

**Report of Literature Review
On Discharges from the Rio Grande and
Arroyo Colorado and their Impacts**

Coastal Impact Monitoring Program

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Report of Literature Review on Discharges from the Rio Grande and Arroyo Colorado and their Impacts

Coastal Impact Monitoring Program

Abstract

The literature is reviewed on water quality and water-related natural resources of the Rio Grande between Falcon Dam and the Gulf of Mexico, the geographical area within 100 km of this river reach, and the Gulf of Mexico within a 100 km radius of the mouth of the Rio Grande. In addition to this river reach, water bodies reviewed are the Arroyo Colorado, resacas, the Lower Laguna Madre of Texas, and the Laguna Madre de Tamaulipas.

The purpose of the literature survey is to identify information relevant to discharges from the Rio Grande and Arroyo Colorado and the potential and known impacts of these discharges within the project area, identify those areas where there is an absence or paucity of data, and make recommendations for future studies.

Focus is on (1) freshwater inflows, (2) toxic substances, (3) non-point pollution, (4) pollutant dispersal patterns, (5) areas of known and potential sinks, (6) known and potential impacts of hazardous wastes on flora and fauna, (7) known and potential impacts of nutrient loading on flora and fauna, and (8) habitat changes, status, and trends in aquatic resources, and (9) identities and status of endangered and threatened species within the project area.

The review is current to 1 March 1994. A print and a computer-accessible, annotated bibliography is separately published in association with this report: Water-related Natural Resources of the Lower Rio Grande Valley of Texas.

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PREFACE

The project area is defined in Texas General Land Office Contact 94-099R as “that area within 100 kilometers on either side of the international border from Brownsville, Texas, to the mouth of the Rio Grande and including that area within a 100-kilometer radius into the Gulf of Mexico from

the mouth of the Rio Grande.” This definition includes the tidal segment of the Rio Grande and a small portion of the “Rio Grande Below Falcon Reservoir” segment. Thus, the definition does not provide a geographically or biologically pertinent starting point for coverage of the Rio Grande. We have used Falcon Dam as the starting point for consideration of the Rio Grande. Doing so also permits inclusion of the starting point of the Main Floodway and Arroyo Colorado drainage system in the report.

The tasks of the literature survey are to: (1) conduct a search for information relevant to discharges from the Rio Grande and Arroyo Colorado, and the potential or known impacts of these discharges within the project area; (2) identify those areas where there is an absence of data; and (3) produce an annotated bibliography of the relevant literature in written and electronic formats. The review is to focus on literature pertaining to: (1) freshwater inflows, (2) toxic substances, (3) nonpoint pollution, (4) pollutant dispersal patterns, (5) areas of known and potential sinks, (6) known and potential impacts of hazardous wastes on flora and fauna, (7) known and potential impacts of nutrient loadings on flora and fauna, and (8) habitat changes, status, and trends in aquatic resources. Riparian communities along the Rio Grande, Arroyo Colorado, and resacas are included because they buffer these aquatic habitats from nonpoint pollution and they provide significant portions of the remaining habitat for wildlife in the area.

This review is organized into sections by major aquatic habitats; i.e., Rio Grande, Arroyo Colorado, Laguna Madre, and Gulf of Mexico. A section on endangered and threatened species of the area is also included. Each of these sections includes identification of gaps in the literature and recommendations for future studies. A comprehensive contamination study conducted throughout the Lower Rio Grande Valley of Texas in 1985-86 by the U.S. Fish and Wildlife Service (USFWS) is reviewed separately because data were summarized for localities, and contamination can't be compared between sites such as the Rio Grande and Arroyo Colorado. Problem areas identified in the study are discussed in the pertinent sections of this report.

The literature cited in this report was taken from a larger base of citations included in the bibliography.

SUMMARY OF INFORMATION GAPS AND RECOMMENDATIONS

Rio Grande

Information gaps

- Monitoring data are insufficient, either because there are too few monitoring stations, existing stations are monitored infrequently, or too few parameters are monitored to properly evaluate the factors that impact water quality.
- Insufficient monitoring data makes it difficult to assess nonpoint-source pollution and limits the conclusions that can be drawn regarding toxic material loadings.
- The existing toxic substance database is inadequate to assess the risk to aquatic life and human health.

Recommendations

- A toxic substance loading inventory for the lower reach of the Rio Grande needs to be developed.
- All point sources of discharge into the Rio Grande below Falcon Dam need to be identified and routinely sampled.
- Plans for providing drinking water and wastewater services to “colonias” in the lower Rio Grande Valley should be pursued.
- Study is needed of how future reservoirs in Mexican tributaries to the Rio Grande will affect salinity in the river during low flow periods.
- Testing is needed to document pesticide contamination and its effects on wildlife, including invertebrates, in the riparian corridor.
- Species suspected to be particularly sensitive to toxic substances and increasing salinity should be identified and their populations monitored. Data analyses should include attempts to establish relationships between biological parameters (such as density) and physicochemical water quality variables.
- Much basic research on the life histories of species in the Rio Grande and its floodplain biotic communities is needed.
- A unified, statewide data management system for storing and retrieving data pertinent to the Rio Grande is needed.
- A detailed land classification of land use and vegetation type and density should be prepared for the area one km on each side of the Rio Grande from Falcon Dam to the Gulf of Mexico.

Resacas

Information gaps

- The water quality of resacas is inadequately known.
- The areal extent of resacas is inadequately quantified.
- Species composition and abundance in resacas is inadequately known.

Recommendations

- Municipalities should be responsible for monitoring water quality within their boundaries.
- A monitoring program for those portions of resacas outside municipalities should be established.
- Standardization of water quality parameters and methodology for all municipal and non-municipal resacas is needed.
- A replicable survey of the aquatic and riparian fauna, including invertebrates, and flora, including nonvascular plants, of resacas is needed.
- A detailed physical survey of the Rio Grande Valley resacas is needed and should be used for preparing a GIS base map.

Arroyo Colorado

Information gaps

- Insufficient monitoring data are available to assess nonpoint-source pollution and toxic material loadings.
- Absence of a monitoring station at the mouth of the Arroyo Colorado makes it difficult to determine the quantity of nutrients discharged into the Lower Laguna Madre.
- The distribution of nutrients with depth is not known since only surface samples are taken.
- The effect of nutrient loading resulting from the discharge water from shrimp culture farms to the Arroyo Colorado is inadequately known.

Recommendations

- A comprehensive study to identify and quantify the inputs for point and nonpoint sources and toxic materials loading should be initiated.
- A monitoring station should be established at the mouths of the Arroyo Colorado and North Floodway that would permit quantification of the volumes of flow and loading of nutrients and toxic materials.
- Existing sampling programs should be expanded to provide for multi-depth quantification of nutrient concentration.
- A study throughout a year is needed to establish seasonal and operational variability of the nutrient load of the discharge of the shrimp culture farms at the Arroyo Colorado.
- A comprehensive study of the fishes of the Arroyo Colorado is needed.

Lower Laguna Madre

Information gaps

- Studies of water quality of the Lower Laguna Madre have been relatively limited in geographic coverage and have focused on harbors and channels.
- Present studies of water quality have been conducted over very short time periods, so little is known about seasonal variation.
- Studies on the effects of brown tide on the Laguna Madre ecosystem have been restricted to the Upper Laguna Madre.
- The effect of waters from the Arroyo Colorado and North Floodway on Lower Laguna Madre biotic communities is inadequately known.

Recommendations

- A comprehensive water quality study covering the entire Lower Laguna Madre is needed. The focus should be on contaminants known, or found, to be present in the major drains.
- A comprehensive water quality study should include sampling at least four times during each year, and should be done for at least three years.
- Sediment concentrations of heavy metals should be determined at a series of stations throughout the Lower Laguna Madre to provide comparison of values to the sediment of harbors and channels. Stations should include the mouths of major drains.
- The effects of brown tide on Lower Laguna Madre ecosystem deserves study.
- A three-year study focusing on the impacts of the Arroyo Colorado and North Floodway, and their dilution with increasing distance from the mouths, on Lower Laguna Madre biotic communities should be initiated.
- The water quality of San Martin Lake and the Brownsville Ship Channel should be monitored at a frequency sufficient to quantify seasonal and annual variations.
- Siltation effects on oyster reefs in South Bay should be quantified.
- The types and magnitudes of influence of the Gulf of Mexico, and its dilution with increasing distances from the inlets, on the environment of the Lower Laguna Madre should be studied.
- Routine studies done in the Lower Laguna Madre that including measurements of water, sediment, tissue or physical parameters should be coordinated, when practical, to allow the eventual evaluation of the nutrient and contaminant fluxes in the lagoon. Likewise, intensive studies designed to evaluate the Lower Laguna Madre as an integrated system should be supported.

Gulf of Mexico

Information gaps

- Information on contaminants and their concentrations in water and in organisms offshore from the mouth of the Rio Grande is inadequate.
- The relationship between concentration of pollutants and distance from the mouth of the Rio Grande is not known.
- The kinds and concentrations of chemicals that may be carried northward from Mexico into U.S. waters by the prevailing longshore current is not known.
- The possible effect of contaminants from the Rio Grande and other Mexican rivers on species and biotic communities in the Gulf of Mexico is not known.

Recommendations

- Studies are needed to identify specific contaminants and their concentrations in water and organisms offshore from the mouth of the Rio Grande.
- The relationship between concentration and distance from the mouth of the Rio Grande needs to be established for pollutants known to be in river water.
- A study is needed to determine the kinds and concentrations of chemicals that may be carried northward from Mexico into U.S. waters by the prevailing longshore current.
- The effect of contaminants from the Rio Grande and other Mexican rivers on species and biotic communities in the Gulf of Mexico should be determined.

Note

- The Gulf of Mexico Regional Marine Research Program held a workshop 28 to 29 January 1993 to identify areas of deficient information and understanding in the Texas portion of the Gulf of Mexico. Topics identified at the workshop are included in this report.

Endangered and Threatened Species

Information gaps

- Information on population density and other measures of abundance are lacking for most of the endangered and threatened species in the project area.
- Basic life history information is poorly known for many endangered and threatened species in the project area.
- The status of these species in Mexico is largely unknown.

Recommendations

- Studies on the basic life history, population density, and other measures of abundance for all the endangered and threatened species in the project area should be done.
- The status in Mexico of species endangered or threatened in the project area should be determined.
- Because endangered and threatened fish species are directly dependent upon the water quantity and quality of the Rio Grande, studies should be initiated to determine their population sizes and assess seasonal and annual variation. Their habitat requirements should be quantified.
- The presence and abundance of species, including endangered and threatened species, associated with the riparian corridor of the Rio Grande and the terrestrial biotic communities of the Arroyo Colorado and their habitats should be determined.
- More information on the marine mammals in the study area is needed.
- An investigation of suitable habitats for the West Indian Manatee is needed to determine whether the Mexico population has dispersed into the study area.

General

Recommendation

- A comprehensive set of Geographic Information System (GIS) coverages should be prepared and made available to all interested agencies and researchers. These coverages should contain data critical to continuation of the Coastal Impact Monitoring Program (CIMP) and understanding of the project area. The information should be prepared in a format and to standards consistent with state and federal data standards and strategic plans, and should be accessible both in hard copy and in an electronic format, preferably on-line computer access via Internet or a similar utility. Provision should be made to update the information periodically to maintain its usefulness and to make it available to Mexican universities, and state and federal agencies.

**AREA-WIDE CONTAMINATION STUDY
U.S. FISH AND WILDLIFE SERVICE 1985-86**

Introduction

Gamble et al. (1988) conducted an extensive two-phase study to determine the extent of organochlorine, trace element, and petroleum hydrocarbon contamination in the Lower Rio Grande Valley of Texas (LRGV) in 1985 and 1986. Phase 1 involved the collection of sediment samples throughout the LRGV for analysis of trace elements, organochlorines, and polycyclic aromatic hydrocarbons. Phase 2 involved the collection of fish, birds, oysters, blue crabs and aquatic vegetation for similar analyses. Because of its comprehensive coverage (both geographically and compounds) this study is reviewed separately.

Sediment was collected at 95 sites throughout the LRGV in July and August 1985 and biota were sampled at 64 sites in July and August 1986. The scientific and common names of organisms collected are provided in Table 1. Gamble et al. (1988) identified the species collected at each site in their Table B-2, which also describes the sites. It is five pages long and not repeated here. Similarly, sediment sites are described in their Table B-1. It is seven pages long and not repeated here. The compounds and elements analyzed in this study are provided in Table 2.

Gamble et al. (1988) combined their results for sample sites, so that data are not provided for individual sites. Thus, one cannot compare contamination between sites such as the Rio Grande and Arroyo Colorado. However, the authors identify problem areas in their discussion.

Organochlorines

Fifteen organochlorine compounds were found above detection limits in all samples (sediment

Table 1. Scientific and common names of species sampled in 1985-1986 contaminants study of Lower Rio Grande Valley. Taken from Gamble et al. (1988).

	Common Name	Scientific Name
Aquatic Vegetation	Chara (musk grass)	<i>Chara sp.</i>
	Shoal grass	<i>Halodule wrightii</i>
	Manatee grass	<i>Syringodium filiforme</i>
Marine Invertebrates	Blue crab	<i>Callinectes sapidus</i>
	Eastern oyster	<i>Crassostrea virginica</i>
Reptiles	Texas spiny softshell turtle	<i>Trionyx spiniferus emoryi</i>
Mammals	Hispid cotton rat	<i>Sigmodon hispidus</i>
Fish	Freshwater drum	<i>Aplodinotus grunniens</i>
	Sea catfish	<i>Arius felis</i>
	Sheepshead minnow	<i>Cyprinodon variegatus</i>
	Common carp	<i>Cyprinus carpio</i>
	Gizzard shad	<i>Dorosoma cepedianum</i>
	Gulf killifish	<i>Fundulus grandis</i>
	Mosquitofish	<i>Gambusia affinis</i>
	Blue catfish	<i>Ictalurus furcatus</i>
	Channel catfish	<i>Ictalurus punctatus</i>
	Alligator gar	<i>Lepisosteus spatula</i>
	Largemouth bass	<i>Micropterus salmoides</i>
	Striped bass hybrid	<i>Morone chrysops x Morone saxatilis</i>
	Sailfin molly	<i>Poecilia latipinna</i>
Tilapia	<i>Tilapia sp.</i>	
Birds	Red-winged blackbird	<i>Agelaius phoeniceus</i>
	Black-necked stilt	<i>Himantopus mexicanus</i>
	Herring gull	<i>Larus argentatus</i>
	Laughing gull	<i>Larus atricilla</i>
	Ring-billed gull	<i>Larus delawarensis</i>
	Franklin's gull	<i>Larus pipixcan</i>
	Plain chachalaca	<i>Ortalis vetula</i>
	American white pelican	<i>Pelecanus erythrorhynchos</i>
	Pied-billed grebe	<i>Podilymbus podiceps</i>
	Great-tailed grackle	<i>Ouiscalus mexicanus</i>
Forster's tern	<i>Sterna forsteri</i>	

Table 2. Compounds and elements analyzed in sediment and biota from the Lower Rio Grande Valley of Texas, 1985-1986. Taken from Gamble et al. (1988).

ALKANES	ORGANOCHLORINES	ELEMENTS
n - DODECANE (n-C12) ⁴	OXYCHLORDANE	ALUMINUM(AL)
n - TRIDECANE (n-C13)	c - CHLORDANE	ANTIMONY(SB) *
n - TETRADECANE (n-C14)	t - CHLORDANE	ARSENIC (AS)
OCTYLCYCLOHEXANE (n-C14)	c - NONACHLOR	BARIUM(BA)
n - PENTADECANE (n-C15)	t - NONACHLOR	BERYLLIUM(BE)
NONYLCYCLOHEXANE	HEPTACHLOR	BORON(B)
n - HEXADECANE (n-C16)	HEPTACHLOR EPOXIDE	CADMIUM(CD)
n - HEPTADECANE (n-C17)	METHOXYCHLOR	CHROMIUM(CR)
PRISTANE	o,p' - DDE	COPPER(CU)
n - OCTADECANE (n-C18)	o,p' - DDD	IRON(FE)
PHYTANE	o,p' - DDT	LEAD(PB)
n - NONADECANE (n-C19)	p,p' - DDE	MAGNESIUM(MG)
n - EICOSANE (n-C20)	p,p' - DDD	MANGANESE(MN)
n - HENEICOSANE (n-C21)	p,p' - DDT	MERCURY(HG)
	MOLYBDENUM(MO)	ENDRIN
	NICKEL(NI)	DIELDRIN
	SELENIUM(SE)	ALDRIN
	SILVER(AG)	alpha-BHC
	STRONTIUM(SR)	beta-BHC
	THALLIUM(TL)	gamma-BHC
	TIN(SN) *	delta-BHC
AROMATIC	HEXACHLOROBENZENE	VANADIUM(V)
HYDROCARBONS	ENDOSULFAN I	ZINC(ZN)
	ENDOSULFAN II	
	ENDOSULFAN SULFATE	* SEDIMENT
	MIREX	ONLY
	DCPA	
	DICOFOL	
NAPHTHALENE	TETRADIFON	
FLUORENE	AROCHLOR 1221	
PHENANTHRENE	AROCHLOR 1016	
ANTHRACENE	AROCHLOR 1232	
FLUORANTHRENE	AROCHLOR 1242	
PYRENE	AROCHLOR 1248	
1,2 - BENZANTHRACENE	AROCHLOR 1254	
CHRYSENE	AROCHLOR 1260	
BENZO(b)FLUORANTHRENE	AROCHLOR 1262	
BENZO(k)FLUORANTHRENE	TOTAL PCB'S	
BENZO(e)PYRENE	TOXAPHENE	
BENZO(a)PYRENE		
1,2,5,6-DIBENZANTHRAC		
BENZO (g,h,i) PERYLENE		

- 1 ALKANES - BIOTA ONLY
- 2 ORGANOCHLORINES - BIOTA AND SEDIMENT
- 3 ELEMENTS -BIOTA AND SEDIMENT
- 4 CARBON NUMBER IN THE COMPOUND
- 5 AROMATICS - BIOTA AND SEDIMENT

and biota) analyzed, but only nine were common; i.e., detected in more than 10 percent of the samples. These nine common organochlorine compounds were DDD, DDE, DDT, dieldrin, endrin, methoxychlor, oxychlorane, t-nonachlor, and toxaphene. All nine were detected in fish. DDE occurred in all samples, DDD in 76 percent of the samples, and DDT in 42 percent of the samples.

All but one of the 15 organochlorines, hexachlorobenzene, was detected in the softshell turtle (*Trionyx spiniferus*). A white pelican (*Pelecanus erythrorhynchos*) carcass, found at the Pharr Settling Basin, contained eight of the nine most common organochlorines. The residues of DDE (46.1 ppm), dieldrin (0.8 ppm), and endrin (0.29 ppm) were the highest concentrations found in the biota samples. Cotton rats (*Sigmodon hispidus*) contained six of the common organochlorines, and five were detected in blue crabs (*Callinectes sapidus*). Gamble et al. (1988) pointed out that detection of 15 different organochlorine insecticides in soil and a wide variety of animal tissues was a consequence of their use in the widespread agriculture of the LRGV. Most of these organochlorines have been banned, have restricted uses, or are being phased out of use (Gamble et al., 1988). Several have been restricted from use on most crops for many years but still persist in soil and animal tissue.

DDE and toxaphene residues were elevated compared to national baseline data, but the maximum levels were much lower than the levels that White et al. (1983) reported for the Arroyo Colorado for a collection made 8 to 10 years earlier. Thus, Gamble et al. (1988) concluded that DDE levels were declining in the area. However, they also concluded that DDE levels in fish were sufficiently high to cause some degree of eggshell thinning in fish-eating birds, but not high enough to cause bird population declines. Toxaphene was detected in fish at levels associated with reduced growth, reduced fecundity, and abnormal bone growth (Gamble et al., 1988), and toxaphene concentrations had not declined like those of DDE. Four locations were identified as having especially high DDE and toxaphene residues in turtle and fish. These were the Llano Grande on the Arroyo Colorado, Laguna Atascosa and Cayo Atascosa, the Rio Grande above Anzalduas Dam, and the Resaca de los Cuates.

Trace Elements

Trace elements were generally low in the biota, but some fish samples had elevated chromium and copper levels. Three fish samples had high chromium concentrations (whole body, dry weight).

One tilapia (*Tilapia* sp.) composite sample from the upper end of Resaca de los Cuates had 14.0 ppm chromium. One gizzard shad (*Dorosoma cepedianum*) composite sample from Pintail Lake at Santa Ana National Wildlife Refuge contained 7.7 ppm. And the concentration of one carp composite collected from Falcon Reservoir was 4.8 ppm. It is important to note that sediment and other biota from these locations had much lower concentrations of chromium. Six fish samples (locations not given) had elevated copper concentrations.

Petroleum Hydrocarbons

Aliphatic hydrocarbons (alkanes) were detected most frequently in softshell turtles (*Trionyx spiniferus*), fish (species not given), blue crabs (*Callinectes sapidus*), and cotton rats (*Sigmodon hispidus*). Gamble et al. (1988) concluded that both petroleum hydrocarbon and biogenic sources contributed to the concentrations, but that biogenic sources were the major contributors.

Polycyclic aromatic hydrocarbons were found in five sediment samples. The sample with the highest levels was from the Turning Basin of the Brownsville Ship Channel, also known as the Brownsville Harbor Channel. The second highest level was from Resaca Lozano Banco near downtown Brownsville. All but one of the compounds analyzed for was found here. Except for these two sites, polycyclic aromatic hydrocarbon levels were generally low or below detection limits. Spillage of petroleum products was the suspected source at the Brownsville Ship Channel, and automobile emissions were thought to be the source at the resaca.

Comments

This study identified compounds and trace elements of concern and areas where contamination in sediment and/or tissues was high. Future studies should examine these same materials and areas. Duplication of this study soon will be especially beneficial to allow comparison of possible changes over an approximately ten-year period. It is important to obtain data over several years at the same sites so that trends may be identified.

RIO GRANDE

Description

The Rio Grande is legendary for its role in the history of the southwestern U.S.A. and Mexico, and it is the second longest river system in the U.S.A. (Horgan, 1954). The river extends 3,040 km (1,888 miles) from its source in the San Juan Mountains of Colorado to the mouth at the Gulf of Mexico (Gilpin, 1949).

The lower reach of the Rio Grande has generally been considered the portion of the river from the entry of the Rio San Juan (near Rio Grande City, Texas) to the Gulf of Mexico (Bowman, 1993), but it may be appropriate to designate the starting point of the lower reach as Falcon Dam, which is located approximately 40 km upriver at Ciudad Guerrero, Mexico, and Falcon Heights, Texas (Edwards and Contreras-Balderas, 1991).

Floodplain. The Rio Grande floodplain is less than 1.6 km wide in northwestern Starr County where the river leaves the impoundment of Falcon Dam. The floodplain is approximately 10 km wide in Hidalgo County and broadens into a wide delta fronting the Gulf of Mexico near the mouth of the river in Cameron County. The delta includes old meanders of the river (resacas) that are fringed by natural levees (Lonard et al., 1991). Soil associations along the Rio Grande belong either to the Rio Grande-Matamoros or Rio Grande-Reynosa associations and are characterized as deep, moderately to slowly permeable, nearly level, silty loams or silty clays (Thompson et al., 1972; Williams et al., 1977; Jacobs, 1981). Except for a low rise known as the Mission Ridge, all of the area on the Texas side of the river has been subject to flooding in the past (Clover, 1937). However, dams (particularly Falcon Dam in 1953) and drainage projects have eliminated the cyclic flooding of the river.

Flow. Flow in the lower reach of the Rio Grande consists of releases from Falcon Dam, runoff from local rains, field runoff from irrigation, and industrial and municipal effluent from Texas and Mexico (Breuer, 1970; Jahrsdoerfer and Leslie, 1988).

Droughts occur periodically in the region, but the only time flow ceased in the lower reach of the Rio Grande (in recorded history) was during the severe drought of the 1950s (Edwards and

Contreras-Balderas, 1991). During that time, flow ceased from the mouth to a point east of Brownsville (Trevino-Robinson, 1955; 1959).

Dams and Diversions. There are three dams in the lower reach of the Rio Grande: Falcon, Anzalduas, and Retamal. Falcon Dam is by far the largest. It has a capacity of 3,978,000 acre-ft (2,677,000 acre-ft for conservation storage and 1,311,000 acre-ft for flood control storage). Anzalduas Dam (south of Mission, Texas) was completed in 1960, and this construction project also included alteration of the floodway system along the Rio Grande (Jahrsdoerfer and Leslie, 1988). At Anzalduas Dam, the Mexico share of irrigation water is diverted into a main irrigation canal, and more than eighty percent of the U.S.A. share of floodwaters is diverted into Banker Floodway (Jahrsdoerfer and Leslie, 1988). Between Anzalduas Dam and Brownsville, Texas, 16 major pumping stations lift water from the Rio Grande into conveyance canals that serve irrigation districts and industrial and municipal water users in Cameron, Hidalgo, and Willacy counties. Retamal Dam (south of Weslaco, Texas) is a diversion dam lacking flood storage capabilities. It diverts flood flows that exceed 20,000 cubic feet per second to the Retamal Floodway in Mexico (Jahrsdoerfer and Leslie, 1988). Several weirs in the Rio Grande below Retamal Dam raise the water level and facilitate pumping into conveyance canals.

Fish

Edwards and Contreras-Balderas (1991) report that the fish fauna of the lower Rio Grande has not been well studied. They examined historical series of fish collections from this part of the Rio Grande during the last 150 years to discern changes in the fish fauna that might be correlated with changes in the river's physical environment. Apparently, there are two fish fauna assemblages in the lower Rio Grande (Edwards and Contreras-Balderas, 1991). One is upstream, composed of mostly freshwater species, and the other is a downstream assemblage composed of a mixture of upstream elements and estuarine species. Recent collections indicated that major alterations in these fish communities have occurred. The upstream fauna has lost many of its characteristic freshwater species. Here, native freshwater species have been replaced by exotic (= non-native) or estuarine species. The downstream fauna had many fewer freshwater taxa, and absent elements

were replaced by estuarine and marine species. Edwards and Contreras-Balderas (1991) state that these faunal changes appear to be correlated with decreasing stream flows, the proliferation of exotic species, and increases in chemical pollution.

Riparian Forest

Description. Riparian forest and woodland communities are small, narrow corridors of vegetation along rivers and streams that add significant diversity to areas, especially in semi-arid regions such as southern Texas and northern Mexico. Typically, riparian communities are characterized by species unique from those of the adjacent uplands (Lowe, 1964). The only quantitative studies of the floodplain vegetation of the Texas-Mexico portion of the Rio Grande are those of Butterwick and Strong (1976) and Vora (1990). Butterwick and Strong (1976) studied a 20 km stretch in Starr County immediately downstream from Falcon Dam that is known as the “Rio Grande-Falcon Thorn Woodland.” They listed the species identified in a survey of the area and provided cover and density data for species encountered in nine 100 m-long line transects. Vora (1990) identified floodplain plant communities in the Santa Ana Wildlife Refuge. He provided percent cover values and density estimates of trees and shrubs based on data obtained from 31 plots of 0.1 hectares. Other studies providing information about the composition and structure of riparian woodland along the lower reach of the Rio Grande include Clover (1937), Davis (1942), Lonard and Judd (1985, 1991), and Lonard et al. (1991). Lonard et al. (1991) characterized the floodplain vegetation of the river in the lower Rio Grande Valley, drawing on the earlier studies of Clover (1937) which described the vegetation of the entire LRGV. Davis (1942) listed species and described the general aspects of the *Sabal texana* forest in Cameron County. Lonard and Judd (1975, 1991) provided information on woody species present and their susceptibility to freezing temperatures. There has been no comprehensive quantitative study of the floodplain vegetation along the entire lower reach of the Rio Grande.

Wildlife Corridor. Riparian forest along the lower reach of the Rio Grande has been identified by the USFWS and Texas Parks and Wildlife Department (TPWD) as an area where wildlife habitat is rapidly vanishing and in dire need of protection. To preserve (and to re-establish) the

riparian forest and establish a “wildlife corridor” along the Rio Grande, the Texas and U.S. governments are purchasing land parcels. The goal is to acquire a continuous riparian corridor along the Rio Grande from Falcon Dam on the west to the mouth at Boca Chica on the east (Jahrsdoerfer and Leslie, 1988).

Flooding. Gehlbach (1981) emphasizes that periodic flooding is a critical physical factor needed to maintain natural conditions in subtropical, floodplain forests. Apparently, the riparian communities along the Rio Grande already suffer from loss of annual or semi-annual floods. Controlled release of water prevents normal flooding cycles and contributes to the replacement of mesic riparian woody species such as cedar elm (*Ulmus crassifolia*) and Montezuma bald cypress (*Taxodium mucronatum*) with more xeric species such as mesquite (*Prosopis glandulosa*) (Judd, 1985b; Ramirez, 1986).

Importance of Riparian Communities. Changes in the plant community along a stream such as the Rio Grande can affect the stability of the banks, flood behavior, wildlife, and aesthetic values (Harris, 1986). Riparian trees help reduce bank erosion, and their roots contribute to riffle and pool morphology of a stream (Mason et al., 1984).

A body of evidence is accumulating that riparian forests and associated vegetation provide significant water quality protection for their associated stream ecosystems and groundwater supplies. Phillips (1989) indicated that all riparian forests provide significant water supply protection, and that a buffer forest width of 60 m is generally adequate for soils likely to be used for agriculture. Brenner et al. (1991) reported that total phosphates are significantly lower at stations where riparian vegetation is at least 50 percent intact within 100 m of a stream. Lowrance (1992) reported that nitrates in groundwater decrease by a factor of seven to nine in the first 10 m of riparian forest. Therefore, denitrification potentials in surface soils are significant, especially near agricultural field and forest interfaces. Brenner et al. (1991) and Paterson and Schnoor (1992) have shown that riparian woodlands are effective in abating fecal coliform bacteria, suspended solids, and agricultural pesticides (alachlor and atrazine) in water supplies.

Current Status. Since the early 1900s, vegetation along the Rio Grande has been cleared for farming, improved range and pastures, urban development and industrialization (Jahrsdoerfer and

Leslie, 1988). Water development projects have also resulted in the clearing of native vegetation. Today along the Rio Grande below Falcon Dam it is estimated that 99 percent of the land has been cleared for agriculture and development (Jahrsdoerfer and Leslie, 1988). There has been no effort to quantify the density, width, or linear extent of riparian forest that may serve as a buffer zone for runoff from agricultural fields near the river. And pesticide use is great. Indeed, more than 100 pesticides are used on agricultural crops throughout the Lower Rio Grande Valley of Texas (USFWS, 1986; Jahrsdoerfer and Leslie, 1988).

Water Quality and Quantity

Texas Water Quality Inventory. The Texas Water Quality Inventory is prepared and submitted to the United States Environmental Protection Agency (EPA) by the Texas Natural Resource Conservation Commission (TNRCC), formerly the Texas Water Commission (TWC), in accordance with Section 305(b) of the Clean Water Act (Texas Water Commission, 1992b). The report is prepared every two years and describes the status of the state's waters based on the most recent four years of monitored surface and groundwater quality data. An overview is provided of water quality trends, the extent to which surface water quality standards are attained, the relative impacts of pollutants from various sources, water bodies where additional actions are needed, and existing and planned water pollution control programs. Surface water quality data are summarized for individual, river, reservoir number, bay number, estuary, and Gulf of Mexico segments. Information is provided on the state's wetlands. Groundwater quality within each major river basin is described.

Elevated fecal coliform levels occur in the river downstream of major United States-Mexico border cities due to municipal waste treatment facilities in Texas and untreated or partially treated wastewater in Mexico (Texas Water Commission, 1992a). Levels of chloride, sulfate, and total dissolved solids are increasing in the Rio Grande downstream of Falcon Reservoir due to groundwater seeps and return flows from irrigated lands.

Designated Uses. The Texas Water Commission (1992a) divides the lower reach of the Rio Grande into two segments. Segment 2301 is designated as "Rio Grande Tidal" and extends upriver from the mouth at Boca Chica 79 kilometers (49 miles) to a point 10.8 km (6.7 miles) downstream

of the International Bridge at Brownsville, Texas. Segment 2302 is designated as “Rio Grande Below Falcon Reservoir” and extends 371 km (231 miles) from a point 10.8 km (6.7 miles) downstream of the International Bridge at Brownsville, Texas, to Falcon Dam in Starr County. There is one monitoring station for Segment 2301 and five monitoring stations for Segment 2302. There are two permitted domestic outfalls and one permitted industrial outfall in the Rio Grande Tidal segment. The Rio Grande Below Falcon Reservoir segment has nine permitted domestic outfalls and three permitted industrial outfalls. The Rio Grande Tidal segment is designated for contact recreation and exceptional-quality wildlife habitat. It has elevated dissolved oxygen levels due to algal metabolism and elevated mean phosphorus and chlorophyll *a* levels (Texas Water Commission, 1992a), but water quality criteria for designated uses are met. The Rio Grande Below Falcon Reservoir segment is designated for contact recreation, but a portion of this segment does not meet the criteria for contact recreation use due to elevated fecal coliform bacteria levels. Supersaturated dissolved oxygen concentrations occur due to algal metabolism, and there are elevated levels of chloride, sulfate, and total dissolved solids.

Toxic Chemicals. TNRCC has launched a cooperative international study of the entire reach of the Rio Grande within Texas to evaluate possible toxic chemical contamination (Texas Water Commission, 1992b). Samples will be taken to determine residual contamination and toxicity of water and sediment, and to evaluate the health of benthic macroinvertebrates. Major tributary flows to the Rio Grande from both sides of the river will be sampled and fish will be collected upstream and downstream of each U.S.-Mexico border city. The TNRCC has added a wide spectrum of organic compounds (including solvents) and metals in water, sediment, and fish tissue, along with toxicity testing of water and sediment to its routine monitoring schedule.

Agricultural pesticides are used throughout the year in the area and may enter aquatic systems (such as the Rio Grande) directly as a result of aerial application or indirectly as runoff from treated fields. A preliminary study by the TNRCC reported finding deformed fish and pesticides and heavy metals in some fish downstream from Laredo (Texas Water Commission, 1992b).

Anencephaly. Reports of this sort, coupled with a high incidence of anencephaly, a lethal birth defect, in Matamoros and Brownsville have apparently caused some health workers to suggest that

anencephaly could be related to contamination from pesticides carried in agricultural runoff, but proof is lacking (Bowman, 1993). In April 1991, several health care providers in Brownsville, Texas, became concerned when three anencephalic deliveries occurred in a 36-hour period (Texas Department of Health, 1992). A preliminary review showed that six anencephalic deliveries occurred at one Brownsville hospital between March 27 and May 7, 1991. Cameron County reports about 6,000 births per year. Based on data from the Metropolitan Atlanta Congenital Defects Program from 1986 to 1990, fewer than two cases of anencephaly per year in Cameron County would be expected. Members of the community suggested that this cluster of anencephalic births was caused by environmental exposures in the area, such as the pesticide contamination, and releases from the maquiladora industry in Mexico. A resulting study by the Texas Department of Health (1992) showed that the overall rate of anencephalic births in Cameron County over the period 1986 to 1991 was 19 per 10,000 births. This was less than the highest historical rates reported in the United States, and less than rates currently reported in Mexico. But, the rate was more than double the current U.S. rate, and the rate for 1990-91 in Cameron County was about double the rate for 1986-89. Recommendations for environmental monitoring focused on toxic industrial air emissions, but recommendations for monitoring of the Rio Grande were also forwarded.

Maquiladora Industry. The maquiladora industry has been identified as a possible source of toxic chemicals in the Rio Grande, but there is little data on what kinds of wastes maquiladoras generate, how much is produced, and how they are actually disposed of. In 1990, the National Toxic Campaign Fund, an environmental organization which provides support to local citizens' groups in the United States, was asked by concerned citizens from several neighborhoods in northern Mexico to help them evaluate toxic pollution sources in their communities (Lewis et al., 1991). In response to this request, the National Toxic Campaign Fund and its affiliate, the Citizens' Environmental Laboratory, visited several cities along the northern Mexico border to test industrial discharges and receiving water. The Rio Grande was one of four border waterways investigated.

Sampling near industrial parks and maquiladoras in Matamoros revealed high levels of toxic organics and heavy metals. From a discharge adjacent to the Rimir automobile trim plant (parent corporation: General Motors) located at the Finsa Industrial Park, xylene was detected at 2,800,000

parts per billion (Lewis et al., 1991). This concentration is more than 6,000 times the U.S. drinking water standard of 440 parts per billion. This discharge was reportedly (Lewis et al., 1991) dumped into a soil canal where it could travel through the ground to the nearby Rio Grande. A canal that runs from the property of Stephan de Mexico (parent corporation: Stephan Chemicals, Northfield, Indiana) in Aldusa Industrial Park reportedly contained xylene concentration of 23,200,000 parts per billion (Lewis et al., 1991). Pentachlorophenol was reported at 505 parts per billion in discharge from Productos de Preservacion, a pesticide production facility whose parent corporations (Preservation Products, Inc., and Iacon) are from Texas.

Effects of Pesticides on Wildlife. The effects of pesticides on wildlife in the Lower Rio Grande Valley are poorly documented. White et al. (1983) reported DDE residues at “fairly high levels” in fish (*Ictalurus furcatus*, *I. punctatus*, and *Dorosoma cepedianum*) taken from the Rio Grande near Mission over the years 1968 to 1979. Gamble et al. (1988) conducted an extensive study of organochlorine, trace element, and petroleum hydrocarbon contamination in the Lower Rio Grande Valley of Texas. They identified the Rio Grande above Anzalduas Dam as having especially high residues of DDE and toxaphene in softshell turtles (*Trionyx spiniferus*) and fish (species not reported). The chromium concentration in one carp (*Cyprinus carpio*) composite sample from Falcon Lake was slightly elevated. Several papers (e.g. Thornton, 1977; Edwards and Contreras-Balderas, 1991) emphasize the relationship of high pesticide use and decline in species number and diversity of individuals in the LRGV, but few papers provide direct links. Judd (1985a) reported a die-off of Rio Grande siren (*Siren intermedia*) that was apparently due to contamination of a farm pond with insecticide (meant to deter ants from eating insulation on lines at a telephone line terminal). Forty-five Franklin’s gulls (*Larus pipixcan*) were found dead in Santa Ana National Wildlife Refuge after they ate cicadas that were contaminated with azodrin (White and Kolbe, 1985).

Water Quantity. One of the main issues confronting the Lower Rio Grande area is the scarcity of water (Bowman, 1993). Population growth has greatly increased municipal and industrial use. During the 1980s, population along the entire U.S.A.-Mexico border increased by 27 percent in the U.S.A. and by 23 percent in Mexico (Eaton and Hurlbut, 1992). The McAllen-Edinburg-Mission metropolitan area in the LRGV is the fourth-fastest growing metropolitan area in the nation, ac-

ording to 1990-92 population statistics (Valley Morning Star, Feb. 4, 1992., page B7). This area grew by 9.8 percent in the two years, from 383,545 residents in 1990 to 420,955 in 1992. During the same period the population of the Brownsville-Harlingen-San Benito metropolitan area grew 6.7 percent, from 260,120 in 1990 to 277,517 in 1992. Continued growth is expected in the future.

Water Use. Irrigation accounts for more than 70 percent of the total water consumption in the LRGV. The primary source of water for irrigation is surface water from the Rio Grande. The Texas Water Commission District 11 office (1992) reports that the main reservoir (Falcon Lake) is full, but since all water rights to the river have been allocated, water supply becomes a critical factor to continued economic growth. Water withdrawals for irrigation do not reenter the river as “return flow”; rather, the irrigation water flows into floodways and irrigation systems and eventually into the Laguna Madre, or it evaporates (Edwards and Contreras-Balderas, 1991). Bowman (1993) reports that by the year 2040, the Rio Grande water supply is expected to fall short of demand by about 274,000 acre-ft per year (demand is by users on the U.S.A. side of the river).

Water Quality. Water quality standards specifying desired water uses and numerical criteria for some parameters have been established for all segments of the Rio Grande by the TNRCC. These standards require that (where attainable) water quality support aquatic life and recreational uses; i.e., the water must be fishable and swimmable. Fecal coliform counts downstream of Brownsville, Texas (ten year, 1981-90, average = 226 colonies/100 ml) exceed the criterion (200 colonies/100 ml). The persistently elevated fecal coliform levels suggest that the Rio Grande is not suitable for contact recreation and that individuals entering the river, especially downstream of major border cities, have an increased probability of becoming infected with waterborne pathogens. These downstream sites also have generally higher nutrient levels (ammonia, nitrate nitrogen, and orthophosphorus) than upstream sites due to wastewater discharge (Texas Water Commission District 11, 1992). Temperatures have not been higher than criterion levels, and dissolved oxygen concentrations have not been lower than the minimum criterion (3 mg/l) in the lower reach of the Rio Grande (Texas Water Commission District 11, 1992).

The tissues of fish from the Rio Grande have been found to contain toxic materials (mainly DDE, Chlorodane, dieldrin, and some metals), but at levels generally below criteria established by

the U.S. Food and Drug Administration. Fish captured downstream of Laredo showed external physical deformities (fins, mouth parts, and lesions) that were not present in fish taken from sites upstream of Laredo. The cause(s) of these deformities has (have) not been identified.

Ten-year average values for chloride and sulfate have been below criterion levels in the lower reach of the Rio Grande, but the ten-year average level for total dissolved solids (938 mg/l) exceeds the criterion (880 mg/l) downstream of Brownsville (Texas Water Commission District 11, 1992). During the fall and winter months (October through February) when flow is low, the Rio Grande downstream of Falcon Dam periodically exceeds criterion levels of chloride, sulfate, and dissolved solids. These elevated levels reduce the usefulness of Rio Grande waters for irrigation (advisories occasionally have been issued against its use) and occasionally have caused damage to salt-sensitive crops such as spinach. Joint investigations by the TWC and the International Boundary Water Commission (IBWC) indicated that the elevated salinity of the Rio Grande during low flow periods is due to bank seepage of groundwater high in salt content (nonpoint sources) rather than to water from tributaries and drains (point sources). The Texas Water Commission District 11 (1992) data on chloride concentrations below Brownsville reveals a trend of gradually increasing levels from 1981 to 1990.

Wastewater. Mexico and the United States also plan to substantially increase their support for the construction and expansion of wastewater treatment facilities in the border area. Increased funding will be made available for international wastewater treatment facilities, the construction and operation of which are the responsibility of the binational IBWC, and for other facilities that are the responsibility of state and local governments (U.S. Environmental Protection Agency, 1992). The IBWC will work to ensure that industrial facilities that send their wastewater to a new or expanded treatment facility pretreat their effluent adequately. To ensure that pretreatment programs are effective, the IBWC will monitor and characterize the raw wastewater entering binational wastewater treatment facilities. The IBWC will assess whether industrial sources are complying with Mexican and U.S. environmental law (U.S. Environmental Protection Agency, 1992).

Drinking Water. Primarily due to unplanned population growth in and near sister border cities, hundreds of thousands of people (on both sides of the border) do not have access to safe drinking

water. Consequently, untreated drinking water poses a human health concern in many communities along the border (U.S. Environmental Protection Agency, 1992). The IBWC will use information supplied by Mexico's Secretaria de Desarrollo Urbano y Ecologia (SEDUE), EPA, and state and local authorities to develop an inventory of the sources, quality, and processes at existing water treatment facilities in all pairs of sister cities along the border. On the U.S. side of the border, funds will be available for the construction and improvement of water treatment systems in colonias.

Solid Waste. Mexico intends to invest approximately \$25 million to expand solid waste collection capacity and construct new landfills in several border cities. For example, about \$2 million have been pledged to purchase containers, collection vehicles, and heavy equipment for landfills in Matamoros, as well as \$2 million for similar investments in Reynosa (U.S. Environmental Protection Agency, 1992). SEDUE and EPA will improve cooperative efforts to detect illegal cross-border movement of hazardous wastes and encourage proper waste disposal.

Mediation Efforts. The U.S. Environmental Protection Agency (1992) proposes to work with SEDUE to strengthen the enforcement of existing laws. To accomplish this, the two agencies will (1) form a new binational workgroup on enforcement (the Cooperative Enforcement Strategy Workgroup), (2) build enforcement capacity, (3), share enforcement information, and (4) undertake new cooperative enforcement initiatives.

Mexico and the United States plan to emphasize pollution prevention. Pollution prevention projects affecting municipal wastewater treatment, water use efficiency, and agricultural chemical use may be especially beneficial in the border area. EPA will explore ways to support university-based pollution prevention research and education centers in the border area. EPA will work with SEDUE and border-area universities to develop model pollution prevention and recycling demonstration projects for local communities.

Information Gaps, Current Studies, and Recommendations

The TNRCC (1992c) reports that the monitoring data for each river authority in Texas was insufficient, either because there were too few monitoring stations, existing stations were monitored infrequently, or too few parameters were monitored to allow proper evaluation of the factors that

impact the quality of water in the basin. As an example of inadequate monitoring effort, Texas Water Commission (1991) standards for contact recreation require fecal coliform evaluation of not fewer than five samples collected over no more than 30 days. Within the project area, both segments of the Rio Grande, both segments of the Arroyo Colorado, the North Floodway, and the Laguna Madre are all designated for contact recreation, but routine sampling is typically one sample collected each quarter at each station. One Arroyo Colorado above tidal segment station and the only North Floodway station are sampled only once each year. All Rio Grande stations are sampled four times each year (Texas Natural Resource Conservation Commission, 1993). Thus, the lack of adequate monitoring data prevents the TNRCC from assessing fecal coliform levels according to the established criterion. This lack of data also affects the commission's ability to efficiently assess nonpoint-source pollution and limits the conclusions that can be drawn regarding toxic material loadings to streams and rivers.

Major water quality problems include risk of waterborne disease, potential for elevated toxic pollutants, increasing salinity, and an overappropriated water supply (Texas Water Commission, 1992b). Area residents are concerned about the health risk associated with ingesting toxic substances from the water and fish from the Rio Grande, but the existing toxic substance database is not adequate to assess the risk to aquatic life and human health (Texas Water Commission, 1992b). Similarly, the Texas Department of Health (1992) emphasizes that additional monitoring of the Rio Grande is needed. Surface water sampling to date cannot address specific concerns such as the impact of discharges from industrial enterprises.

Toxic Materials Contamination. Ongoing studies may help to provide the needed information. In June, 1992, the EPA awarded the TNRCC a \$352,000 grant to jointly conduct a baseline study of toxic material contamination in the Rio Grande with the TPWD, Texas Department of Health (TDH), EPA, and IBWC. This monitoring project will provide for the collection and analysis of water, sediment, and fish tissue samples for the presence of 175 toxic substances, including 30 pesticides. It is a screening study designed to determine whether materials are present in the Rio Grande (Texas Water Commission, 1992c). These monitoring results should be available in 1994. In 1993, contracts from the Texas General Land Office (GLO) (through a grant from the EPA) to

the TNRCC and TPWD extended the scope of this study to include the tidally influenced portions of the river. In 1993, EPA's Environmental Monitoring and Assessment Program (EMAP) sampled three sites along the most downstream 10 miles of the river. Results due in 1994 will characterize the biological communities, bottom dissolved oxygen, sediment toxicity, and contamination levels in bottom sediments and fish fillets.

In June, 1992, the EPA initiated a study of pollution along the border in conjunction with the U.S. Department of Health and Human Services and the State of Texas. This study will examine potential human exposure to polluted air, food, water, and soil. It will determine the level of risk from exposure to any detected levels of contamination along the border (Texas Water Commission, 1992c).

These studies should help to characterize the impact of toxic chemical contamination in the Rio Grande and identify specific contaminants for which additional sampling may be required to protect the water quality of the river. But additional studies are needed. A toxic substances loading inventory for the lower reach of the Rio Grande should be developed. This can be accomplished by (1) gathering information on wastewater discharges, (2) using a hazardous waste simulation model, and (3) developing current land use information (Texas Water Commission, 1992b). It will be important to identify and collect samples from all point-source discharges into the river.

Wastewater. The Texas Water Commission (1992b) lists elevated fecal coliform and waterborne disease as priority concerns for the Rio Grande. The Commission recommends pursuing Texas Water Development Board (TWDB) plans for providing water and wastewater services to "colonias" in the lower Rio Grande Valley. The commission also recommends that the United States and Mexico federal governments assist Mexican border cities in constructing wastewater treatment facilities.

Dissolved Solids. The Rio Grande downstream of Falcon Reservoir experiences elevated dissolved solids during periods of low flow. Irrigation return flows and saline bank seepage during these periods of low water result in river water that is too saline for irrigation. The TNRCC, the IBWC, and the U.S. Geological Survey (USGS) should continue to monitor trends in dissolved solids in the lower Rio Grande below Falcon Dam, as well investigating how reservoir manage-

ment, particularly of future reservoirs in Mexico, will affect salinity during low flow periods (Texas Water Commission, 1992b).

Effects on Wildlife. The growing demand for water could have severe impacts on instream communities, wetlands, and other aquatic habitats dependent upon the Rio Grande. Testing is needed to document pesticide contamination and its effects on wildlife other than fish. Invertebrate populations have received little study; thus, their status is largely unknown (Jahrsdoerfer and Leslie, 1988). That pesticide and herbicide use is great in the lower Rio Grande Valley is well documented, and Gamble et al. (1988) have shown that contaminants are widely distributed in sediment and organisms, but the effects on populations are poorly known. Species suspected to be particularly sensitive to toxic substances and increasing salinity should be identified and their population densities monitored. Data analysis should include attempts to establish relationships between biological parameters and physicochemical water quality (and quantity) variables. Population density and species richness, for example, might be correlated to levels of nutrients or specific toxic substances.

Riparian Communities. Efforts to preserve the remnant, native riparian vegetation and to acquire lands along the Rio Grande for revegetation should be supported. In addition to providing wildlife habitat, a continuous corridor of vegetation along the lower reach of the Rio Grande would help to buffer the river from nonpoint sources of pollution. Land acquisition effort on the U.S. side of the Rio Grande is well established, but no equivalent measure has been undertaken in Mexico. Such an acquisition program should be established there.

Much basic research is needed on the native species of trees, shrubs, and grasses that provide habitat and food for wildlife in Rio Grande floodplain communities (Jahrsdoerfer and Leslie, 1988). Indeed, little is known about riparian communities along the Rio Grande. Knowing the composition of the native floodplain communities will be crucial for informed revegetation efforts associated with establishment and management of the "Rio Grande Wildlife Corridor." For example, it will be difficult for wildlife managers to hasten succession if they do not know the composition of existing natural, remnant riparian forests. Judd and Lonard (1993) are currently conducting a study of the riparian vegetation on the Texas side of the Rio Grande between Falcon Dam and the Gulf of Mexico. This study is designed to: (1) provide a description of the floristic composition of Rio

Grande riparian plant communities, (2) ascertain if the plant communities are being perpetuated through reproduction, and (3) identify the topographic, edaphic, and other factors that are responsible for the community structure. A similar study is needed on the Mexico side of the river. A land classification is needed for the presence, type, and width of riparian communities along the linear extent of both sides of the Rio Grande from Falcon Dam to the Gulf of Mexico. Because periodic flooding is a crucial physical factor needed to maintain natural conditions in the floodplain forests, flood management should be investigated in the National Wildlife Refuges along the Rio Grande.

There is a need for a focused, unified, statewide data management system for storing data pertinent to the Rio Grande. The system should be GIS-based and available for access by all state and federal agencies and researchers.

RESACAS

Description

Rivers frequently alter their courses in response to changes in flow characteristics of the stream system (Brown et al., 1980). This is particularly common in the lower reaches of a river. Shifting of the Rio Grande has resulted in the creation of cut-off channels, formed when high flood flows choked the existing channel with silt and cut a new channel in the floodplain (Perez, 1986). Locally, two names have been applied to these cut-off channels. “Resaca” is used for channels with considerable linear extent (several kilometers long), and “banco” is used for oxbow lakes formed by the meandering of the Rio Grande. However, many do not distinguish between the two and use the word “resaca” for any cut-off channel. Brown et al. (1980) report that there are about 130 square miles in Cameron and Willacy counties of these meander channels and that approximately 190 linear miles of water-filled cut-off channels are part of the extensive freshwater system in the area.

Recharge. Historically, periodic flooding of the Rio Grande, together with runoff and precipitation, flushed the resacas and recharged them with nutrients. Construction of dams and other flood control measures have eliminated the flood input from the Rio Grande so that now recharge is restricted to rainfall and runoff. When intense hurricane-related storms, are centered over the lower Rio Grande Valley, rainwater floods the abandoned channels, and resacas are filled. Hurricane aftermath rains may maintain discharge through the resacas for several weeks. Some of this discharge flows to the Laguna Madre.

Uses and Status

Resacas provide for storage of surface water. They serve as conveyance channels for transportation of water for the Rio Grande, and the water in them is used for drinking water and for irrigation by agricultural and residential users. Resacas provide important habitat for wildlife (both terrestrial and aquatic), and they are used for recreation. This includes boating, fishing, swimming, personal watercrafting, water skiing, and wind surfing. Commercial land developers have taken advantage

of the aesthetic attraction of resaca frontage for the sale of residential lots. Indeed, resaca-fronting lots are far more valuable than adjacent non-resaca lots.

Riparian Communities. Undeveloped resacas retain the riparian vegetation characteristic of the main river channel (Clover, 1937; Perez, 1986). Shrub and tree species include anaqua (*Ehretia anacua*), cedar elm (*Ulmus crassifolia*), Berlandier ash (*Fraxinus berlandieriana*), brazil (*Condalia hookeri*), sugar hackberry (*Celtis laevigata*), tepeguaje (*Leucaena pulverulenta*) and Texas ebony (*Pithecellobium flexicaule*). Wildlife utilizing the riparian habitats of resacas are similar to those found in the riparian community of the Rio Grande. Perez (1986) suggests that threatened and endangered species found in resaca riparian communities include the southern yellow bat (*Lasiurus ega*), jaguarundi (*Felis yagouaroundi*), ocelot (*Felis pardalis*), Rio Grande siren (*Siren intermedia texana*), black-spotted newt (*Notophthalmus meridionalis*), speckled racer (*Drymobius margaritiferus*), and northern cat-eyed snake (*Leptodeira septentrionalis*). We think that Coues' rice rat (*Oryzomys couesi*), black-striped snake (*Coniophanes imperialis imperialis*), Texas indigo snake (*Drymarchon corais erebennus*), white-lipped frog (*Leptodactylus fragilis*), and Mexican treefrog (*Smilisca baudini*) should be added to the list of threatened and endangered species present.

A number of freshwater fish species may be present depending on water quality and permanency (Perez, 1986), and the freshwater turtles spiny softshell (*Trionyx spiniferus*), yellow mud turtle (*Kinosternon flavescens*), and red-ear slider (*Trachemys elegans*) are expected to occur in the resacas.

Water Quality. Resacas receive runoff from agricultural fields and residential areas. Because fields may be immediately adjacent to them, some of the resacas receive pesticide input from aerial application to the fields. During heavy rains that cause municipal flooding, resacas receive sewer overflow runoff. Gamble et al. (1988) reported that the softshell turtle (*Trionyx spiniferus*) and fish (species not given) from Resaca de los Cuates had elevated residues of DDE and toxaphene, and a tilapia (*Tilapia* sp.) composite sample from the upper end of the resaca had a high chromium concentration (14.0 ppm, whole body, dry weight). Sediment from Resaca Lozano Banco, near downtown Brownsville, had detectable concentrations of 13 polycyclic aromatic hydrocarbons (Gamble et al., 1988); automobile emissions were thought to be the source.

Monitoring. Water districts transport water from the Rio Grande through canals and resacas

and use the resacas as storage reservoirs, but they do not have a legal obligation to monitor the water quality of resacas. Consequently, the water quality of resacas is not monitored except for those portions that occur within municipalities, and monitoring within municipalities may not be routine and consistent. A volunteer group that is part of the Texas Watch Program is currently monitoring water quality of some resacas in the Brownsville area.

Information Gaps and Recommendations

Resacas constitute a major aquatic habitat in the Lower Rio Grande Valley of Texas, and riparian communities along the margins of undeveloped resacas provide a significant portion of native vegetation remaining in the area. Despite their importance and extent, the fauna and flora of resacas are poorly known, and there is little monitoring of water quality, particularly in those portions that are outside the limits of municipalities. However, on 9 July 1993 the TWC published a request for proposals to conduct a study of water quality impairment of resacas in the Brownsville area. This research was previously selected for funding under the pilot project programs of the Texas Clean Rivers Program to provide data which supports management of urban nonpoint-source pollution.

The overall objectives of the pilot project are to identify and characterize nonpoint-source pollution, design and implement a field assessment (sampling) program, identify the cause and source of any impairments identified, and provide information necessary to make a supporting or non-supporting beneficial use determination for the resacas. Field objectives include the measurement of ambient water quality, stormflow, and concentration of pollutants in runoff, and the calculation of pollutant loading. The study calls for measurement of the macroinvertebrate and fish communities in two resacas impacted by urban and suburban or agricultural nonpoint-source pollution respectively, and of a resaca impacted by nonpoint-source pollution to serve as a reference site.

The extent of resacas needs to be more accurately quantified, perhaps through the use of aerial photography. These results should be incorporated into a comprehensive GIS for the area. A survey of the aquatic and terrestrial fauna and flora of resacas is needed. A monitoring program for those portions of resacas outside municipalities should be established if the initiative begun in 1993 is not continued.

ARROYO COLORADO

Description

The Arroyo Colorado originated as a distributary of the Rio Grande, but has been altered by dredging (in the lower reach) and channelization. It extends from FM 2062 southwest of Mission, Hidalgo County, approximately 144 km eastward to its confluence with the Laguna Madre in Cameron County, Texas (Davis, 1989). The Arroyo Colorado is divided into two segments. The above tidal reach (Segment 2202) starts at the Rio Grande (at the site identified above) and extends 101.5 km to a point 0.1 km below Cemetery Road near the Port of Harlingen, Cameron County (Davis, 1989). The tidal reach (Segment 2201) extends 42.1 km from the lower boundary of Segment 2202 to the Laguna Madre (Davis, 1989).

At its beginning, the Hackney Lake and Mission inlets divert flows into a portion known as Banker Floodway. Banker Floodway empties into the Main Floodway which runs between Mission and Mercedes. Near Mercedes, the Main Floodway divides into the North Floodway and the Arroyo Colorado *per se*. The channel is designed so that all flows of less than 40 m³/s pass into the Arroyo Colorado, and flows greater than 40 m³/s are divided between the Arroyo Colorado and the North Floodway (Texas Water Commission, 1990). Downstream from Mercedes, the Arroyo Colorado continues as a natural channel to a point southeast of Harlingen. Here, the Arroyo Colorado becomes a tidally influenced dredged navigation canal that extends from the Turning Basin at the Port of Harlingen to the mouth at the Laguna Madre (Texas Water Commission, 1990). Thus, the Arroyo Colorado may best be considered as a system consisting of both natural and artificial hydrologic components that form a continuous waterway 143.5 km long and have a drainage area of 6,070 km².

Hydraulic conditions, even under low flow conditions, are considered to support rapid, unrestricted flow. Factors contributing to unrestricted flow include the entrenched steep-walled configuration of the pilot channel, absence of vegetation, extensive channelization, and absence of major impoundments. Average flows at El Fuste Siphon (near Mercedes) are 5.6 m³/s (Texas Water Commission, 1990). Factors that tend to impede flow include the moderate slope of the channel

(about 0.0002 m/m), restriction of flow through flood control levees, and minor impoundments caused by erosion control drop structures (Texas Water Commission, 1990).

Natural overland drainage is restricted by the level topography and intense land development. Subsurface drainage is similarly limited because of the generally saturated soils due to irrigation of agricultural fields. Consequently, a high water table and highly permeable host sediments produce a high degree of interaction between groundwater and surface waters.

Uses

The Arroyo Colorado primarily serves as a floodway for overflow waters from the Rio Grande. Secondary uses include an inland waterway for barge traffic and a recreational resource for boating and fishing (Davis, 1989). Perennial flow is maintained by municipal wastewater discharges supplemented by irrigation return flows and urban runoff. In 1989 Taiwanese financiers established shrimp culture ponds adjacent to the Arroyo Colorado at Arroyo City. Arroyo Colorado water is diverted into the ponds, and untreated effluent is discharged back into the Arroyo .

Water Quality

Bryan (1971) reported on salinity, dissolved oxygen, pH, and temperature in the Arroyo Colorado from 1966 through 1969 (dates of initiation and ending not given). Hurricane Beulah (September 1967) occurred during the study, and rainfall resulting from the storm caused widespread flooding and many changes in the Arroyo. Large portions of ox-bow areas were filled and the channel was widened substantially (Bryan, 1971).

Salinity. At a depth of 0.6 m, salinity in August 1967 (prior to Hurricane Beulah) ranged from 27.8 ppt at km 3.2 (from mouth) to 18.9 ppt at km 40. At a depth of 3.0 m, salinity ranged from 32.2 ppt at km 3.2 to a level of 21.1 ppt at km 40. At a depth of 4.2 m, salinity ranged from 44.4 ppt at km 3.2 to a level of 33.3 ppt at km 40. Thus, the water became more saline at all levels as it progressed downstream, and salinity increased with depth at all five stations (Bryan, 1971).

Dissolved Oxygen. During the study period, dissolved oxygen ranged from zero at the bottom (4.2 m) to 11 ppm at the surface (0.6 m). But in August 1967, surface dissolved oxygen values

ranged from 1.4 to 3.4 ppm and the bottom contained no oxygen (Bryan, 1971). Zero readings were also recorded from midwater (3.0 m) samples at km 19.2, 32, and 40. There was a significant inverse relationship between salinity and dissolved oxygen (Bryan, 1971).

Temperature and pH. Bryan (1971) found that mean pH varied little between the surface (8.2) and bottom (8.3) at km 2. At km 40 the mean pH ranged from 7.7 at the bottom to 7.9 at the surface. Temperatures ranged from 11.0°C in winter to 32.0°C in summer. The greatest difference between surface and bottom temperatures occurred in January (5.0°C), but the mean difference was only 1.2°C (Bryan, 1971).

Metals. The Texas Department of Water Resources (1983) reported on heavy metals in sediment of the Arroyo Colorado at Harlingen, based on data collected for the period 1972 to 1978. Heavy metals detected were arsenic, cobalt, lead, manganese, and zinc. The value for arsenic equaled dredged spoil criteria. It was based on the analysis of a single sample. Other heavy metals detected were based on analyses of two samples. DDD, DDE and lindane were detected in sediment samples obtained at the Harlingen site, and DDE was also found in sediment samples at the mouth of the Arroyo.

Bacteria. Bowles (1986) reported on bacteriological water quality of Segment 2201 based on fecal coliform samples collected from December 1982 to March 1984. He found that point and nonpoint sources of bacteriological indicator organisms were significantly greater downstream of the Harlingen-San Benito area than at the upstream control station. There were five monthly samples (at two stations) that exceeded fecal coliform criteria for water quality. However, in the four-year period from 1 September 1987 through 31 August 1991, 15 samples taken from the Arroyo Colorado tidal segment were all below the criterion of 200 colonies/100 ml (Texas Water Commission, 1992b). In this same period, 20 samples from the Arroyo Colorado above tidal segment were analyzed for fecal coliforms. Thirteen of the 20 samples exceeded the criterion of 200 colonies/100 ml, and the maximum value was 5,100 colonies/100 ml. The mean was 399 colonies/100 ml, essentially double the criterion value (Texas Water Commission, 1992b). Clearly, a portion of the Arroyo Colorado above tidal segment does not qualify for contact recreation use, and the remainder of the segment is only partially meeting this criterion (Texas Water Commission, 1992b).

Nutrients. The Texas Water Commission (1992b) characterizes the tidal segment of the Ar-

royo Colorado as having supersaturated dissolved oxygen levels due to algal metabolism. The average inorganic nitrogen, phosphorus, and chlorophyll *a* levels are similarly elevated. Municipal effluents appear to be a major contributor of nutrients to the segment (Texas Water Commission, 1992b). The excessive phytoplankton productivity contributes to the elevated dissolved oxygen levels (Texas Water Commission, 1992b).

The Texas Water Commission (1992a) ranked 80 estuary segments with respect to eutrophication. The Arroyo Colorado tidal segment was rated the worst in the state for eutrophication and the third worst in the state for overall water quality. Only the Houston Ship Channel and the tidal segment of the Nueces River were ranked as having lower overall water quality.

Pesticides. The TDH has issued a fish consumption advisory for this segment. The Department recommends that fish consumption be limited to one meal per month due to elevated levels of chlordane, toxaphene, and DDT in fish tissue.

Eighteen years ago (in 1976) White et al. (1983) found high levels of toxaphene and DDE in Rio Grande perch (*Cichlasoma cyanoguttatum*) and shad (*Dorosoma cepedianum*) from an impounded section of the Arroyo Colorado above-tidal segment known as Llano Grande Lake. Subsequent sampling in 1978 and 1979 (White et al., 1983) showed elevated levels of DDE and toxaphene in freshwater fishes at all sites where they occurred along the Arroyo, above the Port of Harlingen. White et al. (1983) also examined fish-eating birds, great-tailed grackles (*Quiscalus mexicanus*), and red-winged blackbirds (*Agelaius phoeniceus*) for tissue concentrations of DDE, toxaphene, and PCBs. Elevated levels of DDE occurred in birds collected at Llano Grande Lake and near the mouth of the Arroyo Colorado. Toxaphene was detected in 54 percent of the bird carcasses, but the levels were low; i.e., less than 1.0 ppm in all cases. This is likely due to the fact that birds (unlike fish) readily metabolize and excrete toxaphene so that little accumulation takes place (Haseltine et al., 1980). PCB concentrations were generally low, but some of the laughing gulls had residues up to 23 ppm, and ring-billed gulls from Llano Grande Lake had residues of 15 ppm. Gamble et al. (1988) identified Llano Grande as one of four sites in the Lower Rio Grande Valley of Texas having especially high DDE and toxaphene residues in softshell turtles (*Trionyx spiniferus*) and fish (species not given).

White et al. (1983) reported that the impacts of DDE and toxaphene on the fishes of the Arroyo Colorado were unknown, but pointed out that experimental studies have shown that both compounds are toxic to fish in minute quantities (Johnson and Finley, 1980). That DDE impairs reproduction in birds is well-established, and White et al. (1983) reported that birds with the contamination levels that they found in laughing gulls would be expected to encounter reproductive difficulties.

Based on analysis of tissue samples obtained from the Arroyo Colorado in December 1987, Davis (1989) concluded that long-term human health risks may be associated with consumption of fish from the Arroyo Colorado due to elevated concentrations of chlordane, dieldrin, p, p' dde, and dacthal. The first three compounds all exceeded EPA lifetime human health criteria while chlordane exceeded the U.S. Federal Drug Administration criterion by a factor greater than two. No criteria exist for dacthal, but it is a suspected carcinogen and it exceeded the EPA criteria for known carcinogens (Davis, 1989).

In the Arroyo Colorado, toxic chemicals identified in screening as “of interest” included chlorine, ammonia, copper, nickel, selenium, zinc, methylene chloride, chloride, chlordane, dacthal, dieldrin, and p, p' dde. Potential sources of input were identified as urban runoff, municipal effluents, and agricultural runoff and return flows.

Biotic Impacts

Davis (1989) characterized the benthic community structure of the above-tidal segment of the Arroyo Colorado as “generally poor”, with pollution-tolerant species predominating and pollution-sensitive species absent. He concluded that absence of a good control station confounds the issue, but that toxic chemicals are judged to be exerting slight-to-moderate impacts on the macrobenthos of this segment.

Bryan (1971) sampled fish and invertebrates in the Arroyo Colorado below Harlingen using a 3 m wide otter trawl and a 91.4 m long by 3.7 m deep trammel net, supplemented with gill nets of various sizes and with hook-and-line. Random samples of plankton were taken from km 3.2 to 32. An annotated list of species is provided. The list of flora includes four genera of algae (species not given) and one species of seagrass; i.e., widgeon grass (*Ruppia maritima*). Invertebrate species listed include one copepod, one barnacle, two shrimp, two crabs, and three mollusks. Fifty-six fish

species are listed. Juvenile menhaden (*Brevoortia* sp.), redfish (*Sciaenops ocellata*), and white shrimp (*Penaeus setiferus*) were the most numerous economically important species found in the survey (Bryan, 1971). Brown shrimp (*Penaeus aztecus*) and blue crab (*Callinectes sapidus*) were present but less abundant.

The spotted seatrout (*Cynoscion nebulosus*) was the most abundant adult species taken. Redfish (*Sciaenops ocellata*), black drum (*Pogonias cromis*), sheepshead (*Achosargus probatocephalus*), and southern flounder (*Paralichthys lethostigma*) were less abundant. Adults of these species were concentrated in the lower 19.2 km of the Arroyo and were not found beyond km 32.

Bryan (1971) reported that eight fish kills occurred during his study in 1966-69 of the lower reach of the Arroyo Colorado. Most of these occurred between June and September. No direct sources of pollution were found in any of the cases, but in two kills that were investigated while in progress there was no oxygen at any level of the water column. The majority of fish found dead were menhaden, but other species were usually included.

Bryan (1971) submitted a total of 107 fish and invertebrate samples collected between September 1965 and July 1969 from the lower Arroyo Colorado for analysis of DDT, dieldrin and endrin to the Bureau of Commercial Fisheries at Gulf Breeze, Florida. All 107 contained DDT, and 84 had either or both dieldrin and endrin. DDT concentrations in menhaden (species not given) ranged from 0.048 to 8.1 ppm. Ovaries from spotted seatrout (*Cynoscion nebulosus*) had DDT concentrations ranging from 1.16 to 7.98 ppm. He suggested that pesticides might be affecting reproduction in spotted seatrout in the Lower Laguna Madre.

In the tidal segment of the Arroyo Colorado, the “high” use level currently designated is not being met (Davis, 1989) and macrobenthic community characteristics are considered worthy of an “intermediate” aquatic life use rating. Davis (1989) concludes that toxic chemicals do not appear to be an important causative factor. Rather, he suggests that likely stress-inducing factors include salinity stratification and high primary productivity which occasionally result in depressed dissolved oxygen in bottom waters, and periodic maintenance dredging which disturbs the benthic environment. And he points out that the fine-particled substrate is very homogeneous, which is not conducive to colonization by a diverse macrobenthic assemblage.

Laguna Atascosa and Cayo Atascosa

Laguna Atascosa drains through the Cayo Atascosa and into the Arroyo Colorado immediately upstream of the Arroyo's intersection with the Laguna Madre. Ahr (1973) documented the persistence of DDT in sediment from the principal drain (Resaca de Los Fresnos) to the Laguna Atascosa, in the Laguna Atascosa itself, and in the Cayo Atascosa. The highest concentrations of DDT were found near the surface and ranged from 16 ppb at the drain site to about 5 ppb at the Cayo site. DDT was found in relatively high concentrations in sediments deeper than 100 cm. This relocation of DDT was thought to be due to burrowing animals such as crabs and worms. Increasing concentrations of DDT were shown as higher trophic levels were encountered.

Gamble et al. (1988) reported that DDE and toxaphene residues were elevated in softshell turtles (*Trionyx spiniferus*) and fish (species not given) from Laguna Atascosa and Cayo Atascosa.

North Floodway

The North Floodway begins west of Mercedes in Hidalgo County and extends 77.3 km to its confluence with the Laguna Madre in Willacy County. It is an artificial distributary arm of the Arroyo Colorado Main Floodway designed to divert water from the main channel during periods of high flow (40 m³/s or greater) (Texas Water Commission, 1990). Due to total channelization, flow in the North Floodway tends to be unrestricted. A review of International Boundary and Water Commission flow data collected at the US-77 bridge (approximately 42.5 km above the confluence with the Laguna Madre) confirmed mean annual flows of 106 and 88.6 cfs for 1991 and 1992, respectively. Six flows as measured by the Texas Natural Resources Conservation Commission approximately 20 km downstream (FM-1420) since 1990 have ranged from 14.2 to 60 cfs, with a mean of 27.8 cfs.

In general, the TNRCC has classified streams, rivers, reservoirs, and estuarine/coastal waters in order to establish water quality criteria and protect water used (Texas Water Commission, 1992a.) Many smaller water bodies, including the North Floodway, are collectively grouped as "unclassified" and are provided protection under general criteria (Texas Water Commission, 1992a). In the absence of available data, unclassified waters are assumed to have high aquatic life and contact

recreational uses. Criteria are 5/3 mg/L (24-hour average/minimum) dissolved oxygen and 200 colonies/100 ml fecal coliform density (30-day geometric mean), respectively.

Uses. The North Floodway serves primarily as a floodway for overflow water from the Arroyo Colorado. Though little information is available in the literature regarding hydrology and drainage specific to the North Floodway, the Arroyo Colorado and associated floodways drain approximately 1.5 million acres in the Lower Rio Grande Valley of Texas (Lower Rio Grande Valley Development Council, 1978). Perennial flow in the North Floodway is maintained by irrigation return flow, agricultural runoff and municipal wastewater discharges (Webster, Texas Natural Resources Conservation Commission, Personal Communication, 18 April 1994).

Water Quality. Insufficient data exists to adequately evaluate water quality in the North Floodway. The TNRCC collects flow, nutrient and basic physicochemical data once a year at km 2.5 (FM-1420). Dissolved oxygen and fecal coliform values determined since 1987 have ranged from 6.8 to 12.4 mg/L and <9 to 840 colonies/100 ml, respectively. In addition, no pesticides were detected in water and sediment samples collected in 1989 (Webster, Texas Natural Resources Conservation Commission, Personal Communication, 18 April 1994).

Information Gaps and Recommendations

Toxic Chemicals. Perennial flow in the Arroyo Colorado is sustained by municipal discharges (24 permitted), industrial outfalls (6 permitted), urban and agricultural runoff, and irrigation return flow (Texas Water Commission, 1992a). These inputs are apparently contributing toxic chemicals to the Arroyo Colorado and through it to the Laguna Madre. A comprehensive study such as the one now in progress for the Rio Grande (by TNRCC, TPWD, TDH, EPA, and IBWC) should be initiated for the Arroyo Colorado. The sampling by EPA's EMAP may help to provide the needed information. In 1993, EMAP sampled ten sites evenly spaced from the mouth of the Arroyo to within a few miles downstream from Harlingen.

Sampling Depth. The TWC monitors nutrient levels in the surface waters at four stations on the Arroyo Colorado and at one lower Laguna Madre station (located just outside the mouth of the Arroyo Colorado). However, a saltwater wedge extends beneath the surface water throughout the

tidal section of the Arroyo Colorado. The distribution of nutrients with depth (and differing salinity) is unknown. Thus, estimates based solely on quantification in the surface waters may be inaccurate. A study of nutrient concentrations at differing depths is needed.

Flow. Estimates of gauged freshwater inflows and nutrient loading from the Arroyo Colorado to the Lower Laguna Madre have apparently been derived from flow information obtained from above tidal gauging stations and do not account for inputs into the Arroyo Colorado along the tidal segment. Irrigation return flow, runoff and rainfall inputs are not monitored and there is no flow gauge near the mouth of the Arroyo Colorado to quantify discharge volumes to the lower Laguna Madre. There is a station at the confluence of the Arroyo Colorado and Gulf Intracoastal Waterway (GIWW), but flow volume from the Arroyo cannot be determined here. Flow monitoring equipment should be established at the mouth of the Arroyo Colorado to permit calculation of the volume of water entering the Laguna Madre from the Arroyo Colorado. This is necessary so that the loading of toxic chemicals and other materials can be calculated.

Shrimp Farms. In 1989, investors from Taiwan began establishing shrimp culture ponds at Arroyo City on the south bank of the Arroyo Colorado tidal segment. There are now approximately 1,000 acres of ponds. Water is pumped from the Arroyo Colorado for use in shrimp mariculture for human consumption. The effluent from the ponds flows through a common drainage ditch and back into the Arroyo Colorado. The shrimp farms monitor their discharges and report the data to the TNRCC, conducts periodic checks. Because of the large volume of water diverted and evaporation from the shallow ponds, water re-entering the Arroyo Colorado may raise downstream salinities in the Arroyo Colorado. This is significant because the Arroyo Colorado is the main source of freshwater input into the Lower Laguna Madre. It should be noted that there have been escapes of exotic shrimp from these farms.

LAGUNA MADRE

Description

The Laguna Madre of Texas is a long, narrow, coastal, hypersaline lagoon extending in an arc about 200 km from Corpus Christi on the north to near the Rio Grande on the south (Hedgpeth, 1947). It is five to eight km broad at most places and 15 km at its widest (Hedgpeth, 1947; Quammen and Onuf, 1993). Over most of its area it is very shallow, and the average depth, excluding Baffin Bay, is 75 cm (Hedgpeth, 1947; Quammen and Onuf, 1993). The natural depth is less than 1.5 meters in all portions (Hedgpeth, 1947). 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 (Warshaw, 1975). Wind also contributes to the variability of the shore/water boundary and, when strong, is capable of reversing the direction of tidal flow (Warshaw, 1975).

Hypersalinity. Gunter (1967) reported that the Laguna Madre of Texas is one of only three large hypersaline lagoons in the world. The others are the Laguna Madre de Tamaulipas in Mexico (separated only by the delta of the Rio Grande from the Laguna Madre of Texas) and the Sinash, adjacent to the Sea of Azov on the Crimean Peninsula, Ukraine (Quammen and Onuf, 1993). Hypersalinity is a result of negligible freshwater inputs, small connections with the Gulf of Mexico (relative to the volume of the Laguna Madre), and a high rate of evaporation (Texas Department of Water Resources, 1983).

Water Balance. The Laguna Madre lies across two climatic areas, subhumid in the north and semiarid in the south. The line of separation between these regions lies roughly at Baffin Bay (Hedgpeth, 1947). To the north, precipitation and evaporation are in balance; below the line (to the south) there is more evaporation than precipitation (Hedgpeth, 1947).

Land Bridge. The lower Laguna Madre is separated from the upper Laguna Madre by extensive, sporadically inundated tidal flats. These flats are variously referred to in the literature as the Land Bridge, Laguna Madre Flats, Saltillo Flats, and the South Texas Sabkha. The Land Bridge begins at a point about 16 km south of the lower border of Baffin Bay and extends southward 56 km. The portion of the study area within the Laguna Madre is confined to the Lower Laguna Madre.

GIWW. The Gulf Intracoastal Waterway is a dredged channel, 3.6 m deep by 38.1 m wide, paralleling the Gulf Coast from Florida to Brownsville (Warshaw, 1975). Deposition of material removed during the original construction (dredging) and subsequent maintenance dredging of the GIWW has produced an extensive chain of emergent “spoil” islands along the channel (Warshaw, 1975). The GIWW extends the length of the Lower Laguna Madre and intersects the Brownsville Ship Channel and Brazos-Santiago Pass at Port Isabel/South Padre Island, Texas. The Brownsville Ship Channel is 11 m deep and its width varies from 30 to 300 m (Breuer, 1962). It is 24 km long.

Construction of the GIWW increased circulation within the Laguna Madre and exchange with the Gulf of Mexico (Warshaw, 1975). The upper and lower portions of the Laguna Madre that were formerly separated by the Land Bridge (except during extremely high tides) are now permanently connected. The portion of the GIWW that passes through the Land Bridge is locally referred to as the “Land Cut,” and it allows water exchange between the lower Laguna Madre and Baffin Bay.

Water Exchange and Inflows. Brazos-Santiago Pass and Mansfield Channel were constructed in 1938 and 1957, respectively, and serve as permanent exchange points with the Gulf of Mexico (Allison, 1987). The Brazos-Santiago Pass is 91.4 m wide and 11.6 m deep. The Mansfield Channel is 30.5 m wide and 3.6 m deep. Freshwater inflow is provided by the North Floodway, Arroyo Colorado, and Cayo Atascosa. The North Floodway and Arroyo Colorado have been discussed in a previous section. They serve as floodways for overflow waters of the Rio Grande and carry municipal wastewater discharges supplemented by irrigation return flows and urban runoff. The Cayo Atascosa also carries drainage and irrigation water into the Lower Laguna Madre. But the Laguna Atascosa National Wildlife Refuge impounds most of this water and little reaches the lagoon (Breuer, 1962). The Cayo Atascosa empties into the Arroyo Colorado about 3.2 km west of its confluence with the GIWW. There is no other source of freshwater-stream flow into the Lower Laguna Madre.

Water exchange is provided by the GIWW, the Brazos-Santiago Pass, the Mansfield Channel, and the Land Cut. Current direction varies with the season. During the summer months, the prevailing wind is from the southeast. These prevailing winds, together with the south-to-north longshore current in the Gulf of Mexico, cause the water of the Gulf of Mexico to enter the Lower Laguna Madre through the Brazos-Santiago Pass and flow northward through the Lower Laguna

Madre and through the Land Cut into the Upper Laguna Madre. Some water also exits through the Mansfield Channel. During the winter months, the prevailing wind is from the north, and the entire situation is reversed. Lowest salinities occur at Brazos-Santiago Pass and salinity gradually increases northward. Highest salinities are at the northern end of Redfish Bay (Breuer, 1962).

Bay Areas. Breuer (1962) divided the Lower Laguna Madre into four parts. The northernmost part, Redfish Bay, extends from the Land Cut southward to a point about 6.4 km south of Port Mansfield. The “middle area” extends from this point southward to Three Islands. The third area, Port Isabel Bay, extends from Three Islands southward to the Brownsville Ship Channel. The portion of the lagoon south of the Brownsville Ship Channel is South Bay.

The water area of Redfish Bay is about 21,450 hectares (Breuer, 1962). About one-third (7,285 hectares) is 1.8 or more meters deep at mean low tide. This deep water forms a long, narrow, irregular patch paralleling the mainland shore some 20.9 km through Redfish Bay (Breuer, 1962). The middle area encompasses approximately 19,223 water hectares (Breuer, 1962). Except for the GIWW, water depth is one meter or less, and the average is about 0.3 m. There are considerable areas of flats along the mainland shore of this entire section due to deltas built by the North Floodway, Arroyo Colorado, and Cayo Atascosa. The Port Isabel Bay area contains 19,223 hectares of water (Breuer, 1962) and average depth is about one meter. The mainland shores are well-defined. South Bay contains 1,416 hectares of surface water. The maximum depth is one meter and the average depth is only about 0.5 meter. South Bay is surrounded by exposed flats resulting from siltation.

Freshwater Inflow

The Texas Department of Water Resources (1983) published an extensive and comprehensive study of the influence of freshwater inflows to the Laguna Madre (both the Upper and Lower portions). This 286-page report (each chapter is paged separately) provides information on physical characteristics, economic characteristics, hydrology, circulation and salinity, nutrient processes, primary and secondary bay production, fisheries, and estimated freshwater inflow needs. Some sections of the report provide separate coverage for the upper and lower portions of the Laguna Madre.

Freshwater need estimates were computed using an “Estuarine Mathematical Programming Model” developed in the study. This model was used to calculate the monthly freshwater flows from the Baffin Bay drainage area, and those of the Arroyo Colorado and North Floodway, which best achieve the specified objectives. The objectives could be varied to produce various desired estuarine conditions, but three long-term (multi-year average) alternative need levels were selected for estimation. Alternative I, the ecosystem subsistence level, had the objective of minimizing the annual combined freshwater inflow while meeting monthly salinity viability limits that provide an opportunity for survival, growth, and reproduction of estuarine-dependent organisms. The Alternative I freshwater inflow need was estimated to average 344 thousand acre-feet (424 million m³) per year. Alternative II, the level for maintenance of the fisheries, was calculated to average 578 thousand acre-feet (713 million m³) annually and had the same objectives as Alternative I, plus providing sufficient inflows to give predicted fisheries harvests at no less than their average historic levels. Alternative III, the level of inflow necessary for fisheries harvest enhancement, was estimated at an annual average of 602,000 acre-feet (743 million m³) and had the same objectives as Alternative I, but also included maximizing the fish harvest in the Upper Laguna Madre and the shrimp harvest offshore of the Lower Laguna Madre without causing the Lower Laguna Madre fish harvest to fall below its historical average.

The average annual inflow to the Lower Laguna Madre (gaged and ungaged estimates) over the years 1941-1976 was estimated to be 532,000 acre-feet. But when evaporation was accounted for over this period, the mean freshwater inflow balance was -768,000 acre-feet annually; i.e., average annual evaporation exceeded mean annual inflow.

Biota

Breuer (1962) provided an annotated list of the flora and fauna of the Lower Laguna Madre. He listed 26 alga species, five seagrass species, 104 invertebrate species, and 80 fish species. His principal conclusions are summarized below. Plankton were most varied near the passes and during summer months. Brown algae were common in Port Isabel Bay. Of the five seagrasses present,

Halodule wrightii was the most widely distributed. Sponges and coelenterates were largely confined to the area adjacent to the Gulf of Mexico. Ctenophores were common throughout the Lower Laguna Madre, especially in winter months. Annelids were present throughout the area. Many species of copepods were present (20 were listed), but only *Acartia tonsa* was abundant throughout the Lower Laguna Madre. Barnacles were present wherever there were places for attachment. Amphipods were plentiful during summer months. Shrimp were common, with juvenile brown shrimp (*Penaeus aztecus*) and the grass shrimp (*Palaemonetes intermedius*) being the most abundant. Crabs were plentiful in both kind and number. Oysters (*Crassostrea virginica*) from the Lower Laguna Madre were capable of spawning, setting, and rapid growth at salinities of 32 to 42 ppt. Fishes of greatest importance to the sport and commercial fishery of the area included spotted seatrout, redfish, black drum, flounder, croaker, sheepshead, snook, and tarpon. The important bait fishes were anchovies, silversides, mullet, pinperch, pigfish, skipjack, killifishes, and gobies.

Hedgepeth (1967) reported on the flora and fauna of the entire Laguna Madre and identified some of the principal elements in the Lower Laguna Madre. He points out that meadows of turtle grass (*Thalassia testudinum*) occur in South Bay. *Gracilaria blodgettii* is identified as the most conspicuous macroscopic alga, and extensive stands of *Penicellus capitatus* are reported from the Port Isabel area. The flats in many parts of the Laguna Madre, especially along the Padre Island side, are covered with algal mat communities consisting mostly of the blue-green alga *Lyngbya confervoides*. *Acetabularia crennulata* occurs in scattered patches throughout the Lower Laguna Madre (Hedgepeth, 1967).

Mollusks. Wilhite et al. (1982) studied the distribution, diversity, and species composition of the living molluscan community of the Lower Laguna Madre of Texas based on collections from 540 core samples from four stations and 47 Ekman dredge samples from 24 random sites. The permanent stations yielded 13 species, with an average of only 0.29 specimens per sample. Shannon's diversity index ranged from 0.13 to 2.56. Samples from the random sites produced 12 species with a mean of 1.9 mollusks per sample. *Tellina tampaensis* was the dominant species. Wilhite et al. (1982) concluded that the low density of living species might reflect human-influenced changes. And they suggested that the Lower Laguna Madre probably receives a greater pesticide and sewage

load than the more isolated Upper Laguna Madre. However, no data were provided to support this claim. Pulich (1980) also suggested that the Lower Laguna Madre had undergone shifts in species abundance due to pollutants, such as pesticides and metals, drained from the Rio Grande Valley agricultural and residential areas. Sorenson (1979) reports that *Penicillus capitatus* disappeared from the Lower Laguna Madre after hurricane Beulah in 1967.

Plankton. The Texas Department of Water Resources (1983) reported the results of an aquatic biota survey of the Lower Laguna Madre based on field studies performed July 12-16, 1977. Phytoplankton and zooplankton samples were collected at 13 sites and benthic macroinvertebrates from 15 sites. Seventy phytoplankton species representing seven divisions were collected during this survey. The Chlorophyta (green algae) and Bacillariophyta (diatoms) exhibited the greatest species richness, contributing about 70 percent of the species collected. The diatoms were the most numerically abundant group, comprising 90 percent of the total organisms collected (Texas Department of Water Resources, 1983). Phytoplankton abundance was greatest in the drains (but not at the mouth of the Arroyo Colorado) and shallow inland bays where salinities ranged from 3.7 to 21.1 ppt (Texas Department of Water Resources, 1983).

A total of 47 zooplankton representing 12 phyla were collected in the survey (Texas Department of Water Resources, 1983). The phylum Arthropoda exhibited the greatest species richness, accounting for 40 percent of the species, and rotifers were numerically the most abundant. The greatest densities of zooplankton were recorded at an isolated flat off the mouth of the North Floodway. Lowest densities occurred in open Laguna Madre waters and at the mouth of the Arroyo Colorado cutoff (Texas Department of Water Resources, 1983).

Benthos. Diversity of benthic macroinvertebrates was correlated with substrate composition, and greater diversities occurred in areas having variable substrates. Nutrient availability also affected benthic macroinvertebrate diversity. Areas receiving freshwater inflows (Raymondville Drain and Arroyo Colorado) generally exhibited increased diversities (Texas Department of Water Resources, 1983).

Armstrong (1987) reviewed the ecology of open-bay bottoms of Texas. The vast majority of information for the Laguna Madre was based on the Upper Laguna Madre. Comments on the Lower

Laguna Madre were meager. He reported that *Acartia tonsa* was the dominant zooplankton species and that another copepod, *Metis japonica*, was also present, but in much lower numbers. The dominant mollusks were identified as *Mulinia lateralis* and *Tellina tampaensis*. Dominant nekton identified for the Lower Laguna Madre include brown shrimp (*Penaeus aztecus*), white shrimp (*Penaeus setiferus*), blue crab (*Callinectes sapidus*), *Callinectes similis*, mantis shrimp (*Squilla empusa*), and 15 fish species (Armstrong, 1987).

White et al. (1986) provided an extensive and detailed study of the Lower Laguna Madre and other submerged lands in the Brownsville-Harlingen area. The report is 138 pages long. A total of 1,050 benthic samples from the bay-estuary-lagoon system was examined. Most of the samples were used in sediment analyses. Calnan et al. (1986) reported on the benthic macroinvertebrates in a study based on 216 samples. Benthic macroinvertebrates found in the sediments of the Lower Laguna Madre were primarily polychaetes, bivalves, gastropods, and crustaceans. Species counts were highest at seagrass beds near Brazos-Santiago Pass. Distributions of the macroinvertebrates were related to bathymetry and sediment type. Diversity values were lowest in the middle and northern parts of the lagoon and highest at grassflat beds in the southern part. Using cluster analyses, six macroinvertebrate assemblages were identified in the bay-lagoon system (i.e., Lower Laguna Madre, South Bay, Arroyo Colorado): bay margin, open bay center, grassflat, inlet influenced, river influenced, and oyster reef. Numbers of all species and diversity indices were uniformly low in sands adjacent to the wind-tidal flats and in water less than 0.6 m deep. Total numbers of species and diversities were higher in muddy sands.

Inlet Influence. Breuer (1962) reported that, with increased distance northward from Brazos-Santiago Pass, the number of invertebrate species decreases, but the number of individuals representing the remaining species increases. This variation was attributed to salinity change from near 35 ppt at Brazos-Santiago Pass to hypersaline conditions near the Land Cut.

Fish. Hook (1991) pointed out that although considerable data exist on fish species composition of the bays of the middle and northern Texas coast, the Lower Laguna Madre remains one of the least investigated bay systems of the northwestern Gulf of Mexico. South Bay at the southern end of the Laguna Madre has received even less investigation (Hook, 1991). Hook (1991) studied

seasonal variation in relative abundance and species diversity of fishes in South Bay, using seine and trawl samples over a 14-month period in 1984 and 1985. More than 115,000 individuals representing 90 species of 35 families were collected. During the study, water temperatures varied from 5° C in January to 39° C in July. Salinity ranged from 37 to 9 ppt.

Two families, Cyprinodontidae and Sciaenidae, represented 45 percent of the total number of individuals (expressed as catch per unit effort; i.e., CPUE) and 55 percent of the total biomass (CPUE). The most numerous species over all seasons was *Leiostomus xanthurus*, and *Cyprinodon variegatus* had the greatest biomass (Hook, 1991), but these species were not the most abundant during each season. And the most abundant species was seldom the same at all five seining stations in a given month (Hook, 1991). The total number of individuals reached peak values in January and February at each site, which Hook (1991) attributed to recruitment of juvenile *Leiostomus xanthurus* into the population. Biomass peaked in April and May. Mean species diversity and richness values were greater from July through September, but evenness values failed to show a seasonal trend (Hook, 1991). Species richness and diversity were relatively high when compared to some other Atlantic and Gulf bays and estuaries (Hook, 1991). Hook attributed this to proximity to Brazos-Santiago Pass, subtropical climate, and habitat diversity. Oyster beds, mixed seagrass beds, mixed algal flats, tidal channels, and mangrove stands all occur in this small (1,100 ha) bay. Hook (1991) concluded that proximity to Brazos-Santiago Pass probably contributed most to species richness. South Bay receives fresh seawater from the Gulf of Mexico with each incoming tide, which moderates salinity.

Commercial Landings. Each year the TPWD Fisheries Division publishes data on commercial landings and ex-vessel value of selected finfish and shellfish harvested from Texas bays and the Gulf of Mexico. The latest information is provided by Campbell et al. (1992) for the period 1972-1991. These data may be useful in identifying trends in abundance. The weight for all finfish from the Lower Laguna Madre in 1991 was 422,134 lb. This was the highest total reported since 1981, and about 28 percent higher than in 1990. These data suggest that the abundance of commercially important finfishes in the Lower Laguna Madre is not declining. The weight of blue crab (*Callinectes sapidus*) landed in 1991 was 13,029 lb, which was more than double the weight of 977

lb reported in 1990. Eastern oyster (*Crassostrea virginica*) landings have varied from a high of 84,491 lb. in 1989 to zero in 1981. The landing for 1991 of 5,029 lb was typical of most years since 1972.

Water Quality and Its Biotic Effects

Salinity. Salinity in the Lower Laguna Madre generally exceeds 35 ppt (Warshaw, 1975), but prior to construction of the GIWW, salinities were often greater than 60 ppt (Quammen and Onuf, 1993). Allison (1987) reports that recent maxima do not exceed 46 ppt.

Sharp declines in salinity occur as a result of precipitation during hurricanes and tropical storms. The period of recovery following major declines may be up to four years (Warshaw, 1975). For example, following Hurricane Beulah in 1967, salinities in the Lower Laguna Madre did not return to pre-hurricane levels until 1971 (Warshaw, 1975).

Declines in salinity may also be caused by floodwaters entering the Lower Laguna Madre from the Arroyo Colorado and North Floodway. Breuer (1962) reported that in the fall of 1958, these two channels carried an estimated 5 million acre-feet of water into the laguna from the flooding Rio Grande. Salinity in the Lower Laguna Madre was affected for at least six months. For example, salinity at Three Islands in August 1958 was 35.6 ppt before the floodwaters entered. After the floodwaters entered the laguna, salinity dropped to 13.2 ppt in November 1958. In December 1958 it rose to 17.4 ppt, and in April 1959 salinity was 31.2 ppt (Breuer, 1962).

Allison (1987) attributed differences in the molluscan fauna of the Upper and Lower Laguna Madre to a general lowering of salinity (since the 1940s) in the Lower Laguna Madre. He reported 107 species of molluscs from the Lower Laguna Madre and 72 species for the Upper Laguna Madre. The two share only 42 species.

Recently, Quammen and Onuf (1993) suggested that shifts in cover of seagrass species in the Lower Laguna Madre are due to a reduction in salinity maxima. They show that in 1965 *Halodule wrightii* dominated the entire Lower Laguna Madre, except for a meadow of *Syringodium filiforme* and small patches of *Thalassia testudinum* close to the Brazos-Santiago Pass and a bare, deep area north of Port Mansfield. By 1988 cover by *Halodule wrightii* had decreased from 550 km² to 220

km² (a 60 percent decline) and cover by *Syringodium filiforme* and *Thalassia testudinum* had increased from 70 km² to 260 km² (a 270 percent increase). The area of bare bottom in the Lower Laguna Madre had increased from 50 km² to 190 km² (a 280 percent increase).

Quammen and Onuf (1993) point out that the bare areas are confined to the deeper parts of the laguna, and they suggest that increased turbidity caused by maintenance dredging of the GIWW is the probable cause of the loss of seagrass cover. Eutrophication resulting from drain nutrient inputs might also be involved (Quammen and Onuf, 1993), but phytoplankton monitoring data they report suggests that this is not so.

Quammen and Onuf (1993) report that three factors working together appear to be responsible for the moderation of hypersaline conditions in the Lower Laguna Madre: (1) increased exchange with the Gulf of Mexico resulting from channel dredging, (2) increased precipitation since 1965, and (3) increased flow from the Arroyo Colorado and North Floodway. They show that flows from the Arroyo Colorado and North Floodway have increased over time. During 1941-52 the combined flows were greater than 10 m³ s⁻¹ only 8 percent of the time, but increased to 35 percent of the time in the 1966-1975 period and to 72 percent of the time during 1976-1986. Some of the increase is due to increased population and consequent discharges from wastewater treatment plants, but Quammen and Onuf (1993) maintain that increased agricultural drainage is the principal cause. Increased agricultural drainage is thought to be due to greater clearing of shrublands and grasslands and to the installation of subsurface drains in cropland to counteract salinization. This water, rather than evaporating, percolates down through the soil, is drawn off at depth in drainage pipes and is discharged into drainage channels (Quammen and Onuf, 1993). Allison (1987) had earlier suggested that the clearing of brushland for agriculture and the extensive construction of irrigation and floodway systems throughout the lower Rio Grande Valley had probably increased the amount of fresh water that reaches the Lower Laguna Madre.

Quammen and Onuf (1993) point out that the seagrass species that is declining in the Lower Laguna Madre, *Halodule wrightii*, is almost the sole source of food for redhead ducks (*Aythya americana*) during their winter residence. They suggest that in the future there will be further reduction in the cover by *Halodule wrightii* and possibly serious consequences for redhead ducks.

Temperature. High water temperatures apparently are not a problem in the Lower Laguna Madre (Warshaw, 1975; Bowles, 1983; Webster, 1986). Conversely, Breuer (1962) reported that drops in water temperature during excessively cold and prolonged northers have done catastrophic damage to marine life in the Lower Laguna Madre and will undoubtedly do so in the future. They have. The most recent “freezes” were in 1983 and 1989. Both freezes resulted in massive fish kills in the Lower Laguna Madre. Bennett and Judd (1992) cited personal communication with Bill Balboa (TPWD), who reported that TPWD personnel estimated more than 29 million fish were killed along the southern Texas coast by cold fronts in the 1980s.

Freezing temperatures in 1983 and 1989 have also killed black mangroves (*Avicennia germinans*) in the Lower Laguna Madre back to ground level (Lonard and Judd, 1985, 1991). Everitt and Judd (1989) used color infrared aerial photography to assess the recovery of black mangrove after the 1983 freeze. They found that populations at Port Isabel-South Padre Island and at Harbor Island near Port Aransas had recovered, but a population at Cavallo Pass was severely reduced.

Dissolved Oxygen. Most surface levels of dissolved oxygen reported in studies of the Lower Laguna Madre have been greater than the 5 mg/l criterion established in Texas Surface Water Quality Standards (Warshaw, 1975; Bowles, 1983; Webster, 1986). Exceptions were reported by Warshaw (1975) for a station at the intersection of the Arroyo Colorado and the GIWW where a value of 3.8 mg/l was obtained 20 June 1974, and at the intersection of the Port Mansfield Channel and the GIWW on September 11, 1973, where a value of 1.5 mg/l was obtained. Both values occurred during warm months when the capacity of water to hold oxygen is lowest and oxygen demand of the biological community is highest.

Bowles (1983) found that dissolved oxygen levels were reduced with depth and progression toward the dead-end turning basin in the Brownsville Ship Channel. This is a predictable consequence of the dead-end structure of the channel. Bowles (1984) reported that sampling for benthic organisms in the Port Mansfield harbor area indicated that anaerobic conditions exist in the sediment at all stations sampled. He stated, “This duplicates earlier results of numerous studies in the last 15 years.”

Total Coliform Count. The water quality standard for the Laguna Madre for contact recreation is currently 200 fecal coliform colonies/100 ml; for shellfish harvestry areas it is 14 colonies/100 ml. Warshaw (1975) reported that the median values in the lower Laguna Madre were low, but individual values at Port Mansfield (1,300 colonies/100 ml) and the intersection of Arroyo Colorado and the GIWW (240,000 colonies/100 ml) were elevated greatly.

Bowles (1983) reported fecal coliform counts of 200 colonies/100 ml from San Martin Lake, which is a tertiary embayment with a connection to the Brownsville Ship Channel. San Martin Lake receives discharges from the Brownsville Navigation District port complex sewer treatment plant and the Brownsville Public Utilities Board Northside sewer treatment plant. In the past it also received industrial wastewater from the Union Carbide industrial wastewater treatment facility (now closed). nonpoint-source agricultural runoff and irrigation return flows connect with San Martin Lake through a series of drainage ditches and canals.

Nutrients. Warshaw (1975) reported that nutrients were considerably higher at a station where the Arroyo Colorado intersects the GIWW than at other stations in the Lower Laguna Madre. Generally, concentrations of ammonia and nitrate were below their respective detectable limits of 0.1 and 0.03 mg/l, but median values at the Arroyo Colorado station were 0.3 and 0.18, respectively (Warshaw, 1975). Median phosphate concentrations at this station were 0.32 mg/l, about three times higher than at other stations in the Lower Laguna Madre.

The Texas Department of Water Resources (1983) reported data on total nitrogen, phosphorus, organic carbon, and Kjeldahl nitrogen from a 1980 field survey. Tables 3 and 4 contain this data. The sequence of locations is rearranged from TDWR tables so that sites are in sequence from north to south and Upper and Lower Laguna Madre locations are identified.

The field survey data show that the Raymondville Drain, North Floodway, and Arroyo Colorado experienced at least eight times higher mean concentrations of total nitrogen than all other points sampled (Table 3). The North Floodway, Arroyo Colorado, and Raymondville Drain had at least 10 percent higher concentrations of total phosphorus than all other locations except Baffin Bay (Table 3). Total organic carbon was highest at Raymondville Drain, and values for the Raymondville Drain, Arroyo Colorado, and North Floodway were markedly higher than at other locations in the

Lower Laguna Madre (Table 4). The Raymondville Drain, Arroyo Colorado, and North Floodway had markedly higher values than all other locations.

Annual nutrient loading to the Lower Laguna Madre was estimated from freshwater inflows by the Texas Department of Water Resources (1983). Mean annual inflows were 185,000 kg for ammonia nitrogen, 386,000 kg for nitrate nitrogen, 513,000 kg for total phosphate, and 4,008,000 kg total organic carbon (Texas Department of Water Resources, 1983).

Webster (1986) found nutrient values were low in the Port Isabel fishing harbor, but he reported that they compared favorably with nutrient values generally observed in southern Texas estuarine waters.

Pesticides. In the past, pesticides contributed to the Arroyo Colorado have been identified as a water quality problem by the TPWD (Warshaw, 1975). Specifically, a decline in spotted sea trout in the Lower Laguna Madre, as evidenced by decreased commercial catches and fewer juveniles in nursery areas, was attributed to the effects of DDT residues on reproduction. Evidence for the relationship was based on a rough correlation between residue concentrations in trout and the timing of the decline. Bowles (1983) reported that relatively high levels of the organophosphate insecticide Parathion (0.25 ug/l) were found in water samples taken from San Martin Lake. These samples were taken in conjunction with the investigation of a fish kill in San Martin Lake that began June 14, 1982, and lasted through June 16, 1982. More than 375,000 fish of several species were affected (Bowles, 1983).

Dead fish found in the Los Fresnos Drain (Number 2) suggested that this was the route of entry into the San Martin System. San Martin Lake connects with the Brownsville Ship Channel and through it with the Lower Laguna Madre.

Webster (1986) provided data on 21 pesticides in water and 19 pesticides in sediment at the Port Isabel fishing harbor. No pesticides were present at levels detectable by TDH laboratory methods. This investigation included DDT, DDD, DDE, and Parathion. Bowles (1983) reported finding polychlorinated biphenyls in the sediment at the Brownsville Ship Channel turning basin at a concentration of 121 ug/kg. Gamble et al. (1988) found high levels of polycyclic aromatic hydrocarbons in the sediment of the turning basin. Spillage of petroleum products was the suspected source.

Table 3. Texas Department of Water Resources 1980 field survey data for total nitrogen and phosphorus (TDWR, 1983).

Locations	Total Nitrogen			Total Phosphorus		
	No. samples	X (mg/l)	variance (mg /l)	No. samples	X (mg/l)	variance (mg /l)
Upper Laguna Madre						
JFK Causeway	27	0.048	0.00084	27	0.068	0.00059
Baffin Bay	13	0.04	0.0	13	0.10	0.0006
No. Land Bridge	14	0.074	0.00027	14	0.086	0.00064
Lower Laguna Madre						
So. Land Bridge	13	0.046	0.00027	13	0.049	0.00064
Raymondville Drain	14	0.81	0.055	14	0.20	0.00048
Mansfield Entrance Channel	13	0.04	0.0	14	0.042	0.00011
North Floodway	14	2.51	0.0143	14	0.23	0.0025
Arroyo Colorado	13	0.61	0.0033	13	0.21	0.0042
Brazos-Santiago	13	0.04	0.0	13	0.03	0.000052
South Bay Pass	13	0.04	0.0000071	13	0.05	0.00089
Brownsville Ship Channel	14	0.04	0.000027	14	0.05	0.0011

Table 4. Texas Department of Water Resources 1980 field survey data for total organic carbon and Kjeldahl nitrogen (TDWR, 1983).

Locations	Total Organic Carbon			Total Kjeldahl Nitrogen		
	No. samples	X (mg/l)	variance (mg /l)	No. samples	X (mg/l)	variance (mg /l)
Upper Laguna Madre						
JFK Causeway	27	7.96	1.37	27	1.2	0.039
Baffin Bay	13	8.00	0.923	13	1.6	0.027
No. Land Bridge	14	7.43	2.53	14	1.1	0.018
Lower Laguna Madre						
So. Land Bridge	13	5.50	0.249	13	0.95	0.010
Raymondville Drain	14	9.60	1.67	14	3.1	0.372
Mansfield Entrance Channel	13	3.80	1.67	13	0.77	0.022
North Floodway	14	6.90	0.209	14	2.1	0.163
Arroyo Colorado	13	7.40	1.31	13	2.6	0.734
Brazos-Santiago	13	2.40	0.852	13	0.52	0.021
South Bay Pass	13	3.20	4.64	11	0.60	0.007
Brownsville Ship Channel	14	2.30	0.204	14	0.61	0.007
Brownsville Ship Channel	14	2.30	0.204	14	0.61	0.007

Heavy Metals. The Texas Department of Water Resources (1983) reported detection of heavy metals in sediment based on data collected for the period 1972 to 1978. Heavy metals detected at Port Mansfield and the Laguna Madre below the Arroyo Colorado were cadmium, cobalt, lead, manganese and zinc. The Laguna Madre location also included arsenic. Only the cadmium concentrations (at both locations) exceeded dredge spoil criteria. Each value was based on analysis of a single sample.

Bowles (1983) reported finding high levels of arsenic, cadmium, copper, chromium, lead, mercury, manganese, silver, and zinc in the water at the Brownsville Ship Channel turning basin. High levels of copper and oil and grease were found in sediment at the Brownsville fishing harbor, where many shrimping and fishing boats are moored and repaired. Bowles (1984) reported that high levels of zinc were found in sediments in Port Mansfield harbor. Two stations in Port Mansfield harbor had high levels of barium (Bowles, 1984). These were suggested to be the result of drilling mud spills that occurred during the loading of service boats. Bowles (1984) points out that it is not unusual to find relatively high concentrations of zinc in port sediments due to dezincification of brass used in marine vessels and equipment, as well as corrosion of zinc sacrificial cathodic protectors and other anode systems. Webster (1986) reported that iron, copper, and zinc were detected in Port Isabel fishing harbor water samples. Concentrations of all other metals were below detection limits. Concentration of iron at two stations (310 ug/l and 650 ug/l) were relatively high, but below the EPA recommendation of 1,000 ug/l for the protection of freshwater life. Webster (1986) suggested that the source of iron may be numerous steel-hulled craft in the harbor. Concentrations of copper and zinc were low in water, but zinc and arsenic were relatively high in sediment and elevated over 1982 data from the same locality (Webster, 1986). Arsenic levels in sediment equaled or exceeded the EPA dredge disposal screening criterion (Webster, 1986). Concentrations ranged from 4.2 to 10.9 mg/kg. Webster (1986) reports that background arsenic levels vary throughout the south Texas area, and high levels of arsenic are not uncommon.

Sediments in the Lower Laguna Madre contain a relatively high proportion of sand and a low proportion of clay, compared to sediments in other Texas bays (Warshaw, 1975). Bottom areas containing a large amount of clay are restricted to deltas at the mouths of floodways and to

South Bay, which formerly received a large amount of silt from the Rio Grande (Warshaw, 1975). The sand deposits are derived from material washed or blown from Padre Island.

Biotic Diversity. The diversity of a biological community is generally considered to reflect the effects of toxic substances, environmental extremes, and other factors that place stress on the organisms present. Benthic animals are relatively immobile and require a substantial period of time to regenerate their populations following exposure to a stressor. For these reasons, benthic species diversity is taken as an appropriate indicator of habitat quality. Bowles (1983) reports that benthic macroinvertebrate data for the Brownsville Ship Channel indicate unfavorable conditions for bottom dwelling organisms throughout the study area. Surveys at the Port Mansfield harbor provided similar results (Bowles, 1984).

Webster (1986) found a total of 37 species representing seven phyla of animals in benthic diversity collections in Port Isabel fishing harbor. Species diversity at four stations ranged from 1.04 to 2.65. Webster (1986) concluded that diversity indices indicated moderate water quality while equability values indicated good to excellent water quality.

Brown Tide

In May 1990 an occurrence of brown tide (due to an unidentified aberrant Chrysophyte species) spread rapidly throughout Baffin Bay and the adjoining Upper Laguna Madre (Buskey and Stockwell, 1993; Stockwell et al., 1993; Whitley, 1993). During maximal distribution, the brown tide reached densities of 10^9 cells/liter and ranged from Baffin Bay northward to Rockport (Stockwell et al., 1993). Apparently, the prevailing southeasterly winds in summer and fall prevented transportation of the brown tide into the Lower Laguna Madre. But with the onset of winter and the passage of several "northers" (cold fronts with winds from the north), brown tide began invading the Lower Laguna Madre in November and December 1990 (Stockwell et al., 1993).

Buskey and Stockwell (1993), Stockwell et al. (1993), and Whitley (1993) reported on aspects of the brown tide after it had persisted for 18 months. It is still present in the Laguna Madre. The organism is as yet unidentified, but is similar in several aspects to *Aureococcus anophagefferens* (Buskey and Stockwell, 1993). Stockwell et al. (1993) suggest that it is a new species not previously described.

Stockwell et al. (1993) propose the following scenario for bloom initiation. Bloom conditions were established by the concomitant effects of a regional drought and localized hypersalinity. The higher salinities may have favored preferential growth of the organism. The December 1989 freeze and resultant fish kill may have added limiting organic and inorganic compounds essential to the rapid growth of the chrysophyte. Increased resident time within the bay waters allowed for further accumulation of brown tide during the initial blooming. Stockwell et al. (1993) point out that this accumulation of events in the past has not resulted in such major bloom occurrences. They suggest that another mechanism triggered the onset of the bloom. An uncoupling of water column processes and the benthos was induced by the exposure and freezing of extensive tidal flats during the December 1989 to January 1990 freeze, and the reduction of benthic control together with reduced microzooplankton grazing allowed the chrysophyte to become established in the upper reaches of Baffin Bay. Once established, the reduction in zooplankton grazing pressure on the chrysophyte permitted physical processes to rapidly disperse the brown tide.

Reduced grazing pressures and reduced washout effects, combined with elevated salinities, have allowed the brown tide to persist within the Laguna Madre (Stockwell et al., 1993). Stockwell et al. (1993) report that this persistent brown tide has temporarily changed the phytoplankton/seagrass production ratio, reduced standing stocks and grazing efficiency of higher trophic levels, and altered nutrient cycles with the Laguna Madre.

Buskey and Stockwell (1993) reported on the effects of the brown tide in Baffin Bay and the Upper Laguna Madre. Their study began in March 1989, over a year before onset of the bloom, and continued through July 1991. Two major stations were located in the Upper Laguna Madre in shallow water (< 1 m) over seagrass beds, and two stations were located in Baffin Bay in water about 3 m deep over a muddy bottom. They found that mesozooplankton populations, dominated by the copepod *Acartia tonsa*, were abundant before the onset of the brown tide. At the beginning of the brown tide, the mesozooplankton populations declined sharply and remained low until the brown tide began to diminish in the late spring of 1991 (Buskey and Stockwell, 1993). During the brown tide, prosome lengths of *A. tonsa* were reduced, suggesting poor nutrition and growth, and egg release by adult females decreased significantly (Buskey and Stockwell, 1993). Gut pigment concentrations were also significantly decreased, indicating that *A. tonsa* was not eating the brown

tide chrysophyte (Buskey and Stockwell, 1993). Microzooplankton populations and grazing rates were also reduced significantly following onset of the brown tide.

Buskey and Stockwell (1993) suggest that the small size of the brown tide cell may have prevented it from being captured efficiently by *Acartia tonsa*. They also report that ctenophore abundance was high before the beginning of the brown tide, but ctenophores remained scarce or absent after the tide began. Buskey and Stockwell (1993) note that microzooplankton are of an appropriate size for grazing on the brown tide chrysophyte, and they suggest that the microzooplankton may not do so because the chrysophyte produces a substance or substances that inhibit grazing. Alternatively, *Acartia tonsa* may have shifted to feed on the microzooplankton, thus keeping their populations below a level where the microzooplankton could exert grazing pressure on the brown tide chrysophyte (Buskey and Stockwell, 1993).

Whitledge (1993) reported on the nutrient and hydrographic conditions prevailing in the Laguna Madre before and during the brown tide bloom. Samples were collected at monthly intervals for 15 months prior to the bloom and 18 months after onset. There was a total of 57 stations between the John F. Kennedy Causeway in the Upper Laguna Madre and the Mansfield Pass in the Lower Laguna Madre. Figure 1 of his paper shows 10 stations in the Lower Laguna Madre from the land cut to the Port Mansfield channel and three stations in the channel.

Whitledge (1993) found a north-to-south gradient in salinity above the land cut with maximum values in the upper reaches of Baffin Bay. Salinity was markedly lower at stations in the Lower Laguna Madre and generally between 35 and 40 ppt. Dissolved inorganic nitrogen concentrations also showed maximum concentrations in Baffin Bay with ammonium accounting for 60-95 percent of the total preceding the bloom. There were very small amounts of nitrate in the land cut and Lower Laguna Madre waters, and Whitledge (1993) proposed that the relatively higher nitrate in Baffin Bay must be produced *in situ*, perhaps by nitrification or nitrogen fixation. Enhanced chlorophyll concentrations showed that the phytoplankton responded to the nitrate in the water of Baffin Bay (Whitledge, 1993).

Whitledge (1993) suggested that nonpoint enrichment from fertilizer might be the source of the high ammonium concentrations. Alternatively, he suggests that decaying fish carcasses result-

ing from the December 1989 freeze could have produced a substantial quantity of dissolved inorganic nitrogen and/or ammonium. Furthermore, the freeze could have killed most of the infauna at low tide on the exposed flats that make up a large fraction of the Laguna Madre ecosystem.

Laguna Madre de Tamaulipas

The Laguna Madre de Tamaulipas is a double basin hypersaline lagoon system largely isolated from Gulf of Mexico waters by sandy barrier island strands (Britton and Morton, 1989). The barrier islands of Tamaulipas, Mexico, are generally more narrow and have dunes of lower elevation than Padre Island. They are cut by several tidal channels that are filled with sand after storms.

The northern portion of the Laguna Madre de Tamaulipas is floored by deltaic deposits of the Rio Grande and the central portion by deltaic river deposition from the Rio de San Fernando (Britton and Morton, 1989). Today, the Laguna Madre de Tamaulipas receives little river discharge from any source.

Brine-filled basins rimmed by exposed tidal flats lie to the north and south of the Rio San Fernando delta. The northern basin is the largest and most isolated. It is about 20 km wide and 55 km long and has a maximum depth of about 3.0 m (Britton and Morton, 1989). The southern basin is narrower and shallower. Maximum depth is approximately 1.3 m (Britton and Morton, 1989). The widest point (17 km) is immediately south of the Rio San Fernando delta. The width decreases to less than 3 km near the mouth of the Rio Soto la Marina.

Evaporation exceeds precipitation in the Laguna Madre de Tamaulipas area, and while salinity varies seasonally, it tends to remain high (Britton and Morton, 1989). Most of the “passes” or tidal channels are filled with sand, except shortly after major storms, so there is little exchange with the Gulf of Mexico. Salinities in excess of 110 ppt are common in the northern portion of the northern basin. In the northern part of the southern basin they may be 130 ppt or greater.

Information Gaps and Recommendations

Except for the Texas Department of Water Resources (1983) report on nutrient distribution, studies of water quality of the Lower Laguna Madre have been relatively limited in geographic coverage and have focused on harbors and channels (e.g., Warshaw, 1975; Bowles, 1983, 1984;

Webster, 1986). A comprehensive study of the entire Lower Laguna Madre is needed. Furthermore, recent studies have been conducted at single points in time (over a one- to four-day period, typically); thus, little is known about seasonal variation. A comprehensive study should include provision for sampling at least four times during the same year. It would be most beneficial if such a study could be conducted over a three year period so that trends might be identified. The study by Quammen and Onuf (1993) points out marked change in the seagrass community of the Lower Laguna Madre. Similar analyses should be undertaken for other biotic elements such as the benthic macroinvertebrates. Data provided by Allison (1987) suggest that there may have been marked changes in the molluscan fauna as well. Because the decline in *Halodule wrightii* may adversely affect redhead ducks wintering in the Lower Laguna Madre, it will be particularly important to monitor the numbers of this species present each year. The study of the effects of the brown tide on Lower Laguna Madre ecosystems should be continued and expanded to include additional locations and more elements and processes.

When the Brownsville Ship Channel was completed in 1938, much of the spoil from the east end of the channel was placed in a line along the north end of South Bay. This spoil and subsequent spoil from maintenance dredging greatly narrowed the entrance to South Bay (Breuer, 1962). As a consequence, the circulation of water from the Gulf of Mexico through South Bay and Boca Chica Pass back into the Gulf was eliminated because Boca Chica Pass silted in and closed permanently in 1945 (Breuer, 1962). Since that time, circulation in South Bay has been greatly reduced, water depth has decreased, and much of the oyster population was killed by siltation (Breuer, 1962). Although Breuer (1962) maintains that siltation has killed oysters (*Crassostrea virginica*) in South Bay there are no data, beyond his report, of average depths. Siltation rates relative to the oyster reefs should be quantified. Hockaday et al. (1989) show that approximately 90 percent of the oyster reefs in South Bay occur in the southwest quadrant of the bay. We do not know if these reefs are stable, increasing, or decreasing in size. The South Bay oyster population is of considerable interest because it tolerates higher salinity concentration than any other oysters on the Atlantic or Gulf coasts and is genetically distinct from all other populations (Buroker, 1983). Siltation on seagrass beds as a consequence of maintenance dredging of the GIWW, Arroyo Colorado, and other chan-

nels needs to be quantified. Relatedly, spoil islands may impede circulation in the Lower Laguna Madre, and the release of materials from the dredged spoil should be studied.

Waters entering the Laguna Madre from the Arroyo Colorado are of special concern because they are low in dissolved oxygen, high in coliform bacteria, high in nutrients, and a source of heavy metals and pesticides (Warshaw, 1975; Texas Department of Water Resources, 1983). A three-year study of water quality from the Arroyo Colorado and North Floodway should be initiated. Sampling should provide for assessment of seasonal variation and its impact on key faunal and floral elements, such as benthic macroinvertebrates and seagrasses. This study should quantify the dilution effect with increasing distance from the mouths of the Arroyo Colorado and North Floodway. Similarly, the water quality of San Martin Lake and the Brownsville Ship Channel deserves special focus and regular monitoring at a frequency sufficient to quantify seasonal and annual variation. Webster (1986) recommends determination of sediment iron concentrations in Port Isabel fishing harbor along with continuing surveillance of all heavy metals in sediment. He also recommends monitoring of the disposal of dredge materials and a wider survey of arsenic concentrations in sediment.

GULF OF MEXICO

Introduction

The Gulf of Mexico is a semi-enclosed oceanic basin extending from about 18° N to 30° N and 81° W to 97° W on the western side of the Atlantic Ocean (Rezak et al., 1990). It encompasses 15,552,000 hectares and contains a great diversity of ecosystems. Water enters the Gulf of Mexico from the Yucatan channel, 176 km wide, and exits through the Florida Straights, 144 km wide (Rezak et al., 1990). The loop current, which directs this flow, is restricted to the eastern Gulf. Warm core rings spin off the loop current and move westward causing them to impinge on the upper continental slope of the northwest Gulf of Mexico even during winter months (Rezak et al., 1990).

The Gulf continental shelf is at its narrowest, 86 km, just north of the Brownsville area (Espey, Huston and Assoc., 1982). Also, the shelf slope is steeper in this area than elsewhere along the Texas coast (Brown et al., 1980). Other than deltaic deposits from the Rio Grande, the shelf in this area is bathymetrically featureless (Espey, Huston and Assoc., 1982). Offshore from South Padre Island, accumulation of Modern sediment is slow, and the area is floored by relict Holocene sand, shelly sand, muddy sand, mud, shelly mud, and sandy mud (Brown et al., 1980). Modern and Holocene deposits are thin, only centimeters thick, in many places so that Pleistocene deposits are patchily exposed on the seafloor (Brown et al., 1980).

Southeasterly winds are predominant throughout most of the year and generate a northward longshore drift (Brown et al., 1980). Winter cold fronts cause a temporary reversal of wind (Britton and Morton, 1989). The arctic fronts displace the subtropical airflow with strong northerly or northeasterly winds. The northern limit of the area is near Big Shell, north of Mansfield Pass on Padre Island. Big Shell also marks the location of the most acute flexure of the Texas coastal arc. This is where the northward longshore current from southernmost Texas converges with the southward moving longshore current of the upper and midcoasts (Britton and Morton, 1989). Mean annual precipitation is 63 to 66 cm, and the astronomical tidal range on the Gulf shore is 0.4 m (White et al., 1986). Hurricane probability in any given year is eight percent (White et al., 1986).

The Rio Grande empties directly into the Gulf of Mexico through a relatively narrow channel. Thus, there is no large estuary to dilute toxic materials in the river water, nor is there marsh vegetation present to absorb such materials. The prevailing northward-moving longshore current could transport toxic materials from the Rio Grande to the beaches of South Padre Island and through the channels at Brazos-Santiago Pass and the Port Mansfield Channel into the Laguna Madre.

Rio Grande Discharges and Pollution

The section on the Rio Grande in this report establishes that the river transports pollutants. These materials include DDE (White et al., 1983; Gamble et al., 1988), fecal coliform bacteria (Texas Water Commission, 1992a), toxaphene (Gamble et al., 1988) and xylene (Lewis et al., 1991). Additionally, there are elevated levels of chloride, sulfate, and total dissolved solids. These materials might directly affect the fauna and flora of the offshore Gulf of Mexico, but we have not found any reports documenting decreases in abundance due to pollutants discharged from the Gulf of Mexico.

Offshore nekton are a combination of species present on the continental shelf throughout the year, species that migrate into the area from farther south during the warmer months, and species utilizing both the Laguna Madre and Gulf of Mexico (Hoese and Moore, 1977; Espey, Huston and Assoc., 1982). The health of this latter group is of great concern because most of the Gulf of Mexico commercial fishes are estuarine dependent (Texas Department of Water Resources, 1983). Some species, such as redfish (*Sciaenops ocellata*), spawn in the fall and the young are particularly dependent on migration to and utilization of nursery habitats at this time. Other species, such as penaeid shrimp, spawn primarily in the spring and early summer, and their young move inshore to nursery grounds for growth and development at this time. Toxic materials transported northward from the Rio Grande might enter the passes at Brazos-Santiago and Port Mansfield and induce stresses that could inhibit reproduction and growth of these estuarine-dependent species.

The principal form of pollution documented in the offshore area is petroleum. The oil well, Ixtoc-1, being drilled in the Bay of Campeche, Mexico, blew out 3 June 1979. More than 3.5

x 10⁶ tons of crude oil reached Texas coastal waters (Lee et al., 1980). Chapman (1979) reported on the effects of the spill on marine bird populations from Aransas Pass to Brazos-Santiago Pass, but not on Padre Island National Seashore. Royal terns were heavily oiled (Chapman, 1979). Thebeau et al. (1981) sampled intertidal and subtidal infaunal populations along the coast between the Rio Grande and Port Aransas prior to and after the spill. Species richness did not change significantly after the spill, but there were significant reductions in pooled subtidal population densities. Changes in population density could not be attributed directly to oil from Ixtoc-1 because of other potential effects, including seasonal variation, beach erosion, and beach cleaning activities (Thebeau, et al., 1981). Laboratory experiments using weathered Ixtoc-1 oil showed that oil reduced the depth of the oxygenated layer of the benthos by about half (Kalke et al., 1982). They suggested that this reduction might reduce subsurface benthic production and alter processes such as nutrient regeneration. Rabalais and Flint (1983) found that a temporary tar reef created by Ixtoc-1 reduced the total number of organisms in the infauna near the tar reef and excluded some elements of the fauna completely. For example, haustoriid amphipods were common on Padre Island before the spill, but were not seen in the area of the tar reef (Rabalais and Flint, 1983).

Trends in Abundance

Trends in estuarine dependent-fishery abundance may provide information useful in assessing the health of organisms and the habitat quality of an area. Shrimp are Texas' most valuable commercial fishery (Samson, 1991). Brown shrimp (*Penaeus aztecus*), white shrimp (*P. setiferus*), and pink shrimp (*P. duorarum*) make up the bulk of the landings (Samson, 1991). The brown shrimp is the principal species landed in Texas and generally comprises 70 to 80 percent of the total landing for food (Samson, 1991). Nance et al. (1989) reported that fishing effort for both brown and white shrimp has increased dramatically since 1960. Nance et al. (1989) discuss causes of shrimp mortality but do not mention pollutants.

In 1992 shrimp landings totaled 19.2 million lb heads-on weight at Brownsville-Port Isabel (Newlin, 1993). This was a 33 percent decrease from 1991. Conversely, total finfish landings for the area increased to 1.4 million lb in 1992 (Newlin, 1993). Nance (1992) provides data on

May-August landings for Port Isabel and Brownsville ports over the years 1977 through 1992. The percent of the Gulf of Mexico total produced by these two ports was similar and consistent from 1977 through 1990 before reaching a high in 1991 followed by a decline to a record low in 1992.

Information Gaps and Recommendations

The on-going study by the TNRCC and TPWD funded by the Rio Grande Coastal Impact Monitoring Program (RGCIMP) will include two sampling sites in the Gulf of Mexico. This study should help to identify specific contaminants that may be impacting the water quality and organisms in the Gulf of Mexico near the mouth of the Rio Grande. However, studies are needed to establish the relationship between concentration and distance from the mouth of the Rio Grande of pollutants known to be in river water.

Because the longshore current is from south to north, a study is needed to determine the kinds of chemicals and their concentrations that may be entering United States waters from Mexico. It is crucial to ascertain what effect contaminants from the Rio Grande or from farther south in Mexico have on species and communities in the Gulf of Mexico. Apparently, these data do not now exist.

The EPA created the multi-agency Gulf of Mexico Program in 1988 in response to concerns about the deterioration of the Gulf, including waste and pollutant discharges. An undated 98-page draft report titled "Gulf of Mexico Regional Research Plan" from the Gulf of Mexico Regional Marine Research Program provides useful information about what many marine resource managers and research scientists think are priority areas of research. Certainly, this diversity of professionals is better able to comment on research needs than is a single individual; e.g., the author of this report. The following information is extracted from the draft report.

The Gulf of Mexico Regional Marine Research Program identified 13 topics as areas of priority research (Table 5). To facilitate gathering information from research scientists and marine and resource managers, the Gulf of Mexico was divided into three subregions (Eastern = Florida; Central = Alabama, Mississippi, and Louisiana; Western = Texas), and subregional workshops were held to review, rank, and discuss the 13 priority topic areas. At the Texas workshop, areas of deficient information and understanding for the nearshore zone, shoreline to 25 m depth, included: (1) circulation, (2) population dynamics, (3) nutrient enrichment and cycling, (4) onshore and offshore transport of nutrients, (5) influence of storm events, frontal boundaries, turbidity, and the nephloid

layer, (6) light penetration and attenuation, (7) predator-prey relationships, (8) biology of migrating species, and (9) significance of barrier island passes on population dynamics. The zone of interchange and transition where the continental shelf breaks over to the continental slope was denoted as an area of deficient knowledge.

Research areas for the offshore zone (seaward of the 25 m contour) included: (1) transport of sediments, nutrients, and pelagic organisms, (2) the effect of the Loop Current on the coupling and mixing of waters of the continental shelf, slope, and abyssal depths, and (3) productivity and the basic chemical and biological parameters and interactions affecting productivity.

Other specific topics identified as requiring study in the Texas subregion were: (1) remobilization of sediments and toxicants due to natural and anthropogenic activities, (2) impacts of ocean dumping, (3) agricultural runoff and associated contaminants, (4) sublethal effects of toxics on different organisms and life stages, (5) description of food webs and impacts upon productivity, and (6) circulation, interface, and exchange of nutrients and organisms throughout the marine ecosystem. These areas of study were for the entire Texas portion of the Gulf of Mexico. However, all certainly apply to the area defined in this study because it is one of the least studied areas of the Texas Gulf Coast.

ENDANGERED AND THREATENED SPECIES

Identities and Status

Table 6 provides a list of the endangered and threatened freshwater fishes (including estuarine) and amphibians, and terrestrial vertebrates species that, based on geographic ranges, may occur in the project area. The list was compiled from information provided in U.S. Fish and Wildlife Service (1986), Texas Herpetological Society (1986), Hubbs et al. (1991), and Jones (1993). It also draws upon experience of biologists at The University of Texas-Pan American.

Fish. Two fish are listed as endangered and two as threatened in the area (Table 1; Hubbs et al., 1991). The phantom shiner (*Notropis orca*) is thought to be extinct (Miller et al., 1989; Hubbs et al., 1991). It once occurred from near El Paso to the mouth of the Rio Grande (Hubbs et al., 1991). It is thought to have disappeared in Texas as a result of dam construction and resultant lowered water levels below the dams. All three of the other species are directly dependent upon the Rio Grande.

Table 5. Gulf of Mexico regional research plan research priorities (Gulf of Mexico Regional Marine Research Program, Draft undated).

1. Freshwater input (riverine and watershed).
2. Saltwater intrusion.
3. Nutrient enrichment and cycling.
4. Toxic materials, anthropogenic and natural.
5. Modifiers such as non-point source contaminants (including nutrients), transport mechanisms, rates of discharge, dispersion, transformation, and fates.
6. Trophic dynamics.
7. Population stability of marine organisms including factors such as predator-prey relationships and reproductive and colonization success.
8. Nuisance/exotic species.
9. Habitat use, assessment, loss, restoration, and enhancement. To include but not limited to wetlands, seagrass beds, natural and artificial reefs, mangrove swamps, hyper and hyposaline bays, estuaries, and nurseries.
10. Physical modifications including dredging, sediment dumping and alterations of freshwater input, current patterns or habitats.
11. Coastal erosion, sediment transfer and loss.
12. Catastrophic events (e.g. storms, spills, red and brown tides, etc.).
13. Global change.

The river goby (*Awaous tajasica*) is known from the Atlantic and Gulf coasts of the United States south through the West Indies and Central America. In Texas, this species is known only from the lower Rio Grande (Edwards et al., 1986). The blackfin goby (*Gobionellus atripinnis*) is known only from a few records in southern Texas and northern Mexico (Gilbert and Randall, 1979). It was originally described from the lower Rio Grande and now occurs near the mouth in estuarine habitat (Hubbs et al., 1991). The opossum pipefish (*Microphis brachyurus*) is found in Texas only in the lowermost reaches of the Rio Grande in Cameron County (Hubbs et al., 1991). It is widespread throughout the brackish waters of Central America, the Antilles, and scattered localities along the eastern Gulf and Atlantic coasts of the United States (Hubbs et al., 1991).

Three additional species that occur in the area are considered as deserving “special concern” status (Hubbs, et al., 1991). The fat snook (*Centropomus parallelus*) is known in Texas only from the lower Rio Grande near its mouth (Hubbs et al., 1991). Its range extends from Florida through the Gulf of Mexico southward to Brazil. Throughout its range, it is known to ascend great distances in coastal streams (Rivas, 1986). The common snook (*Centropomus undecimalis*) occurs in coastal waters from North Carolina through the Gulf of Mexico southward to Brazil. It commonly inhabits the lower reaches of coastal streams, especially in southern Texas (Hubbs et al., 1991). Hubbs et al. (1991) report that the Rio Grande shiner (*Notropis jemezanus*) has declined in abundance in recent years and appears spottily distributed within the Rio Grande basin. It formerly occurred throughout the basin.

Amphibians. Two of the amphibians listed as endangered (in Texas) are aquatic: the black-spotted newt (*Notophthalmus meridionalis*) and Rio Grande lesser siren (*Siren intermedia texana*). The black-spotted newt does not transform into a land-stage eft (Garrett et al., 1987) and is essentially aquatic, although it seeks shelter on land when ponds dry up. It occurs in shallow water of quiet streams, and in ditches and other man-made depressions. It may occur in the Rio Grande. The Rio Grande lesser siren retains gills throughout its life and attains sexual maturity in the larval form. If its habitat dries up, it burrows into the mud and secretes a mucous cocoon that dries into a protective covering allowing it to survive a drought of up to two months (Garrett et al., 1987). The Rio Grande lesser siren is found in shallow water with submerged vegetation. It occurs in resacas, lakes, ponds, irrigation canals, and return flow ditches. It may be found in the Rio Grande and Arroyo Colorado.

Clearly these aquatic species could be affected by toxic substances entering the Rio Grande. Changes in water level of the river could also affect their distribution and abundance.

Four species of toads and frogs that occur in the area are listed as threatened or endangered (Table 6). None of these are directly tied to the Rio Grande or Arroyo Colorado. They may be found along these streams, but they are not limited to them. Similar statements can be made about all the birds and reptiles listed in Table 6. Discussing the requirements and distribution of each species is beyond the scope of this investigation.

Mammals. Jones (1993) reviewed the status of endangered and threatened mammals in Texas. Those occurring in the study area are listed in Table 6. The manatee (*Trichechus manatus*) is an aquatic mammal of coastal bays and estuaries. Recent Texas records include a sighting near Corpus Christi in 1979 and a dead animal stranded near the Texas-Louisiana border in February 1986 (Fernandez and Jones, 1990). Don Hockaday (University of Texas-Pan American, Coastal Studies Laboratory) recovered a badly decomposed specimen on 2 December 1992 at South Padre Island, Texas. The available evidence suggests that manatees have always been rare in Texas waters, but not unprecedented along the southernmost Texas coast at Port Isabel (Gunter, 1941). Three live specimens were captured in 1911 (Gunter, 1941), and Alvarez (1963) cites a 1955 report of a manatee from the mouth of the Rio Grande. There is no evidence of a breeding population in the study area,

Table 6. Endangered and threatened freshwater fishes and amphibians and terrestrial vertebrate species that might occur in the project area. En = endangered, Th = threatened.

Scientific Name	Common Name	Federal		Texas	
		En	Th	En	Th
MAMMALS					
<i>Lasiurus ega</i>	Southern Yellow Bat				X
<i>Oryzomys couesi</i>	Coues' Rice Rat				X
<i>Felis onca</i>	Jaguar	X		X	
<i>Felis yagouaroundi</i>	Jaguarundi	X		X	
<i>Felis wiedii</i>	Margay	X		X	
<i>Felis pardalis</i>	Ocelot	X		X	
<i>Nasua narica</i>	Coati			X	
<i>Trichechus manatus</i>	Mantee	X		X	
BIRDS					
<i>Pelecanus occidentalis</i>	Brown Pelican	X		X	
<i>Egretta rufescens</i>	Reddish Egret				X
<i>Mycteria americana</i>	Wood Stork				X
<i>Plegadis chihi</i>	White-faced Ibis				X
<i>Grus americana</i>	Whooping Crane	X		X	
<i>Charadrius melodus</i>	Piping Plover				X
<i>Numenius borealis</i>	Eskimo Curlew	X		X	
<i>Sterna antillarum athalasses</i>	Interior Least Tern	X		X	
<i>Sterna fuscata</i>	Sooty Tern				X
<i>Haliaeetus leucocephalus</i>	Bald Eagle	X		X	
<i>Elanoides forficatus</i>	American Swallow-tailed Kite				X
<i>Buteo nitidus</i>	Gray Hawk				X
<i>Buteo albicaudatus</i>	White-tailed Hawk				X
<i>Buteo albonotatus</i>	Zone-tailed Hawk				X
<i>Buteogallus anthracinus</i>	Common Black Hawk				X
<i>Falco femoralis</i>	Aplomado Falcon	X		X	
<i>Falco peregrinus anatum</i>	American Peregrine Falcon	X		X	
<i>Falco peregrinus tundrius</i>	Artic Peregrine Falcon				X
<i>Glaucidium brazilianum</i>	Ferruginus Pygmy Owl				X
<i>Camptostoma imberbe</i>	Northern Beardless Tryannulet				X
<i>Pachyramphus aglaiae</i>	Rose-throated Becard				X

Scientific Name	Common Name	Federal		Texas	
		En	Th	En	Th
<i>Parula pitaiayumi</i>	Tropical Parula				X
<i>Dendroica chrysoparia</i>	Golden Cheeked Warbler	X		X	
<i>Aimophila botterii</i>	Botteri's Sparrow				X
REPTILES					
<i>Gopherus berlandieri</i>	Texas Tortoise				X
<i>Crotaphytus reticulatus</i>	Reticulate Collared Lizard				X
<i>Phrynosoma cornutum</i>	Texas Horned Lizard				X
<i>Coniophanes imperialis</i> <i>imperialis</i>	Black-striped Snake				X
<i>Drymarchon corais</i> <i>erebennus</i>	Texas Indigo Snake				X
<i>Drymobius margaritiferus</i> <i>margaritiferus</i>	Speckled Racer			X	
<i>Leptodeira septentrionalis</i> <i>septentrionalis</i>	Northern Cat-eyed Snake			X	
AMPHIBIANS					
<i>Notophthalmus</i> <i>meridionalis</i>	Black-spotted Newt			X	
<i>Siren intermedia texana</i>	Rio Grande Lesser Siren			X	
<i>Rhinophrynus dorsalis</i>	Mexican Burrowing Toad				X
<i>Leptodactylus fragilis</i>	White-lipped Frog			X	
<i>Smilisca baudini</i>	Mexican Treefrog				X
<i>Hypopachus variolosus</i>	Sheep Frog				X
FISH					
<i>Awaous tajasica</i>	River Goby				X
<i>Gobionellus atripinnis</i>	Blackfin Goby			X	
<i>Notropis orca</i>	Phantom Shiner			X	
<i>Microphis brachyurus</i>	Opossum Pipefish				X

and the animals that have been reported appear to be stragglers from populations farther south in Mexico.

The jaguar (*Felis onca*) is now thought to be extinct in Texas (Jones, 1993). According to Jones (1993) the coatimundi (*Nasua narica*) is listed as a Texas endangered species primarily because of its sporadic occurrence along the southern border of the state from the lower Rio Grande Valley to the Trans-Pecos. Frank W. Judd has studied the mammals of the lower Rio Grande Valley for over 20 years and has not seen a coatimundi alive or dead, nor is he aware of reports that others have seen, captured, or killed one.

All four of the remaining mammal species are documented as occurring in the study area. Vegetation adjacent to the Arroyo Colorado (at Laguna Atascosa National Wildlife Refuge) is crucial habitat for the ocelot and jaguarundi. Both may also use the riparian corridor along the Rio Grande. The population of ocelots is estimated at 80 to 120 individuals in the lower Rio Grande Valley (Tewes, 1990). The population of jaguarundis is estimated at no more than 15 individuals (Tewes, 1990). Jones (1993) suggested that with such low numbers, the survival of the jaguarundi is doubtful.

Coues-rice rat (*Oryzomys couesi*) is known to occur in stream margin communities and probably occurs along the Rio Grande and Arroyo Colorado. The southern yellow bat (*Lasiurus ega*) requires tall palm trees as roost sites. Most Texas specimens have been collected along the Rio Grande near Brownsville, where this bat is known to inhabit the Audubon Sabal Palm Sanctuary (Schmidly, 1991).

Marine Mammals. Table 7 provides a list of endangered and threatened marine mammals and sea turtles expected to occur in the project area. Sixteen species of cetaceans are listed. All are known to occur in the Gulf of Mexico, but only six species are known from the study area defined herein. These are: *Feresa attenuata* (James et al., 1970, Fritts et al., 1983); *Globiocephala macrorhynchus* (Schmidly, 1981, Fritts et al., 1983 to genus); *Mesolophodon europas* (Fritts et al., 1983, to genus; stranding recorded at The University of Texas-Pan American, Coastal Studies Laboratory in 1989); *Orcinus orca* (Schmidly, 1981); *Physeter macrocephalus*. (Schmidly, 1981, Fritts et al., 1983); and *Stenella plagiodon* (Schmidly, 1981; Fritts et al., 1983 to genus). In addition, while

this report was in preparation, Frank W. Judd investigated a whale in the study area that is tentatively identified as *Ziphius cavirostris*.

Sea Turtles. All five species of sea turtles listed in Table 7 have been documented to occur in the study area (The University of Texas - Pan American Sea Turtle and Salvage and Stranding Network reports). Loggerheads (*Carretta caretta*) are most common in strandings and were seen by Fritts et al. (1983) in aerial surveys. Fritts et al. (1983) did not see leatherbacks (*Dermochelys coriacea*), but Judd et al. (1991) reported two strandings. Even though green turtle (*Chelonia mydas*) strandings are rarely reported in South Texas, we recovered more than two dozen, cold-stunned green turtles in a one-week period during February 1989. Most were recovered in the Lower Laguna Madre and Brazos Santiago Pass, and several lived for subsequent release. Hawksbills (*Eretmochelys imbricata*) are rare in stranding reports in the Gulf of Mexico, but we have recovered a few small individuals, most of which were alive and subsequently released. The Kemp's ridley (*Lepidochelys kempi*) is the most endangered sea turtle. Manzella and Williams (1992) documented 20 strandings of this species in the South Padre Island area between the late 1940's and April 1990. Two live Kemp's ridley turtles were salvaged by The University of Texas - Pan American this month (April 1994) and transferred to Gladys Porter Zoo at Brownsville, Texas, for rehabilitation. Kemp's ridley nesting is restricted almost exclusively to the Rancho Nuevo, Tamaulipas beach, but there have been sporadic nestings at other locations in Tamaulipas and on Padre Island. Other than at Rancho Nuevo, Tamaulipas, the only location where a mass nesting (20 or 30 individuals) has been recorded is Playa Lauro Cuellar, just south of the mouth of the Rio Grande (Pritchard and Marquez, 1981) in the study area.

Plants. Table 8 provides a list of endangered, threatened, and extinct plant species that occur in the project area. Except for *Echinoacactus berlandieri v. angusticeps*, which may be extinct, all are listed to occur within the four-county area that comprises the lower Rio Grande Valley of Texas. Only two species, Johnston's Frankenia (*Frankenia johnstonii*) and ashy dogweed (*Thymophylla tephroleuca*), are on the federal endangered list (U.S. Fish and Wildlife Service, 1986). Most occur at upland sites.

Information Gaps and Recommendations

Information on population density or other measures of abundance are lacking for most of the endangered and threatened species in the project area. Thus, it is difficult to assess the impacts of perturbations. Basic life history information and habitat requirements are poorly known for many species. The status of these species in Mexico remains largely unknown.

Because the fish species are directly dependent upon the Rio Grande and its water quantity and quality, studies should be initiated to determine their population sizes and to assess seasonal and annual variation. Their habitat requirements should be quantified. A study of the fishes of the Arroyo Colorado is needed. The presence and abundance of species associated with the riparian corridor of the Rio Grande and the terrestrial communities of the Arroyo Colorado is needed. These studies should survey both the U.S.A. and Mexico sides of the Rio Grande corridor and they should include sampling at intervals throughout a year for at least two years.

Information on marine mammals in the study area is needed. A study drawing information from a variety of platforms of opportunity could provide useful data. Especially needed soon, is an intensive search for manatees in the lower Rio Grande and in other suitable habitats in Tamaulipas. Recent mild winters may have encouraged northward dispersal in the Mexican population.

Table 7. Endangered and threatened marine mammals and reptiles expected to occur in the project area. En = endangered, Th = threatened.

Scientific Name	Common Name	Federal		Texas	
		En	Th	En	Th
MAMMALS					
<i>Balenoptera boealis</i>	Sei Whale	X			
<i>Balenoptera musculus</i>	Blue Whale	X		X	
<i>Balenoptera physalus</i>	Finback Whale	X		X	
<i>Eubalaena glacialis</i>	Northern Right Whale	X		X	
<i>Feresa attenuata</i>	Pigmy Killer Whale				X
<i>Globicephala macrorhynchus</i>	Short-finned Pilot Whale				X
<i>Kogia breviceps</i>	Pigmy Sperm Whale				X
<i>Kogia simus</i>	Dwarf Sperm Whale				X
<i>Mesoplodon europas</i>	Gervais' Beaked Whale				X
<i>Megaptera novaeangliae</i>	Humpback Whale	X			
<i>Orcinus orca</i>	Killer Whale				X
<i>Physeter macrocephalus</i>	Sperm Whale	X		X	
<i>Pseudorca crassidens</i>	False Killer Whale				X
<i>Steno bredanensis</i>	Rough-toothed Dolphin				X
<i>Stenella plagiodon</i>	Atlantic Spotted Dolphin				X
<i>Ziphius cavirostris</i>	Goose-beaked Whale				X
REPTILES					
<i>Caretta caretta</i>	Loggerhead Sea Turtle	X		X	
<i>Chelonia mydas</i>	Green Sea Turtle		X		X
<i>Dermochelys coriacea</i>	Leatherback Sea Turtle	X		X	
<i>Eretmochelys imbricata</i>	Hawksbill Sea Turtle	X		X	
<i>Lepidochelys kempi</i>	Kemp's Ridley Sea Turtle	X		X	

Table 8. Endangered, threatened, and extinct plant species that may occur in the project area. Status proposed by Texas Organization for Endangered Species, Texas Natural Heritage Program, or U.S. Fish and Wildlife Service. Data taken from Ideker (1993), and U.S. Fish and Wildlife Service (1986).

Scientific Name	Common Name	Comments
ENDANGERED		
<i>Taxodium mucronatum</i>	Montezma Bald Cypress	Cameron, Hidalgo, and Starr counties
<i>Manfreda longiflora</i> (<i>Polianthes runyonii</i>)	Runyon's Huaco	Endemic to Lower Rio Grande Valley
<i>Achyranthes aspera</i>	Chaff-flower	Hidalgo County
<i>Lesquerella thamnophylla</i>	Shrubleaf Bladderpod	Endemic to Starr and Zapata counties
<i>Esenbeckia runyonii</i>	Jopoy	Cameron County
<i>Manihot walkerae</i>	Tamaulipan Manihot	Hidalgo County
<i>Ayenia limitaris</i>	Texas Ayenia	Cameron and Hidalgo counties
<i>Frankenia johnstonii</i>	Johnston's Frankenia	Starr and Zapata counties Federal endangered list
<i>Hybanthus verticillatus</i> v. <i>platyphyllus</i>	Cameron Green Violet	Endemic to Cameron County
<i>Enchinocactus berlandieri</i> v. <i>angusticeps</i>	LinnYellow Alichoe	Endemic to Hidalgo County. May be extinct
<i>Astrophytum asterias</i>	Star Cactus	Starr County
<i>Ambrosia cheiranthifolia</i>	South Texas Ambrosia	Cameron County
<i>Thymophylla (Dyssodia) tephroleuca</i>	Ashy Dogweed	Starr and Zapata counties Federal endangered list
THREATENED		
<i>Sabal texana</i>	Texas Sabal Palm	Cameron and Hidalgo County
<i>Tillandsia baileyi</i>	Bailey's Ballmoss	Along Arroyo Colorado in Harlingen
<i>Echandia chandleri</i>	Lila de los Lomas	Cameron County
<i>Atriplex klebergorum</i>	Kleburg Saltbush	Starr County
<i>Cardiospermum dissectum</i>	Dissected Balloon-vine	Hidalgo, Starr and Zapata counties
<i>Amoreuxia wrightii</i>	Yellowshow	Cameron, Hidalgo, and Starr counties
<i>Opuntia strigil</i> v. <i>flexospina</i>	Flexible-spined Prickly Pear	Starr and Zapata counties
<i>Thelocactus bicolor</i>	Yellow-spined Glory-of-	Starr County

<i>v. flavidispinus</i>	Texas Cactus	
<i>Coryphantha macromeris</i>	Runyon's Pincushion	Cameron, Hidalgo and Starr counties
<i>v. runyonii</i>	Cactus	
<i>Asclepias prostrata</i>	Prostrate Milkweed	Starr and Zapata counties
<i>Matela radiata</i>	Falfurrias Milkvine	Hidalgo and Starr counties
<i>Citharexylum spathulatum</i>	Mission Fiddlewood	Hidalgo and Starr counties
<i>Justicia runyonii</i>	Runyon's Water-willow	Lower Rio Grande Valley
<i>Grindelia oolepis</i>	Plains Gumweed	Cameron County
Scientific Name	Common Name	Comments

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