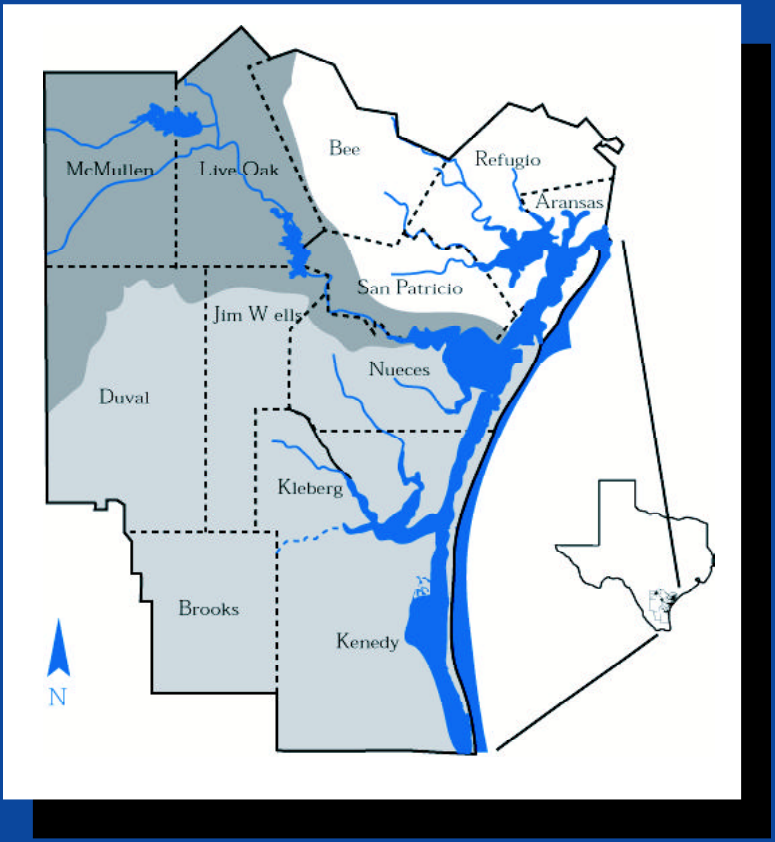
Current Status and Historical Trends of Ambient Water, Sediment, Fish and Shellfish Tissue Quality in the Corpus Christi Bay National Estuary Program Study Area

Summary Report



Corpus Christi Bay National Estuary Program
CCBNEP-13 • March 1997

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Current Status and Historical Trends of Ambient Water, Sediment, Fish and Shellfish Tissue Quality in the Corpus Christi Bay National Estuary Program Study Area

Summary Report

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CORPUS CHRISTI BAY NATIONAL ESTUARY PROGRAM

The Corpus Christi Bay National Estuary Program (CCBNEP) is a four-year, community based effort to identify the problems facing the bays and estuaries of the Coastal Bend, and to develop a long-range, Comprehensive Conservation and Management Plan. The Program's fundamental purpose is to protect, restore, or enhance the quality of water, sediments, and living resources found within the 600 square mile estuarine portion of the study area.

The Coastal Bend bay system is one of 28 estuaries that have been designated as an **Estuary of National Significance** under a program established by the United States Congress through the Water Quality Act of 1987. This bay system was so designated in 1992 because of its benefits to Texas and the nation. For example:

- Corpus Christi Bay is the gateway to the nation's sixth largest port, and home to the third largest refinery and petrochemical complex. The Port generates over $1 billion of revenue for related businesses, more than $60 million in state and local taxes, and more than 31,000 jobs for Coastal Bend residents.
- The bays and estuaries are famous for their recreational and commercial fisheries production. A study by Texas Agricultural Experiment Station in 1987 found that these industries, along with other recreational activities, contributed nearly $760 million to the local economy, with a statewide impact of $1.3 billion, that year.
- Of the approximately 100 estuaries around the nation, the Coastal Bend ranks fourth in agricultural acreage. Row crops -- cotton, sorghum, and corn -- and livestock generated $480 million in 1994 with a statewide economic impact of $1.6 billion.
- There are over 2600 documented species of plants and animals in the Coastal Bend, including several species that are classified as endangered or threatened. Over 400 bird species live in or pass through the region every year, making the Coastal Bend one of the premier bird watching spots in the world.

The CCBNEP is gathering new and historical data to understand environmental status and trends in the bay ecosystem, determine sources of pollution, causes of habitat declines and risks to human health, and to identify specific management actions to be implemented over the course of several years. The 'priority issues' under investigation include:

- altered freshwater inflow
- declines in living resources
- loss of wetlands and other habitats
- bay debris
- degradation of water quality
- altered estuarine circulation
- selected public health issues

The **COASTAL BEND BAYS PLAN** that will result from these efforts will be the beginning of a well-coordinated and goal-directed future for this regional resource.

STUDY AREA DESCRIPTION

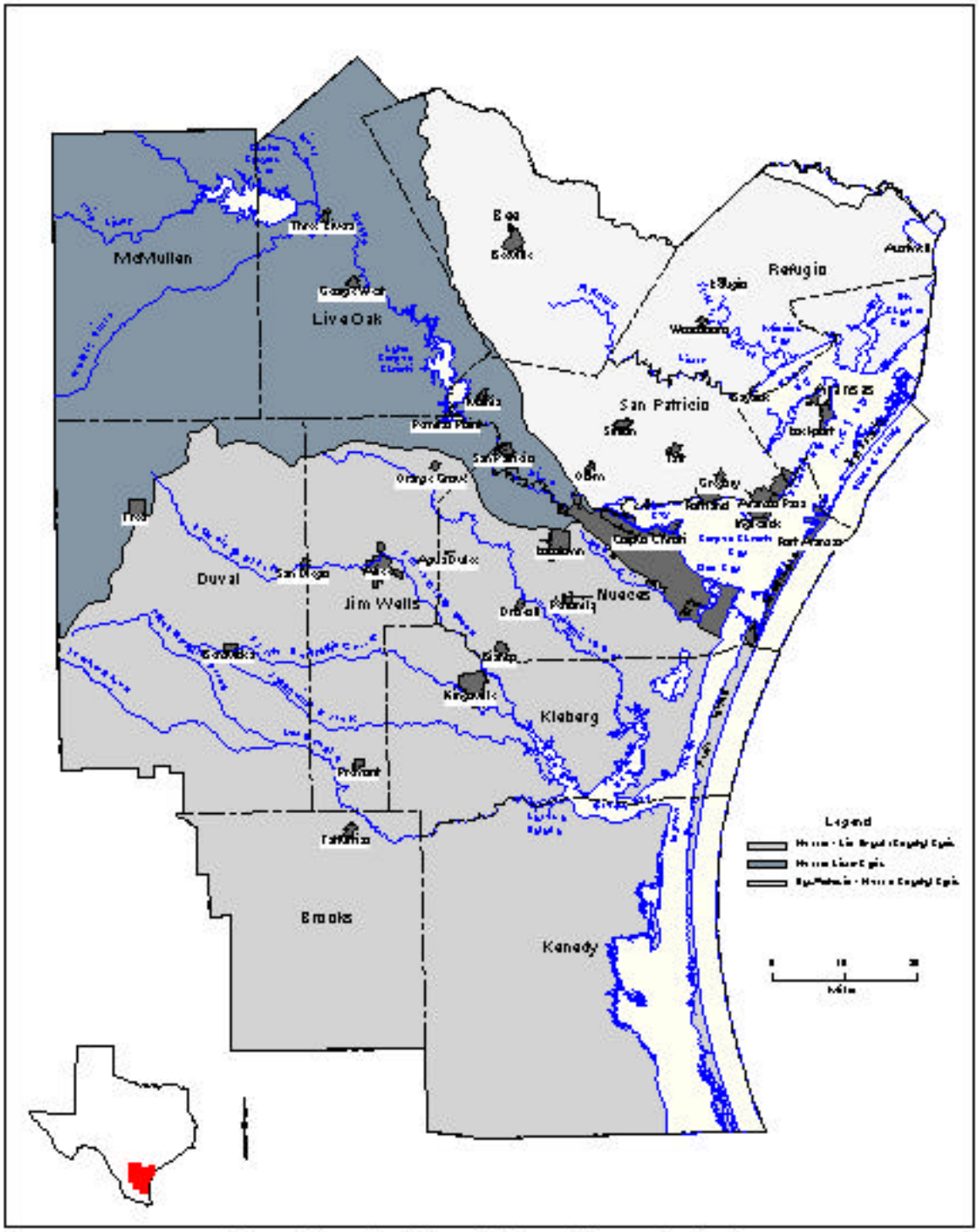
The CCBNEP study area includes three of the seven major estuary systems of the Texas Gulf Coast. These estuaries, the Aransas, Corpus Christi, and Upper Laguna Madre are shallow and biologically productive. Although connected, the estuaries are biogeographically distinct and increase in salinity from north to south. The Laguna Madre is unusual in being only one of three hypersaline lagoon systems in the world. The study area is bounded on its eastern edge by a series of barrier islands, including the world's longest -- Padre Island.

Recognizing that successful management of coastal waters requires an ecosystems approach and careful consideration of all sources of pollutants, the CCBNEP study area includes the 12 counties of the Coastal Bend: Refugio, Aransas, Nueces, San Patricio, Kleberg, Kenedy, Bee, Live Oak, McMullen, Duval, Jim Wells, and Brooks.

This region is part of the Gulf Coast and South Texas Plain, which are characterized by gently sloping plains. Soils are generally clay to sandy loams. There are three major rivers (Aransas, Mission, and Nueces), few natural lakes, and two reservoirs (Lake Corpus Christi and Choke Canyon Reservoir) in the region. The natural vegetation is a mixture of coastal prairie and mesquite chaparral savanna. Land use is largely devoted to rangeland (61%), with cropland and pastureland (27%) and other mixed uses (12%).

The region is semi-arid with a subtropical climate (average annual rainfall varies from 25 to 38 inches, and is highly variable from year to year). Summers are hot and humid, while winters are generally mild with occasional freezes. Hurricanes and tropical storms periodically affect the region.

On the following page is a regional map showing the three bay systems that comprise the CCBNEP study area.



Corpus Christi Bay National Estuary Program Study Area

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AMBIENT WATER, SEDIMENT AND TISSUE QUALITY OF CORPUS CHRISTI BAY STUDY AREA: PRESENT STATUS AND HISTORICAL TRENDS

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EXECUTIVE SUMMARY

For many years, data on the physico-chemical quality of water and sediment have been collected in the Corpus Christi Bay system by a variety of organizations and individuals. The purpose of this project was to compile these data, and to perform a quantitative assessment of water and sediment quality of Corpus Christi Bay and its evolution over time. Tissue quality was included as well in the project scope. There were three key objectives:

(1) compilation of a comprehensive data base in machine-manipulable format;
(2) analysis of space and time variation in water, sediment and tissue quality parameters;
(3) identification of probable causal mechanisms to explicate the observed variations.

Their accomplishment provides a foundation for further scientific study of the Corpus Christi Bay system, and for a general understanding of the controls and responses of its water and sediment quality, which must underlie rational management of the resources of the system.

A principal product of this study is the compilation of a digital data base composed of water-quality, sediment-quality and tissue-quality data from 30 data collection programs performed in Corpus Christi Bay. This compilation included data from the three most important ongoing monitoring programs in Corpus Christi Bay: the Texas Natural Resource Conservation Commission (TNRCC) Statewide Monitoring Network, the Texas Parks and Wildlife Department (TPWD) hydrographic observations from its Coastal Fisheries program, and the hydrographic and biochemical data of the Texas Department of Health Seafood Safety Division program. The important surveys and research projects sponsored by the Texas Water Development Board (TWDB) and maintained in its digitized Coastal Data System are included. Several recent federal data-collection projects are represented, namely those of the U.S. Corps of Engineers (USCE) Galveston District, Environmental Protection Agency (EPA), National Ocean Service, and U.S. Fish & Wildlife Service.

This compilation also entailed keyboarding of other major data sets, many of which exist in limited hardcopy and are virtually unobtainable, including the U.S. Corps of Engineers Galveston District water and sediment surveys of the 1970's, data of the Texas Game Fish & Oyster Commission from the 1960's, the Reynolds-sponsored "baseline" surveys of the early 1950's, the Submerged Lands Project of the Bureau of Economic Geology, and the data collections by the now-defunct Ocean Science and Engineering Laboratory of Southwest Research Institute. Other entries in this compilation include research projects whose data are published only in limited technical reports or academic theses, all of which were keyboarded. A major data compilation effort of the project was devoted to determination of latitude/longitude coordinates based upon historical sampling station location information, so that all of the data could be unambiguously georeferenced. In addition to supporting the spatial-distribution analyses of this study, this georeferencing data will facilitate incorporation of the data base into geographical information systems.

All told, the digital compilation is the most extensive and detailed long-term record of water and sediment quality ever assembled for Corpus Christi Bay. The study area for this compilation and analysis extends from the landbridge of the Laguna Madre to the southern limit of San Antonio Bay, and includes Baffin Bay, Corpus Christi Bay proper, the Aransas-Copano system, and Mesquite/Ayres Bay. We refer to Aransas, Copano and their secondary systems (including Mesquite) as the upper bays, and to Baffin Bay and the Upper Laguna Madre as the lower bays. The entire CCBNEP study area is referred to as the Corpus Christi Bay "system," to differentiate it from Corpus Christi Bay proper, unless it is clear in context that the CCBNEP study area is intended (such as the first sentence of this paragraph). The complete data base approaches half a million independent records of which water:sediment:tissue are in the approximate ratios 100:10:2, and about 43% of the water-phase data are the "field" parameters temperature/salinity/pH/dissolved oxygen. Each measurement record includes the date, sample depth, latitude and longitude of the sample station, measured variable, estimated uncertainty of measurement expressed as a standard deviation, and a project code identifying the origin of the data. (For tissue data, the sample depth field is replaced by a code identifying the organism.)

The extant period of record for Corpus Christi Bay, with adequate continuity for trends analysis, extends back only to about 1965, except for some traditional parameters and for certain areas of the bay, for which the record can be extended back to the 1950's. As salinity and temperature are the most easily measured variables, they represent the densest and longest data record. For metals and for complex organics, the period of record may extend back only a decade or so. Many of these measurements are below detection limits. For sediment, the data base is even more limited, amounting to one sample per 50 square miles per year, and extending back in time at most to the 1970's.

Spatial aggregation of the data was accomplished by two separate segmentation systems for Corpus Christi Bay, the TNRCC Water Quality Segmentation of 27 segments, and a system of 178 hydrographic segments devised by this project and designed to depict the effects of morphology and hydrography on water properties. (The 27 TNRCC segments include the

original 15 specified by the Scope of Work, to which we added 5 classified segments and 7 unclassified.) For each segment of both systems, detailed statistical analyses were performed of 109 water-quality parameters and 83 sediment-quality parameters, in addition to supplementary, screened, or transformed variables. Each statistical analysis included basic sampling density information, means and standard deviations, with three different treatments of measurements below detection limits (BDL), and a linear trend analysis over the period of usable record, with confidence limits on the slope. Therefore, statistical analyses addressing water/sediment quality were performed of about 200 parameters in about 200 different segments, a total of about 40,000 independent statistical analyses, since each parameter/segment comprises an independent data set. For tissue data, an even more extensive suite of analytes were compiled, but the statistical analyses were confined to a subset of these analytes because of the sparsity of the data base. In addition to parameter differentiation, tissue data had to be further separated according to organism, portion of organism analyzed (i.e., whole versus fileted), and reporting by dry- or wet-weight, each combination of which represented an independent statistical analysis.

A summary of the findings on the water and sediment quality "climate" begins with salinity, which acts as a water mass tracer and general habitat indicator for Corpus Christi Bay. In contrast to the estuaries on the upper Texas coast, salinity gradients across Corpus Christi Bay from the sea to the regions of inflow are on average rather flat. The most substantial gradient of salinity is, rather, from north to south, from Copano Bay to Baffin Bay, a combined result of diminishing inflow with distance to the south and increasing evaporation. Mean salinities often exceed seawater concentrations, sometimes by large amounts, especially in the lower bays (the Upper Laguna and Baffin Bay). Vertical salinity stratification of bay waters is slight by estuarine standards, generally averaging less than 0.6 ppt/m. There is no apparent correlation between mean salinities and ship channels, suggesting that density currents as a mechanism of salinity intrusion are rarely important in Corpus Christi Bay. While freshwater inflow is the ultimate control on salinity, inflow proves to be a poor statistical predictor of individual measurements of salinity, even with long-term averaging of the antecedent inflow. This illustrates that the variability of salinity is influenced by factors other than simply the level of inflow.

In the bays more influenced by freshwater inflow, *viz.* Copano Bay, the main body of Corpus Christi Bay and Nueces Bay, there has been a general increase in salinity over the three-decade period of record, on the order of 0.1 ppt per year. During the same period there has been a declining trend in monthly-mean inflow to these same bays, over 50% in Corpus Christi and Nueces Bays, less in Copano (which also logged a smaller increase in salinity). Our favored hypothesis is that this decline in mean inflow, which appears to be due to diminishing frequency and magnitude of freshets, is responsible for the increase in salinity. No clear trends in salinity emerged for the Upper Laguna or Baffin Bay.

The principal variation in water temperature in Corpus Christi Bay is the seasonal signal, ranging about 14 to 30 C from winter to summer, which means that temperature is primarily controlled by surface fluxes, especially the seasonal heat budget, and much less by peripheral

boundary fluxes and internal transports. The horizontal gradient across the study area is from north to south, ranging 2-4 C. There is little systematic stratification, on average a slight upward increase on the order of 0.1 C/m, due to near-surface heat absorption. Over the three-decade period of record, water temperature in the upper bays and main body of Corpus Christi Bay, especially in the open waters, has declined at a nominal rate of 0.05 C/yr. There are no clear trends in the lower bays. It is interesting to note that the same decline in temperature, at approximately the same rate, was discovered in Galveston Bay (Ward and Armstrong, 1992a).

TNRCC applies a 35 C temperature standard uniformly to the entire Texas coast, without cognizance of the natural gradient of increasing temperatures toward the south (a gradient to which the indigenous organisms would have presumably acclimated). The shallow, poorly circulated sections of the Corpus Christi system are most prone to higher temperatures, especially those in the lower bays, and exceedances of the TNRCC 35 C standard occur at a low rate a couple of percent mainly in summer. Only two regions have substantially higher frequencies of exceedance, in Nueces Bay and Oso Bay, both affected by return flows from power plants. Given this low frequency of exceedance coupled with the general decline in water temperatures over time, we conclude that hyperthermality is not a problem in Corpus Christi Bay.

Dissolved oxygen (DO) consistently averages near (and above) saturation through-out the CCBNEP study area, with frequent occurrence in the data record of substantial supersaturation. Exceptions to this are in poorly flushed tributaries and areas influenced by wasteloads, especially the Inner Harbor. The pre-dominant variation in DO is due to seasonal changes of solubility. In the open, well-aerated areas of the bay, vertical stratification is slight, averaging on the order of 0.1 ppm/m, and is considered to be the result of DO aeration at the surface in concert with water-column and sediment biochemical oxygen consumption.

We examined episodic occurrence of low DO's. Hypoxia (which we define to be DO 2 ppm) is rare, occurring at most in several percent of the data in a minority of regions of the bay, and primarily in measurements near the bottom in deeper water. The exception is the Inner Harbor, where hypoxia has occurred more frequently, in about one-fourth of the measurements, but still primarily near-bottom. Near-zero DO (defined to be DO 0.5 ppm) is rarer yet, representing perhaps half of the hypoxia events, mainly confined to the Inner Harbor and Nueces River.

Most areas of the bay have a relative frequency of DO below the TNRCC standard of 5 ppm (without vertical averaging, diurnal-excursion allowance, or screening by flow, as required for its direct applicability) of a couple of percent, almost always in the summer or early fall. There are scattered higher frequencies of violations, especially in proximity to sources of inflow and wasteloads, and in the shallow, poorly-circulating areas near the barrier island, especially in the Upper Laguna. The apparent contradiction between the observation that the system is at or above saturation much of the time, and yet has a nonnegligible frequency of

standard violation, 10-20% in a few areas, is reconciled by noting that much of the year DO solubility falls very close to the standard, because of the high natural tempera-tures and salinities in this area. This also implies that the clearance between solubility and a level of DO stress is small, so under these conditions the assimilative capacity for oxygen demands may be limited.

Conventional water-phase organic contaminants as measured by biochemical oxygen demand (BOD), oil & grease, volatile suspended solids (VSS) and volatile solids, are generally highest in the Inner Harbor. The frequency of measurement of these parameters has declined substantially in recent years, and trends are therefore uncertain. In the open waters of Corpus Christi Bay, BOD seems to be declining, and wherever adequate data for analysis exist, VSS is declining, probably the result of improved waste treatment.

Like all of the Texas bays, Corpus Christi is turbid. Long-term average total suspended solids (TSS) range 20-100 ppm throughout most of the study area, higher in Nueces, Copano and Corpus Christi Bay, as well as in Baffin. Stratification in TSS is noisy, but on the order of 5 ppm/m declining upward, which is consistent with settling of larger particles to the bottom as well as a near-bottom source of particulates from scour of the bed sediments. The highest TSS concentrations and highest stratification are found in Nueces Bay.

The most remarkable feature of TSS is its decline over time, increasing in signifi-cance from north to south across the study area, at a rate sufficient to have reduced the average concentration by about 25% in the upper bays and by about 50% in the lower bays over the last two decades. This could be caused by several factors, including a general reduction of TSS loading to the bay or altered mobilization within the bay system itself. Suspended sediment is an intrinsic and important aspect of the Corpus Christi Bay environment; its decline is not necessarily beneficial.

Nitrogen and phosphorus nutrients in the water column are highly variable. Ammonia nitrogen is generally higher in regions affected by waste discharges, especially the Inner Harbor, while nitrate nitrogen and phosphorus are typically highest in regions affected by runoff and inflow. Concentrations of inorganic nitrogen are about 0.1 ppm, except much higher, around 0.5 ppm, in Copano and in the Inner Harbor (the latter due to high ammonia). Total phosphorus is about 0.05 ppm, except around 0.15 ppm in Nueces Bay, Copano Bay and Baffin Bay. These mean concentrations are more-or-less typical of other Texas bays (e.g., Longley, 1994), though total inorganic nitrogen is about half the levels found in Galveston Bay and total phosphorus is about one-fourth (Ward and Armstrong, 1992a). Generally where the nitrogen species are high in concentration, they exhibit a declining trend. No clear trends are apparent in the phosphorus data. In the sediment phase, highest concentrations of Kjeldahl nitrogen occur in the Inner Harbor region, and the Upper Laguna. Sediment phosphorus is relatively uniform throughout the system.

Generally water-phase total organic carbon (TOC) values decrease southward from 20-30 ppm in Copano to 5-15 ppm in Baffin and the Laguna, with a seasonal peak in early summer.

Larger values (by an order of magnitude) occur in the Inner Harbor. Sediment TOC distributions generally run counter to the water phase, increasing southward across the study area with the lowest values of sediment TOC in the Inner Harbor. Nueces Bay shows substantially depressed values of TOC in both water and sediment. There is a widespread declining trend in water-phase TOC at a rate that would reduce concentrations by about one-fourth over two decades. (The prominent exception to this is in the Inner Harbor, where average water-phase TOC is the highest in the study area, and is increasing in time.) Where sufficient sediment TOC data exist to establish a trend, this trend generally is also declining in time. Unfortunately, the data for chlorophyll-a is too sparse and noisy to determine whether any correlated time trends occur in it as well, so we cannot judge whether the decline in TOC is due to reduced primary production or to reduced loadings.

Contaminants such as coliforms, metals and trace organics show elevated levels in regions of runoff and waste discharge, with generally the highest values in the Inner Harbor, and low values in the open bay waters. The highest average coliforms in the system occur in the nearshore segments of Corpus Christi Bay from Corpus Christi Beach to Oso Bay. Nueces Bay is a region consistently high in metals, in both the water column and the sediment, as are Baffin Bay, Copano Bay, a region of the Upper Laguna around the Bird Islands, the La Quinta Channel, and Redfish Bay near Aransas Pass. The metals copper, nickel and zinc, in particular, have elevated concentrations in water generally throughout Corpus Christi Bay. The water-phase metals data were so sparse and noisy in time that reliable trends could not generally be established. With respect to sediment metals, arsenic, cadmium, mercury, and zinc are elevated, with concentrations generally on the same order as Galveston Bay. Inner Harbor sediment metals are similar to the upper Houston Ship Channel except zinc, for which its sediments are an order of magnitude *higher* than those of the Houston Ship Channel. This raises the speculation of whether the Inner Harbor could be the ultimate source for elevated zinc in the system. For sediment metals in the principal components of the system, where a trend can be reliably established it is generally declining. An exception to the general declining trends is sediment zinc, for which widespread possible increasing trends are indicated in large areas of the open waters of Corpus Christi Bay and Baffin Bay.

No definitive statements can be made about water-phase semi-volatile organics such as pesticides and PAH's, because data is sparse, and very few measurements are uncensored, most being simply reported as below detection limits. For example, the best-monitored pesticide is DDT, for which most areas of the bay do not have data. Only four non-zero average values occur in the entire study area, two in Ayres Bay, and one each in Nueces Bay and Baffin Bay. For toxaphene, only one non-zero value occurs, in Nueces Bay. The situation is similar for the other organics, with only one or a few non-zero values, and inadequate data to determine any trends or spatial variation.

The situation is a little better for sediment-phase data, but still most of the system is unsampled, and much of the data which does exist is below detection limits. The highest concentrations of the common pesticides are found in Baffin Bay and Copano Bay. Concentrations of sediment pesticides in Nueces Bay are not especially high, except for

toxaphene. PCB's and PAH's exhibit very high concentrations in the Inner Harbor. Elevated concentrations of PCB's also occur in Redfish Bay. There are consistent elevated concentrations of some of the PAH compounds in Nueces Bay, Copano Bay, and Mesquite Bay, but not in the Upper Laguna.

Considering the effort required to obtain, digitize and compile the tissue data for the CCBNEP study area, the information yield is disappointing. Pooling and analysis of the data are hampered by the noncomparable attributes of organism sampled, portion of organism analyzed (whole versus edible portions), and reporting convention (wet-weight versus dry-weight), in addition to the usual discriminants of analyte and geographical position. The most-sampled organism is the American oyster, with most samples from Nueces and Aransas Bays, followed by the blue crab, speckled trout, red drum and black drum. There is one sample each of brown shrimp and white shrimp. By far, the greatest quantity of analyses have been performed for the metals. For the oyster, Nueces Bay and Copano Bay exhibit systematically elevated metals in the tissue, Nueces Bay having the highest mean tissue concentrations in the study area for cadmium, copper, lead and zinc. This conclusion generally agrees with the relative concentrations in the sediments, if the Inner Harbor and tertiary bays are discounted. Blue crab data in Redfish Bay and Baffin Bay show elevated levels of most metals. Statistical analysis of the black drum data base was possible only for Nueces Bay, which indicated some elevated metals concentrations, especially for mercury and zinc, and when a time trend could be resolved, it is increasing. The data base of *detected* PAH's and related hydrocarbons is negligible. For only a few, such as pyrene, have there been detects logged in the data.

From a systemic point of view, the most significant potential problems affecting the study area as a whole are suspended particulates, nutrients and salinity. As summarized above, declines of TSS, inorganic nitrogen and TOC were found. More data is needed to determine whether there is a decline in productivity, or what the optimum levels are for Corpus Christi Bay. Salinity of Corpus Christi Bay has been a major source of controversy, especially within the past decade, because of its perceived value as a habitat indicator that also measures freshwater inflow. At this writing, the City of Corpus Christi water supply in the Nueces River reservoirs is threatened by a drought, and the conflict between human water-supply requirements and the needs of the estuary ecosystem has been brought into sharp relief. One result of the present study, disclosure of increasing salinity that seems to be associated with declines in mean inflow, suggests that salinity will continue to be at the center of management issues and strategies for this system, even after the current drought has abated.

Several deficiencies of this data set are noted, as they relate to the interpretation of water and sediment quality. Adequacy of a data base is judged relative to the ability to resolve the various scales of variation, and in this respect Corpus Christi Bay is undersampled. An estuary such as Corpus Christi Bay is subject to a variety of external controls, all of which contribute to variation in space and time. The intermixing of fresh and oceanic waters imposes spatial gradients in both the horizontal and the vertical. The effects of tides,

meteorologically driven circulations, and transient inflows all contribute to extreme variability in time. Superposed upon all of this are the time- and space-varying influences of human activities.

Despite the hundreds of thousands of separate measurements compiled in this study, from extensive and overlapping routine monitoring and survey programs by several state agencies and numerous special surveys, when these data are subdivided by specific parameters, each of which measures a different aspect of the water/sediment quality "climate," aggregated by region of the bay (segments) and distributed over time, the data record is seen to be rather sparse. Continuity in space is undermined by too few stations, and by inconsistency in the suite of measurements at different stations. Ability to resolve long-term trends in the face of high intrinsic variability requires data over an extended period. Continuity in time is undermined by infrequent sampling, and the replacement of one parameter by another without sufficient paired measurements to establish a relation.

After a relative peak in the mid-1970's, data collection, as reflected in the number of sampling programs underway and the density of the network of stations, has been declining. Considering that Corpus Christi Bay is undersampled, this trend is in the wrong direction. (There are some exceptions: there have been recent increases in salinity and DO sampling, mainly due to the activities of TPWD, and in trace constituent sampling, due to increased concern with metals and organic toxicants and to the advancement of instrumental analysis.) To maintain a monitoring project within limited resources requires a compromise between station density, temporal frequency, and the extent of the suite of analytes. Cost for all three have been increasing, the last due to more precise and expensive laboratory methodologies. There is no doubt that economics is one of the prime factors forcing the recent decline in all of these, especially in the spatial and temporal intensity of sampling. That does not mitigate the fact that our ability to understand and manage Corpus Christi Bay is concomitantly diminished.

Data management is generally poor. Both modern and historical data bases have been compromised in various ways. Too many entries in the data record had to be excluded from the analyses presented here because the data were unreliable. It is our belief that much of this unreliability was not introduced in the original measurement but in the subsequent handling of the data. The most pressing management problem for historical data in the Corpus Christi area, as well as in other areas of the Texas coast, is preservation of the older data. Much irreplace-able and invaluable information on the Corpus Christi Bay system has been lost.

Recommendations are offered for data-collection procedures, data management, historical data management, and specific research topics.

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ABBREVIATIONS AND ACRONYMS

AA	atomic absorption
AE	atomic emission
APHA	American Public Health Association
BaP	benzo(a)pyrene
BDL	below detection limits
BEG	Bureau of Economic Geology
BOD	biochemical oxygen demand
BOGAS	Based On Graphical or Arithmetical Suppositions
CBI	Conrad Blucher Institute of TAMU Corpus Christi
CCBNEP	Corpus Christi Bay National Estuary Program
CC-NCHD	Corpus Christi-Nueces County Health Department
CCSC	Corpus Christi Ship Channel
CD	compact disc
CD-ROM	compact disc-read-only medium [memory]
CDS	Coastal Data System of TWDB
cfs	cubic feet per second
COD	chemical oxygen demand
CP&L	Central Power and Light
DDT	dichlorodiphenyltrichloroethane
DL	detection limit
DO	dissolved oxygen
EM	electromagnetic
EMAP	Environmental Monitoring and Assessment Program
EPA	Environmental Protection Agency, also USEPA
FTU	Formazin Turbidity Unit
GBNEP	Galveston Bay National Estuary Program
GC-MS	gas chromatograph-mass spectrometer
GIWW	Gulf Intracoastal Waterway
GOM	Gulf of Mexico
GPS	Geographical [Geodetic, Global] Positioning Systems [Satellites]
HDR	Henningson, Durham and Richardson, Inc.
HSPF	Hydological Simulation Program FORTRAN
TU	Jackson Turbidity Unit
LORAN	Long-Range [Radio] Navigation
MGD	million gallons per day
MW	megawatts
NIST	National Institute of Standards and Technology
NOAA	National Oceanic and Atmospheric Administration
NOS	National Ocean Service of NOAA
NOS S&T	National Ocean Service Status and Trends Program
NTU	Nephelometric Turbidity Unit
O&M	Operations and Maintenance
PAH	polycyclic aromatic hydrocarbon
PCB	polychlorinated biphenyl

PI	Principal Investigator
QA/QC	quality assurance and quality control
SEE	standard error of the estimate
SES	steam-electric station
SMN	Statewide Monitoring Network
SWRI	Southwest Research Institute
TAMU	Texas A&M University
TDH	Texas Department of Health
TDWR	Texas Department of Water Resources
TGFOC	Texas Game, Fish and Oyster Commission
TNRCC	Texas Natural Resource Conservation Commission
TOC	total organic carbon
TPWD	Texas Parks & Wildlife Department
TSS	total suspended solids
TWC	Texas Water Commission
TWDB	Texas Water Development Board
USCE	U.S. Corps of Engineers, U.S. Army Corps of Engineers, U.S. Army Engineer
USEPA	U.S. Environmental Protection Agency, also EPA
USF&WS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
VSS	volatile suspended solids

Abbreviations for water and sediment quality analytes are given in Table 2-4.

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1. INTRODUCTION

1.1. Background and project motivation

The Corpus Christi region could be characterized as geographically and culturally transitional, lying between the chaparral brush country to the south and the coastal-plain grassland prairies to the north, and influenced by the vast coastal-plain ranches of south Texas, the planters from the east, and Spanish traditions from the south. The region is also transitional from a perspective of hydroclimatology, being tropical much of the time, but still far enough north to be influenced by the midlatitude westerlies. It is also usually arid, but the exceptions are extreme: freshets on the Nueces and diluvial tropical storms, either of which can result in flooding and render much of the bay fresh. These extremes in hydroclimatology are also the primary external forcings of Corpus Christi bay that ultimately govern its quality.

Urbanization and industry are relative latecomers to the area. The boom of prosperity in Texas in the last quarter of the Nineteenth Century expressed itself in the Corpus Christi area as expansions in ranching, agriculture, and commercial fishing, in synergism with incursions of railroads and shipping, and, of course, tourism. But the population increase attending this expansion was modest in comparison to that of the upper coast. By 1900, Houston and its port had become a major industrial center, while Corpus Christi was regarded as primarily a tourist resort. Only in the 1930's did heavy industry begin to develop with construction of the Southern Alkali Corporation plant (which used oyster shell from Nueces Bay) situated on the industrial canal. Oil production began in this same decade of the 1930's near White Point and in the Saxet Field which stimulated shipping and later refining, and was the major impetus for growth in the area.

For Corpus Christi Bay and the adjacent systems of Aransas-Copano Bay and Laguna Madre, concerns about the quality of the system have arisen rather more recently than for the urbanized and industrialized bays on the upper Texas coast. Up to World War II, there appear few reports or indications of perceived pollution problems in the Corpus Christi area, in contrast to the upper coast. Far more fish kills had occurred in the Corpus Christi Bay system due to freshets and freezes than to contamination. In the last two decades public attention and concern for the Corpus Christi Bay system has changed. With accelerating urban develop-ment, awareness of the potential impacts on the bay has increased, and maintenance of the health of the system and its reconciliation with goals of municipal growth and industrial development has become a major issue. With this concern is the recognition that the quality of Corpus Christi Bay must be managed.

The cornerstone of management of a natural system like Corpus Christi Bay is the ability to determine responses of the system to changes in external or controlling factors, i.e. its "controls," in the form of cause-and-effect relations. Two elements are needed in order to appraise variation in water quality and to identify its cause. First is a

quantitative measure, i.e. identification and analysis of a parameter (or parameters) indicative of water quality. Complaints of declines in a fishery, for example, are dramatic evidence of something, but offer little basis for scientific evaluation. Instead, a physical or chemical parameter (or several, or many) is needed upon which the viability of that fishery depends, and which represents the impacts of some natural or human process on waters of the bay. The second element needed is an extensive data base on the parameter. The data base must have sufficient spatial and temporal resolution to establish the variation of the parameter, and must also encompass a considerable period of time. This extensive data base, of course, is the real obstacle.

Generally, any single data-collection program lacks the resources and longevity to develop a data base sufficiently comprehensive for analysis of water quality levels and trends in a system such as Corpus Christi Bay. This is due to the extreme natural variability of the water-quality parameters. The best prospect for a definitive study is to begin with a synthesis of data from a number of programs, using the entire spatial and temporal scope of each program.

1.2 Project approach and prosecution

For many years, data relating to the quality of water and sediment have been collected in the Corpus Christi Bay system by a variety of organizations and individuals. The objectives of data collection have been equally varied, including the movement and properties of water, the biology of the bay, waste discharges and their regulation, navigation, geology and coastal processes, and fisheries. While the specific purposes of the individual data collection projects have limited each project in time and space, the data have great potential value to the Corpus Christi Bay National Estuary Program (CCBNEP) if they can be combined into a comprehensive data base yielding a historical depiction of the quality of the bay environment.

The purpose of this project was to compile and evaluate these data, and to employ these data in a quantitative assessment of water and sediment quality of Corpus Christi Bay and its evolution over time. There were several subordinate objectives in the project, as outlined in the following sections. However, the key objectives were threefold, *viz.*:

(1) compilation of a comprehensive data base in machine-manipulable format,

(2) analysis of time and space variation (including “trends”) in quality parameters,

(3) identification of possible causal mechanisms to explicate the observed variations.

Securing these objectives will provide a foundation for further scientific study of Corpus Christi Bay, for identifying and prioritizing specific problems affecting the

quality of the Bay, for formulation and specification of future monitoring programs for the Bay, and for a general understanding of the controls and responses of Bay water quality, which must underlie rational management of the resources of the system.

The Scope of Work for this project also included compilation and analysis of fish and shellfish tissue data. This has a logical appeal in that most of the agencies engaged in the collection of tissue chemistry data are also those from which water/sediment chemistry data were to be sought. This tissue data, however, proved to be more trouble than it was worth. There is very little of it, over a relatively short period of record, and it is reported inconsistently, which required a disproportionate effort for its compilation and analysis. While this report focuses on the water and sediment quality analyses, tissue data will be reported wherever appropriate.

The study area for this project encompasses the estuarine and coastal nearshore areas of the Coastal Bend area, extending from the mud flats (a.k.a. middle ground, a.k.a. landbridge, a.k.a. landcut) of the Laguna Madre to the southern limit of San Antonio Bay, and includes Baffin Bay, Corpus Christi Bay proper and its secondary embayments, the Aransas-Copano system, and Mesquite/Ayres Bay. We refer to Aransas, Copano and their secondary systems (including Mesquite) as the upper bays, and to Baffin Bay and the Upper Laguna Madre as the lower bays. We attempt to differentiate between the Corpus Christi Bay "system," i.e. the CCBNEP study area, and the subregion of Corpus Christi Bay proper by appropriate qualifiers when necessary, but generally rely upon the context to clarify. Procedures of data processing and the overall data base for Corpus Christi Bay are summarized in Chapter 2, the analyzed water, sediment and tissue quality data are presented in Chapter 3, the possible cause-and-effect processes suggested by associations in the data are discussed in Chapter 4, and a summary of conclusions and list of recommendations are given in Chapter 5. These are all abridged from the Project Final Report (Ward and Armstrong, 1997a), which should be consulted for technical details.

Many of the data sets employed in this study exist only in a limited number of hard copies. A major part of the effort of this project was invested in keyboarding this data to create a digital data base. Even when the data could be obtained in a digital format on magnetic media, a still-substantial effort was necessary to reformat and georeference the data. The problems of acquiring such data sets would be a formidable obstacle to any future researcher's compiling an adequate data base for Corpus Christi Bay. Therefore, we regard the synthesized digital data base as a major product of the project as it allows future researchers much greater scope in analysis than could be afforded by the data sets normally available to individual scientists. A companion report (Ward and Armstrong, 1997b) addresses the data base itself, documenting the sources for the data, formatting of the data, and data base conventions, and should function as a Users Guide to the data base.

The core of the project results is considered to be the analyzed water and sediment quality data, summarized here in Chapter 3. Our philosophy is to differentiate the *facts*

of the data, as presented in Chapter 3, from the *interpretation* of the data, reserved for Chapter 4. The interpretations postulate conceptual models and may be biased by the predilections of these investigators. Certainly, they will be subject to revision upon additional data collection or more sophisticated analyses. However, the results of the data presentation should stand as *facts*, circumscribed only by the statistical measures employed, and the criteria for rejection or weighting.

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