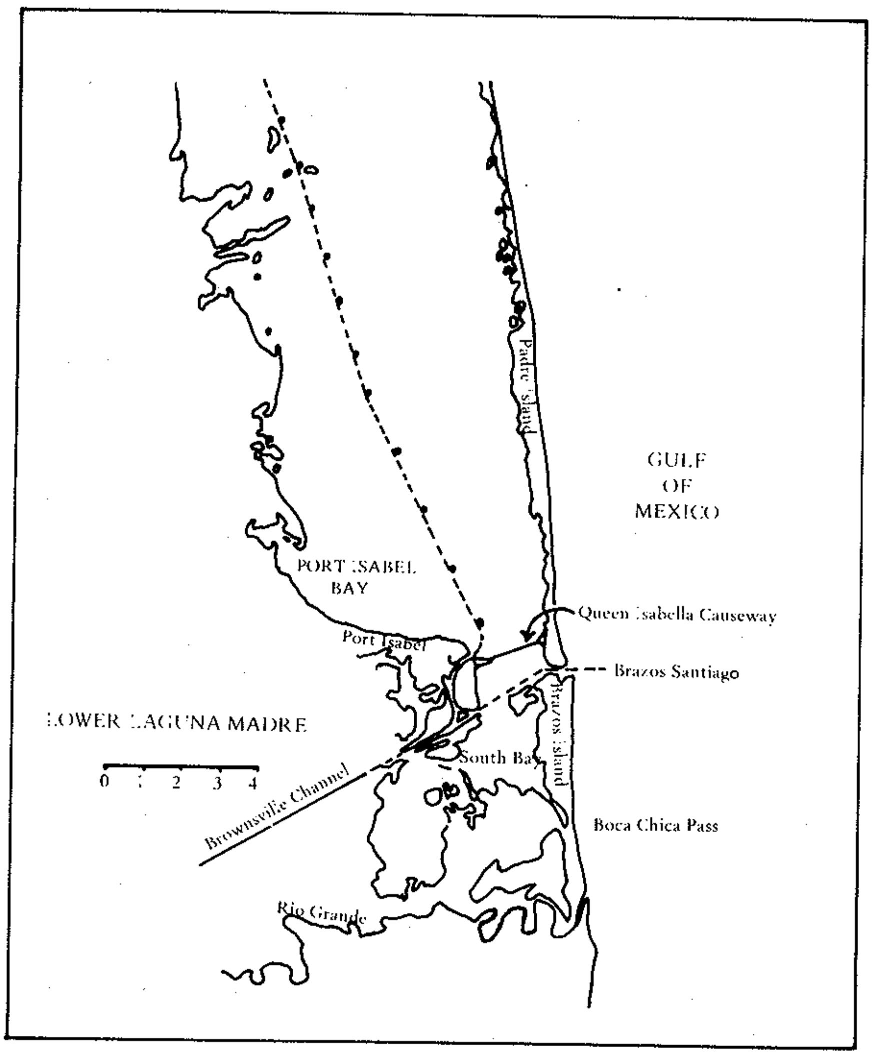

FIGURE 5

Location map of principal features in the South Bay area. Map redrawn from Breuer (1962).

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APPENDIX

APPENDIX. Water quality at Station 2491.0050

Sample Date	Water Temp Fahn	Cnductvy Micromho	DO Mg/l	%	PH SU	NO_3-N Total Mg/l	NH_3-N Total Mg/l	T PO4 PO4 Mg/l	Chlrphyl A Mg/l
12/20/71	64.0	40544	5.1	60		<.030	<.100	.28	
02/16/72	63.0		7.6	92	8.50				
03/29/72	71.0		9.5	122	8.30				
04/25/72	80.0	58800	7.9	114	8.60	<.030	<.100	.18	.036
05/16/72	81.0		6.3	91	7.20				
06/12/72	86.0		8.3	130	8.90				
07/07/72	86.0	53424	11.1	168	9.20	<.030	<.100	.13	.010
09/19/72	87.0	69440	5.9	100	8.80				
10/27/72	70.0		10.5	140	8.60	.060	.200	<.03	.009
11/27/72	56.0		4.3	50	8.60				
12/08/72	52.0		8.5	97	8.50				
01/19/73	60.0	60760	6.1	72	8.60	<.030	<.100	.06	.006
02/14/73	61.0		6.5	77	8.60				
03/21/73	68.0		8.4	114	8.60				
04/23/73	78.0	65408	8.3	119	8.50	<.030	<.100	.08	.014
05/18/73	77.0		6.9	100	8.90				
06/30/73	89.0		8.1	135	9.00				
07/30/73	89.0	79296	6.2	105	9.30	<.030	<.100	.08	.007
08/30/73	84.0		5.8	89	8.70				
09/17/73	84.0		4.5		8.65				
10/03/73	86.0	52752	8.3	126	8.90	<.030	<.100	<.03	<.004
11/14/73	74.5				8.81				
12/17/73	58.0		9.3		8.29				
01/17/74	61.6	58800	8.5	93	7.89	<.030	<.100	.08	<.004
03/31/74	76.5	53088	6.1	83	8.20	<.030	<.100	.31	.015
04/22/74	80.0	58800	5.8	84	8.10	<.030	<.100	.09	.004
06/11/74	81.0		5.7	87	8.35				
07/02/74	84.0	72576	3.4	53	8.50	<.030	<.100	<.03	<.004
07/12/74	84.2	60760	2.8	43	8.20	<.030	.500	1.00	.006
08/15/74	82.0		3.8	63	7.80				
09/19/74	83.0		5.2	83	7.25				

APPENDIX (Con't) Water Quality at Station 2491.0100

Sample Date	Water Temp Fahn	Cnductvy Micromho	DO Mg/l	DO %	PH SU	NO_3-N Total Mg/l	NH_3-N Total Mg/l	T PO4 PO4 Mg/l	Chlrphyl A Mg/l
02/27/72	70.0	43400	8.1	101	8.70	.050	<.100	.23	.025
04/18/72	80.0	54768	7.7	111	8.20	<.030	<.100	.10	.060
07/07/72	83.0	48720	8.5	123	8.70	<.030	<.100	.13	.027
10/27/72	70.0	74592	7.3	100	8.70	.110	<.100	.08	.018
01/19/73	52.0	64288	8.1	88	8.70	<.030	.200	.10	.006
04/10/73	70.0	71680	8.0	106	8.70	<.030	<.100	.11	.031
07/03/73	86.0	73472	5.7	90	8.60	.050	<.100	.14	<.004
10/23/73	75.0	8120	10.4	125	8.60	<.030	<.100	.17	.021
01/17/74	60.0	25032	11.7	148	8.08	<.030	<.100	.14	.017
04/09/74	72.0	46480	7.5	91	8.00	<.030	<.100	.11	.006
07/17/74	84.0	83664	4.9	80	8.35	<.030	<.100	.10	<.004

Water Quality at Station 2491.0200

10/23/73	75.0	19152	8.7	107	8.50	<.030	<.100	.10	<.004
01/17/74	60.0	51744	11.2	143	7.90	<.030	<.100	.10	.009
04/09/74	71.0	45080	10.6	96	8.05	<.030	<.100	.07	<.004
07/17/74	84.0	85176	5.1	83	8.10	<.030	.200	.10	<.004

APPENDIX (Con't) Water Quality at Station 2491.0300

Sample Date	Water Temp Fahn	Cnductvy Micromho	DO Mg/l	%	PH SU	NO3-N Total Mg/l	NH3-N Total Mg/l	T PO4 PO4 Mg/l	Chlrphyl A Mg/l
11/17/71	78.0	67816	5.7	90		<.030	<.100	.05	
02/24/72	68.0	70952	10.5	140	8.50	<.030	<.100	.18	.010
06/02/72	77.0	73920	5.7	85	8.50	<.030	<.100	<.03	
09/12/72	86.0	77504	5.7	95	8.70	<.030	<.100	.05	<.004
12/19/72	60.0	68096	6.5	79	8.40	<.030	<.100	.04	.006
03/20/73	68.0	67200	7.0	92	8.30	<.030	.200	.53	.009
06/26/73	80.0	68992	7.0	104	8.00	<.030	<.100	.10	<.004
09/13/73	86.0	69048	6.5	103	9.80	<.030	<.100	<.03	<.004
11/01/73	73.6	59776	8.2	110	7.80	<.030	.300	.14	.007
03/26/74	61.9	58800	8.3	99	8.50	<.030	<.100	.15	.011
06/20/74	82.0	76608	5.8	90	8.00	<.030	<.100	.06	<.004
09/19/74	82.0	77056	5.4	84	8.30	<.030	<.100	.11	<.004

Water Quality at Station 2491.0400

Sample Date	Water Temp Fahn	Cnductvy Micromho	DO Mg/l	%	PH SU	NO3-N Total Mg/l	NH3-N Total Mg/l	T PO4 PO4 Mg/l	Chlrphyl A Mg/l
12/20/71	61.0	23688	5.5	58		.400	.580	.76	
02/18/72	70.0	40320	17.5	216	8.40	<.030	.330	.24	.070
05/08/72	78.0	57624	10.7	150	8.70	.050	<.100	.08	<.004
09/02/72	86.0	58800	6.5	100	8.20	<.030	.300	.28	
03/22/73	68.0	36960	7.0	84	9.00	.180	.300	.32	.024
06/27/73	80.0	6348	7.0	87	7.70	2.900	<.100	.61	<.004
09/12/73	84.0	36512	5.5	78	7.50	<.030	.200	.33	.006
11/19/73	74.8	51744	8.8	118	7.90	.230	<.100	.07	<.004
03/18/74	73.0	64072	6.1	90	8.00	.200	.300	.20	.009
06/20/74	82.0		3.8	52	8.10	.200	.500	.41	.007
09/18/74	85.6	59976	6.5	101	8.30	<.030	<.100	.50	<.004

APPENDIX (Con't) Water Quality at Station 2491.0500

Sample Date	Water Temp Fahn	Cnductvy Micromho	DO Mg/l	%	PH SU	NO_3-N Total Mg/l	NH_3-N Total Mg/l	T PO4 PO4 Mg/l	Chlrphyl A Mg/l
11/26/71	67.0	43680	7.1	85		< .030	< .100	.15	
02/23/72	70.0	45080	8.5	107	8.50	< .030	< .100	.18	.060
06/09/72		63112	4.5		8.70	< .030	< .100	.07	
09/12/72	87.0	85176	6.3	108	8.80	< .030	< .100	.10	< .004
12/20/72	60.0	71232	7.3	91	8.60	< .030	< .100	.09	.033
03/21/73	68.0	51072	7.5	92	6.80	< .030	< .100	.07	.066
06/28/73	82.0	45640	11.5	164	8.70	< .030	< .100	.26	< .004
09/11/73	87.0	68096	1.5	24	7.60	< .030	< .100	.10	< .004
11/16/73	77.0	40992	8.5	113	7.80	< .030	< .100	.04	< .004
03/25/74	57.0	62720	7.7	89	8.30	< .030	< .100	< .03	< .004
06/19/74	83.0	68544	5.2	77	8.50	< .030	< .100	.08	< .004
09/17/74	83.0	79296	5.6	95	8.20	< .030	< .100	.08	

Water Quality at Station 2491.0600

Sample Date	Water Temp Fahn	Cnductvy Micromho	DO Mg/l	%	PH SU	NO_3-N Total Mg/l	NH_3-N Total Mg/l	T PO4 PO4 Mg/l	Chlrphyl A Mg/l
02/23/72	69.0	45080	5.5	67	8.60	< .030	< .100	.22	.070
06/09/72	78.0	58016	5.5	77	8.90	< .030	< .100	.07	
09/13/72		77504	7.0		9.00	< .030	< .100	.04	.013
03/21/73	68.0	59584	6.9	88	8.20	< .030	< .100	.07	.038
06/28/73	82.0	64288	7.5	111	8.40	.060	< .100	.04	< .004
09/11/73	82.0	67200	6.5	98	7.80	< .030	< .100	.10	.007
11/16/73	77.0	37632	6.6	82	7.90	< .030	.200	.07	< .004
03/25/74	55.9	56112	8.0	89	8.30	.090	.600	.25	.007
06/19/74	82.0	74368	4.8	74	8.80	< .030	.300	.12	< .004
09/17/74	83.3	94080	5.2	88	8.20	< .030	< .100	.12	.006

GLOSSARY

GLOSSARY

ACTIVATED SLUDGE PROCESS - A biological wastewater treatment process in which a mixture of wastewater and activated sludge is agitated and aerated. The activated sludge is subsequently separated from the treated wastewater (mixed liquor) by sedimentation and disposed of or returned to the process as needed.

ADSORPTION - The adherence of a gas, liquid, or dissolved material on the surface of a solid.

AERATION - The process or method of bringing about intimate contact between air and a liquid.

AEROBIC - In the presence of air.

ALGAE - Simple plants, many microscopic, that contain chlorophyll. Algae form the base of the food chain in aquatic environments.

AMMONIA NITROGEN - It is generally formed from the decomposition of nitrogenous organic matter. Most unpolluted waters contain very low concentrations of ammonia nitrogen, usually less than 0.2 mg/l.

ANAEROBIC - In the absence of air.

ANOXIC - Refer to anaerobic.

AQUIFER - An underground geologic formation, a group of formations, or a part of a formation that is water bearing, and that is usually capable of yielding water in quantities sufficient to constitute a useable supply.

ASSIMILATION - Conversion or incorporation of absorbed nutrients into body substances.

AUTOTROPHIC - Self nourishing; denoting those organisms that do not require an external source of organic material but can utilize light energy and manufacture their own food.

BACTERIA - A group of universally distributed, rigid, essentially unicellular microscopic organisms lacking chlorophyll.

BASIN - The surface area within a given drainage system.

BENTHIC ORGANISMS - Those bottom dwelling organisms that live in or on the substrate.

BIOCHEMICAL OXYGEN DEMAND (BOD) - An index of the amount of oxygen required for the biological oxidation of the organic matter in a liquid. The standard BOD test conditions include dark incubation of 20° C for a specified time period (usually five days).

BIOTA - The total number of plants and animals found in a specific region.

BRACKISH WATER - Those areas where the saline content is between fresh and salt water.

BRINE - Concentrated salt solution that is a by-product of some industrial processes; also naturally occurring from some geological rock formation.

CHEMICAL OXYGEN DEMAND (COD) - A measure of the amount of oxygen-demanding substances present in water. The COD test is performed in unnatural conditions and in the presence of a strong acid.

CHLORIDES - Minerals that occur in practically all natural waters in varying concentrations. They may be of a natural origin or from sea water, oil field brine, human and animal wastes, and industrial effluents.

CHLORINATION - The application of chlorine to water, generally for the purpose of disinfection, but frequently for accomplishing other biological or chemical results.

CHLORINE RESIDUAL - The amount of unreacted chlorine remaining at the end of a specified period of time known as the chlorine contact time.

CHLOROPHYLL - Green photosynthetic pigment present in many plant cells. There are seven types of chlorophyll and their presence and abundance varies from one group of photosynthetic organisms to another.

CHLOROPHYLL A - Used as an indicator for the presence of algae and for the rate of photosynthesis.

COLIFORM–GROUP BACTERIA - A group of bacteria predominantly inhabiting the intestines of man or animal, but occasionally found elsewhere.

CONDUCTIVITY - Conductivity or specific electrical conductance is the measurement of the specific ion concentration of water.

CONSUMERS - Organisms which feed upon other organisms; often divided into primary consumers (herbivores) and secondary consumers (carnivores which eat primary consumers).

CONTACT STABILIZATION PROCESS - A modification of the activated sludge process in which raw wastewater is aerated with a high concentration of activated sludge for a short period, usually less than 60 minutes, to obtain BOD removal by sorption. The solids are subsequently removed and transferred to a stabilization tank where aeration continues until their reintroduction to the raw wastewater flow.

CUBIC FEET PER SECOND (cfs) - A unit of measure of the rate of liquid flow past a given point; equal to the number of cubic feet of flow in one second.

DECOMPOSERS - Those organisms, usually bacteria or fungi, that break down complex organic material into simpler compounds.

DIEL - Refers to changes that occur during a 24-hour day-night period.

DISCHARGE - To deposit, conduit, drain, emit, throw, run, allow to seep, or otherwise release or dispose of.

DISINFECTION - The process of killing the larger portion of micro-organisms in or on a substance with the probability that all pathogenic bacteria are killed by the agent used.

DISSOLVED OXYGEN - The oxygen dissolved in water, wastewater, or other liquid. It is usually expressed in milligrams per liter, parts per million, or percent of saturation.

DIURNAL - Refers to an event or process that occurs every day; usually associated with changes from day to night.

DIVERSION - The taking of water from a stream or other body of surface water into a canal, pipeline, or other conduit.

ECOLOGY - The study of inter-relationships between organisms and their environment.

ECOSYSTEM - A community, including all the component organisms, together with the environment, forming an interacting system.

EFFLUENT - A liquid which flows out of a reservoir, basin, treatment plant, or part thereof.

ENVIRONMENT - All external influences and conditions affecting the life and development of an organism.

EPILIMNION - The water mass extending from the surface to the metalimnion in a stratified body of water; the epilimnion is less dense, wind-circulated, and usually contains more dissolved oxygen than the lower waters.

ESTUARY - A partially enclosed body of water that has a free connection with the open sea and within which sea water is diluted with fresh water derived from land drainage.

EUTROPHICATION - The intentional or unintentional enrichment of water by nutrients, which stimulates the excessive or nuisance growth of algae and aquatic weeds; the aging process of a body of water.

EXTENDED AERATION PROCESS - A modification of the activated sludge process which provides for aerobic sludge digestion within the aeration system. The concept encompasses the concept of the stabilization of organic matter under aerobic conditions.

FAUNA - Animal life.

FECAL COLIFORM BACTERIA - Micro-organisms which have no chlorophyll and can be seen only through a microscope. They are used to detect the source and type of fecal pollution that enters a body of water. A good indicator of the number of disease-causing bacteria present.

FLORA - Plant life.

FLOW - The movement of a stream of water from place to place; a stream of water, sand or other material.

FOOD CHAIN - Dependence of a series of organisms, one upon the other, for food. The chain begins with plants and ends with the largest carnivores.

GROUND WATER - Subsurface water occupying the saturation zone, from which springs and wells are fed.

HABITAT - A specific type of place that is occupied by an organism, a population, or a community.

HETEROTROPHIC - Pertaining to organisms that are dependent on organic material for food.

HYPOLIMNION - The region of a body of water that extends from the metalimnion to the bottom and is essentially removed from major surface influences.

IMHOFF TANK - A deep, two-storied wastewater tank that consists of an upper continuous-flow sedimentation chamber and a lower sludge-digestion chamber.

INDICATOR ORGANISMS - A species, whose presence or absence may be characteristic of environmental conditions in a particular area or habitat.

INVERTEBRATES - Animals without a vertebral column e.g., insects, mollusks, crayfish.

LENTIC - Pertaining to standing (nonflowing) waters such as lakes, ponds, and swamps.

LIMNETIC ZONE - The open-water region of a lake. This region supports plankton and fish as the principal plants and animals.

LITTORAL ZONE - The shallow area that extends from shore to the lakeward limit of rooted aquatic plants; the shoreward region of a body of water.

LOTIC - Pertaining to flowing waters such as streams and rivers.

METALIMNION - The transition zone between the warm epilimnion and the cold hypolimnion.

MILLION GALLONS PER DAY (MGD) - 1 MGD x 1.54723 = 1 cfs; a unit of measuring flow.

NATURAL SELECTION - Processes occurring in nature which result in survival of the fittest and elimination of individuals less well adapted to their environment.

NEKTON - Swimming organisms that are able to navigate at will in water; e.g., fish.

NITRATE NITROGEN - It is the end product of the aerobic stabilization of organic nitrogen. It serves as a food source for all types of plants, but excessive concentrations may cause deleterious effects in a body of water.

NITRIFICATION - The conversion of nitrogenous matter into nitrates by bacteria.

NUTRIENTS - Any substance assimilated by organisms which promotes growth and replacement of cellular constituents.

ORGANIC MATTER - The wastes from homes or industry of plant or animal origin. It can be broken down by bacteria.

OXIDATION - The introduction of oxygen into a system whereby the organic matter is converted to a more stable form.

PATHOGEN - An organism or virus that is capable of causing a disease.

pH VALUE - A term used to express the acid or alkaline condition of a liquid. Neutrality=pH7.0; lower values indicate increasing acidity; higher values indicate increasing alkalinity.

PHOTOSYNTHESIS - The metabolic process by which simple sugars are manufactured from carbon dioxide and water by plant cells using light as an energy source.

PLANKTON - Suspended organisms that have relatively low powers of locomotion, or that drift in the water subject to the action of waves and currents.

POLLUTION - A general term signifying the introduction into water of micro-organisms, chemicals, wastes or sewage which renders the water unfit for its intended purpose.

POTABLE - Water fit for human consumption.

PPD - Pounds per day.

PRODUCERS - Organisms that synthesize organic material from inorganic substances, e.g., plants.

PROLIFIC - Pertaining to organisms that have a high reproduction rate and normally produce large numbers of young.

QUALITY - A term to describe the composite chemical, physical, and biological charactertistics of a water with respect to its suitability for a particular use.

RECEIVING WATERS - Rivers, lakes, oceans, groundwater, or other water courses that receive treated or untreated wastewaters.

RESERVOIR - A pond, lake, or basin, either natural or created in whole or in part by the building of engineering structures, which is used for storage, regulation, and control of water.

RUNOFF - That part of the precipitation which runs off the surface of a drainage area and reaches a stream or other body of water.

SALINITY - The relative concentrations of salts, usually sodium chloride, in a given water.

SESTON - All material, both organic and inorganic, suspended in a waterway.

SEWAGE - Waterborne human waste and waste from domestic activities, such as washing, bathing, and food preparation.

SOLIDS, SETTLEABLE - Solids which will subside in quiescent water, sewage, or other liquid in a reasonable period. Such period is commonly taken as 1 hour.

SOLIDS, SUSPENDED - Solids that either float on the surface of, or are in suspension, in water, sewage, or other liquids, and which are largely removable by laboratory filtering.

SOLIDS, TOTAL - The solids in water, or other liquids; includes the suspended solids and the filterable solids.

SOLIDS, TOTAL DISSOLVED - Solids physically dissolved chemically dispersed in water or as they are sometimes called filterable residue.

SOLIDS, VOLATILE - The quantity of solids in water, sewage, or other liquid, lost on ignition of the total solids.

SPECIES - An organism or organisms forming a natural population, or groups of populations, that transmit specific characteristics from parent to offspring. Each species is reproductively isolated from other populations with which they might breed.

STABILIZATION POND - A basin used for retention of wastewater before final disposal. Oxidation of organic material is effected by the transfer of oxygen to the water from air.

STRATIFICATION - A condition in a body of water, usually a reservoir or lake, where aerobic conditions exist in the upper portion of the containment and anaerobic conditions exist in the bottom portion; the distinct horizontal layers of water may be caused by density gradient, temperature, or dissolved solids.

SUBSTRATE - The bottom material of a waterway; the base or substance upon which an organism is growing.

SULPHATES - Minerals that occur naturally in waters as a result of leaching.

TAILWATER - Excess surface water from irrigational practices that may eventually reach a water course.

THERMOCLINE - Point of maximal decrease in temperature with depth.

TIDE - The alternate rising and falling of water levels, twice in each lunar day, due to gravitational attraction of the moon and sun in conjunction with the earth's rotational force.

TOXIC MATERIALS - Those materials which, when introduced to an organism, produce an injurious or lethal effect.

TRICKLING FILTER - A filter consisting of an artificial bed of coarse material over which wastewater is applied. The wastewater trickles to the underdrains giving the bacteria the opportunity to clarify and oxidize the wastewater.

TROPHOGENIC ZONE - The area of a body of water where organic production takes place on the basis of light energy and photosynthetic activity.

TROPHOLYTIC ZONE - The deep area of a body of water where organic breakdown predominates because of light deficiency.

TURBIDITY - Any finely divided, insoluble impurities that mar the clarity of the water.

WASTEWATER - A combination of the liquid and water-carried wastes from a community; includes domestic sewage, industrial wastes, wastes from agricultural practices such as feedlots and irrigation tailwaters, and any other unwanted liquids.

WATERBORNE - The movement of material in or on a body of water.

WATERSHED - The area contained within a drainage basin above a specified point on a stream, sometimes used synonymously with river basin.

WATER YEAR - A twelve month period which extends from October of the previous year to September of the current year, i.e., Water Year 1974 is from October 1973 thru September 1974.