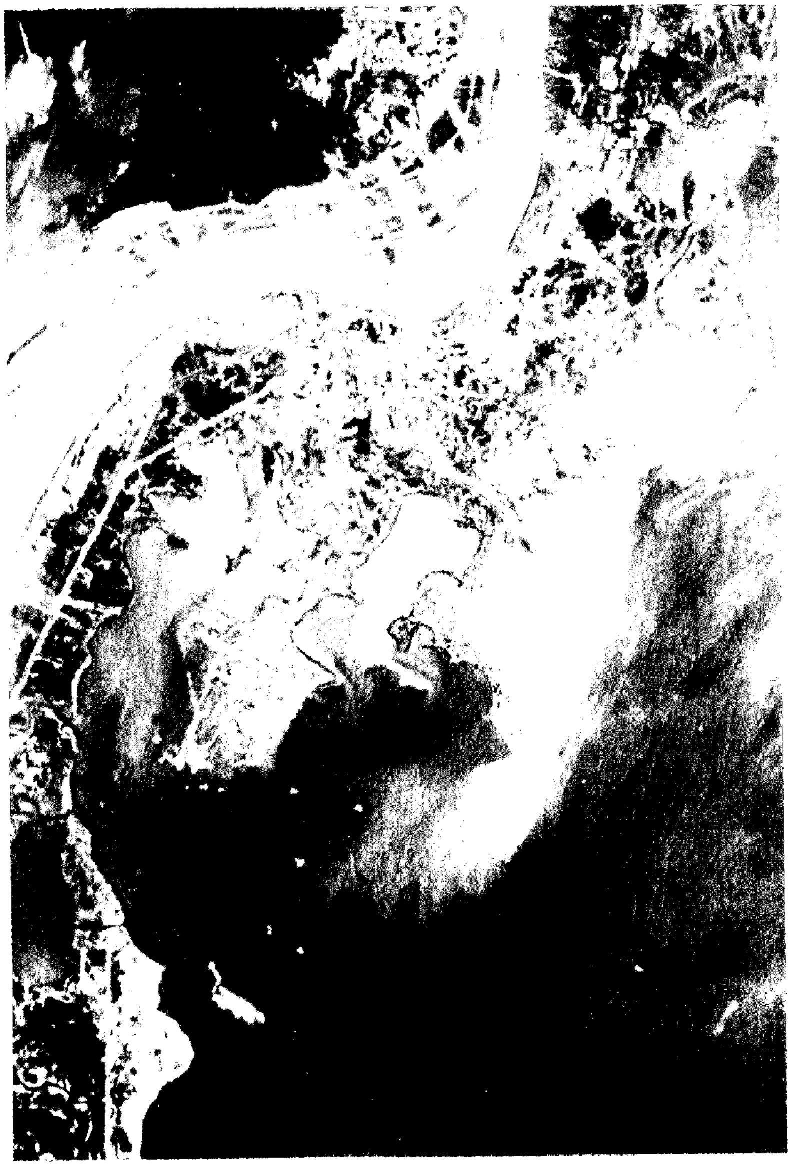

RECOMMENDATIONS FOR FRESHWATER DIVERSION TO LOUISIANA ESTUARIES EAST OF THE MISSISSIPPI RIVER

DEPARTMENT OF NATURAL RESOURCES
COASTAL MANAGEMENT SECTION

Cover:

A plume of turbid water emanates from Bayou Lamoque as freshwater is diverted from the Mississippi River into the Breton Sound estuary to control salinity levels and enhance oyster production (p. 2).

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RECOMMENDATIONS FOR FRESHWATER DIVERSION TO LOUISIANA ESTUARIES EAST OF THE MISSISSIPPI RIVER

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TABLE OF CONTENTS

LIST OF PHOTOS

LIST OF FIGURES

LIST OF TABLES

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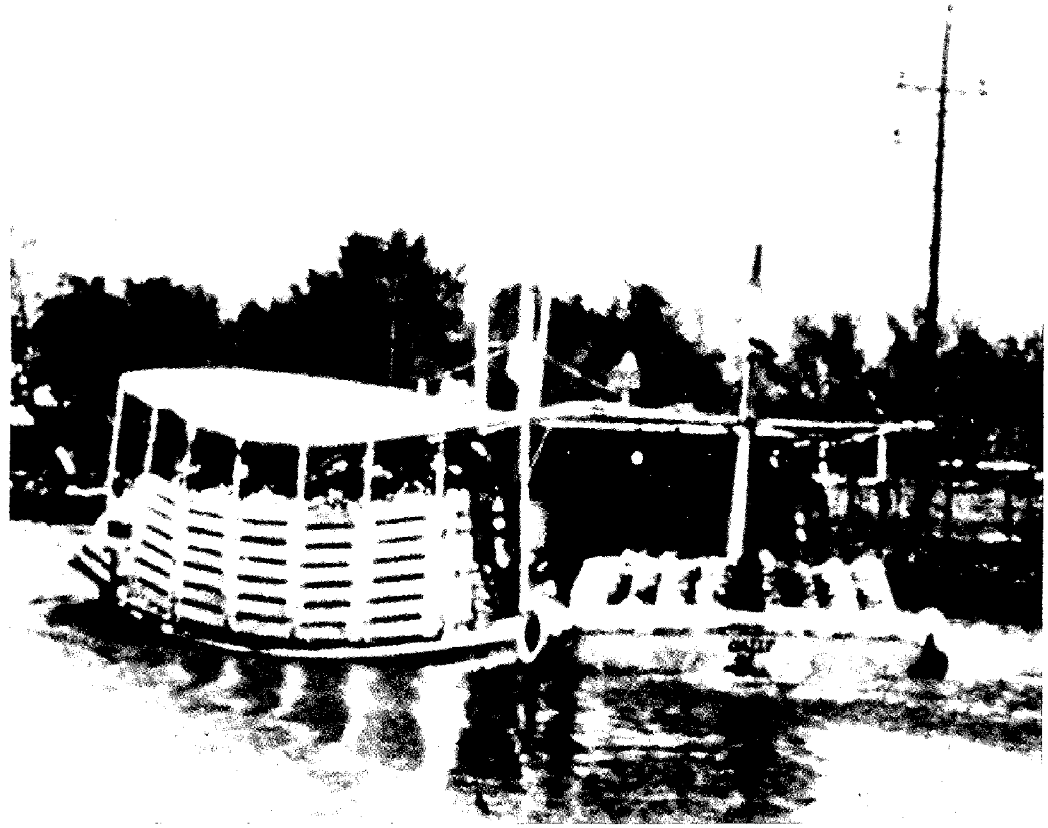


Oyster boat returning to dock.

CHAPTER I
INTRODUCTION

In recent years, a growing awareness of the environmental problems in coastal Louisiana has increased interest in implementing major diversions of freshwater and sediment from the Mississippi River into rapidly deteriorating wetland areas. This interest is evident at Federal, state and local levels. In recognition of the state's interest in such projects, in 1979 the Louisiana Legislature enacted an amendment to Section 213.10 of Title 49, adding Subsection F, which directed preparation of a freshwater diversion plan under the State and Local Coastal Resources Management Act. It is under this mandate that the present study has been authorized.

Implementation of at least one major freshwater diversion structure was brought a step further in 1981 when Governor David C. Treen and the State Legislature established the Coastal Environment Protection Trust Fund. Associated projects recommended for consideration by the Senate and House Committees on Natural Resources include the Caernarvon Freshwater Diversion Project in Plaquemines Parish. This same project has received renewed local support. Varnell and Lozes (1981) produced a working draft plan for a diversion at that location, striving to overcome most of the problems associated with the diversion projects at Scarsdale and Bohemia authorized in 1964.

Review of Past Work

The concept of diverting freshwater from the Mississippi River into the surrounding swamps and marshes is not a new one. In 1906, the second biennial report of the Oyster Commission of Louisiana recommended that gaps be permitted in the east bank levee in Plaquemines Parish to revitalize oyster beds made extinct by salty water. Ahead of his time in many ways, Percy Viosca, Jr. (1927, 1928) described the dependence of Louisiana's fisheries and wetlands on the freshwater resources of the Mississippi River. He foresaw a great problem in the harnessing of the river and suggested irrigation of the wetlands with siphons, as well as conservation of rainfall and groundwater for wetland management. Of the conflict between flood control and wetland resources, he states, "It should be considered a state and national problem equal in significance to agricultural development, to the end that the state and nation may enjoy a more balanced diet, more healthful recreation, and enduring prosperity" (Viosca 1928).

Twenty years later, the economic consequences of inadequate freshwater supplies to the oyster-producing areas of Plaquemines Parish had become severe enough to warrant action. In 1956, the Louisiana Wildlife and Fisheries Commission completed construction of the Bayou Lamoque Diversion Structure on the east bank of the river. Discharges from this structure have been responsible for maintaining oysters on several thousand acres of water bottoms since that time (Dugas 1981, personal communication). Another structure was built in 1977 at Bayou Lamoque to more than double the capacity, and both are presently operated solely to meet the needs of the oyster industry in Breton Sound.

The first comprehensive plan for freshwater diversion to benefit waterfowl and furbearers, as well as commercial fisheries, through habitat enhancement, was published through the U.S. Fish and Wildlife Service (FWS) (1964) and was included in volume V of the U.S. Army Corps of Engineers (USACE) Mississippi River and Tributaries Project. The report recommended four diversion sites: the Barataria Waterway and Empire on the west bank of the river and Scarsdale and Bohemia on the east bank of the river. At that time, the total implementation cost for the plan was estimated at $8.7 million, with a favorable benefit/cost ratio of 1.65. These four diversions were authorized by Congress, however, the state and local governments did not agree to grant the $741,000 as local assurance, and the plan was never implemented. For the purposes of this study, it should be mentioned that the 1964 plan was only intended to meet the needs of the Barataria Basin and the Breton Sound Estuary (Hydrologic Units IV and II, respectively).

In order to quantify the freshwater needs throughout coastal Louisiana, a series of studies were funded through the USACE in the late 1960s. These studies, together with contributions by other Federal and state agencies, documented salinity regimes, defined salinity goals considered desirable from a wildlife (primarily furbearer) and fisheries (primarily oyster) point of view, and determined to what extent freshwater requirements to meet defined goals could be met by available surpluses (Gagliano et al. 1971). Requirements and surplus determinations were based on continuous monthly water balance calculations (Gagliano et al. 1970) and statistical analyses of relationships between calculated freshwater inflow and measured salinities in each of Louisiana's estuaries (Light and Alawady 1970).

Scope of Present Work

The present study re-emphasizes the interest of the State of Louisiana in the development and implementation of a comprehensive freshwater diversion plan for its afflicted coastal wetlands. The state's position is described in Guideline 7.4 of the Louisiana Coastal Resources Program: "The diversion of freshwater through siphons and controlled conduits and channels, and overland flow to offset saltwater intrusion and to introduce nutrients into wetlands shall be encouraged and utilized whenever such diversion will enhance the viability and productivity of the outfall area. Such diversions shall incorporate a plan for monitoring and reduction and/or amelioration of the effects of pollutants present in the freshwater source" (Louisiana Department of Natural Resources [DNR] 1980).

This report constitutes Phase I of a planning effort by DNR, Coastal Management Section, directed at implementation of a freshwater diversion plan for the Louisiana coastal zone. This phase deals with the estuarine environments to the east of the Mississippi River as combined into Hydrologic Units I and II, respectively. Unit I comprises the estuarine systems, inclusive of directly contributing watersheds, associated with Lakes Maurepas, Pontchartrain, Borgne, and the Chandeleur and Mississippi Sounds. Unit II is made up of Breton Sound and surrounding wetlands and levee ridges.

The primary objective here is to make detailed recommendations as to location, manner, and quantity of discharge diversion from the Mississippi River into adjacent estuaries to the east. In attaining this objective, recommendations, concepts, and data developed in previous work were utilized as a basis and built upon. Partially for that reason the time period considered relative to salinity regimes extends from 1967 to 1979. The present report is further intended to supplement parallel studies by the USACE as part of the Louisiana Coastal Areas Study (1982) and the Louisiana and Mississippi Estuarine Areas Study (1981a).

Recommendations as set forth in this report are based on the following major elements:

1. Analysis of habitat changes and relationship to hydrologic and salinity regimen.
2. Development of management goals for the various environmental units as related to past and present uses and as affected by freshwater inflow.
3. Development of workable statistical models that define present relationships between salinity and freshwater inflow.
4. Analysis of possible diversion sites and scenarios including structure size vs. needs, delivery systems, and outfall plans.
5. Discussion of expected beneficial results and possible adverse impacts of freshwater diversion.

CHAPTER II

ANALYSIS OF SALINITY - INDUCED HABITAT CHANGE, 1955-1978

Overlays of FWS habitat maps (Wicker et al. 1980) produced at a 1:24,000 scale for the years 1955 and 1978 were compared to assess and map changes in wetland habitat types due to salinity intrusion during the 23-year period. Types of habitat change between the two years that were considered included transitions of fresh habitats to non-fresh types, and baldcypress swamps to fresh-intermediate marsh. Areas where wetland habitats showed transition to developed types, including urban and agricultural, were not mapped. Areas of change were first mapped at a scale of 1:24,000 then generalized onto 1:125,000-scale maps.

In addition, areas of baldcypress swamp that appeared to be in the early stages of deterioration and transition due to salinity intrusion were mapped. These stressed baldcypress swamps were identified from 1978 color infrared imagery by the presence of a white mottled pattern, representing a dead or stressed condition of the ground cover, showing through a thinned, sparse canopy cover. Swamps being stressed by continual impoundment rather than by salinity intrusion were not mapped.

Dead cypress swamp in St. Bernard Parish.

On the FWS 1955 habitat maps (Wicker et al. 1980) marshes were classified as either fresh or non-fresh. The non-fresh marshes were not further defined by salinity level such as intermediate, brackish, and saline as was done for the 1978 habitat maps. Therefore, it was impossible to delineate salinity-induced changes between the years within the non-fresh marsh type, such as intermediate to brackish or brackish to saline marsh.

The map of the Louisiana coastal marsh types by O'Neil (1949) was used as an important data base by Wicker et al. (1980) in producing the 1955 habitat maps. Because O'Neil's map is somewhat more generalized than later efforts, such as the coastal marsh vegetative type map of Chabreck and Linscombe (1978), the intermediate marsh type, an ecotone between fresh and non-fresh marsh habitats, was delineated more accurately on the 1978 habitat maps. As a result, some of the transitions from fresh to non-fresh habitats that are shown may be due, in part, to this difference in detail between data bases, in addition to the actual changes transpiring during the period considered.

Pontchartrain Watershed

Rising salinity levels in Lake Pontchartrain and Lake Maurepas have caused substantial transitions of habitats in this watershed (Plate 1). Approximately 25,000 ac of formerly fresh habitats, including fresh marsh and baldcypress swamp, were converted to non-fresh habitats by 1978 (Table 2-1). This occurred predominantly in the lower Pearl River drainage near the Rigolets and in the vicinity of Pass Manchac. In the lower Pearl River, fresh marsh changed to intermediate marsh, while south of Pass Manchac baldcypress (Taxodium distichum) swamp also showed transition to intermediate marsh.

Almost 21,000 ac of baldcypress swamp showed transition to marsh classified as fresh by the 1978 habitat maps. The large majority of this transition took place between Lake Maurepas and Lake Pontchartrain along Pass Manchac. About 36,000 ac of baldcypress swamp were interpreted as being in a stressed condition. Such stressed swamp occurs over substantial areas on both the north and south shores of Lake Maurepas. Additional stressed swamp occurs southeast of the Bonnet Carre Spillway in St. Charles Parish, while only a small bit occurs along the north shore of Lake Pontchartrain.

Generally, the baldcypress swamps flanking Pass Manchac, Lake Maurepas, and the western end of Lake Pontchartrain have been subjected to slight increases in salinity during the last 25 years (Wicker et al. 1981). The fall months of September, October, and November produce the lowest discharge from the Tickfaw and Tangipahoa Rivers, yet the highest water stage at Pass Manchac is due to predominant east to northeast winds that push water from Lake Pontchartrain into the Lake Maurepas Basin (Wicker et al. 1981). As a result, the highest mean salinities for Pass Manchac also occur during these months. During climatic events in southeast Louisiana, such as the occurrence of hurricanes, waters of salinities of 5-10 ppt have been driven into the baldcypress swamps surrounding Lake Maurepas. By increasing soil salinities, such events have been a major factor in the gradual transition of these wetlands from swamp to marsh. Other exacerbating factors include general subsidence of the land surface, disruption of the natural runoff pattern from the Pleistocene terrace through the baldcypress swamps by canal development, and in some instances impacts from the cypress logging industry.

Lake Borgne Watershed

The completion of the Mississippi River-Gulf Outlet (MRGO) in the mid-1960s brought about substantial changes within the wetlands of St. Bernard Parish in the vicinity of Lake Borgne. In 1955, baldcypress swamps existed at the base of the Mississippi River natural levee and graded into fresh marsh and brackish marsh toward Lake Borgne (O'Neil 1949). Relatively low salinity conditions were maintained due to the protection afforded the area by the natural ridge of Bayou La Loutre. When the MRGO breached this ridge an avenue was provided for higher salinity Gulf waters to intrude into these wetlands. Natural drainage patterns were disrupted, part of the area was semi-impounded by the large spoil deposition, and tidal amplitudes increased. In short, the MRGO became the major hydrologic force. As a result of the increased salinities, approximately 9705 ac of formerly fresh marsh and baldcypress swamp have been changed to brackish marsh (Plate 2) (Table 2-1) in the area now termed the Central Wetlands of St. Bernard Parish (CEI 1976). About 914 ac of baldcypress swamp still exist but are in a decidely stressed condition (Plate 2).

Table 2-1. Approximate Acreages of Salinity-Induced Habitat Change in the Lake Pontchartrain, Lake Borgne, and Breton Sound Watersheds.

Habitat Change	Lake Pontchartrain	Lake Borgne	Breton Sound
Fresh to non-fresh	24,934	9,705	23,090
Swamp to fresh-marsh	20,925	0	0
Stressed Swamp	36,010	914	0

Source: Wicker et al. 1980.

Although not mapped, changes have also occurred in the marsh types classified as non-fresh in 1955. Much of the brackish marsh in 1955 was dominated by three-cornered grass (Scirpus olneyi), a preferred marsh plant species for furbearers and, in particular, muskrat (Ondatra zibethicus) (O'Neil 1949). With increased mean salinities and tidal amplitudes due to the MRGO, the brackish marshes have reverted to large expanses of predominantly wiregrass (Spartina patens), which is a less valuable species for both furbearers and waterfowl (CEI 1982; Palmisano 1971a). Concurrently, St. Bernard Parish has experienced a substantial reduction in harvestable furbearer populations. In addition, marshes occurring along the northeast side of the MRGO are exposed to ship wake wash as well as increased salinities and tidal amplitudes. The result has been severe erosion of marsh along this side of the MRGO and the conversion of about 6250 ac of brackish marsh to salt marsh dominated by oystergrass (Spartina alternifora) (CEI 1982).

Breton Sound Watershed

In 1955, a substantial acreage of fresh marsh existed along the flank of the natural levee of the Mississippi River in Plaquemines Parish (Wicker et al. 1980). By 1978, about 20,000 ac of fresh marsh here and along the northern perimeter of the Lake Lery marsh (Plate 3) had transformed to non-fresh marsh, predominantly brackish (Wicker et al. 1980).

Several factors interacting concurrently apparently have precipitated these changes. Construction of back levees along the Mississippi River tended to deny marshes outside the levees freshwater runoff that before had helped to moderate salinities. A rather severe drought in the early 1960s, coupled with hurricane Betsy in 1965, brought higher salinity water into the upper reaches of the Breton Sound Watershed. In addition, the expansion of the oil and gas industry in the area produced an increase in the number of rig cuts and pipeline canals. The maze of canals and spoil banks worked both to accelerate saltwater intrusion into the formerly well-protected fresh marshes and, in other cases, impounded some marsh areas with subsequent deterioration. The result was a transition from fresh marsh to brackish marsh and major transitions from marsh to open water (Wicker et al. 1980).

CHAPTER III

GOALS FOR ENVIRONMENTAL RESOURCE MANAGEMENT

Wetland habitats of southeast Louisiana are recent environments formed for the most part within the last 5000 years as a direct result of Mississippi River alluvium (Kolb and van Lopik 1958). Through the shifting course of the Mississippi River, delta progradation created the deltaic plain and associated swamp and marsh habitats. Overbank flooding of the Mississippi River mainstem and its distributaries resulted in deposition of fine sands, silts, and clays into marine and paludal basins. Baldcypress swamps formed on the back slope of the natural levees and extended over large interdistributary basins in areas protected from waters influenced by encroaching Gulf salinities. Marsh habitats tended to be formed farther seaward of the baldcypress swamps in areas of increased tidal fluctuation and higher water salinities. The distribution of wetland environments is governed by a number of interrelated factors such as soil composition, water level regime, tidal energy, and soil and water salinities. Each habitat also has its particular intrinsic fish and wildlife resources for which environmental factors theoretically can be optimized. Although salinity is only one of many elements which tend to define the wetland habitats, in the context of freshwater diversion it will be the parameter most directly affected. Thus, optimum salinity regimes are discussed for the various habitats to formulate goals for resource management.

Healthy cypress tupelogum swamp.

Habitat Types and Optimum Salinity Regimes

Baldcypress swamps are relatively low-energy, essentially freshwater environments located on predominantly clay soils. Plant associates in addition to baldcypress often include tupelogum (Nyssa aquatica), swamp red maple (Acer rubrum var. drummondii), black willow (Salix nigra), green ash (Fraximus pennsylvanica), and swamp black gum (Nyssa sylvatica var. biflora) (Penfound 1952, Conner and Day 1976, Conner et al. 1981). Although baldcypress swamps are inundated for much of the year, water levels must recede below the soil surface periodically for normal functioning and maintenance of productivity (Conner et al. 1981). Permanent flooding, which does not allow germination of seeds of baldcypress and many of its associates (Mattoon 1915, Demaree 1932, Penfound 1952), results in lowered productivity and loss of recruitment (Conner et al. 1981). Seasonal flooding and draining are vital for maintenance of species diversity and for proper functioning as nursery and spawning grounds and nesting sites.

Salinity tolerance in swamp forest has not been studied thoroughly. However, in the study of the baldcypress swamps in Tangipahoa Parish in the vicinity of Pass Manchac, severe impacts were evident where over several years water salinities reached 2 ppt or greater for 50 percent of the time the swamp was inundated (Wicker et al. 1981). It appears then that salinities must be kept below 2 ppt continuously for maintenance of the health of the forest.

Baldcypress swamps in Louisiana serve as important nesting, brood rearing, roost sites, and wintering areas for the Wood Duck (Aix sponsa), a resident species dependent on tree cavities for nest sites (Bellrose 1976, Sincock et al. 1964). Other waterfowl, in particular Mallards (Anas platyrhynchos), also utilize swamp forest as wintering areas. As overflow bottomland hardwood areas, which are high-qualtiy waterfowl habitats for these species, continue to become reduced in areal extent in Louisiana (FWS 1979), baldcypress swamps will increase in importance to waterfowl. Other avian species utilizing swamp forests to a great degree include wading birds such as herons, egrets, and ibises that feed largely on small fish and crustacean populations in shallow water areas. Great Egrets (Casmerodius albus) and Great Blue Herons (Ardea herodias) commonly nest in swamp forests, and the White Ibis (Eudocimus albus) is known to nest in substantial numbers in the baldcypress swamps of Tangipahoa Parish (Lowery 1974a, Portnoy 1977).

Other important wildlife species utilizing swamp forests include furbearers, such as raccoon (Procyon lotor) and mink (Mustela vison), which take advantage of abundant crayfish populations as prey. During the early part of this century, mink were particularly numerous and heavily trapped in the cut-over swamps around Lake Maurepas (Palmisano 1971b). Populations have since declined considerably. Along ridge-swamp interfaces sport hunting for white-tailed deer (Odocoileus virginianus) and squirrel (Sciurus sp.) is common.

Fresh marsh occurs at slightly lower elevations and is subject to more frequent flooding than swamp forests. Water salinities in the fresh marsh vegetative type have been reported to range up to 6 ppt (Chabreck 1972), but typically average less than 2 ppt (Palmisano and Chabreck 1972). Organic content is quite high, generally averaging over 50 percent (Palmisano and Chabreck 1972). Fresh marsh exhibits the highest diversity of plant species of all marsh types, with 93 species reported by Palmisano and Chabreck (1972) to occur in this type along coastal Louisiana. The major species of these include paille fine (Panicum hemitomum), comprising 25.62 percent, bulltongue (Sagittaria lancifolia) with 15.15 percent, spikerush (Eleocharis sp.) with 10.74 percent, alligator weed (Alternanthera philoxeroides) with 5.34 percent, and wiregrass with 3.74 percent (Chabreck 1972).

The high diversity of plant species and low salinities make the fresh marsh vegetative type valuable wildlife habitat. The coastal marshes of Louisiana in some years may winter up to 4,000,000 ducks and 500,000 geese (Sanderson 1976, Bellrose 1976), which account for more than two-thirds of the migratory waterfowl population in the Mississippi Flyway. During the 1975-76 waterfowl season, Louisiana hunters accounted for about one-third of the 2,083,831 birds harvested in this flyway (Sorenson et al. 1977). The value of fresh marshes in southeastern Louisiana is exemplified by the fact that about 65 percent of the puddle ducks recorded here in some years utilize this vegetative type (Palmisano 1973) (Table 3-1). Major environmental factors influencing waterfowl usage of winter habitat include water depth, food availability, distribution of aquatic habitat, climatic conditions, and soil and water salinity (Chabreck et al. 1974, Chabreck 1979). Tradition also plays an important part in selection of winter habitat in that areas that are used presently are generally those that have been used in the past. However, continued use during the winter is dependent upon habitat quality and particular preferences of individual species (Chabreck 1979). The several species of waterfowl that annually winter in Louisiana have varying food preferences, water depth requirements, and pond size needs. However, the fresh marsh type appears to meet the various requirements to the greatest extent.

The fresh marsh vegetative type is also important as commercial furbearer habitat. Although catch records are not always completely indicative of population levels due to variations in trapping techniques and intensity of effort, fresh marsh evidently produces the highest means and maximum harvests of nutria (Myocastor coypus) and mink, as well as the highest maximum harvests of raccoon (Palmisano 1973) (Table 3-2). The nutria is now the most important furbearer in Louisiana in terms of number of animals harvested and total monetary value to the trapper, having overtaken the muskrat in this regard in the early 1960s (Lowery 1974b).

Since the 1960s, alligator (Alligator mississippiensis) populations have increased continually through protection, research, and management efforts of the Louisiana Department of Wildlife and Fisheries (O'Neil and Linscombe 1977). A legal harvest season now takes place each fall throughout coastal Louisiana. The estimated population by 1977 was about 92,000 in the subdelta marshes, with fresh marsh holding 13.8 percent of the alligators present (McNease and Joanen 1978). The substantial nutria populations in fresh marsh are an important food source for alligators (McNease and Joanen 1977) and contribute to the value of this vegetative type as alligator habitat.

In summary, swamp and fresh marsh habitats require salinity regimes under 2.0 ppt almost continuously to maintain community structure, species diversity, and productivity. Wading birds, waterfowl, furbearers, and the alligator are among important wildlife resources utilizing these habitats in substantial numbers.

The protected inland waters of less than 2 ppt are inhabited by characteristic freshwater fishes and invertebrates. Some of the most common are crawfish (Procambarus clarkii), river shrimp (Macrobrachium ohione), gars (Lepisosteus sp.), bream (Lepomis sp.), crappie (Pomoxis sp.), largemouth bass (Micropterus salmoides), channel catfish (Ictalurus punctatus), and flathead catfish (Pylodictis olivaris). In Louisiana, the primary factors that influence population size of these species are dissolved oxygen, overflow regime, and salinity. Low dissolved oxygen is a primary cause of mass mortalities (fish kills) in the Pontchartrain Basin (W. C. Dixon, personal communication 1982) and is fostered by the combination of an overabundance of organic matter and sluggish water movement. Man affects both through nutrient loading (Craig and Day 1977; Seaton 1979) that promotes growth of aquatic vegetation and channeliziation that slows water movement during dry periods. The highest productivity of freshwater species is correlated with flooding of swamps and bottomland hardwood forests in the spring (Bryan and Sabins 1979, Sabins 1977). This overflow situation provides an abundance of spawning habitat and food and protection for fry and juveniles. As floodwaters recede, the numerous organisms become concentrated in the permanent waterbodies, increasing feeding efficiency and facilitating rapid growth.

Table 3-1. Percentage Habitat Utilization by Puddle Ducks in Coastal Louisana.

	Southwestern La.		Southeastern La.		Entire Coast	
Vegetative Type	Puddle Ducks Recorded	Habitat Sampled	Puddle Ducks Recorded	Habitat Sampled	Puddle Ducks Recorded	Habitat Sampled
Saline Marsh	0.60	1.19	5.33	24.90	1.67	8.66
Brackish Marsh	29.28	19.92	21.59	35.49	27.66	24.82
Intermediate Marsh	33.05	15.15	8.04	7.59	27.03	12.77
Fresh Marsh	26.82	15.67	65.04	32.02	35.91	20.82
Agricultural	10.25	48.06	-0-	-0-	7.73	32.93

Source: Palmisano 1973.

Table 3-2. Estimated Fur Catch Per 1000 Acres of Coastal Marsh.

	SALINE		BRACKISH		INTERMEDIATE		FRESH	
Species	Mean [a]	Maximum	Mean	Maximum	Mean	Maximum	Mean	Maximum
Muskrat	b	b	84.4	6477.7	97.5	513.9	78.5	646.8
Nutria	b	b	86.4	191.1	284.9	499.6	512.7	884.4
Mink	b	b	1.1	12.8	0.9	11.9	2.1	14.2
Raccoon	b	b	b	15.6	b	6.3	b	31.0
Otter	b	b	0.2	0.7	0.4	1.3	0.5	1.3

[a] Mean values determined from recent records. Maximum valuies are an average of long term maximum catch figures.
[b] Inadequate Records

Source: Palmisano 1973.

Salinities below 2 ppt not only promote the growth of swamp and fresh marsh, but also are ideal for most freshwater fauna. Catfish are important commercial species that tend to prefer river and shallow, intermediate-salinity lake habitats. Salinity greater than 2 ppt apparently causes competition between blue catfish (Ictalurus furcatus) and channel catfish and their estuarine counterpart, the sea catfish (Arius felis). Commercial fishermen around Pass Manchac reportedly move their trotlines from western Lake Pontchartrain in the spring, to Lake Maurepas in the summer, and finally remove them entirely by fall as their catch becomes dominated by the unmarketable sea catfish (Tangipahoa Parish Coastal Advisory Committee, personal communication 1981).

Marshes of intermediate salinities represent an ecotone or transition zone between the fresh and non-fresh marshes and usually make up only a small percentage of the total wetland acreage, especially in Hydrologic Units I and II (Chabreck 1972). Water salinities in intermediate marshes vary somewhat across the state in different hydrologic units, but a typical range of values is 2-5 ppt (Palmisano and Chabreck 1972). Intermediate marsh vegetation includes a large number of species indicative of both fresh and brackish environments (Palmisano and Chabreck 1972). Wiregrass is the dominant species in southeastern Louisiana, with three-cornered grass, bulltongue, and dwarf spikerush being important associates (Chabreck 1972). The low salinity values and high plant diversity of this marsh type contribute to its value as wildlife habitat. On a per-acre basis, intermediate marsh receives high utilization by waterfowl in southeastern Louisiana (Table 3-1) and also produces high yields of nutria and mink (Table 3-2) (Palmisano 1973). In addition, intermediate marsh supported the highest densities of alligator (1 alligator per 7.9 ac) in 1977 on a coastwide basis (McNease and Joanen 1978).

Aquatic habitat of 2-5 ppt salinity supports many species of freshwater fish as well as a low-salinity-tolerance estuarine faunal assemblage, some of commercial importance. In late winter through early summer, postlarval forms of white shrimp (Penaeus setiferus), blue crab (Callinectes sapidus), Atlantic croaker (Micropogonias undulatus), and menhaden (Brevoortia patronus) actively seek nursery habitat where salinity is less than 5 ppt (Fruge and Ruelle 1980, Thompson and Verret 1980, Hinchee 1977). During this life stage, vegetative cover is of utmost importance to survival and growth. In this salinity range, the dominant vegetation is intermediate marsh and beds of submerged aquatic weeds and grass, which are generally low-energy environments with little daily water level fluctuation. Consider the benefits of stable waters and gentle currents to very small and fragile organisms. Even with an abundance of food, energy expenditures in maintaining a desired position detract from the growth rate of the animal. Where water levels fluctuate greatly, the protection and food source of marsh vegetation are not as continuously accessible, promoting greater predation and lower survival. Desirable, low-energy hydrologic conditions have occurred historically in low-salinity areas of estuaries, where the residence time of freshwater is longer and the tidal energy lower than other parts of the estuary. From this, it might be concluded that these post-larval estuarine organisms have evolved to seek low salinity regimes for the better protection typically afforded there. If so, then the acreage of intermediate marsh nursery is more important to production of white shrimp, blue crab, croaker, and menhaden than the absolute salinity values of surrounding open water bodies.

Fresh marsh dominated by cattail (Typha sp.).

Seaward of intermediate marsh higher water salinities and increased tidal energy lead to establishment of brackish marsh. This marsh type has a wide range of salinities, with Chabreck (1972) reporting a range for Hydrologic Units I and II of about 5-15 ppt. For purposes of this report this vegetative type has been broken into low-salinity brackish marsh (5-10 ppt) and high-salinity brackish marsh (10-15 ppt). Although similarities are apparent between the two, relative value for particular fish and wildlife species can be differentiated, primarily on the basis of tidal influence and water level fluctuation.

An assemblage of estuarine species different from the low-salinity assemblage mentioned previously utilizes the low-salinity brackish marsh (5-10 ppt) during early post-larval and juvenile stages, presumably for similar hydrologic reasons. Brown shrimp (Penaeus aztecus), spot (Leiostomus xanthurus), spotted seatrout (Cynoscion nebulosus), and red drum (Sciaenops ocellata) tend to prefer nursery habitats above 5 ppt (Fruge and Ruelle 1980). Juvenile spotted seatrout are found in low-salinity brackish nursery in the summer, and red drum utilize the area in late fall and early winter. Rapid decreases in water temperature during frontal passages can cause mortality of the juvenile red drum. Post-larval brown shrimp enter the area in early spring and are also adversely affected by low water temperature (less than 20° C or 68° F). Before leveeing of the Mississippi River, annual overbank flooding in the spring not only reduced salinities, but also decreased the temperature of the water in the estuary. Larval brown shrimp seeking low-energy nursery areas probably encountered low temperatures in the 2-5 ppt range and therefore evolved to utilize higher energy nursery in the 5-10 ppt range. In the late spring and summer, overbank flooding subsided and water temperatures rose sufficiently to encourage white shrimp immigration into 2-5 ppt intermediate nursery. This system allowed maximum utilization of the marsh resources, less competition, and maximum secondary productivity.

The dominant vegetative species in both low- and high-salinity brackish marsh is wiregrass, which was found by Palmisano and Chabreck (1972) to comprise 55 percent of the vegetation in all brackish marshes. Other important species include saltgrass (Distichlis spicata), three-cornered grass, dwarf spikerush, and oyster grass in southeastern Louisiana (Chabreck 1972). Brackish marshes historically have been the major producer of muskrat (O'Neil 1949), which constituted the real strength of the trapping industry in coastal Louisiana for

Louisina trapper skinning muskrat.

many years until the nutria took its place in the 1960s (Lowery 1974b). Three-cornered grass marshes produce the highest densities of muskrat, with 80 percent of the harvest coming from these marshes in some years (Table 3-2) (O'Neil 1949). Management for three-cornered grass, which is also considered a good waterfowl food (Palmisano 1971a), *is dependent primarily on water levels and* secondarily on salinity regime (Ross 1972), with annual burning used to retard competition from wiregrass (O'Neil 1949). Ideally water levels should be maintained a few inches above the soil surface (Palmisano 1967), and although three-cornered grass occurs in a wide range of salinities, Ross (1972) reported that a salinity range of 5-10 ppt may provide for best growth. Considering the lower tidal influence with this type as compared to the high-salinity brackish marsh, management potential for three-cornered grass appears substantially greater in the low-salinity-regime brackish marsh. The lower salinity regime also favors alligator production, with population densities here about equal to the fresh marsh (McNease and Joanen 1978). Newly hatched alligators cannot tolerate salinities above 10 ppt for extended periods (Joanen and McNease 1972).

Waterfowl usage of brackish marshes is not as great as fresh or intermediate types on a per-acre basis (Table 3-1) but still is important due to the large expanse of the brackish type present (Palmisano 1973). The brackish vegetative type has the greatest density of ponds and lakes (Chabreck 1972) that aids in its attractiveness for waterfowl. Widgeon grass (Ruppia maritima) is an important waterfowl food and is most prolific in conditions of low turbidity and stabilized water levels in shallow, brackish-water ponds (Chabreck and Condrey 1979). Such conditions can be found in both low- and high-salinity brackish marshes, but the lesser tidal influence in low-salinity brackish marsh may make it somewhat more amenable to widgeon grass propagation.

High-salinity brackish marsh (10-15 ppt) is utilized by all major estuarine species at some life stage, either as larval forms moving into the estuary or as juveniles and immature adults moving out. The hydrologic regime promotes export of plant material into water bodies to serve as a food source. The flux of organisms and organic matter through this environment provides abundant food for mature adult fish, and it is therefore a prime sportsfishing area. The majority of effort during the inshore shrimping seasons is spent in the high-salinity brackish marsh. This area is also the most productive for the American oyster (Crassostrea virginica). In short, the aquatic productivity of an estuarine system as a whole is best displayed in the 10-15 pt salinity range where there is intense interaction among many species, including man.

In areas with greater tidal energy and salinities above 15 ppt for much of the year, the saline marsh type is dominant. The salt marsh has less plant diversity, with oyster grass the dominant species (Palmisano and Chabreck 1972). Other common species include saltgrass, black rush (Juncus roemerianus), and wiregrass. Although saline marsh does support furbearers such as raccoon, mink, and muskrat, pelts from this vegetative type are of poor quality and are seldom sought (Palmisano 1971b). Waterfowl usage of this marsh type is slight (Table 3-1) (Palmisano 1973), and *alligators cannot tolerate its high salinity regime* (Joanen and McNease 1972). The salt marsh is valuable habitat for shorebirds, seabirds, and Clapper Rails (Rallus longirostris) and serves as a buffer to the more inland marshes against extreme salinities and storm tides (Palmisano 1971b).

Aquatic habitats above 15 ppt are not only utilized by estuarine-dependent organisms but are frequently invaded by true marine species. One marine species that frequently invades 15-18 ppt areas of the estuary in search of food is the southern oyster drill (Thais haemostoma) (Pollard 1973). Predation by the oyster drill, along with parasitism by marine fungi (Dermodestidium sp.) and boring sponges (Cliona sp.), produces natural limits on the expansion of the American oyster into saline environments. In Louisiana, the oyster drill is considered a nuisance on private oyster leases in the lower estuary because its predation is a direct economic loss to oystermen. More importantly, heavy predation of the easily penetrated seed oysters (1 to 3 in) on the public grounds represents an indirect economic loss because additional effort is necessary to gather seed oysters for transplanting. It is therefore advantageous to exclude the drill from the oyster grounds by keeping the salinity at or below 15 ppt. However, oyster reproduction occurs only above 10 ppt (Galtsoff 1964), larval development of oysters in the summer is most favorable at 25 ppt, and metamorphosis (spatfall) peaks in waters of 20 ppt (Tabony 1972). For lower salinity tolerance, concentrations less than 5 ppt when temperatures are greater than 20°C are fatal to all life stages (Lindall et al. 1972). Optimum conditions for increased oyster populations should include a short period of 20 ppt salinity in the midsummer on the seed grounds for spatfall, with salinities below but near 15 ppt for the rest of the year. Commercial oysters grow better and have a more desirable flavor at salinity greater than 10 ppt (Dugas 1977), making the optimum range for private leased areas 10-15 ppt. A description of oyster life history stages and salinity requirements is presented in Table 3-3.

Table 3-3. Summary of Life History and Habitat Data for the American Oyster.

Reproduction (spawning)	Larval Development	Larval Metamorphosis (Spatfall)
May - October *Waters greater than* 10 ppt and near 27°C	June - November *Most favorable in waters* of 25 ppt and 29°C; Growth inhibited below 12 ppt; No survival below 10 ppt	June - October *Peak in late August in* waters greater than 20 ppt and 29°C; No survival below 10 ppt
Seed Oysters* (1-3 in)	**Commercial Oysters* (greater than 3 in)**	**Adult Oysters***
All year Most favorable waters between 5-15 ppt	All year Most favorable waters between 10-25 ppt	All year General tolerance for waters between 5-30 ppt

* Oyster drill predation, incidence of disease, and competition of fouling organisms increase significantly for seed, commercial, and adult oysters when salinities exceed 15 ppt. Also, tolerance to salinities below 10 ppt is reduced when temperatures exceed 23°C.

In summary, animal resources are related to the wetland habitat types found in an area. Differentiation of wetland habitat types is determined by hydrological conditions such as salinity and tidal energy. The description of optimum hydrological conditions, habitat types, and biological resources is presented in Table 3-4.

Environmental Units and Management Goals

PONTCHARTRAIN WATERSHED

Wetland areas in the Pontchartrain Watershed were partioned into environmental units on the basis of historic conditions and intrinisic suitability for environmental management. The environmental units are delineated on Plate 1.

Lake Maurepas Freshwater Wetlands Unit

This unit is predominated by baldcypress-tupelogum swamps except in the vicinity of Pass Manchac where swamp has been replaced by marsh habitats within the last 20 years. Goals for this unit include providing a salinity regime of 0-1 ppt for as much of the year as is realistically possible and to keep salinities at Pass Manchac below 2 ppt continuously. This would allow maintenance of a healthy swamp system and increase the potential for restoration of the stressed and dead swamp areas. A healthier swamp system would benefit a diverse array of wildlife species including waterfowl such as Wood Ducks and Mallards, various wading birds such as ibises, egrets, and herons, and commercially important furbearers such as mink, nutria, and raccoon.

Freshwater aquatic organisms are dominant over most of the Lake Maurepas Freshwater Wetlands Unit. Suitable salinity goals would be maintenance of 0-1 ppt in the winter and spring and prevention of salinities above 2 ppt in the summer and fall. Other goals for localized management would include structural control of water levels approximately 1-2 ft above the swamp floor from February through May for spawning and recruitment with subsequent release and possible draw-down of water levels from June through August for aeration of the substrate and seed germination.

St. Charles Marsh Unit

This environmental unit is comprised of brackish and intermediate marsh grading into baldcypress swamp that shows evidence of salinity stress. Goals here are to moderate salinities such that salinities less than 2 ppt exist for the swamp and most inland marsh, grading into a regime of 2-5 ppt near Lake Pontchartrain. This would improve the condition of the swamp habitat and potentially increase diversity in the marsh. Wiregrass is now dominant in the marsh environments, and lowering salinities would facilitate structural management to induce establishment of plant associations more valuable for wildlife. The St. Charles Marsh Unit is a very important nursery area for estuarine-dependent organisms in Lake Pontchartrain. This area has historically accommodated the low salinity estuarine assemblage, as well as a resident freshwater fish assemblage. Salinity goals should be to maintain 2-5 ppt over the year. A more important goal would be to protect the remaining marsh and create new marsh whenever possible.

Table 3-4. Summary of Wetland Habitats, Salinity Regimes, and Their Associated Wildlife and Fisheries Resources.

HABITAT TYPE	OPTIMUM SALINITY (ppt)	WATER LEVEL REGIME	WILDLIFE AND FISHERY RESOURCES		
			TERRESTRIAL	AVIAN	AQUATIC
Swamp	0-2	Seasonal flooding due to heavy precipitation, very slight tidal influence	Mink, raccoon, white-tailed deer, swamp rabbit	Wood Duck, Mallard, White Ibis, Great Blue Heron	Crawfish, bream, largemouth bass; crappie
Fresh Marsh	0-2	Frequent and seasonal flooding, some tidal influence	Nutria, mink raccoon, alligator river otter	Mallard, Teal, Pintail Little Blue Heron	Blue catfish, channel catfish, flathead catfish
Intermediate Marsh	2-5	Low amplitude tidal fluctuation, low daily water exchange	Alligator, nutria, river otter	Mallard, Gadwall, Teal, Pintail	White shrimp, blue crab, croaker, menhaden, Rangia clam
Low-Salinity Brackish Marsh	5-10	Medium amplitude tidal fluctuation, significant daily water exchange	Muskrat, nutria	Gadwall, Widgeon, Shoveler	Brown shrimp, spot, red drum, spotted seatrout, oysters
High-Salinity Brackish Marsh	10-15	High amplitude tidal fluctuation, almost complete daily water exchange	Muskrat	Gadwall, Lesser Scaup, Red Head duck, Louisiana Heron, shorebirds	Commercial oysters, adult brown and white shrimp, adult sportfish
Saline Marsh	Above 15	Highest amplitude tidal fluctuation, virtually total daily water exchange	--	Terns, gulls, Louisiana Heron, Brown Pelican, Clapper Rail, Lesser Scaup, Snowy Egret, shorebirds	Seed oysters on public grounds, adult brown and white shrimp, adult sportfish

Ecotone of cypress swamp and fresh marsh, St. Charles Parish.

Goose Point and North Shore Marsh Units

Both these units of marsh habitat are presently valuable for fish and wildlife, although they showed losses of fresh marsh habitat between 1955 and 1978. Goals here are to moderate salinities slightly to possibly increase areas of fresh and intermediate marsh, especially in the Goose Point Unit, and thus increase the diversity of habitat types and increase the value as wildlife habitat. Brackish marshes, in particular the North Shore Marsh Unit, should be maintained in the low-salinity brackish range (5-10 ppt) for maximum value to fish and wildlife.

The Goose Point Marsh and adjacent submerged grass beds are very important nursery areas, especially for juvenile blue crabs. Salinity goals in the 2-5 ppt range are optimum here. Protection of the grass beds from shoreline modifications should be another environmental management goal. Grass beds could be expanded on the exposed, south-facing shoreline of Goose Point near Bayou Lacombe by construction of artificial reefs to absorb wave energy.

LAKE BORGNE WATERSHED

Environmental unit delineations for the Lake Borgne Watershed appear on Plate 2.

Pearl River Wetlands Unit

This valuable wetlands unit has a diversity of habitats ranging from baldcypress swamps to brackish marsh. Pearl River discharge dictates to a large degree the salinity regimes of these environments, but there was a substantial conversion from fresh marsh to non-fresh marsh between 1955 and 1978. Goals for this unit are to moderate salinities, especially during the fall months, to maintain the present habitat diversity, and to inhibit any further loss of fresh habitats to non-fresh marsh. The brackish marsh near the Rigolets should be maintained as low-salinity brackish marsh (5-10 ppt) due to its higher potential for management for furbearers and waterfowl. The implementation of structural management techniques, such as weirs and flapgates for water level control, can be successful in this salinity regime for establishing productive marsh types (e.g., three-cornered grass for muskrat management) and aquatic vegetation (e.g., widgeon grass to attract waterfowl).

Orleans Parish Marsh Unit

Water salinities in this unit also are controlled to some extent by amount of discharge from the Pearl River as well as salinities in Lake Borgne, the Intracoastal Waterway, and the MRGO. Goals for this unit are to maintain the habitat as low-salinity brackish marsh to maximize its potential as furbearer and waterfowl habitat.

Salinity goals for aquatic organisms in the Orleans Parish Marsh Unit should be in the range from 2-10 ppt. This would provide nursery habitat for brown shrimp, red drum, spotted seatrout, and other members of the typical, high-salinity estuarine assemblage during times of low Pearl River discharges, and nursery habitat for white shrimp and blue crab during high Pearl River discharges. Because of the unique location of these marshes between two large natural tidal passes, they are probably utilized by all estuarine organisms as a staging area for immigration into Lake Pontchartrain. The discharge of the Pearl River probably dictates which species will utilize these nursery areas in a particular year. The salinity goals are correspondingly broad.

MRGO at Southern Natural Gas pipeline looking south.

MRGO Marsh Unit

Water salinities and tidal amplitudes in this unit have increased substantially since construction of the MRGO in the 1960s, with a corresponding loss of baldcypress habitat and conversion of marsh types to higher salinity regimes. The value of these wetlands as wildlife habitat has declined substantially as a result. Substantial reduction of salinities may not be possible under existing conditions dictated by the MRGO. However, establishment of low-salinity brackish marsh (5-10 ppt) in areas most protected from MRGO waters may be feasible, with high-salinity brackish marsh (10-15 ppt) being maintained near the channel. One goal should be to reverse the trend along the MRGO whereby brackish marsh is presently being converted to salt marsh due to high salinities and tidal amplitudes. Marshes in this unit west of the MRGO spoil exist in a semi-impounded condition due to this large spoil barrier. During periods of heavy rains, water levels here may rise to 2-3 ft above marsh level and salinities are reduced to below 1 ppt. These conditions usually exist for only short time periods such as 1 or 2 days, after which water levels recede and salinities may again reach as high as 15 ppt due to the influence of the MRGO. Such rapid and extreme fluctuations in marsh conditions are not conducive to, and can be detrimental to, establishment of high-quality wildlife habitat. The only recourse in such a situation is to implement structural management to moderate extreme conditions.

The MRGO Marsh Unit experiences an unnaturally steep salinity gradient because of the strong vertical stratification in the navigation channel. A complete description of the nursery value of these marshes is found in the St. Bernard Marsh Management Plan (CEI 1982). Following completion of the MRGO, oyster leases became established in western Lake Borgne between Bayou Bienvenue and Martello Castle where salinities were formerly much lower. These leases are presently the most productive in St. Bernard Parish, indicating a salinity regime from 10-15 ppt. However, coliform pollution emanating from New Orleans is often on the verge of exceeding criteria for shellfish harvest. Growth of New Orleans could increase coliform concentrations, causing these leases to be closed to harvest.

Realistic salinity goals for aquatic habitat adjacent to the MRGO would be maintenance of 10-15 ppt, and for parts of the unit farther from the MRGO, 5-10 ppt. Another goal would be to prevent additional marsh loss by stabilizing the northeast bank of the channel that has eroded extensively (CEI 1982).

Biloxi Marsh Unit

Historically, this environmental unit provided high-quality wildlife habitat, but due to salinity intrusion from the MRGO its value has declined. Goals for this unit are to reinstate as closely as possible the salinity regimes present prior to MRGO construction. This would result in an extensive area of low-salinity brackish marsh more amenable to management for furbearers and waterfowl.

Salinities ranging from 5-10 ppt would produce optimum conditions for aquatic organisms in the Biloxi Marsh Unit, providing nursery areas for brown shrimp and other species in the high-salinity assemblage. Construction of weirs for waterfowl management in the late 1950s created low energy conditions in these marshes and promoted growth of extensive beds of submerged grasses. Because of a lack of maintenance, most of the weirs have been breached or cut around (Beter 1980, personal communication). However, the structures probably still dampen tidal energy to some extent, producing good, low-salinity, brackish nursery potential.

Outer Biloxi Saline Marsh and LaLoutre Marsh Units

Historically, the area of highest oyster production in Hydrologic Unit I has been in the Outer Biloxi Saline Marshes and the LaLoutre Marsh bordering Chandeleur Sound. A significant portion of the water bottoms in this area is leased for oyster production today. However, large tracts in Bay Boudreau, Indian Mound Bay, Three-mile Bay, and others are not leased. Possible reasons include heavy oyster drill predation and lack of easily obtainable seed oysters, both of which are related to salinities above 15 ppt. Goals for this area would be to maintain a salinity regime of 10-15 ppt to encourage oyster production. Cultch planting and controlled harvest on some unleased areas could then be practiced to create a reliable source of seed oysters.

BRETON SOUND WATERSHED

The Breton Sound Watershed environmental units are shown on Plate 3.

Intermediate marsh near Caernarvon.

Caernarvon Crevasse Marsh Unit

This environmental unit was subject to extensive transition of fresh marsh to non-fresh marsh, especially between 1955 and 1978 along the Mississippi River. Goals for this unit are to reestablish where possible some of the freshwater wetlands that have proven to be among the most valuable habitats for waterfowl and furbearers, and to broaden the extent of the low-salinity, fresh-to-intermediate marsh habitats in the upper reaches of the Breton Sound Watershed to more closely approximate historical conditions. Salinity goals of 2-5 ppt are desirable, especially for white shrimp, blue crab, menhaden, and croaker nursery habitat. These marshes have historically provided the low-energy hydrologic conditions for these species in Breton Sound.

Upper River aux Chenes and Terre aux Boeufs Marsh Units

These two units border the previous low-salinity Caenarvon Crevasse Marsh Unit and comprise the next step in the salinity gradient toward Breton Sound. These units represent extensive areas of potentially low-salinity brackish marsh. Goals for these units are to establish a salinity regime of 5-10 ppt over this large marsh area to increase management potential in particular for establishment of three-cornered grass for muskrats and valuable aquatic plants such as widgeon grass in ponds for waterfowl. Salinity goals to promote low-salinity brackish marsh in the Upper River aux Chenes and Terre aux Boeufs Marsh Units will increase the nursery value to brown shrimp, spotted seatrout, and red drum.

Lower River aux Chenes Marsh Unit

Higher tidal energy and salinities make this unit less amenable to management for wildlife. Goals here are to moderate salinities slightly and possibly force some seaward movement of the 15 ppt isohaline. Any tendency towards landward movement of this isohaline should be inhibited. In addition, the elimination of salinity extremes above 15 ppt during the fall months is an important goal. This should strengthen the present value of this unit for fish and wildlife, as well as insure its role as a buffer against extreme salinities and tidal energy for wetlands farther inland.

A high density of private oyster leases in the Lower River aux Chenes Marsh Unit dictates that 10-15 ppt salinities be maintained for oyster production.

Reggio Canal Marsh Unit

The location of the Reggio Canal Marsh Unit between the natural levee ridges of Bayous Terre aux Boeufs and LaLoutre has historically made these low-energy marshes. However, the levee ridges also have shielded the area from freshwater input from the Mississippi River and Lake Borgne, and during recent times the proximity of the MRGO has caused increases in the salinity regime. The marshes are best suited to become low-salinity brackish nursery with salinity goals of 5-10 ppt. This salinity regime also would be most suitable for this unit to enhance brackish marsh wildlife habitat for increased furbearer productivity and greater attractiveness for migratory waterfowl.

Outer Breton Saline Marsh Unit

The primary public and seed oyster grounds for southeastern Louisiana are situated in the Outer Breton Saline Marsh Unit. Salinity goals for seed oyster production are generally 15-20 ppt as discussed previously.

CHAPTER IV

FRESHWATER SUPPLEMENTAL REQUIREMENTS

Assuming that freshwater inflow is the primary variable controlling salinity variation in Louisiana's estuaries, the estimation of inflow needed to achieve a particular salinity regime requires three elements. These are: data characterizing freshwater inflow conditions, data characterizing salinity conditions, and a numerical description of the relationship between the two. That is, some kind of numerical model that expresses salinity as a function of at least freshwater inflow, and of other variables if needed.

Method of Analysis

Objectives, as well as limitations relative to modeling and available salinity data, necessitated the use of a relatively simple statistical model. It was therefore decided basically to continue the approach taken in the earlier work (Gagliano et al. 1970, Light and Alawady 1970) and utilize a multiple linear regression model expressing average salinity in a given month as a function of total freshwater inflow during that month and of some additional variables to account for the effect of antecedent conditions.

Previous studies only incorporated antecedent conditions in so far as they concerned freshwater inflow. This was done by lagging monthly freshwater inflows by as much as six months and introducing the successive, lagged inflows as independent variables. This procedure is very cumbersome and also it is believed that effects of antecedent conditions other than available freshwater are often important in controlling salinities during a given month. For example, sustained winds may change water levels and accelerate or reduce freshwater release into the estuary. For these two reasons, the lagged freshwater inflows were replaced by a single variable in the form of average salinity for the preceeding month. The basic model thus became

$$S_{T,L} = f(S_{T-1,L}, F, E)$$

in which $S_{T,L}$ is the average salinity for a given month (T) at a given location (L); $S_{T-1,\ L}$ is the average salinity for the preceeding month at that same location; F is the freshwater introduction from one or more sources; and E is the error term due to factors not incorporated, such as meteorologic and oceanographic conditions during the month T.

As stated earlier, interest and scope of work extended primarily over the period from 1967 to 1979. Data requirements thus were for that period and included the monthly average of salinity values at representative locations throughout Hydrologic Units I and II and estimates of freshwater inflows that controlled these salinities.

Salinity data were obtained mostly in the form of daily observations from a number of sources and reduced to monthly means. To the extent possible, the stations utilized extended over the full range of habitats and related resource uses prevalent within each of the hydrologic units. Station characteristics are listed in Table 4-1. A number of stations necessitated further data processing. To complete the salinity record for some irregularly sampled stations or stations created after 1967, linear regression could sometimes be employed. To obtain adequate coverage for Hydrologic Unit II required that data from closely spaced stations of the Oyster Water Survey, Louisiana Department of Health and Human Resources (DHHR) be lumped. In that event the centroid was plotted as the new station's position. A total of 20 salinity stations (9 in Unit I and 11 in Unit II) were utilized.

Freshwater Inflow Data

Freshwater inflows into Hydrologic Units I and II were divided into a number of sources to be evaluated separately. They included the Mississippi River, the presently operational diversion structures, and four major watersheds designated respectively Pontchartrain, Pearl, Lake Borgne, and Breton Sound. While monthly river discharges for the Mississippi River were available from the USACE, the remaining sources were partially or totally ungaged and required further computations.

Freshwater sources for Hydrologic Unit I are the Pontchartrain, Pearl, and Lake Borgne watersheds (Figure 4-1). The Pontchartrain watershed source combined the gaged discharges of the Amite, Tickfaw, Natalbany, Tangipahoa, and Tchefuncte Rivers' drainage areas, rainfall surpluses generated over the ungaged portions of those areas and receiving lakes, and the occasional diversions of flow from the Mississippi River through the Bonnet Carre Spillway. The gaged and ungaged drainage areas of the Bogue Chitto and Pearl Rivers comprise the Pearl watershed source. The Lake Borgne watershed source is the totally ungaged rainfall surpluses generated on Lake Borgne and the surrounding wetlands.

To estimate monthly freshwater contributions from the ungaged areas of each watershed, continuous daily water balance computations were undertaken for the period of 1967 to 1979 for each watershed.

Table 4-1. Key to Salinity Stations Used in the Study.

ABBREVIATION	STATION ID	SOURCE	COMMENTS
	Hydrologic Unit I		
PM	Pass Manchac at US 51 Bridge, CE 85420	USACE	Daily 1961 - present
NC	North Causeway, CE 85575	USACE	Weekly 1972 - present
MC	Middle Causeway, CE 85600	USACE	Weekly 1972 - present
SC	South Causeway, CE 85624	USACE	Weekly 1972 - present
IC	ICWW at Paris Road, CE 76042	USACE	Twice weekly 1967 - present
CM	Chef Menteur, CE 85750	USACE	Daily 1967 - present
RL	Rigolets, CE85700	USACE	Daily 1967 - present
BL	Bayou LaLoutre at Alluvial City, CE 85775	USACE	Daily 1975 - present
SM	Bayou St. Malo	LDWF	Intermittent 1968 - present
NM	Ninemile Bayou	LDWF	Intermittent 1968 - present
	Hydrologic Unit II		
BG	Bay Gardene	LDWF	Weekly 1968 - present
LP	Lake Petit	LDWF	Weekly 1968 - present
A	Special Stations from oyster water surveys [1]	LDHHR	Combined data-stations 62, 63, 64 - Area II
B	Located at centroid of stations listed [2]	LDHHR	60, 61
C	1,2	LDHHR	68
D	1,2	LDHHR	66, 69, 70
E	1,2	LDHHR	57
F	1,2	LDHHR	32
G	1,2	LDHHR	33, 52, 74
H	1,2	LDHHR	30, 31
I	1,2	LDHHR	28, 29

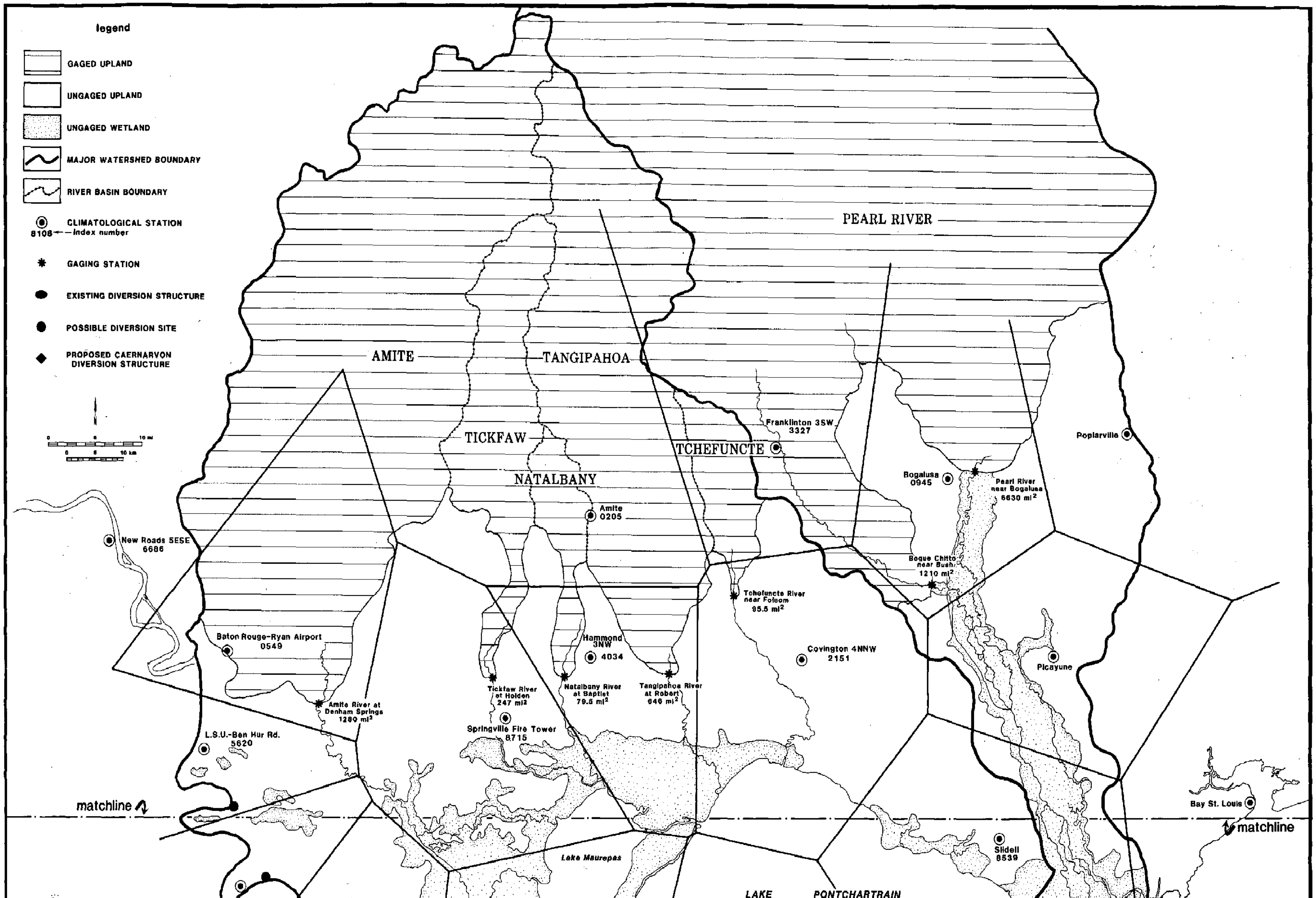


Figure 4-1. Freshwater sources base map for Hydrologic Units I and II.

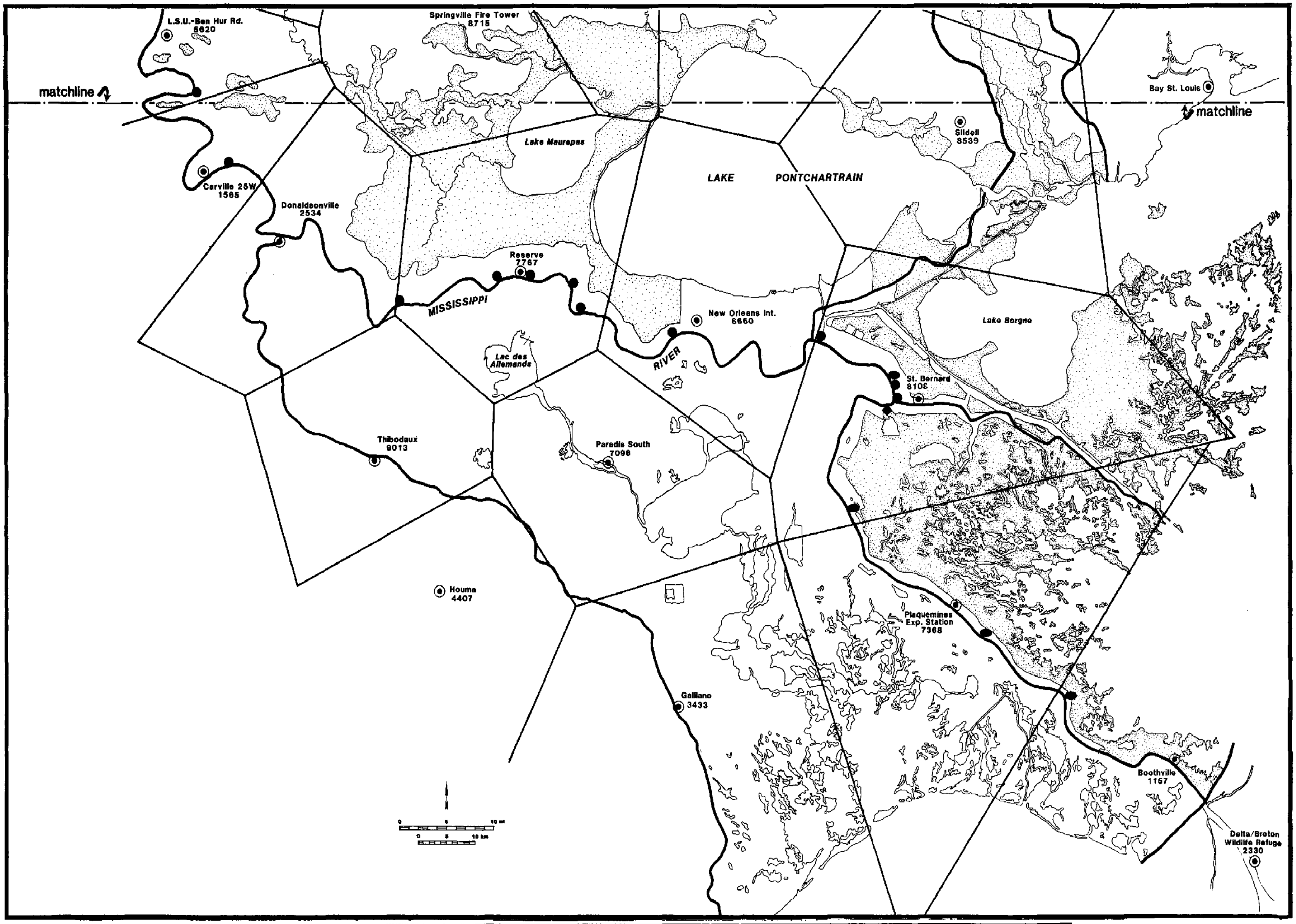


Figure 4-1. (continued)

The ungaged areas were mapped and divided into upland/drained fastland and wetland/open water categories. Using the Thiessen method, each ungaged area was further divided into polygons to define the area represented by each of the climatologial stations for which rainfall and temperature data were available since 1967 (Figure 4-1). For each polygon the size of the wetland/open water and upland/fastland areas was determined using a digitizer. These areal measurements, together with the daily precipitation and temperature readings from the climatolgical stations, formed the data base for the water balance computations.

A modified version (Stone et al. 1971; Wax 1981) of the continuous daily water balance method (Thornthwaite and Mather 1955) was used to obtain monthly runoff and surplus values for each of the ungaged watershed areas. The employed water balance model utilizes a two-layer soil storage component for uplands in which an upper layer exhibits equal availability for water loss and recharge, and a lower layer exhibits a decreasing availability proportional to content. Values for upper and lower soil capacities for each polygon were calculated from vegetation and soils maps. Parish soil surveys made by the Soil Conservation Service (SCS), U.S. Department of Agriculture (USDA), were used to calculate soil storage capacities in inches per foot. Average rooting depths were estimated for the various vegetative cover types, and multiplied by the soil storage capacities to obtain a weighted average of total available water storage capacity for each polygon. Ten millimeters was used as the upper soil layer capacity in each case, with the remainder of the total making up the lower layer. For wetland areas (swamps and marshes), soil storage was not considered, the assumption being that the soils are continuously saturated.

The output of the water balance program was stored in data files and converted to mean monthly discharge (cubic feet per second, cfs) using the acreage values previously entered. Surplus values were used in wetland/open water areas, while runoff from the soil storage component was used in ungaged upland/fastland areas. The ungaged discharge estimates were then added to the gaged river discharges obtained from the USGS, Water Resources Division. The discharges of the Bonnet Carre Floodway were added to the appropriate monthly values for the Pontchartrain watershed. Accordingly, all freshwater sources entering Hydrologic Unit I were documented as three variables, Pontchartrain, Pearl, and Lake Borgne, in terms of mean monthly inflows.

Essentially the same procedure was followed for Hydrologic Unit II. Sources here are the ungaged Breton Sound watershed, the ungaged freshwater diversion from the Mississippi River through the White's Ditch, Bohemia, and Bayou Lamoque structures, and the indirect effects from the Mississippi River via dilution of nearshore waters. Water balance computations as described were applied to the Breton Sound watershed, while Mississippi River discharges were obtained from the USACE, New Orleans District.

Absence of operational records prevented reliable estimates for the small (500 cfs) diversions at White's Ditch and Bohemia. However a diversion record for Bayou Lamoque could be constructed. Discharge equations had been calibrated by the USGS for Bayou Lamoque Structures No. 1 and No. 2 (USGS 1978) in the general form:

$$Q = C \cdot A\,(2 \cdot g \cdot [S_{MR} - S_t])^{0.5} \qquad (1)$$

where: Q = discharge in cfs, C = discharge coefficient (0.65 for No. 1 and 0.72 for No. 2), A = cross-sectional area of gates (400 ft^2 - No. 1 and 576 ft^2 - No. 2), g = acceleration of gravity, S_{MR} = stage of Mississippi River in ft, and S_t = stage of the outfall area in feet. In order to generate mean monthly discharges at Bayou Lamoque, it was assumed that all gates were fully opened (except for known periods of closure) from 1967 to 1979 and that the mean tidal stage was +0.76 ft MSL during this period. Data on daily Mississippi River discharge and stage near Bayou Lamoque were analyzed using the general form of the quadratic equation to derive a relationship between stage and discharge. The resulting equation (R^2 = 0.96) was substituted for S_{MR} in equation (1). Finally, mean monthly Mississippi River discharges were entered into equation (1) to generate estimated mean monthly discharges for Bayou Lamoque. The results were stored as a variable called Lamoque in the same data set with Mississippi River and Breton Sound discharges.

Freshwater and Salinity

The salinity and discharge data sets for Hydrologic Units I and II were concatenated using the Statistical Analysis System (SAS) so that various forms of salinity/discharge functions could be explored. In each case, this involved the station salinities as the dependent variable and discharges as the independent variables. Linear, semi-log, log-log, and inverse function forms were tried. Correlation coefficients were highest for semi-log and log-log models (R^2 = 0.32 to 0.65), with the semi-log form giving slightly higher values overall.

At this point, the one month lagged salinity was introduced as an additional independent variable in semi-logarithmic function. The result was a dramatically increased R^2 value for almost all of the 20 salinity stations. Accordingly, it was decided to define relationships between freshwater inflow and salinity by the general model:

$$S_t = a\,S_{t-1} + b \log Q_1 + c \log Q_2 + d \log Q_3 + e \quad (2)$$

where: S_t = predicted average monthly salinity, S_{t-1} = average salinity during the preceeding month, Q_1-Q_3 are freshwater contributions; a-d are model coefficients, and e is the intercept value.

Result of Analysis

For all Hydrologic Unit I stations except Bayou LaLoutre, the Pearl watershed discharge is found to be the dominant factor in controlling salinity. The coefficients to the models for each salinity station in Hydrologic Unit I are given in Table 4-2. R-square values, or correlation coefficients, shown in the table represent the percentage of the variation in salinity that is accounted for by the models. The model for Chef Menteur (Table 4-2) accounts for 82% of the variation, while the South Causeway model accounts for only 55%. All stations in Table 4-2 have R-square values greater than 0.50. The coefficients for the discharge variables (B, C, and D) logically should be negative in the equation form used because freshwater inflow should reduce salinity. However, the coefficients for the Lake Borgne discharge (c) are positive. This is probably related to the small magnitude and irregularity of rainfall surpluses in the small watershed.

The model for the Intracoastal Waterway at Paris Road gave a very poor correlation and questionable coefficients and is not included in Table 4-2. The cause is probably related to the strong vertical stratification (salt wedge) in this channel and the MRGO. For this reason it may be difficult to accurately predict salinities near the MRGO. Otherwise the models for Pontchartrain and Borgne adequately describe the majority of the variation in salinity and are significant at the 0.0001 level.

The R-square values for stations in Breton Sound (Table 4-3) are slightly lower, with stations C and H below 0.50. This is probably a reflection of the longer interval of time between salinity measurements in this basin (weekly, at best, vs. daily in Pontchartrain/Borgne). The two most influential discharge variables in Breton Sound are the

Mississippi River (B) and Bayou Lamoque (D) (Table 4-3). The coefficients for the Breton Sound watershed surplus (C) are negative, but many could become positive within the range of the standard error (± S.E.), indicating a negligible influence on salinity within. Again, this is attributed to the small magnitude and variability of rainfall surpluses associated with the Breton Sound watershed.

Freshwater Needs

With valid salinity/discharge models, the next step in the analysis was to determine freshwater needs to attain the salinity goals outlined in Chapter III. It is apparent that goals for salinity include both spatial and temporal components (location and season) that may cause conflicts between resource uses. In those cases it must be determined what resource uses are most important and, correspondingly, which goals should govern freshwater diversion. This must be done, however, within the constraints of structure parameters, including size and location, and of the Mississippi River hydrologic regime.

In determining freshwater needs, the desired location of the 15 ppt isohaline for average conditions during the fall became the most important parameter. Various 15 ppt isohalines also were used in previous studies (USACE 1970) as goals relative to oysters (Ford isohaline) and furbearers (Palmisano isohaline). Our analysis of salinities and habitats indicated that average fall salinities of 15 ppt separated brackish from saline marshes and productive from drill-infested oyster grounds.

In the study area, a normal seasonal salinity pattern of lowest salinities in the late winter and spring and highest salinities in the late summer and fall is evident. The mean fall salinity at a point is therefore an estimate of maximum mean salinity that is tolerated by the vegetation, wildlife, and fisheries species. Short-term influxes of higher salinites are doubtless important, especially with regard to vegetation, but sufficient data do not exist on short-term vegetative salinity tolerance, and the resolution of the salinity models does not allow prediction of short-term fluctuations in salinity. Therefore the desired position of the mean fall 15 ppt isohaline was used as a goal.

Having determined the desired location of the 15 ppt mean fall isohaline in each of the hydrologic units on the basis of resources and resource uses within the seaward portion of each unit, the cor-

Table 4-2. Hydrologic Unit I. Pontchartrain/Borgne Basin Salinity/Discharge Models.

STATION NAME	A*	B	C	D	E	R-square
Chef Menteur	0.691 ± 0.038	-2.242 ± 0.372	0.376 ± 0.226	-0.862 ± 0.409	13.021 ± 1.304	0.818
Bayou La Loutre	0.588 ± 0.049	-2.274 ± 0.621	0.561 ± 0.379	-2.596 ± 0.682	22.578 ± 2.317	0.712
Pass Manchac	0.741 ± 0.050	-0.628 ± 0.184	0.047 ± 0.133	-0.166 ± 0.215	3.413 ± 0.646	0.734
Middle Causeway	0.734 ± 0.044	-1.109 ± 0.262	0.276 ± 0.164	-0.497 ± 0.296	6.403 ± 0.876	0.738
North Causeway	0.741 ± 0.050	-0.696 ± 0.236	0.003 ± 0.149	-0.174 ± 0.273	4.099 ± 0.776	0.625
Nine Mile Bayou	0.565 ± 0.048	-4.673 ± 0.685	0.643 ± 0.401	-0.573 ± 0.737	22.984 ± 2.376	0.726
Rigolets	0.608 ± 0.042	-3.653 ± 0.481	0.620 ± 0.286	-0.648 ± 0.516	17.347 ± 1.639	0.795
Bayou Saint Malo	0.519 ± 0.056	-2.304 ± 0.523	0.237 ± 0.315	-1.126 ± 0.570	17.916 ± 1.918	0.611
South Causeway	0.532 ± 0.059	-1.127 ± 0.342	0.246 ± 0.212	-1.008 ± 0.380	9.250 ± 1.124	0.549

*coefficients and standard error for the general form:

Salinity = A (Previous Month Salinity) + B (log Pearl discharge) + C (log Lake Borgne discharge) + D (log Pontchartrain discharge) + E

Table 4-3. Hydrologic Unit II. Breton Sound Salinity/Discharge Models.

STATION NAME	A*	B	C	D	E	R-square
A	0.637 ± 0.066	-3.040 ± 1.291	-0.354 ± 0.551	-1.561 ± 1.654	25.880 ± 6.269	0.552
B	0.650 ± 0.065	-2.323 ± 1.208	-0.513 ± 0.515	-2.045 ± 1.571	24.372 ± 5.886	0.580
C	0.519 ± 0.075	-1.560 ± 1.080	-0.541 ± 0.458	-2.374 ± 1.400	22.788 ± 5.226	0.435
D	0.620 ± 0.062	-2.026 ± 1.010	-0.703 ± 0.432	-2.658 ± 1.317	26.424 ± 5.038	0.611
E	0.618 ± 0.064	-1.247 ± 0.967	-0.624 ± 0.414	-3.061 ± 1.283	23.722 ± 5.023	0.616
F	0.591 ± 0.062	-3.036 ± 1.056	-0.578 ± 0.454	-2.826 ± 1.379	33.842 ± 5.519	0.630
G	0.580 ± 0.061	-4.217 ± 1.274	-0.052 ± 0.546	-3.121 ± 1.614	39.486 ± 6.521	0.624
H	0.445 ± 0.071	-3.699 ± 1.380	-0.023 ± 0.591	-4.083 ± 1.760	43.062 ± 7.263	0.498
I	0.540 ± 0.068	-3.881 ± 1.306	-0.130 ± 0.559	-3.497 ± 1.653	42.763 ± 6.938	0.566
Lake Petit	0.636 ± 0.063	-1.300 ± 1.142	-0.918 ± 0.485	-3.416 ± 1.516	25.973 ± 5.607	0.613
Bay Gardene	0.650 ± 0.056	-4.037 ± 1.186	-0.484 ± 0.509	-2.737 ± 1.537	39.406 ± 6.203	0.692

*coefficients and standard error for the general form:

Salinity = A (previous salinity) + B (log Mississippi River discharge) + C (log Breton discharge) + D (log Bayou Lamoque discharge) + E responding salinities for stations closest to the 15 ppt isohaline were obtained (Bayou St. Malo and Bay Gardene). This in turn allowed computation of freshwater diversion required to attain the identified salinities by use of the regression models. Subsequent use of the specified diversion need as input into the models for the upper estuarine stations provided mean fall isohalines for the brackish to fresh part of the estuary. Comparison of these isohalines with identified goals showed that meeting goals relative to location of the mean 15 ppt isohaline in all cases satisfied or exceeded requirements for the fresher stations. It was furthermore established that fall requirements did indeed exceed requirements during the remaining seasons.

In order to solve the regression equations for the Bayou St. Malo and Bay Gardene stations for maximum supplemental freshwater needs, it was necessary to decide which discharge variable in each hydrologic unit to solve for and what values to assign to the remaining discharge variables in the models. In Hydrologic Unit I, the Pontchartrain watershed variable was chosen even though the Pearl watershed variable exerts more influence in the model. This choice was made because diversion from the Mississippi River would represent a direct input into the Lake Pontchartrain Watershed. Similarly, in Hydrologic Unit II, the Bayou Lamoque discharge variable was chosen to be solved for. Mean monthly discharges from the water balance analysis were used as the Lake Borgne and Breton watershed variables. These variables exert very little influence in the model. However, it was decided to determine long-term discharge characteristics for the Mississippi River and the Pontchartrain and Pearl watersheds because the period of record from 1967 to 1979 can be described as "wetter than average" in Louisiana. In order to eliminate this bias, gaged river discharges for the major watersheds from 1945-1979 were analyzed, using a Log-Pearson distribution, to determine discharges for 50% and 80% exceedance frequencies on a monthly basis. Monthly correction factors were calculated from the water balance data to convert gaged discharge to total discharge for the Pontchartrain and Pearl watersheds. The results appear in Table 4-4.

Using the above method, maximum freshwater requirements thus were defined for Hydrologic Unit I and Hydrologic Unit II as the volume of freshwater inflow required to maintain the 15 ppt isohaline in the desired location during the fall under conditions of a drought having a probability of occurrence of once every five years. By solving the appropriate regression models for the Pontchartrain variable and Bayou Lamoque variable respectively, and subtracting the 80% exceedance discharges calculated to be available from these sources, the maximum supplemental water requirements are obtained. Those are 33,000 cfs for Hydrologic Unit I and 9000 cfs for Hydrologic Unit II.

Table 4-4. Monthly Exceedance Discharges, Gaged and Corrected Total.

Month	% Exceed-ance	Mississippi River Q (cfs)	Pontchartrain Gaged Q (cfs)	Pont.* factor	Pontchartrain Total Q (cfs)	Pearl Gaged Q (cfs)	Pearl factor	Pearl Total Q (cfs)
January	80	272,734	2556	2.114	7959	7708	0.165	8980
	50	437,979	4588		14,287	13,974		16,280
February	80	336,405	3133	2.064	9600	11,094	0.165	12,924
	50	521,614	5452		16,705	18,704		21,790
March	80	493,048	3048	1.696	8230	13,718	0.108	15,200
	50	668,631	5380		14,526	22,191		24,588
April	80	551,309	2458	1.088	5132	10,944	0.093	11,962
	50	734,914	4555		9511	19,383		21,186
May	80	495,012	1780	2.201	5698	7181	0.150	8258
	50	656,714	2957		9465	12,856		14,784
June	80	321,778	1166	2.252	3792	3517	0.185	4168
	50	471,647	1661		5402	5318		6302
July	80	251,240	1255	4.034	6318	3029	0.341	4062
	50	357,094	1738		8749	4342		5823
August	80	177,952	1141	4.146	5872	2929	0.416	4147
	50	240,396	1576		8110	4001		5665
September	80	148,107	1026	3.329	4442	2491	0.352	3368
	50	189,274	1569		6792	3534		4778
October	80	136,173	911	2.725	3393	2154	0.232	2654
	50	195,987	1262		4701	3140		3868
November	80	144,931	944	3.900	4626	2307	0.350	3114
	50	213,760	1542		7556	3746		5057
December	80	195,708	1734	2.776	6548	4264	0.255	5351
	50	300,209	3168		11,962	8263		10,370

*The correction factor is applied as: Total = gaged + (factor) (gaged)

Diversion Volumes

In order to optimize plans for freshwater diversion in relation to a broad spectrum of environmental units and related goals and needs, it was decided to formulate feasible diversion scenarios and evaluate resultant annual salinity regimes for the various estuarine stations. This procedure necessarily included specific locations for the diversion structures since location determines available head and, consequently, discharge for a given structure size. Given the location, various diversion discharges can be expressed in terms of structure size. On the basis of the analysis results presented in Chapter V, freshwater was assumed diverted into Hydrologic Unit I at Bonnet Carre and into Hydrologic Unit II at Caernarvon.

For each location, monthly rates of freshwater diversion were computed for various structure sizes and for 50% and 80% exceedance discharges of the Mississippi River. Necessary stages were obtained from rating curves at Bonnet Carre and Caernarvon as presented together with those for the Bayou Lamoque structure (Table 4-5). From the obtained monthly diversion rates, it soon became apparent that the diversion goals of 33,000 cfs and 9000 cfs into Hydrologic Unit I and Hydrologic Unit II, respectively, could not be met during the fall months because of head constraints. This meant that goals could be met only by diverting sufficient water during the spring months to the extent that its effect would last into the fall.

To determine optimum structure size for attaining the salinity goals in the above manner, the stages and discharges of Table 4-4 were entered as a data set along with mean monthly discharges of the Lake Borgne and Breton watersheds and the model co-efficients for each salinity station. Computer processing of this data using equations (1) and (2) provided predicted salinities for selected structure cross sections. Discharges through the structure and predicted salinities were calculated for each station on a monthly basis using various structure sizes under 50% and 80% conditions. Each model was allowed to stabilize as required by use of the previous month's salinity. Stabilization never required more than 24 monthly iterations.

Table 4-5. Mississippi River Stages Near Existing and Proposed Diversion Sites for 50% and 80% Exceedance Discharges.

		Mississippi River Stage (ft)		
Month	% Exceedence	Bonnet Carre	Caernarvon	Bayou Lamoque
January	80	3.62	2.55	1.94
	50	7.71	5.00	2.82
February	80	5.01	3.52	2.39
	50	10.03	6.19	3.20
March	80	9.30	5.78	3.07
	50	13.57	8.31	3.86
April	80	10.80	6.63	3.32
	50	15.00	9.25	4.18
May	80	9.38	5.80	3.09
	50	13.32	8.13	3.82
June	80	4.71	3.30	2.30
	50	8.68	5.49	2.99
July	80	3.16	2.21	1.67
	50	5.50	3.84	2.48
August	80	1.73	1.03	0.45
	50	2.93	2.04	1.51
September	80	1.12	0.50	—
	50	1.97	1.22	0.68
October	80	0.87	0.29	—
	50	2.07	1.32	0.79
November	80	1.06	0.46	—
	50	2.40	1.59	1.08
December	80	2.07	1.32	0.79
	50	4.25	2.98	2.19

Structure size as used in the following paragraphs refers to the cross-sectional area of the structure opening through which flow is passed from the Mississippi River to the wetlands. For the present determination of structure size, it was assumed that the structure would consist of multiple, gated, concrete box culverts of 2 x 2 feet with a discharge coefficient C = 0.72 (equivalent to the Bayou Lamoque #2 Structure); the implied length being approximately 300 feet. The culverts are assumed to be totally submerged at all times. No consideration is given to resultant velocities and head requirements at the outflow point. Accordingly, the actual required structure size may be larger depending on structure design, including length and shape, and on design criteria for the outflow channel.

Four stations are selected as examples of the above analyses. These are Bayou St. Malo and Middle Causeway for Hydrologic Unit I and Bay Gardene and Lake Petit for Hydrologic Unit II. Tables 4-6 and 4-7 display predicted salinity regimes for Bayou St. Malo under 50% and 80%

Table 4-6. Estimated Discharges (Q) at Bonnet Carre and Resultant Salinities (S) at Bayou St. Malo for Various Structure Sizes (50% Exceedance).

	0 ft²		500 ft²		1000 ft²		1500 ft²		2000 ft²		2500 ft²		3000 ft²	
MONTH	Q (cfs)	S (ppt)	Q (cfs)	S (ppt)	Q (cfs)	S (ppt)	Q (cfs)	S (ppt)	Q (cfs)	S (ppt)	Q (cfs)	S (ppt)	Q (cfs)	S (ppt)
June	0	10.0	7,981	9.6	15,963	9.3	23,944	9.2	31,925	9.1	39,906	9.0	47,888	8.9
July	0	10.6	6,109	10.3	12,219	10.1	18,328	9.8	24,438	9.7	30,547	9.6	36,656	9.4
August	0	11.3	4,001	10.9	8,002	10.6	12,003	10.4	16,004	10.2	20,005	10.1	24,006	9.9
September	0	11.8	2,836	11.4	5,673	11.1	8,509	10.9	11,346	10.8	14,182	10.6	17,019	10.5
October	0	12.5	2,979	12.0	5,958	11.7	8,937	11.4	11,916	11.2	14,895	11.1	17,875	11.0
November	0	12.4	3,408	11.9	6,815	11.6	10,223	11.4	13,631	11.2	17,038	11.0	20,446	10.9
December	0	11.3	5,192	10.9	10,384	10.6	15,576	10.4	20,768	10.2	25,960	10.1	31,152	9.9
January	0	10.2	7,460	9.8	14,921	9.5	22,381	9.3	29,841	9.1	37,301	9.0	44,762	8.8
February	0	9.4	8,654	8.9	17,309	8.6	25,963	8.4	34,618	8.2	43,272	8.0	51,926	7.9
March	0	8.8	10,211	8.3	20,422	8.0	30,632	7.7	40,843	7.5	51,054	7.4	61,265	7.2
April	0	9.0	10,776	8.2	21,552	7.8	32,328	7.5	43,104	7.3	53,880	7.2	64,656	7.0
May	0	9.5	10,109	8.6	20,218	8.2	30,326	7.9	40,435	7.7	50,544	7.5	60,653	7.3
June	0	10.7	7,981	9.7	15,963	9.3	23,944	9.0	31,925	8.8	39,906	8.6	47,888	8.4
July	0	11.2	6,109	10.4	12,219	10.0	18,328	9.7	24,438	9.5	30,547	9.3	36,656	9.2
August	0	11.6	4,001	10.9	8,002	10.6	12,003	10.3	16,004	10.1	20,005	10.0	24,006	9.8
September	0	11.9	2,836	11.4	5,673	11.1	8,509	10.9	11,346	10.7	14,182	10.6	17,019	10.4
October	0	12.5	2,979	12.0	5,958	11.7	8,937	11.4	11,916	11.2	14,895	11.1	17,875	10.9
November	0	12.3	3,408	11.9	6,815	11.6	10,223	11.4	13,631	11.2	17,038	11.0	20,446	10.9

Table 4-7. Estimated Discharges (Q) at Bonnet Carre and Resultant Salinities (S) at Bayou St. Malo for Various Structure Sizes (80% Exceedance).

	0 ft²		500 ft²		1000 ft²		1500 ft²		2000 ft²		2500 ft²		3000 ft²	
MONTH	Q (cfs)	S (ppt)	Q (cfs)	S (ppt)	Q (cfs)	S (ppt)	Q (cfs)	S (ppt)	Q (cfs)	S (ppt)	Q (cfs)	S (ppt)	Q (cfs)	S (ppt)
June	0	10.6	5,547	10.2	11,095	9.9	16,642	9.8	22,189	9.7	27,736	9.6	33,284	9.5
July	0	11.6	4,233	11.2	8,465	10.9	12,698	10.7	16,931	10.5	21,164	10.4	25,396	10.3
August	0	12.2	2,461	11.8	4,921	11.5	7,382	11.3	9,843	11.2	12,303	11.0	14,764	10.9
September	0	12.8	2,057	12.4	4,113	12.2	6,170	11.9	8,227	11.8	10,284	11.6	12,340	11.5
October	0	13.5	2,057	13.0	4,113	12.7	6,170	12.5	8,227	12.3	10,284	12.2	12,340	12.0
November	0	13.6	2,057	13.1	4,113	12.9	6,170	12.6	8,227	12.5	10,284	12.3	12,340	12.2
December	0	12.9	2,979	12.5	5,958	12.2	8,937	12.0	11,916	11.8	14,895	11.7	17,875	11.5
January	0	11.9	4,662	11.5	9,323	11.2	13,985	11.0	18,647	10.8	23,308	10.6	27,970	10.5
February	0	11.0	5,767	10.5	11,534	10.2	17,302	10.0	23,069	9.8	28,836	9.6	34,603	9.5
March	0	10.4	8,297	9.8	16,594	9.5	24,892	9.2	33,189	9.0	41,486	8.8	49,783	8.7
April	0	10.5	9,016	9.7	18,032	9.3	27,047	9.0	36,063	8.8	45,079	8.6	54,095	8.4
May	0	11.0	8,337	10.1	16,674	9.7	25,011	9.3	33,348	9.1	41,685	8.9	50,023	8.8
June	0	12.0	5,547	11.1	11,095	10.7	16,642	10.3	22,189	10.1	27,736	9.9	33,284	9.8
July	0	12.4	4,233	11.7	8,465	11.3	12,698	11.0	16,931	10.8	21,164	10.6	25,396	10.4
August	0	12.6	2,461	12.1	4,921	11.7	7,382	11.5	9,843	11.3	12,303	11.1	14,764	11.0
September	0	13.0	2,057	12.6	4,113	12.3	6,170	12.0	8,227	11.8	10,284	11.7	12,340	11.5
October	0	13.6	2,057	13.1	4,113	12.8	6,170	12.5	8,227	12.4	10,284	12.2	12,340	12.1
November	0	13.6	2,057	13.2	4,113	12.9	6,170	12.7	8,227	12.5	10,284	12.3	12,340	12.2

exceedance conditions, respectively. In essence, 50% exceedance is average conditions, or the situation expected to occur one out of two years, while 80% exceedance describes a "low water" or drought situation expected to occur once in five years.

Two conclusions can be drawn from the tables: 1) there is very little difference between the 50% and 80% fall month discharges for a particular structure size, and 2) there is less difference in discharge from small to large structures in the fall than in the spring. This points to the paradox of freshwater diversion. The fall months are the most critical with regard to salinity goals, but the majority of the freshwater must be diverted in the spring when it is available.

To satisfy the 15 ppt fall isohaline location, fall salinities at Bayou St. Malo should remain limited to about 12.5 ppt. This is seen to require approximately a 1500 ft^2 structure under the dry conditions (80% exceedance). Much larger size structures give only small additional benefits. A diversion of 50,000 cfs produces a decrease from 10.5 to 8.5 ppt in the spring, whereas 26,000 cfs reduces 10.5 to 9.0 ppt (Table 4-7). Hydrologic Unit I is very large, and large amounts of freshwater are required to reduce salinities. However, by establishing a more stable salinity regime with salinities several ppt fresher and without extreme maxima, benefits may be greater than the reduction in monthly mean salinities would indicate.

Information for Middle Causeway in Lake Pontchartrain is shown in Tables 4-8 and 4-9. A similar pattern is evident at this station. The large volume of the lake tends to buffer changes in salinity. Also, as expected, the amount of salinity decrease per volume of freshwater added is less at low salinities than at higher ones. At no time did the investigated structure sizes and discharges result in the lake becoming totally fresh. The identified requirement for a salinity range of 2 to 5 ppt at the Middle Causeway station is estimated to be met by a structure of between 1000 and 1500 ft^2 cross section.

The above analysis procedure was followed for all stations and resulted in a selection of a 1500 ft^2 cross-sectional area for the diversion structure assuming realization of the estimated delivery rate. This structure size was found to most closely attain the goals for all stations within the

Table 4-8. Predicted Discharges (Q) at Bonnet Carre and Resultant Salinities (S) at Middle Causeway for Various Structure Sizes (50% Exceedance).

	0 ft^2		500 ft^2		1000 ft^2		1500 ft^2		2000 ft^2		2500 ft^2		3000 ft^2	
MONTH	Q (cfs)	S (ppt)	Q (cfs)	S (ppt)	Q (cfs)	S (ppt)	Q (cfs)	S (ppt)	Q (cfs)	S (ppt)	Q (cfs)	S (ppt)	Q (cfs)	S (ppt)
June	0	2.9	7,981	2.7	15,963	2.6	23,944	2.5	31,925	2.5	39,906	2.4	47,888	2.4
July	0	3.4	6,109	3.1	12,219	3.0	18,328	2.8	24,438	2.8	30,547	2.7	36,656	2.6
August	0	3.7	4,001	3.5	8,002	3.3	12,003	3.2	16,004	3.1	20,005	3.0	24,006	2.9
September	0	4.1	2,836	3.8	5,673	3.7	8,509	3.5	11,346	3.4	14,182	3.3	17,019	3.2
October	0	4.5	2,979	4.2	5,958	4.0	8,937	3.8	11,916	3.7	14,895	3.6	17,875	3.5
November	0	4.6	3,408	4.3	6,815	4.1	10,223	4.0	13,631	3.8	17,038	3.7	20,446	3.6
December	0	4.3	5,192	4.0	10,384	3.9	15,576	3.6	20,768	3.5	25,960	3.4	31,152	3.3
January	0	3.8	7,460	3.5	14,921	3.3	22,381	3.1	29,841	3.0	37,301	2.9	44,762	2.8
February	0	3.3	8,654	2.9	17,309	2.7	25,963	2.5	34,618	2.4	43,272	2.3	51,926	2.2
March	0	2.8	10,211	2.5	20,422	2.2	30,632	2.1	40,843	1.9	51,054	1.8	61,265	1.7
April	0	2.6	10,776	2.2	21,552	1.9	32,328	1.7	43,104	1.6	53,880	1.4	64,656	1.3
May	0	2.7	10,109	2.2	20,218	1.9	30,326	1.7	40,435	1.6	50,544	1.4	60,653	1.3
June	0	3.2	7,981	2.7	15,963	2.4	23,944	2.1	31,925	2.0	39,906	1.8	47,888	1.7
July	0	3.6	6,109	3.1	12,219	2.8	18,328	2.6	24,438	2.4	30,547	2.3	36,656	2.1
August	0	3.9	4,001	3.5	8,002	3.2	12,003	3.0	16,004	2.8	20,005	2.7	24,006	2.5
September	0	4.2	2,836	3.8	5,673	3.6	8,509	3.4	11,346	3.2	14,182	3.1	17,019	3.0
October	0	4.6	2,979	4.2	5,958	3.9	8,937	3.7	11,916	3.6	14,895	3.4	17,875	3.3
November	0	4.7	3,408	4.3	6,815	4.1	10,223	3.9	13,631	3.7	17,038	3.6	20,446	3.5

Table 4-9. Predicted Discharges (Q) at Bonnet Carre and Resultant Salinities (S) at Middle Causeway for Various Structure Sizes (80% Exceedance).

	0 ft^2		500 ft^2		1000 ft^2		1500 ft^2		2000 ft^2		2500 ft^2		3000 ft^2	
MONTH	Q (cfs)	S (ppt)	Q (cfs)	S (ppt)	Q (cfs)	S (ppt)	Q (cfs)	S (ppt)	Q (cfs)	S (ppt)	Q (cfs)	S (ppt)	Q (cfs)	S (ppt)
June	0	3.2	5,547	3.0	11,095	2.9	16,642	2.8	22,189	2.8	27,736	2.7	33,284	2.7
July	0	3.8	4,233	3.5	8,465	3.4	12,698	3.3	16,931	3.2	21,164	3.1	25,396	3.1
August	0	4.3	2,461	4.0	4,921	3.9	7,382	3.7	9,843	3.6	12,303	3.6	14,764	3.5
September	0	4.8	2,057	4.5	4,113	4.3	6,170	4.2	8,227	4.1	10,284	4.0	12,340	3.9
October	0	5.2	2,057	4.9	4,113	4.7	6,170	4.6	8,227	4.5	10,284	4.4	12,340	4.3
November	0	5.5	2,057	5.2	4,113	5.0	6,170	4.9	8,227	4.7	10,284	4.6	12,340	4.5
December	0	5.4	2,979	5.1	5,958	4.9	8,937	4.7	11,916	4.6	14,895	4.5	17,875	4.4
January	0	5.0	4,662	4.7	9,323	4.5	13,985	4.3	18,647	4.2	23,308	4.0	27,970	3.9
February	0	4.5	5,767	4.2	11,534	3.9	17,302	3.8	23,069	3.6	28,836	3.5	34,603	3.4
March	0	4.1	8,297	3.7	16,594	3.4	24,892	3.2	33,189	3.1	41,486	3.0	49,783	2.9
April	0	4.0	9,016	3.4	18,032	3.1	27,047	2.9	36,063	2.8	45,079	2.6	54,095	2.5
May	0	4.1	8,337	3.5	16,674	3.2	25,011	3.0	33,348	2.8	41,685	2.6	50,023	2.5
June	0	4.5	5,447	3.9	11,095	3.6	16,642	3.3	22,189	3.1	27,736	3.0	33,284	2.9
July	0	4.8	4,233	4.2	8,465	3.9	12,698	3.7	16,931	3.5	21,164	3.4	25,396	3.2
August	0	5.0	2,461	4.5	4,921	4.2	7,382	4.0	9,843	3.8	12,303	3.7	14,764	3.6
September	0	5.3	2,057	4.9	4,113	4.6	6,170	4.4	8,227	4.2	10,284	4.1	12,340	4.0
October	0	5.6	2,057	5.2	4,113	4.9	6,170	4.7	8,227	4.6	10,284	4.4	12,340	4.3
November	0	5.8	2,057	5.4	4,113	5.2	6,170	5.0	8,227	4.8	10,284	4.7	12,340	4.6

Pontchartrain-Borgne estuary. The near maximum diversion of 32,000 cfs associated with this size is in the same range as that identified by the USACE (1981, personal communication). Annual hydrographs representing the predicted salinity regimes for a 1500 ft^2 structure are shown for Bayou St. Malo and Middle Causeway in Figure 4-2. Expected environmental changes are discussed in Chapter VI.

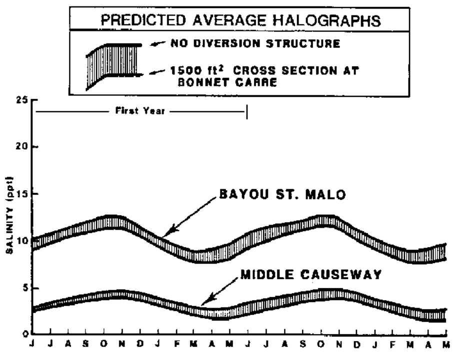


Figure 4-2. Mean monthly predicted salinities for Bayou St. Malo and Middle Causeway with and without the Bonnet Carre diversion for 50% exceedance criteria.

In Hydrologic Unit II, predicted discharges and salinities at Bay Gardene for 50% and 80% exceedance conditions are shown in Tables 4-10 and 4-11, respectively. Bay Gardene is located near the important public oyster grounds where the majority of seed oysters for the region are produced. Development of seed oysters requires a particular seasonal salinity regime. Salinities should not be below 10 ppt during the late spring and early summer months for spawning, larval development, and spatfall. Salinities above 15 ppt in the summer and fall lead to increased predation on the developing seed oysters by the oyster drill (Dugas 1977). Table 4-10 shows that under average conditions these goals are best served with a structure size somewhere between 500 ft^2 and 600 ft^2 (assuming Bayou Lamoque is fully opened), although both criteria cannot be fulfilled simultaneously. To maintain salinity near 15 ppt in the fall, when freshwater is less available, it must dip below 10 ppt in late spring when freshwater is more available. It is possible that the Bayou Lamoque

Table 4-10. Predicted Discharges (Q) at Caernarvon and Resultant Salinities (S) at Bay Gardene for Various Structure Sizes (50% Exceedance).

	0 ft²		200 ft²		400 ft²		500 ft²		600 ft²		700 ft²		800 ft²		900 ft²		1000 ft²	
MONTH	Q (cfs)	S (ppt)	Q (cfs)	S (ppt)	Q (cfs)	S (ppt)	Q (cfs)	S (ppt)	Q (cfs)	S (ppt)	Q (cfs)	S (ppt)	Q (cfs)	S (ppt)	Q (cfs)	S (ppt)	Q (cfs)	S (ppt)
June	0	11.7	2,441	11.4	4,882	11.1	6,103	11.0	7,323	10.9	8,544	10.8	9,764	10.8	10,985	10.7	12,205	10.6
July	0	12.3	1,941	11.8	3,883	11.4	4,853	11.3	5,824	11.1	6,795	11.0	7,766	10.8	8,736	10.7	9,707	10.6
August	0	13.9	1,175	13.3	2,350	12.8	2,937	12.6	3,524	12.4	4,112	12.3	4,699	12.1	5,287	11.9	5,874	11.8
September	0	17.9	540	16.7	1,081	15.9	1,351	15.6	1,621	15.3	1,891	15.1	2,161	14.8	2,432	14.6	2,702	14.4
October	0	19.9	652	18.5	1,303	17.6	1,629	17.2	1,955	16.9	2,281	16.6	2,607	16.4	2,933	16.1	3,258	15.9
November	0	19.6	885	18.4	1,770	17.5	2,212	17.2	2,655	16.9	3,097	16.6	3,539	16.3	3,982	16.1	4,424	15.9
December	0	20.1	1,625	18.1	3,250	17.0	4,063	16.6	4,875	16.2	5,688	15.9	6,500	15.6	7,313	15.3	8,125	15.0
January	0	17.3	2,304	15.7	4,608	14.8	5,760	14.4	6,912	14.0	8,064	13.7	9,216	13.4	10,368	13.2	11,520	12.9
February	0	15.1	2,624	13.8	5,249	12.9	6,561	12.5	7,873	12.2	9,186	11.9	10,498	11.6	11,810	11.4	13,122	11.2
March	0	13.1	3,115	11.9	6,229	11.0	7,787	10.7	9,344	10.4	10,901	10.1	12,459	9.8	14,016	9.6	15,573	9.4
April	0	11.7	3,309	10.5	6,618	9.7	8,272	9.4	9,927	9.1	11,581	8.8	13,235	8.5	14,890	8.3	16,544	8.1
May	0	10.9	3,076	9.8	6,152	9.0	7,690	8.7	9,228	8.4	10,766	8.1	12,304	7.9	13,842	7.7	15,380	7.4
June	0	11.3	2,441	10.3	4,882	9.5	6,103	9.2	7,323	8.9	8,544	8.7	9,764	8.4	10,985	8.2	12,205	8.0
July	0	12.1	1,941	11.1	3,883	10.4	4,853	10.1	5,824	9.8	6,795	9.5	7,766	9.3	8,736	9.1	9,707	8.9
August	0	13.7	1,175	12.9	2,350	12.2	2,937	11.9	3,524	11.6	4,112	11.3	4,699	11.1	5,287	10.9	5,874	10.7
September	0	17.8	540	16.4	1,081	15.5	1,351	15.1	1,621	14.8	1,891	14.5	2,161	14.2	2,432	13.9	2,702	13.7
October	0	19.9	652	18.3	1,303	17.3	1,629	16.9	1,955	16.6	2,281	16.2	2,607	15.9	2,933	15.7	3,258	15.4
November	0	19.5	885	18.2	1,770	17.3	2,212	17.0	2,655	16.6	3,097	16.3	3,539	16.1	3,982	15.8	4,424	15.6

Table 4-11. Predicted Discharges (Q) at Caernarvon and Resultant Salinities (S) at Bay Gardene for Various Structure Sizes (80% Exceedance).

	0 ft²		200 ft²		400 ft²		500 ft²		600 ft²		700 ft²		800 ft²		900 ft²		1000 ft²	
MONTH	Q (cfs)	S (ppt)	Q (cfs)	S (ppt)	Q (cfs)	S (ppt)	Q (cfs)	S (ppt)	Q (cfs)	S (ppt)	Q (cfs)	S (ppt)	Q (cfs)	S (ppt)	Q (cfs)	S (ppt)	Q (cfs)	S (ppt)
June	0	12.6	1,747	12.3	3,494	12.1	4,368	12.0	5,241	11.9	6,115	11.8	6,988	11.7	7,862	11.7	8,735	11.6
July	0	13.9	1,267	13.4	2,534	13.1	3,168	12.9	3,802	12.8	4,435	12.6	5,069	12.5	5,702	12.4	6,336	12.3
August	0	18.0	200	17.4	399	16.8	499	16.6	599	16.4	698	16.2	798	16.1	898	15.9	998	15.7
September	0	21.0	115	20.4	230	19.8	288	19.6	346	19.4	403	19.2	461	19.0	518	18.8	576	18.7
October	0	22.6	115	22.0	230	21.6	288	21.4	346	21.2	403	21.0	461	20.8	518	20.7	576	20.5
November	0	22.0	885	21.3	1,770	20.8	2,212	20.5	2,655	20.3	3,097	20.1	3,539	19.9	3,982	19.7	4,424	19.6
December	0	22.4	652	21.4	1,303	20.6	1,629	20.3	1,955	20.0	2,281	19.8	2,607	19.5	2,933	19.3	3,258	19.1
January	0	20.0	1,434	19.0	2,868	18.3	3,586	18.0	4,303	17.8	5,020	17.5	5,737	17.3	6,454	17.1	7,171	16.9
February	0	17.9	1,829	17.0	3,657	16.3	4,572	16.0	5,486	15.7	6,401	15.5	7,315	15.3	8,229	15.0	9,144	14.8
March	0	15.6	2,519	14.7	5,037	14.0	6,297	13.7	7,556	13.4	8,815	13.2	10,075	12.9	11,334	12.7	12,593	12.5
April	0	14.0	2,733	13.0	5,467	12.3	6,834	12.0	8,200	11.8	9,567	11.5	10,934	11.3	12,300	11.0	13,667	10.8
May	0	13.0	2,524	12.1	5,048	11.4	6,310	11.1	7,572	10.9	8,834	10.6	10,096	10.4	11,358	10.1	12,620	9.9
June	0	13.6	1,747	12.7	3,494	12.1	4,368	11.8	5,241	11.5	6,115	11.2	6,988	11.0	7,862	10.8	8,735	10.6
July	0	14.5	1,267	13.7	2,534	13.1	3,168	12.8	3,802	12.5	4,435	12.3	5,069	12.0	5,702	11.8	6,336	11.6
August	0	18.4	200	17.5	399	16.8	499	16.5	599	16.2	698	16.0	798	15.7	898	15.5	998	15.3
September	0	21.3	115	20.5	230	19.8	288	19.5	346	19.3	403	19.0	461	18.8	518	18.6	576	18.4
October	0	22.8	115	22.1	230	21.6	288	21.3	346	21.1	403	20.9	461	20.7	518	20.5	576	20.3
November	0	22.1	885	21.4	1,770	20.8	2,212	20.5	2,655	20.3	3,097	20.0	3,539	19.8	3,982	19.6	4,424	19.4

structures could be operated to "fine tune" the salinity during the spawning season, but even this could cause higher salinities the following fall. Under drought conditions, oyster drills would be subdued from March to August with the 500-600 ft^2 structure and from March to September with a 1000 ft^2 structure (Table 4-11). This indicates that larger structures would not aid significantly in reducing drill populations.

Under average conditions predicted salinities at Lake Petit meet the goals for low-salinity brackish marsh (5-10 ppt) with a 400 ft^2 structure (Table 4-12). In addition, it should be kept in mind that the diversion discharges are entered in the Bayou Lamoque discharge variable of the models. In other words, predicted salinities are based on freshwater input at the seaward end of the estuary. With introduction at Caernarvon it is likely that Lake Petit salinities will be somewhat less than those in Tables 4-12 and 4-13.

Analysis of the predicted salinity conditions indicates that a structure at Caernarvon with a cross-sectional area between 500 ft^2 and 600 ft^2 would provide the volume of freshwater that most nearly attains the salinity goals in the Breton Sound estuary. A 576 ft^2 cross section was therefore used (this is the size of the four 12 by 12 ft gates in the Bayou Lamoque No. 2 diversion structure) to develop the predicted average halographs for Bay Gardene and Lake Petit shown in Figure 4-3.

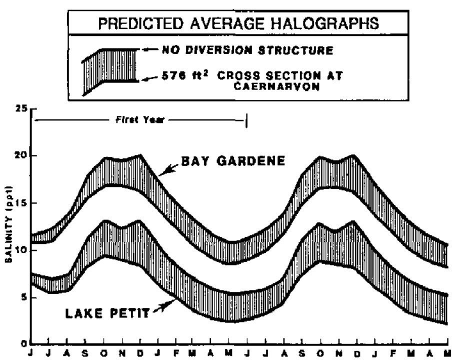


Figure 4-3. Mean monthly predicted salinities for Bay Gardene and Lake Petit with and without the Caernarvon diversion for 50% exceedance criteria.

Table 4-12. Predicted Discharge (Q) at Caernarvon and Resultant Salinities (S) at Lake Petit for Various Structure Sizes (50% Exceedance).

	0 ft^2		200 ft^2		400 ft^2		500 ft^2		600 ft^2		700 ft^2		800 ft^2		900 ft^2		1000 ft^2	
MONTH	Q (cfs)	S (ppt)	Q (cfs)	S (ppt)	Q (cfs)	S (ppt)	Q (cfs)	S (ppt)	Q (cfs)	S (ppt)	Q (cfs)	S (ppt)	Q (cfs)	S (ppt)	Q (cfs)	S (ppt)	Q (cfs)	S (ppt)
June	0	7.3	2,441	7.0	4,882	6.6	6,103	6.5	7,323	6.4	8,544	6.3	9,764	6.2	10,985	6.1	12,205	6.0
July	0	7.0	1,941	6.4	3,883	5.9	4,853	5.7	5,824	5.5	6,795	5.3	7,766	5.1	8,736	5.0	9,707	4.8
August	0	7.6	1,175	6.9	2,350	6.3	2,937	6.0	3,524	5.8	4,112	5.6	4,699	5.4	5,287	5.2	5,874	5.0
September	0	11.3	540	9.8	1,081	8.8	1,351	8.5	1,621	8.1	1,891	7.8	2,161	7.5	2,432	7.3	2,702	7.0
October	0	13.1	652	11.4	1,303	10.2	1,629	9.8	1,955	9.4	2,281	9.0	2,607	8.7	2,933	8.4	3,258	8.1
November	0	12.2	885	10.7	1,770	9.7	2,212	9.3	2,655	8.9	3,097	8.6	3,539	8.3	3,982	8.0	4,424	7.7
December	0	13.1	1,625	10.7	3,250	9.3	4,063	8.8	4,875	8.4	5,688	7.9	6,500	7.6	7,313	7.2	8,125	6.9
January	0	10.4	2,304	8.5	4,608	7.3	5,760	6.8	6,912	6.4	8,064	6.1	9,216	5.7	10,368	5.4	11,520	5.1
February	0	8.5	2,624	6.9	5,249	5.8	6,561	5.4	7,873	5.0	9,186	4.7	10,498	4.4	11,810	4.1	13,122	3.8
March	0	7.0	3,115	5.5	6,229	4.5	7,787	4.1	9,344	3.7	10,901	3.4	12,459	3.1	14,016	2.8	15,573	2.5
April	0	6.0	3,309	4.7	6,618	3.7	8,272	3.3	9,927	2.9	11,581	2.6	13,235	2.3	14,890	2.0	16,544	1.8
May	0	5.4	3,076	4.1	6,152	3.2	7,690	2.8	9,228	2.5	10,766	2.1	12,304	1.8	13,842	1.5	15,380	1.3
June	0	5.7	2,441	4.5	4,882	3.6	6,103	3.2	7,323	2.9	8,544	2.5	9,764	2.2	10,985	2.0	12,205	1.7
July	0	5.9	1,941	4.8	3,883	3.9	4,853	3.6	5,824	3.2	6,795	2.9	7,766	2.6	8,736	2.4	9,707	2.1
August	0	6.9	1,175	5.9	2,350	5.1	2,937	4.7	3,524	4.4	4,112	4.1	4,699	3.8	5,287	3.5	5,874	3.3
September	0	10.9	540	9.2	1,081	8.1	1,351	7.6	1,621	7.2	1,891	6.8	2,161	6.5	2,432	6.2	2,702	5.9
October	0	12.8	652	11.0	1,303	9.7	1,629	9.3	1,955	8.8	2,281	8.4	2,607	8.1	2,933	7.8	3,258	7.4
November	0	12.0	885	10.5	1,770	9.4	2,212	8.9	2,655	8.5	3,097	8.2	3,539	7.9	3,982	7.6	4,424	7.3

Table 4-13. Predicted Discharges (Q) at Caernarvon and Resultant Salinities (S) at Lake Petit for Various Structure Sizes (80% Exceedance).

	0 ft^2		200 ft^2		400 ft^2		500 ft^2		600 ft^2		700 ft^2		800 ft^2		900 ft^2		1000 ft^2	
MONTH	Q (cfs)	S (ppt)	Q (cfs)	S (ppt)	Q (cfs)	S (ppt)	Q (cfs)	S (ppt)	Q (cfs)	S (ppt)	Q (cfs)	S (ppt)	Q (cfs)	S (ppt)	Q (cfs)	S (ppt)	Q (cfs)	S (ppt)
June	0	7.8	1,747	7.5	3,494	7.2	4,368	7.1	5,241	78.0	6,115	6.9	6,988	6.8	7,862	6.7	8,735	6.6
July	0	8.0	1,267	7.4	2,534	7.0	3,168	6.8	3,802	6.6	4,435	6.4	5,069	6.3	5,702	6.1	6,336	6.0
August	0	11.6	200	10.8	399	10.1	499	9.9	599	9.6	698	9.4	798	9.2	898	9.0	998	8.8
September	0	14.0	115	13.2	230	12.5	288	12.2	346	12.0	403	11.8	461	11.5	518	11.3	576	11.1
October	0	15.0	115	14.3	230	13.8	288	13.5	346	13.3	403	13.1	461	12.9	518	12.7	576	12.5
November	0	13.6	885	12.8	1,770	12.1	2,212	11.9	2,655	11.6	3,097	11.3	3,539	11.1	3,982	10.9	4,424	10.7
December	0	14.3	652	13.0	1,303	12.1	1,629	11.7	1,955	11.3	2,281	11.0	2,607	10.7	2,933	10.5	3,258	10.2
January	0	11.8	1,434	10.7	2,868	9.8	3,586	9.5	4,303	9.1	5,020	8.8	5,737	8.6	6,454	8.3	7,171	8.1
February	0	10.0	1,829	8.9	3,657	8.1	4,572	7.7	5,486	7.4	6,401	7.1	7,315	6.8	8,229	6.6	9,144	6.3
March	0	8.3	2,519	7.2	5,037	6.3	6,297	6.0	7,556	5.7	8,815	5.4	10,075	5.1	11,334	4.8	12,593	4.6
April	0	7.2	2,733	6.1	5,467	5.3	6,834	4.9	8,200	4.6	9,567	4.3	10,934	4.0	12,300	3.7	13,667	3.5
May	0	6.5	2,524	5.5	5,048	4.6	6,310	4.2	7,572	3.9	8,834	3.6	10,096	3.3	11,358	3.0	12,620	2.8
June	0	6.9	1,747	5.9	3,494	5.1	4,368	4.7	5,241	4.4	6,115	4.1	6,988	3.8	7,862	3.5	8,735	3.3
July	0	7.4	1,267	6.4	2,534	5.6	3,168	5.3	3,802	4.9	4,435	4.7	5,069	4.4	5,702	4.1	6,336	3.9
August	0	11.2	200	10.1	399	9.3	499	8.9	599	8.6	698	8.2	798	8.0	898	7.7	998	7.4
September	0	13.7	115	12.8	230	12.0	288	11.6	346	11.3	403	11.0	461	10.8	518	10.5	576	10.3
October	0	14.8	115	14.0	230	13.4	288	13.1	346	12.8	403	12.6	461	12.4	518	12.1	576	11.9
November	0	13.5	885	12.6	1,770	11.9	2,212	11.6	2,655	11.3	3,097	11.1	3,539	10.8	3,982	10.6	4,424	10.3

CHAPTER V

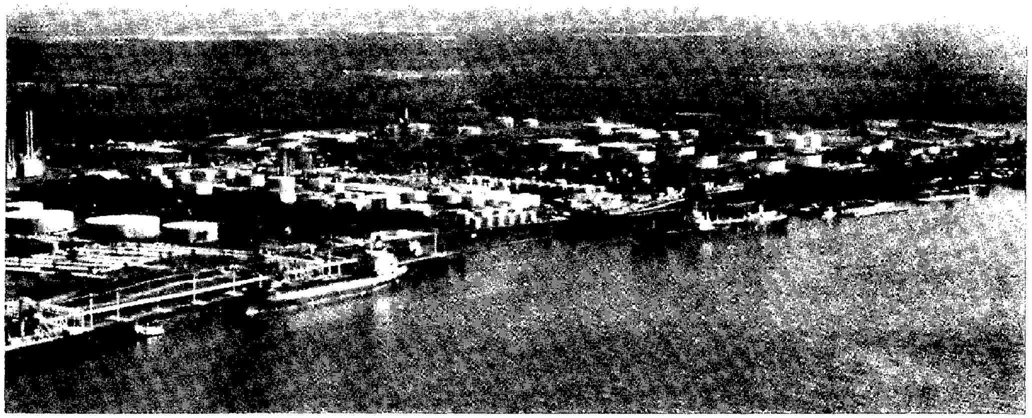
PROPOSED SITES FOR FRESHWATER DIVERSION

The analysis of possible diverison sites includes the east bank of the Mississippi River from the northern boundary of Iberville Parish to Baptiste Collette Bayou. The area upstream of Poydras in St. Bernard Parish contains all possible diversion sites for Hydrologic Unit I, while sites for Hydrologic Unit II must be selected downstream from this point. Siting of potential diversion structures is based on four major considerations:

1) **Goals of the diversion** - This concerns the volume of water needed, where it is needed, and when it is needed.

2) **Delivery structures and existing drainage patterns** - For specific diversion needs consideration must be given to the requirements for conveying freshwater from the river to the estuary in terms of structures and channels. Alteration of drainage patterns and flooding potential must be evaluated.

3) **Existing and proposed land uses** - Agricultural, urban, and industrial development are concentrated along the river because of land suitability and transportation. These and future land uses, local priorities, market values, and ownership patterns of the land are primary factors in siting.



Industry with river frontage, wetlands in the background.

4) **Results of USACE diversion studies** - The USACE has evaluated 12 possible diversion sites in Hydrologic Unit I. Three of these were recommended for detailed studies (USACE 1981a). Results of the USACE feasibility determinations are incorporated in the present site selection.

General Considerations

Before dealing with the specifics of Hydrologic Units I and II, some general comments are in order relative to the selection of size, type, and number of structures. It may be argued that with the objective being the diversion of freshwater for the purpose of a managed salinity regime, diversion should mimic overbank flow to the greatest extent possible. This would provide a greater retention of water within the wetlands, which in turn provides for temperature adjustments, natural treatment, and a more gradual release into the estuarine water bodies. Accordingly, it would be desirable to have a large number of small structures. The implementation of such a plan could be incremental and would facilitate initiation and participation by local governments.

When further analyzing the feasibility of implementing a large number of small structures, it becomes readily apparent that constraints tend to outweigh opportunities along nearly the entire east bank; the two major related reasons being cost and existing development.

Based on detailed analyses of topography, drainage, present and near future development, and constraints posed by these elements on freshwater diversion, it was decided that a limited number of large structures should be favored as being most feasible and cost-effective. Major considerations are summarized in the following paragraphs.

The identified magnitude of the freshwater diversion requirement (Chapter IV) is on the order of 30,000 to 40,000 cfs. It may safely be assumed that small structures, if selected, would be siphons of the type presently operational at the Lake Borgne Canal because siphons do not involve breaching the levee, thereby creating a potentially weak link in the flood protection chain. Having a capacity of about 500 cfs, tens of such structures would be needed. At a per structure cost of some 2.5 million dollars this would more than double the first cost for the diversion when compared with USACE cost estimates for large structures providing a similar total discharge. The structure-related cost differential becomes even greater when taking into account operation and maintenance.

The second major consideration, existing development, involves a number of aspects. One is that the rapid expansion of industrial development along the Mississippi River banks has eliminated nearly all vacant river frontage. At the same time urban development is forced to expand away from the river into adjacent wetlands. The results are limited opportunity for gaining access to river frontage without expropriation and increased distance over which diverted water must be confined prior to release into wetlands. Resultant cost in outfall provisions would be multiplied in case of a large number of smaller structures.

A third aspect concerns the topographic and drainage characteristics. In Hydrologic Unit I, a major constraint is posed by the presence of U.S 61 which is entirely on grade and by Interstate 10, part of which is on grade. The highways would tend to impound water in the area confined between these highways and the river if water were diverted through numerous small structures and introduced into the nearest wetlands. Any such proposal would be expected to generate significant opposition because of anticipated deterioration of already marginal drainage.

Within Hydrologic Unit II, analysis of topography revealed that interior drainage is largely controlled by natural levee ridges that more or less parallel the Mississippi River. Accordingly, a better distribution of freshwater and greater benefit to existing wetlands could be achieved by introduction of water at the upper end of the unit, rather than through multiple structures along its margin.

Site Analysis

HYDROLOGIC UNIT I

The maximum freshwater need for Hydrologic Unit I was determined to be approximately 33,000 cfs (Chapter IV), that need being most apparent in western and southwestern Lake Borgne during the late summer and fall. Yet diversion of freshwater into this lower part of the basin is not viewed as either very feasible or desirable for a number of reasons. Near Lake Borgne, the east bank of the river is fronted by metropolitan New Orleans. Only two potential diversion sites remain in this reach: the Inner Harbor Navigation Canal (IHNR) and the Lake Borgne Canal. The IHNC was eliminated from consideration by the USACE because of interference with navigation and problems with water quality. The canal is separated from Lake Pontchartrain by a navigation lock for which enlargement has been proposed. Space at this location is already at a premium, and it is doubtful that a 33,000 cfs structure could be included in the lock design. Industrial contamination of the canal waters is considered another major constraint in that diversion discharges would carry these contaminants into presently less polluted areas.

The Lake Borgne Canal site was recommended for detailed studies in the USACE evaluation, although a number of problems are apparent. A freshwater diversion siphon presently operates in the Lake Borgne Canal at Violet. It is part of the marsh management program in St. Bernard Parish and has a maximum capacity of 500 cfs. The siphon was installed at a cost of approximately $2.5 million. In order to obtain 33,000 cfs at this site, the Lake Borgne Canal and Bayou Dupre would have to be enlarged greatly. The existing control gate in the hurricane protection levee would have to be enlarged or a new one constructed. Local plans call for structural surface water and marsh management in the wetlands surrounding the siphon outfall. Any further freshwater diversion plans in this area should consider the public investment in the siphon and management plans. A small portion of the needs could be met by enlarging the existing structure at Violet.

A third consideration is the benefit derived from introduction of a given quantity of freshwater. Diversion into the upper end of the basin would result in the fullest use of the freshwater, sediments, nutrients, and dissolved minerals because of longer retention. In the lower basin retention is adversely affected by water exchange through the MRGO. Also, the overall pollutant concentrations in the river are less upstream from New Orleans.

Freshwater siphon at Violet, St. Bernard Parish.

Potential sites upstream from New Orleans can be divided into two groups, those which would discharge into Lake Pontchartrain and those that would discharge into the swamps drained by Lake Maurepas. A dividing line between the groups is U.S. 51 at LaPlace. The USACE evaluated six possible sites upstream from U.S. 51 in LaPlace. All were eliminated from further consideration due to engineering costs and disruption of community aesthetic and social concerns.

The drainage patterns around Lake Maurepas are influenced strongly by backwater effects at the only outlet, Pass Manchac. Because of wind set-up, mean tide stages at Pass Manchac are approximately +1.5 ft MSL in the spring and +2.0 ft MSL in the fall (Wicker et al. 1981). Water levels in Lake Maurepas are elevated during floods on the Amite, Tickfaw, and Natalbany Rivers. In combination with existing development these conditions result in chronic backwater flooding problems in at least the Amite River basin. Proposed drainage projects in this area, which only consider channel excavations and enlargements, will not completely solve the present problems of poor drainage. Consequently, delivery systems for diverted freshwater would experience the same gradient problems and further contribute to backwater flooding.

(Although the Mississippi River stage is progressively higher upstream, stages in the outfall area also increase.) More importantly, the addition of 10,000 to 30,000 cfs to the system would respectively double to quadruple the average discharge at Pass Manchac.

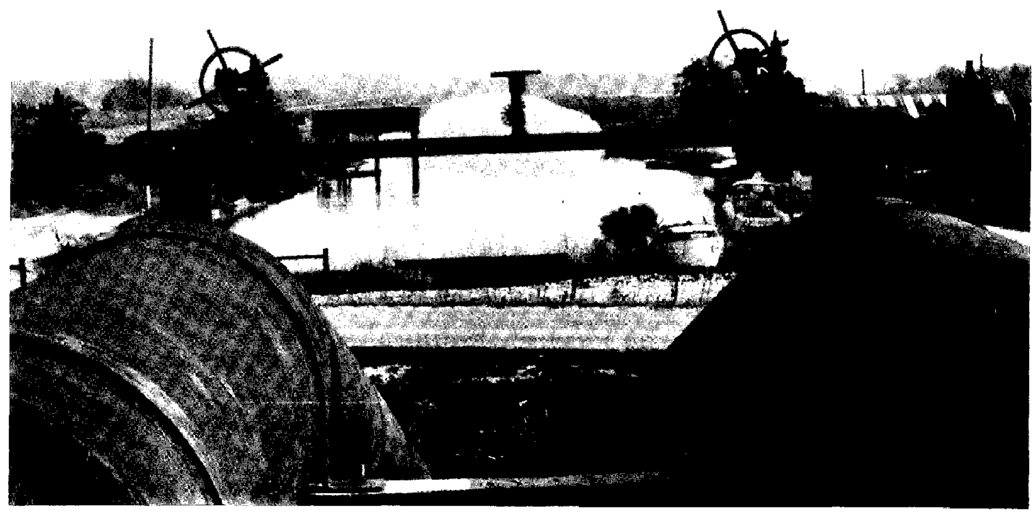
Of further concern is projected development. Acreage of urban and industrial land use is projected to increase 45% in the area drained by Lake Maurepas by the year 2020, replacing present agriculture and forest land uses on the natural levee (USACE 1981b). It is likely that industry will continue to occupy lands with river frontage, causing commercial and residential development to progress down the toe of the natural levee. Agricultural lands that now experience occasional flooding with little consequence will be replaced with residences which cannot tolerate flooding. One large (or several small) diversion structure(s) would not only compete with industry for river frontage but also encumber anticipated subdivision development by requiring additional drainage laterals, back levees, and pumping stations.

Potential sites that would discharge directly into Lake Pontchartrain appear to be the most feasible. Two of three sites evaluated by the USACE were recommended for detailed studies: the canals along the north guide levee of the Bonnet Carre Floodway and the borrow canal within the floodway itself. A site at the Walker and St. Charles Canals was eliminated from further consideration because of the need to relocate a sand mining company, two highways, and two railroads and because of community aesthetic and social concerns. Of the two remaining site the one within the spillway was favored over the north guide levee alignment because the latter required relocation of U.S. 61.

From an environmental standpoint, the St. Charles site has some appeal. A large delivery channel without spoil banks would allow overflow into the marshes and provide for natural water treatment. Presently deteriorating wetlands would be revitalized and new wetlands created in the large, open water bodies near Lake Pontchartrain. However, in view of the required discharge (30,000 cfs), a continuous channel would still be required from the river to Lake Pontchartrain, and the majority of the diverted water would remain in the channel. Bridges would be required at intersections of the channel with the highways and railroads. The proposed Interstate 410 also would require an additional bridge. Flowage easements would have to be purchased from the land owners for overbank flows. Local priorities furthermore include a hurricane protection levee with floodgates to be built from Kenner along the lake to the Bonnet Carre Floodway to protect new development in the area. The relatively small amount of water treatment and marsh buildup do not outweigh the cost of the railroad and highway relocations and public opposition. Therefore, the site within the Bonnet Carre Floodway remains as the least expensive and most compatible alternative. There are no conflicts with development, no cost for flowage easements, and an existing levee and borrow canal already form two components of a delivery channel.

HYDROLOGIC UNIT II

Maximum freshwater needs for Hydrologic Unit II were estimated to be approximately 9000 cfs to maintain the desired positions of the mean fall 15 ppt isohaline. The area of greatest need appears to be in the marshes north of a line from Belair to Delacroix that includes the last acreage of intermediate marsh in the basin; this marsh is slowly becoming saltier. The low-salinity brackish marshes bordering Lake Lery are also becoming more brackish. The encroachment of salinities greater than 10 ppt in the fall is the primary cause of the changes.



Freshwater siphon at Whites Ditch, Plaquemines Parish. View from crest of river levee.

There are four diversion structures already operating in Breton Sound: the Whites Ditch siphon, Bohemia, and the two gated structures at Bayou Lamoque. To protect and expand the remaining intermediate marsh, new diversion sites should be located upstream from Whites Ditch. The area in Breton Sound upstream from Whites Ditch is essentially a wetland cul-de-sac lying between the natural levees of the Mississippi River and Bayou Terre aux Boeufs. It is therefore protected from tidal and marine forces and exhibits the lowest amplitude tidal fluctuation and slowest water exchange rates in the Breton Sound Unit. Diversion into this area would provide maximum use of the freshwater by temporarily retaining it in the wetlands where chemical and thermal changes could take place prior to mixing with waters in lower areas of the Sound. In this manner, suspended sediments, nutrients, and dissolved minerals (along with possible contaminants) could be taken up and contribute to plant growth, the cooler river water would be warmed, and stored freshwater would be slowly released to moderate salinity during the low river stage fall months when the diversion rates are minimal. The best location in terms of optimizing utilization of diverted water while accommodating local plans and priorities is at Caernarvon near the Plaquemines - St. Bernard Parish line. This site offers the best possibility for conveying water from the river to the wetlands without affecting existing development and forced drainage systems or flood protection works. The river frontage is under single ownership, facilitating simple purchase or acquisition of flowage easements. In addition, a large open water area, known as Big Mar, offers an opportunity for outfall management of the diverted water and sediment.

Proposed Diversion Sites

PONTCHARTRAIN AND LAKE BORGNE WATERSHEDS

Since the Bonnet Carre Floodway's intended use is for diversion of water from the Mississippi River at rates up to 250,000 cfs, selection of this site may in many ways seem a foregone conclusion. This is not the case for several reasons--the main one being that its present use is defined as single purpose, namely flood control. Operation of the floodgates, therefore, is regulated and authorized only for relief of flood conditions. Second, continued use of the floodway for its intended purpose and at the necessary capacity requires that sedimentation in the floodway is kept to a minimum. Sedimentation poses a problem even at the infrequent level of present use. Third, to allow diversion of Mississippi River water through the structure other than during flood stages would require major modifications to the structure.

Bayou Lamoque Structure #2, courtesy of Plaquemines Parish.

Operational and structural constraints posed by the Bonnet Carre structure presently require that diversion of Mississippi River water be accomplished by means of an ancillary structure. In principle such a structure could be placed immediately upstream or downstream of the Bonnet Carre structure with outfall directed into the floodway. Assuming a structure similar in type and efficiency to that at Bayou Lamoque, the cross-sectional area required would be approximately 1500^2 to provide the necessary 33,000 cfs during average annual flood conditions.

Without further detailed surveys, recommendations as to whether to place the structure on the upstream or downstream side cannot be more than preliminary. It is on that basis that location of the diversion structure on the upstream end of the Bonnet Carre intake structure is proposed as shown in Figure 5-1. Considerations reflected in the proposed location include river processes, land use, and sedimentation associated with the diversion.

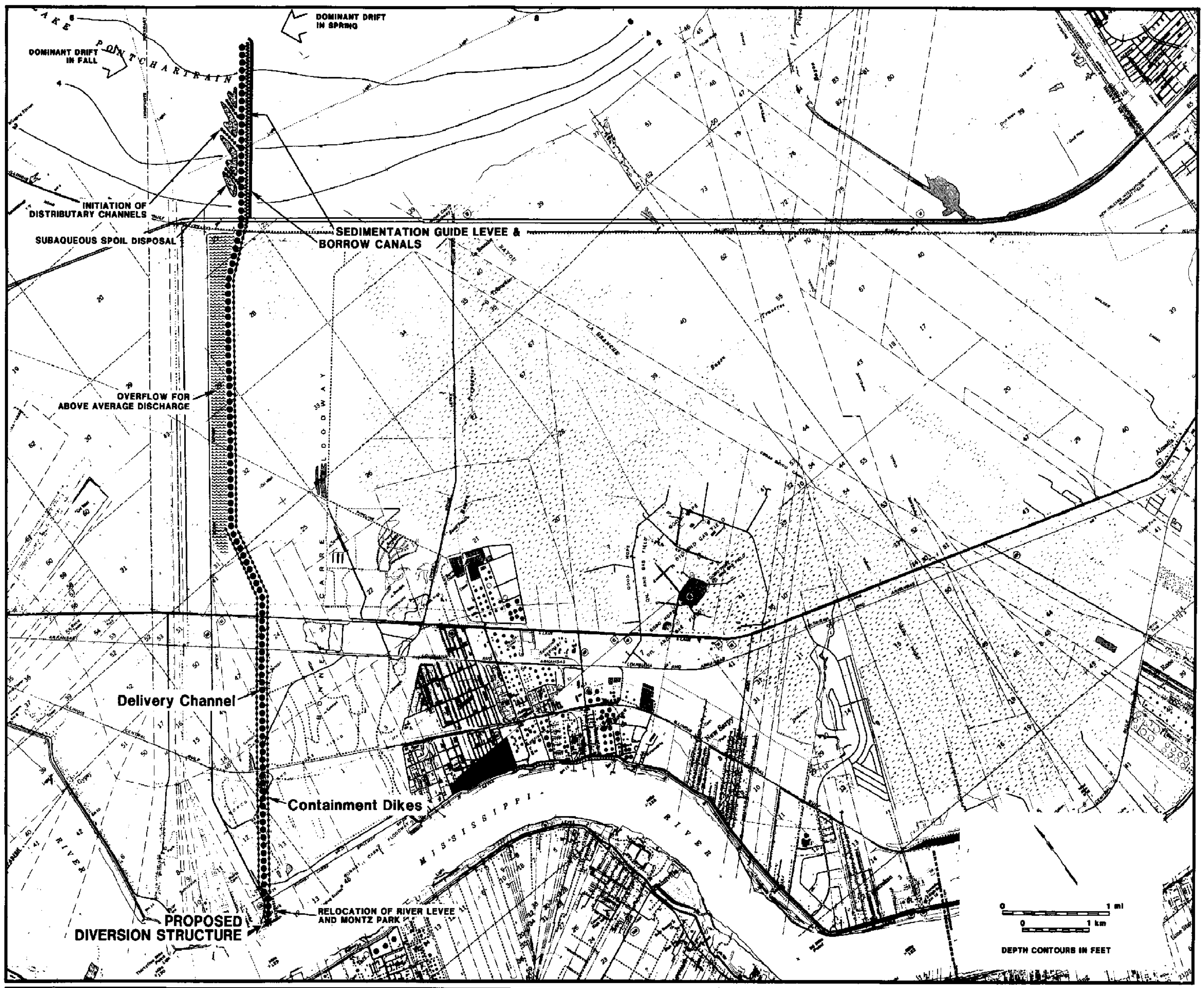


Figure 5-1. Proposed diversion plan for Hydrologic Unit I at Bonnet Carre.

Location of the diversion structure as related to river processes may raise the question of whether the upstream location lies within the accretion zone of the Thirty-five Mile Point's bar. If so, this may result in siltation of the intake channel and a requirement for annual maintenance. Such maintenance must, however, be weighed against maintenance dredging to be expected in Lake Pontchartrain if diversion outfall were to be located along the south side of the floodway. At the Lake, introduced sediments would be subject to a drift that is predominantly westward at the time of highest diversion discharge (Gael 1980), thus causing sediment transport across the floodway outlet.

As shown in Figure 5-1, it is proposed that flows diverted through the ancillary structure remain contained within a leveed channel until reaching Lake Pontchartrain. Below U.S. 61, the alignment utilizes the existing borrow pit, berm, and guidelevee as project elements. New construction of channel and levees would be required between the diversion structure and highway.

Caernarvon Canal (foreground), Big Mar (upper left), and Braithewaite Park and Golf Course (upper right). Courtesy of Plaquemines Parish.

From the water quality point of view it would be most desirable to allow dispersion of the diversion discharge throughout the floodway wetlands. However, associated decreases in flow velocities would result in deposition of sediment load and decrease of floodway capacity. Assuming average discharges as presented in Tables 4-4 and 4-6 an average annual sediment load of 5.7 million tons is expected to be introduced with the diverted Mississippi River water.

Consideration should be given to minimizing height of the levees. First of all, this would allow inclusion of the channel system as part of the floodway at the earliest possible time during operation for flood control. Secondly, this would provide for some overbank flow during above average diversion discharge.

Assuming a stable channel design and limited overbank flow, the sediment load associated with the diverted Mississippi River water would be deposited at the mouth of the outfall channel in Lake Pontchartrain and result in development of a small lacustrine delta. As shown in Figure 5-1, an embankment about 1.5 mi long and extending barely above the water surface is proposed to direct sedimentation away from the floodway outlet. The levee also would promote initial marsh establishment by providing protection from wave erosion. To promote westward deltaic development artificial initiation of distributaries is proposed through functional dredge-and-fill design. On the basis of the 5.7 million tons of sediment estimated to be introduced into the Lake, present bathymetry, and an assumed 40% sediment retention (mainly silt and sand), delta building would amount to 2 mi^2 in 15 years.

BRETON SOUND WATERSHED

The proposed diversion structure at Caernarvon, as shown in detail in Figure 5-2, utilizes a largely undeveloped, 0.25 mi wide corridor across the natural levee of the Mississippi River. Constraints on use for diversion are primarily a highway and railroad crossing and the navigational use of the Caernarvon Canal connecting a small boatyard with Bayou Mandeville. Backwater flood-protection levees confine the corridor until it reaches Big Mar, an abandoned agricultural reclamation project that is permanently flooded. The entire corridor is located within Plaquemines Parish.

To minimize acquisition or easement-related problems, the required area can be limited to a single landowner by locating the structure and outfall channel within the western half of the corridor. This recommendation is coincident with that of Plaquemine Parish (Varnell and Lozes 1981). Furthermore, this would allow separation of diversion flows from the Caernarvon Canal to prevent siltation and resultant hindrance to navigation.

As proposed, to satisfy the freshwater requirements of Hydrologic Unit II, a structure with a cross-sectional area of approximately 550 ft^2 would be placed within the levee corridor at Caernarvon; the size of the structure would be based on assumed similarity to Bayou Lamoque No. 2. To minimize structure size requirements a channel would be excavated from the structure into Big Mar. The channel would be contained between the existing west back protection levee and a newly built dike on the east side (Figure 5-2). The latter levee would extend to the Delacroix Canal in order to prevent shunting flows through Bayou Mandeville into Lake Lery and to prevent siltation of the Caernarvon Canal.

At this point, a major aspect of the diversion remains--that is the management of the outfall in and beyond Big Mar. The management objective must be to distribute the water into the wetlands adjacent to Big Mar in order to provide maximum natural water treatment and to derive maximum benefits from the associated suspended sediment loads. It does not appear desirable to utilize Big Mar as a plenum. This would require construction of a weir in excess of 1 mi long which would elevate water levels, thus requiring a larger diversion structure to meet the diversion requirement. Furthermore, no sediment benefits would be derived and sedimentation within Big Mar could have an adverse effect on diversion efficiency.

To achieve the desired distribution of freshwater and sediment, use must be made of existing canals in the area adjacent to Big Mar as a distribution network. This network could be linked to the primary delivery channel (Figure 5-2) by means of a number of branch channels. Weirs could be incorporated within these channels for the purpose of water allocation. This type of outfall plan cannot be further defined at this point because of dependence on final design of the diversion structure, tidal circulation within the area, and hydraulics of the canal network. All of these are presently unknown and require site-specific data collection and analysis.

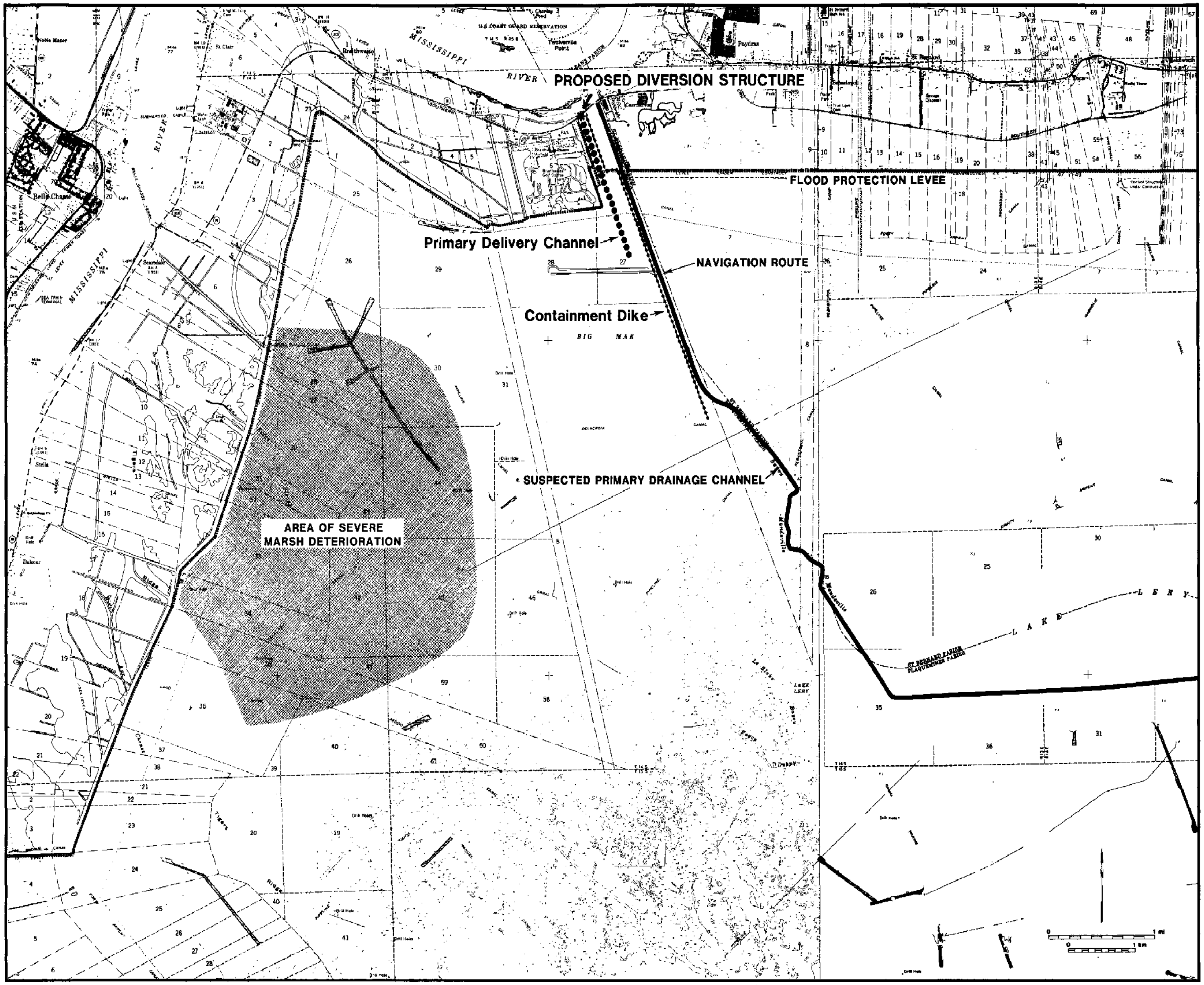


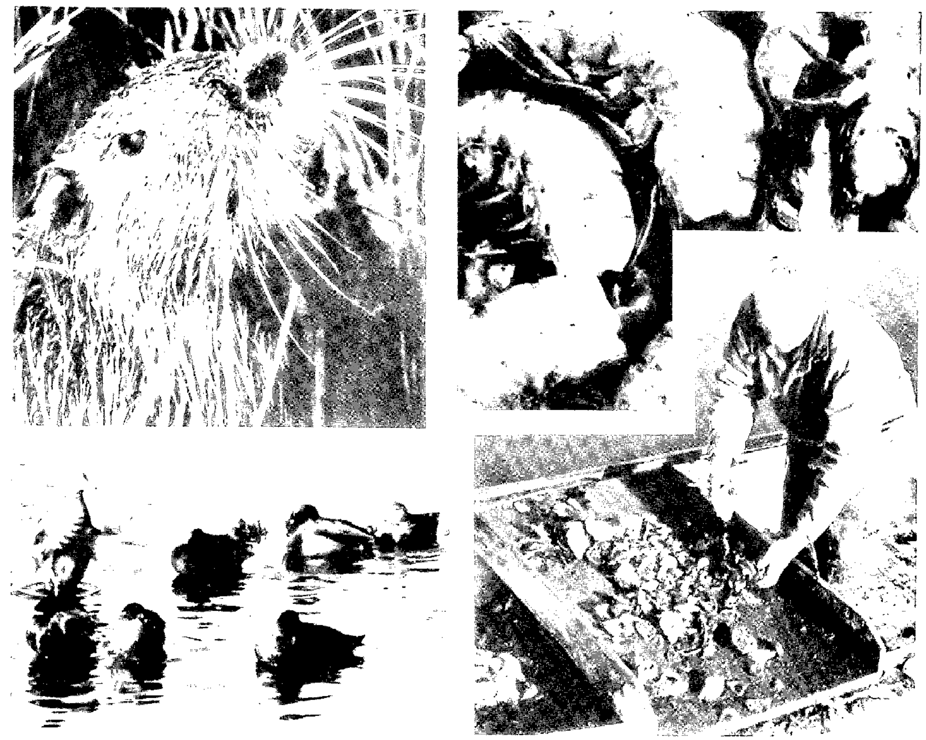
Figure 5-2. Proposed diversion plan for Hydrologic Unit II at Caernarvon.

CHAPTER VI

PREDICTED RESULTS AND POSSIBLE IMPACTS

Pontchartrain Watershed

Diversion of freshwater into Lake Pontchartrain at the Bonnet Carre site will produce a lowered salinity regime throughout the Maurepas-Pontchartrain Basin. Under average conditions, or more accurately, 50% exceedance river flows, salinities at Pass Manchac will be continually less than 2 ppt. Even with drought conditions or 80% exceedance river flows, salinities at Pass Manchac are projected to rise to only about a 2 ppt average during the fall months of September, October, and November (Plate 4). By eliminating salinities above 2 ppt at Pass Manchac during most years, baldcypress swamps will be protected from further salinity stress. Areas that have been in transition from swamp to marsh in the vicinity of Pass Manchac may possibly, in time, be able to revegetate in baldcypress with this regime. The St. Charles marshes should convert to fresh-intermediate types with the potential for increased diversity of vegetative species and enhancement of wildlife habitat. An increase in extent of fresh and intermediate marshes at the expense of some brackish marshes also is expected along the north shore of Lake Pontchartrain, particularly in the Goose Point marshes. The majority of marsh east of Goose Point along the north shore will remain low-salinity brackish marsh.



Louisiana's renewable wetland resources.

Generally, the lowered salinity regime and conversion of some areas to fresher vegetative types are expected to enhance the wetlands of this watershed for most wildlife forms. Fresh and intermediate marsh types have been shown to be among the most productive habitats for nutria, raccoon, and alligator (Palmisano 1973, McNease and Joanen 1978) and are the most heavily utilized by the various species of waterfowl (Palmisano 1973).

Freshwater fish habitat in Lake Maurepas and the surrounding swamps will be improved by elimination of short-duration salinities greater than 3 ppt in the fall. Crawfish populations, although primarily determined by late winter and spring water levels, should expand into the North Pass-Middle Bayou shrub swamp (Wicker et al. 1981) and Manchac Wildlife Management Area. Commercial catfishing will be greatly improved in Lake Maurepas and will become more seasonally consistent in the portion of Lake Pontchartrain between the diversion outfall and the Tchefuncte River (Plate 4). Benthic populations within 1.5 to 2 mi of the diversion outfall will be adversely affected by sediment deposition. However, sediment input from the diversion structures should result in the creation of significant acreages of marsh within the first 15 years of the project (Chapter V). The infrequent operation of the Bonnet Carre Floodway has not created marsh because much of the coarse sediment is deposited in the floodway and because the input is not continuous. The diversion outfall area will receive almost continuous sediment input into shallow waters (2-6 ft). Distributary mouth bars and natural levees are expected to form and become anchors for overbank deposition of finer sediments. During times of maximum diversion discharge in the spring, predominant southeasterly winds will tend to cause westerly longshore currents at the outfall (Figure 5-1) (Gael 1980), resulting in deflection of the freshwater plume to the west and north towards Pass Manchac. This tends to favor distributary formation in that direction as planned. During the low discharge fall months, however, strong, predominantly northeast winds will induce strong, southeastward longshore currents near Ruddock that decrease in strength toward Frenier (Gael 1980). These currents may tend to oppose the low diversion discharge, deflecting it to the east (Figure 5-1). Incoming waves from the northeast will cause erosion of the accreted marsh at the outer fringe.

The outfall area will experience increased concentrations of coliforms, phosphate, lead, arsenic, and cadmium (Table 6-1). Mercury and coliforms exceed EPA criteria in Lake Pontchartrain, and no change in concentration is anticipated. Coliforms should cause no impacts to Lake Pontchartrain shellfish because the only oyster grounds are already permanently closed to harvest. After establishment of marsh vegetation, increased retention of suspended sediments and associated contaminants should improve the quality of the diverted water by incorporating these sediments into the marsh substrate.

No adverse impacts will occur from the limited freshening of Lake Pontchartrain. The 2-5 ppt aquatic habitat will be displaced slightly to the east. Salinities at the Rigolets and Chef Menteur will not exceed 10 ppt, leaving the majority of the lake to remain intermediate- to low-salinity brackish aquatic habitat as it is at present.

Lake Borgne Watershed

The wetlands of the Lake Borgne watershed are located farther from the diversion site and will not be as directly affected as wetlands around Lake Pontchartrain. As a result, conversion of marsh vegetative types to less saline associations will be less likely. There may be some expansion of the intermediate marsh type in the lower Pearl River area, and a possibility of a slight seaward advance of high-salinity brackish marsh at the expense of saline marsh in the Biloxi marsh area of St. Bernard Parish (Plate 5). The extent of low-salinity brackish marsh in the Biloxi Wildlife Management area should also increase somewhat.

The more important effect of freshwater diversion for this watershed will be a more consistent salinity regime from year to year without the extreme high salinities that occur periodically. The major vegetative types in this watershed are brackish marshes of both low- and high-salinity regimes, with wiregrass occurring as the usual dominant plant species. Wiregrass has a wide range of salinities and is in fact found in every marsh type along coastal Louisiana (Chabreck 1972). A widely fluctuating salinity range tends to favor the continued dominance of this species at the expense of other vegetative species more

Table 6-1. Existing Water Quality Near Proposed Diversion Sites in the Mississippi River and Stations in Lake Pontchartrain and Breton Sound.

Station Name*	Coliform, fecal, 0.7 UM-MF (cols.100/ml)	Nitrogen, ammonia +organic dis. (mg/l as N)	Phosphorus, total (Mg/l as P)	Lead, total recoverable (ug/l as Pb)	Mercury, total recoverable (ug/l as Hg)	Phenols (ug/l)	Oxygen demand Biochem uninhib 5-day (mgll)	Solids, residue at 105°c, suspended (mgll)	Arsenic total (ugll as As)	Cadmium, total recoverable (ugll as Cd)	Carbon organic total (mgll as C)
Mississippi River at Luling Ferry	722 ± 388	0.75 ± 0.14	0.28 ± 0.02	15 ± 4	0.04 ± 0.03	2 ± 0.2	2.1 ± 0.7	171 ± 21	2.7 ± 1.6	2.4 ± 1.0	6.6 ± 1.2
Mississippi River at Belle Chasse	2979 ± 970	0.75 ± 0.09	0.24 ± 0.01	41 ± 25	0.05 ± 0.02	--	2.1 ± 0.2	228 ± 9	3.3 ± 0.4	4.1 ± 4.5	6.4 ± 1.4
Lake Pontchartrain at GNO Expressway Bridge	48 ± 46	0.68 ± 0.08	0.11 ± 0.03	8 ± 3	0.04 ± 0.01	2 ± 0.2	1.4 ± 0.4	21 ± 7	1.2 ± 0.2	0.8 ± 0.6	7.0 ± 0.6
Black Bay near Mouth of River aux Chenes	6 ± 1	0.84 ± 0.12	0.11 ± 0.02	8 ± 4	0.04 ± 0.01	--	2.4 ± 1.1	23 ± 4	1.0 ± 0.2	0.3 ± 0.1	11.2 ± 0.8
EPA (1976) Quality Criteria for Water and 1980 revised criteria	14[2]	0.81 ± 7.3[4]	0.1 ± 0.3[4]	25[1]	0.025[1]	30[3]	--	250[3]	508[1]	4.5[1]	--

*all values expressed are means based on data from USGS, 1977-1980.
[1] Criteria for marine organisms.
[2] Criteria for harvesting of shellfish.
[3] Criteria for domestic water supply.
[4] No criteria, but natural range given.

Three-cornered grass marsh near Lake Lery, St. Bernard Parish.

valuable to wildlife. Although a variety of factors govern marsh species composition, a more consistent salinity regime would tend to increase the management potential for the more valuable species such as coco (Scirpus robustus) and three-cornered grass. Conditions for submerged aquatic plants important as waterfowl food, such as southern naiad (Najas guadalupensis) and Eurasian watermilfoil (Myriophyllum spicatum), which can thrive in slightly brackish conditions (Chabreck and Condrey 1976), will also be enhanced under the slightly reduced salinity regime.

It is possible that some private oyster leases in the northwestern corner of Lake Borgne will be impacted by salinities below 5 ppt in the spring (Plate 6). As mentioned in Chapter IV, however, the salinity-discharge models do not adequately describe conditions in the MRGO. Salinities immediately adjacent to the MRGO will probably be higher than the predicted salinities shown and the impacts therefore less. Mixing of the salt wedge through the passes at Martello Castle and Bayou Bienvenue is responsible for the successful establishment of the existing oyster leases.

The areas of high oyster production will expand in the "Louisiana marsh" between Lake Borgne and Chandeleur Sound (Plate 6). Figure 6-1 shows the predicted salinity gradient in Hydrologic Unit I and the corresponding shift in habitats. Optimum oyster habitat will be expanded into the shallow bays, farther from urban influences and pollutants. This will also expand the acreage suitable for leasing. More importantly, the predicted salinity regime indicates that a new public seed oyster ground could be established to provide for the expanded production potential. At present, seed oysters are harvested in Breton Sound and transported to leases in the Lake Borgne area. Creation and maintenance of these new seed grounds is also dependent on expansion of the successful Louisiana Department of Wildlife and Fisheries program of cultch plantings and regulated harvest presently operating in Breton Sound.

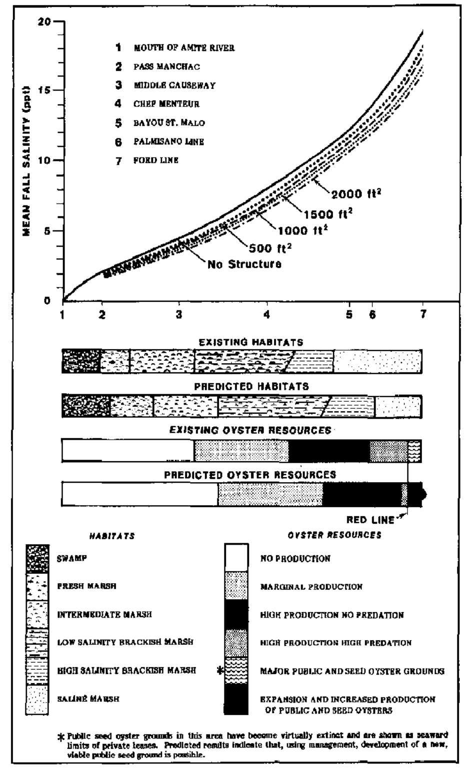


Figure 6-1. Predicted mean fall salinity gradient for 50% exceedance criteria for various Bonnet Carre structure sizes (cross section of gates). Predicted results are based on 1500 ft^2 cross section.

Breton Sound Watershed

Diversion of freshwater at the Caernarvon site will produce an area of fresh marsh in the vicinity of Big Mar that is presently of intermediate salinities (Plate 7). The area of intermediate marsh also will be expanded below Big Mar and will extend throughout most of the marshes north of Lake Lery. Habitat for waterfowl, furbearers, and the alligator should be enhanced substantially in the upper reaches of the Breton Sound marshes. There should be an increase in the extent of low-salinity brackish marsh that favors growth of three-cornered grass, considered the most important food plant for muskrats in coastal Louisiana (O'Neil 1949, Chabreck and Condrey 1976). Although water level regime is of primary importance in management for three-cornered grass (Ross 1972), areas of low tidal energy and low-salinity brackish (5-10 ppt) conditions favor its establishment. Thus, management potential for muskrats should be increased in much of the Breton Sound watershed. With the extension of low-salinity brackish marsh, the range of harvestable alligator populations should also increase since young alligators cannot tolerate salinities greater than 10 ppt for extended periods (Joanen and McNease 1972). The expansion in extent of fresh and intermediate marsh in the upper Breton Sound watershed should favor increases in alligator numbers since these vegetative types have been shown to support the highest nesting densities on a statewide basis (McNease and Joanen 1978).

In the Mississippi River near Caernarvon, coliforms, lead, and mercury exceed EPA criteria (Table 6-1). Outfall management must include plans to remove these and other contaminants from the water. Since most pollutants are associated with suspended sediments, the diversion discharge should be exposed to a large surface area of marsh where sediments could be incorporated in the substrate. Assuming a successful outfall management plan is implemented, there should be negligible adverse impacts on water quality in the basin and substantial increases in productivity from the nutrients and dissolved minerals in the freshwater (Table 6-1).

Acreages of intermediate- and low-salinity brackish nursery will be dramatically increased as a result of the Carenarvon diversion (Plate 8). This should foster an increase in populations of white shrimp, blue crab, and menhaden, as well as other members of this low-salinity assemblage. Brown shrimp populations will not benefit as much as white shrimp, but will have access to an expanded area of low-salinity brackish nursery. Commercial crabbing in Lake Lery should expand and become more consistent from year to year, giving local fishermen another reliable source of income.

Some private oyster leases in the upper portion of the watershed will be impacted by low salinities (Plate 8). However, these leases exhibit marginal oyster production at present under normal conditions and active seeding is probably restricted to high-salinity drought years (Dugas 1981, personal communication). On the other hand, optimum salinity conditions will be established in the area of greatest lease density (Figure 6-2). Decreased predation losses to the oyster drill on the productive leases will give oystermen a better return per oyster seeded. Also, decreased predation on the adjacent seed grounds will make seed oysters more readily available and therefore less expensive to obtain. Another possible benefit would be the expansion of the public oyster reefs, if the Louisiana Department of Wildlife and Fisheries cultch planting program were enlarged in scope. The oyster management program of the Louisiana Department of Wildlife and Fisheries is outlined in Table 6-2. Investments by the state to expand the public oyster reefs with the predicted salinity regime would not only produce dividends in oyster production but also might result in moderation of tide and wave energy. Natural oyster reefs are generally oriented perpendicular to prevailing currents allowing for passage of more water and suspended food over the reef. This not only benefits the oysters but also reduces the energy of the moving water. By providing new substrate (cultch) in the form of shells, rock, or other hard material, new natural reefs could be initiated in suitable areas to moderate tidal exchange and associated removal of freshwater and materials.

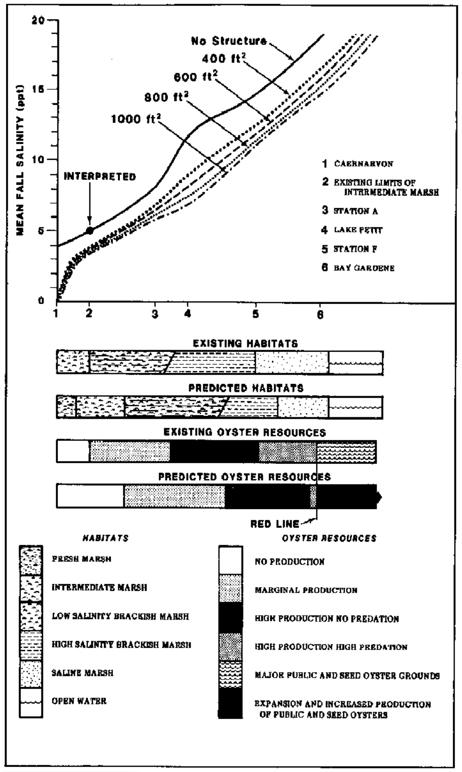


Figure 6-2. Predicted mean fall salinity gradient for 50% exceedance criteria for various Caernarvon structure sizes (cross section of gates). Predicted results are based on 576 ft^2 cross section. (Note: the assumption is made that the Bayou Lamoque structures are kept fully opened.)

Table 6-2. Annual Operating Schedule of the Louisiana Oyster Fishery.

FALL SEASON

Dates

First Wednesday after Labor Day to December 31 (inclusive)

Activities

1) Transplanting of seed oysters (1-3 inches) from public grounds to private leases.
2) Harvesting commercial sack oysters (greater than 3 inches) from public and private grounds and canning oysters from private leases.

Restrictions

1) Oysters less than 3 inches cannot be marketed from public grounds.
2) Periodic closure of certain parts of public grounds for cultch (shell) planting to improve spatfall and seed oyster production.

SPRING SEASON

Dates

January 1 to May 20 (inclusive)

Activities

1) Harvesting of transplanted seed oysters from private leases for canning and sack oyster markets.
2) Harvesting of canning and sack oysters from public grounds.

Restrictions

1) Certain seed ground reservations and depleted regular public grounds may be closed to harvesting.
2) Size limits on oysters harvested from public grounds may be imposed.
3) Periodic closure of certain parts of public grounds for cultch planting.

CLOSED SEASON

Dates

May 21 to the first Tuesday after Labor Day (inclusive).

Activities

1) Some harvesting of larger oysters from private leases that were not harvested in the Spring.
2) Cultch plantings on some parts of public grounds.

Restrictions

No harvesting or transplanting of oysters from public grounds.

Effect on Salinity Regimes of the Capture of Mississippi River Flow by the Atchafalaya River

Until completion of the Old River Control Structure (ORCS) in 1963, steadily increasing volumes of Mississippi River discharge were captured by the Atchafalaya River which provides a shorter route to the Gulf of Mexico. The structure limited discussion to approximately 30% of the Mississippi River dishcarge and interrupted a process that was estimated to have lead to a change in the Mississippi River's course by 1975 (Latimer and Schweizer 1951). While the ORCS effectively controls the discharge distribution, channel development of the Atchafalaya River has continued under the influence of an average annual peak flow of 425,000 cfs and flood control measures related to use of the Atchafalaya Basin as a floodway. Adjustments of the hydraulic gradient have occurred that further favor the capture of Mississippi River by the Atchafalaya River were it not for the ORCS. Accordingly, concern has been expressed as to the ability of the ORCS to prevent such capture in the event of a large flood.

After the 1973 flood, during which the low sill structure was damaged, many expressed fears that the Atchafalaya would become the Mississippi River in one catastrophic event. Kazmann, Johnson, and Harris (1980) describe the physical and economic consequences of such a scenario where 70% or so of Mississippi River flow is captured in a single season. Kolb (1980) notes that although such a massive rapid diversion is unlikely, the engineering constraints and economics of maintaining a 30% flow diversion over the long term makes his suggestions for a planned, gradual increase in Atchafalaya discharge a viable alternative to be considered.

In the context of the present study, these scenarios raise the question of what effects a Mississippi River course change would have on the recommended freshwater diversion plan. Available data are used here to predict the consequences of redistribution of flow between the Atchafalaya and Mississippi Rivers as this relates to salinity regimen and proposed diversion plans in the study area over the standard 50-year project life.

To develop a reasonable rate and manner of flow redistribution, a graph of percent flow down the Atchafalaya from 1910 to 1950 (Latimer and Schweizer 1951) was updated by plotting percent mean annual flow from 1941 to 1963 on the same graph. The distribution of the data points between 1950 and 1963 (when the ORCS began operating) do not fit the extrapolated curve of Latimer and Schweizer (1951). Instead, the annual rate of flow capture appears to be linear. The slope of the line of best fit through these points is 0.44% capture per year. By extending this line to 1982, it appears that the Atchafalaya would be receiving 44% of the mean annual flows of the Mississippi River had the Old River control structure not been built, or approximately 14% more of the total than at present. During the 19-year life of the ORCS, the Atchafalaya River channel has been maturing primarily through scouring in the upper portion and natural levee formation in the lower portion (infilling of Grand and Six-mile Lakes, etc.). This has resulted in a decrease of the water slope by decreasing stage for a given discharge in the upper portion and increasing stage in the lower portion. During the same time period, the Mississippi River channel below the ORCS has been deteriorating with a resultant increase in stage per discharge at the ORCS. The final result has been an increase in head across the structure which is the apparent cause of excessive scouring and possible undermining of the ORCS responsible for the recent concern and apocalyptic predictions.

However, it is important to remember that the present problem of increased head is related to a natural process of maturation of the Atchafalaya River channel, a process that proceeded at an apparently linear rate from 1910 to 1963, and the same process that would have resulted in a present 44% diversion if no action had been taken. The case that will be evaluated here will assume that the ORCS fails during a major flood and results in the capture of 44% of the Mississippi River flow by the Atchafalaya after passage of the flood conditions. It is assumed that the rate of capture will proceed at 0.44% per year from 1982 to 2030.

Under these assumptions, by the year 2030 about 65% of the Mississippi River will be flowing down the Atchafalaya. Discharges at Bonnet Carre will be about half of those at present, ranging from 367,000 cfs in April to 94,600 in September (50% exceedence, average flows). Diversion rates at the proposed Bonnet Carre diversion structure will decrease from an annual mean of 19,930 cfs to

Old River Control Structure

8260 cfs. A maximum discharge of 18,930 cfs would occur in April, but no diversion will be possible from August - November. There will be no drastic changes in the salinity regime of Hydrologic Unit I, however, due to the continued freshwater input from the Pontchartrain and Pearl River Watersheds. Salinities at Bayou St. Malo will range from 10 ppt in April to 14 ppt in October.

The effects on Hydrologic Unit II (Breton Sound) will be more severe. The mean annual discharge of the proposed Caernarvon structure will decrease from 5920 cfs to 2200 cfs. The maximum April diversion will be only 5700 cfs and no freshwater will be available during a 5-month period from August - December. Discharges from Bayou Lamoque will decrease even more substantially. Most importantly, the decreased indirect effect of Mississippi River discharge itself on salinity of nearshore Gulf waters will cause detrimental increases in salinity in the estuary. Even assuming consistent average rainfall, salinity at Bay Gardene will range from a low of 14 ppt in April to 28 ppt or more in October. These salinities will result in total elimination of the fresh and intermediate marsh created by the Caernarvon project and a significant landward shift of the line between saline and brackish marsh.

CHAPTER VII

SUMMARY AND CONCLUSIONS

The basic premise for diversion of water from the Mississippi River into adjacent estuaries is that continued existence of Louisiana's coastal wetland-based resources requires the subsidy of freshwater and associated materials that prevailed under natural conditions. The evidence for that argument is derived from the documentation of environmental change and the understanding of cause-effect relationships. The subsidy provided by Mississippi River waters involves three major elements. These are the seasonal distribution of freshwater inflows that help regulate the distribution and extent of salinity-controlled habitats and biological processes, the contribution of sediments as materials that aid in maintaining required wetland substrate elevation against subsidence, and the organic and inorganic materials including nutrients, salts, and toxicants that are introduced with the sediment and water. A major additional contribution inherent in each is the flow of water through the wetland system as a basis for many physical, chemical, and biological processes.

Diversion of Mississippi River water for the purpose of maintaining and improving estuarine resources related to salinity is the focal point of this report. The area of concern includes the estuarine system associated with Lakes Maurepas, Pontchartrain, Borgne, and Chandeleur Sound as Hydrologic Unit I and the wetland systems linked to Breton Sound as Hydrologic Unit II. Recommendations for freshwater diversion into each of the units are developed in terms of type, location, volume, and seasonal need on the basis of salinity induced habitat changes, present estuarine environments and resource uses, opportunities and goals for future use, and the salinity regimens that can be achieved by introducing given quantities of freshwater.

Salinity encroachment in each of the estuarine units has caused two types of changes. Most obvious has been the landward shift of the saline, brackish, and intermediate salinity wetland zones resulting in the loss of freshwater wetlands in the upper estuaries. Equally important are the salt-induced changes within a given environment that cause a loss of desirable species of plants and animals such as those utilized in trapping and oyster production. Together these changes have resulted in either or both the loss of resources or the relocation of uses such as oyster production. Because of past adjustments in location of resource uses the goal for freshwater diversion cannot be merely the seaward displacement of all salinity zones.

For the above reasons goal development for freshwater diversion was guided in the first place by retention and improvement of present resources. Primary goals therefore included ameliorating salt-induced stress in the freshwater swamps and marshes, improving the quality of the brackish marshes in terms of species composition, and maintaining a salinity regime favorable for oysters in the lower estuary. Major criteria in this regard became the position of the 2 ppt and 15 ppt isohalines, respectively, during the fall months.

Statistical relationships between salinity regimen in each of the hydrologic units and monthly freshwater introduction from direct rainfall, runoff, and presently operational diversion structures formed the basis for determination of freshwater volumes required to most nearly attain the desired goals. The major constraint in attaining goals was the diversion feasibility during the fall as controlled by Mississippi River discharge and stage. This requires that diversions in the spring and early summer be sufficiently large so that their effect lasts until the fall. To achieve desired conditions 80 percent of the time, a required diversion capacity of approximately 32,000 cfs was determined for Hydrologic Unit I and a required capacity of 9000 cfs for Hydrologic Unit II.

Associated with the identified diversion needs are major structural requirements for that purpose. Based on detailed analysis of topography, drainage, present and future development, and desires expressed by local government, a limited number of large structures was found most feasible and cost-effective. Further consideration of the above factors and of state and Federal interests resulted in recommendation of diversion into Hydrologic Unit I through the Bonnet Carre floodway utilizing an ancillary structure and through a smaller structure at Caernarvon into Hydrologic Unit II. Anticipated cross-sectional areas of the structures are respectively in the order of 1500 ft^2 and 550 ft^2, the latter being similar to the operating structure of Bayou Lamoque in Plaquemines Parish.

Predicted results and adverse impacts of the recommended diverisons are expressed in terms of salinity and related resource changes within each of the environmental units. Within the Pontchartrain Basin the benefits derive primarily from the stabilization of the freshwater wetlands in the upper estuary, the improved quality of brackish marshes, and the reduced occurrence of salinity peaks and wide salinity fluctuations experienced by the Lake Borgne environments. The latter will allow seaward expansion of existing oyster production. Primary benefits associated with the diversion of Caernarvon will be the reestablishment of freshwater wetlands and optimum salinity conditions in the area of greatest oyster lease density, and the opportunity for expanded production of public and seed oysters.

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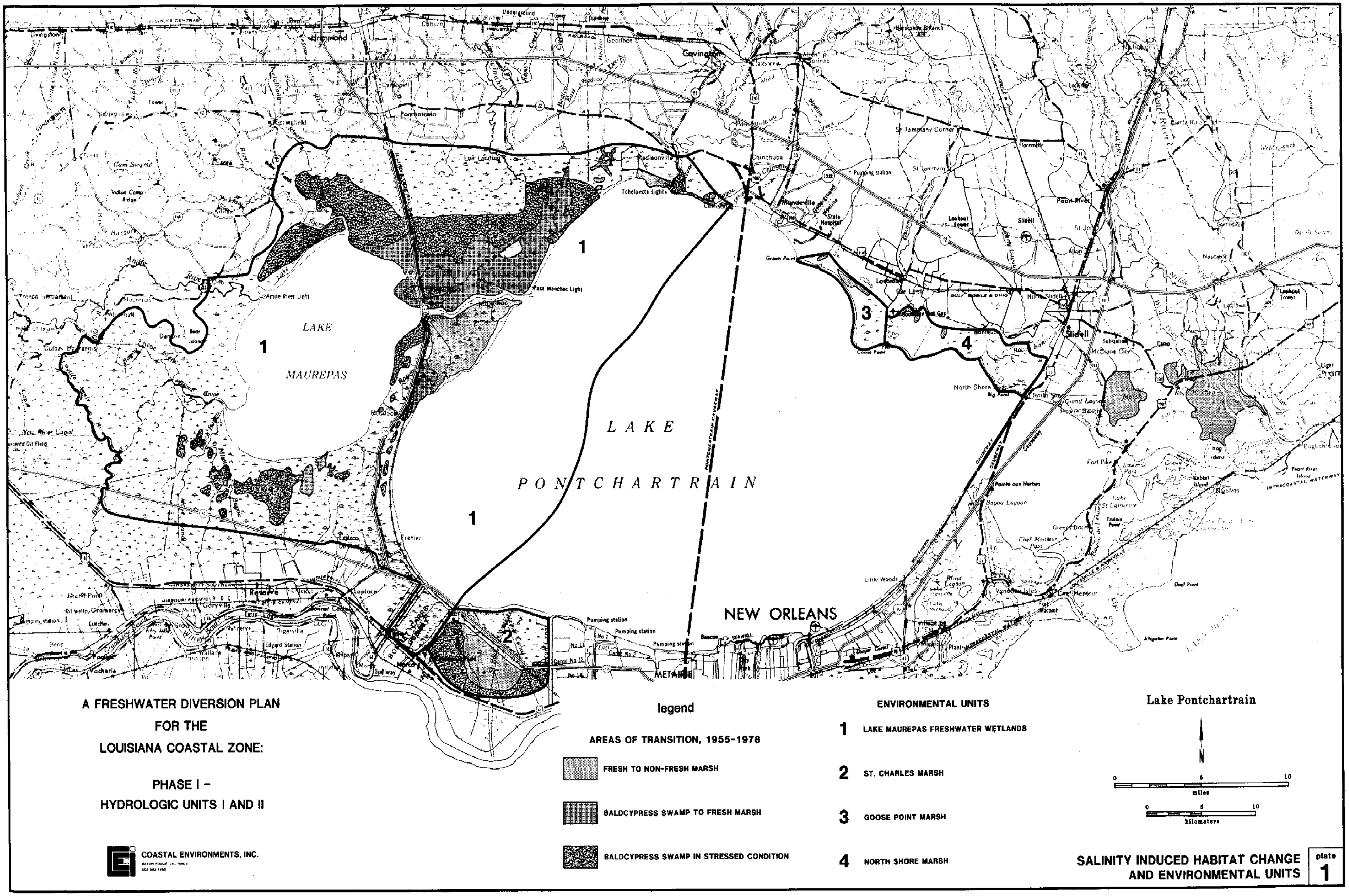
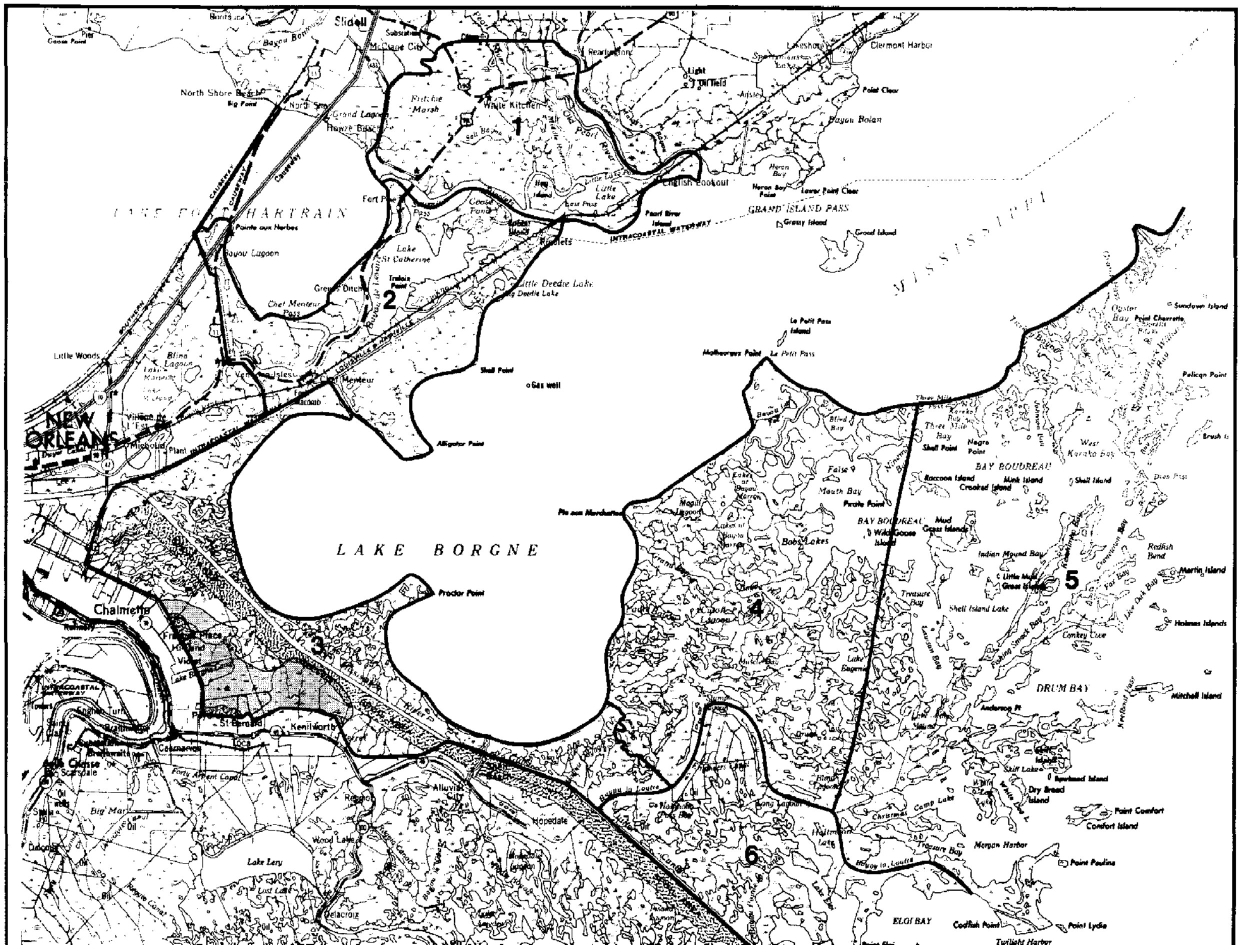

A FRESHWATER DIVERSION PLAN
FOR THE
LOUISIANA COASTAL ZONE:
PHASE I -
HYDROLOGIC UNITS I AND II
COASTAL ENVIRONMENTS, INC.
legend
AREAS OF TRANSITION, 1955-1978
FRESH TO NON-FRESH MARSH
BALDCYPRESS SWAMP TO FRESH MARSH
BALDCYPRESS SWAMP IN STRESSED CONDITION
ENVIRONMENTAL UNITS
1 LAKE MAUREPAS FRESHWATER WETLANDS
2 ST. CHARLES MARSH
3 GOOSE POINT MARSH
4 NORTH SHORE MARSH
Lake Pontchartrain
N
miles
kilometers
SALINITY INDUCED HABITAT CHANGE
AND ENVIRONMENTAL UNITS
plate
1
LAKE
MAUREPAS
LAKE
PONTCHARTRAIN
NEW ORLEANS
Covington
Hammond
Mandeville
Slidell
Ponchatoula
Madisonville
Laplace
Reserve
Metairie



A FRESHWATER DIVERSION PLAN FOR THE LOUISIANA COASTAL ZONE:
PHASE I - HYDROLOGIC UNITS I AND II

Lake Borgne

legend

AREAS OF TRANSITION, 1955-1978

FRESH TO NON-FRESH MARSH

BALDCYPRESS SWAMP IN STRESSED CONDITION

ENVIRONMENTAL UNITS

1 PEARL RIVER WETLANDS
2 ORLEANS PARISH MARSH
3 MRGO MARSH
4 BILOXI MARSH
5 OUTER BILOXI SALINE MARSH
6 LA LOUTRE MARSH

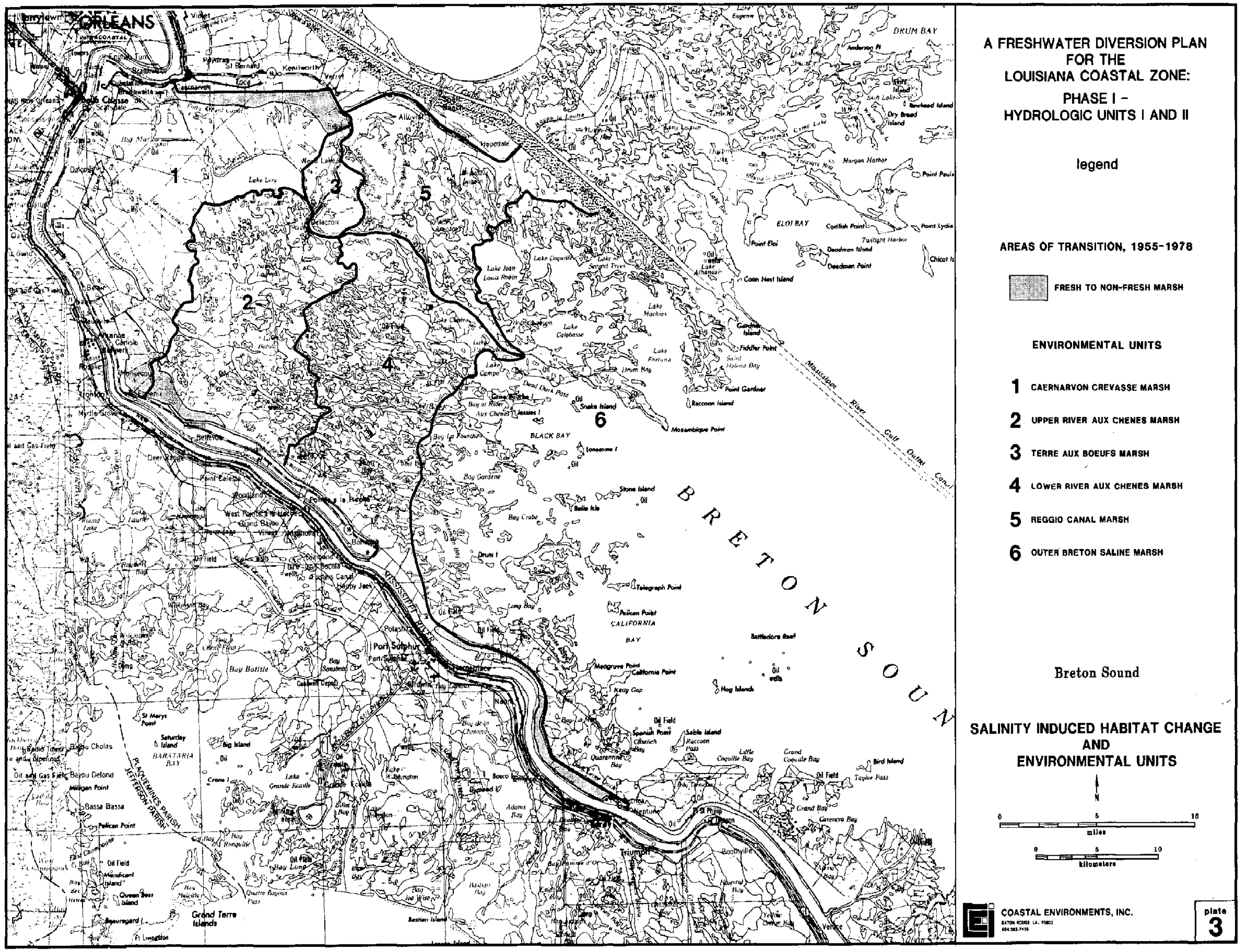
COASTAL ENVIRONMENTS, INC.

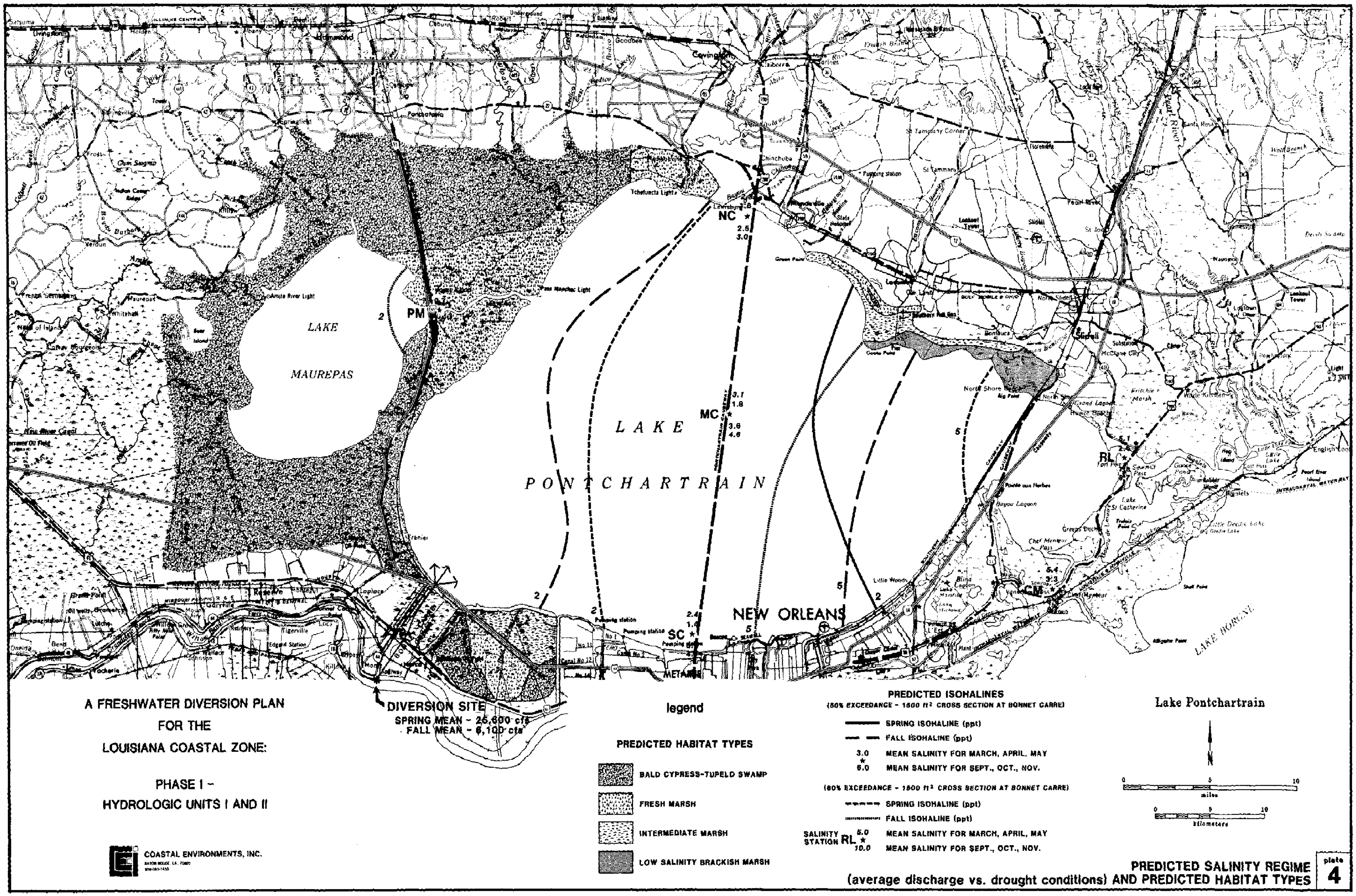
0 5 10 miles
0 5 10 kilometers

N

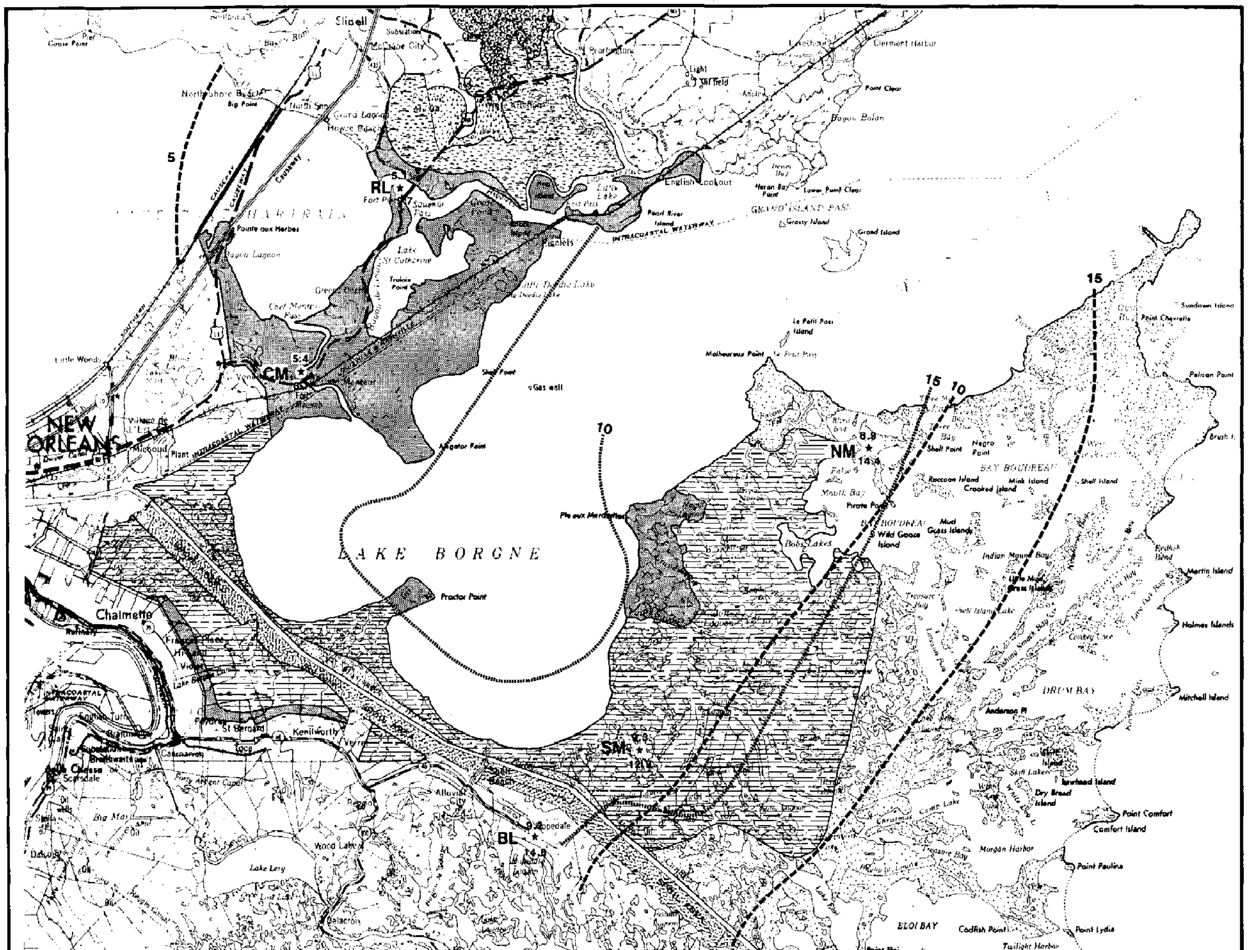
SALINITY INDUCED HABITAT CHANGE AND ENVIRONMENTAL UNITS

plate 2


A FRESHWATER DIVERSION PLAN
FOR THE
LOUISIANA COASTAL ZONE:
PHASE I -
HYDROLOGIC UNITS I AND II
legend
AREAS OF TRANSITION, 1955-1978
FRESH TO NON-FRESH MARSH
ENVIRONMENTAL UNITS
1 CAERNARVON CREVASSE MARSH
2 UPPER RIVER AUX CHENES MARSH
3 TERRE AUX BOEUFS MARSH
4 LOWER RIVER AUX CHENES MARSH
5 REGGIO CANAL MARSH
6 OUTER BRETON SALINE MARSH
Breton Sound
SALINITY INDUCED HABITAT CHANGE
AND
ENVIRONMENTAL UNITS
miles
kilometers
COASTAL ENVIRONMENTS, INC.
plate
3
ORLEANS
BRETON SOUND
DRUM BAY
ELOI BAY
BLACK BAY
CALIFORNIA BAY
BARATARIA BAY
Port Sulphur
Grand Terre Islands



A FRESHWATER DIVERSION PLAN
FOR THE
LOUISIANA COASTAL ZONE:
PHASE I -
HYDROLOGIC UNITS I AND II
COASTAL ENVIRONMENTS, INC.
DIVERSION SITE
SPRING MEAN - 25,600 cfs
FALL MEAN - 6,100 cfs
legend
PREDICTED HABITAT TYPES
BALD CYPRESS-TUPELO SWAMP
FRESH MARSH
INTERMEDIATE MARSH
LOW SALINITY BRACKISH MARSH
PREDICTED ISOHALINES
SPRING ISOHALINE (ppt)
FALL ISOHALINE (ppt)
MEAN SALINITY FOR MARCH, APRIL, MAY
MEAN SALINITY FOR SEPT., OCT., NOV.
SPRING ISOHALINE (ppt)
FALL ISOHALINE (ppt)
SALINITY STATION RL
MEAN SALINITY FOR MARCH, APRIL, MAY
MEAN SALINITY FOR SEPT., OCT., NOV.
Lake Pontchartrain
N
miles
kilometers
PREDICTED SALINITY REGIME
(average discharge vs. drought conditions) AND PREDICTED HABITAT TYPES
plate
4
LAKE MAUREPAS
LAKE PONTCHARTRAIN
NEW ORLEANS
LAKE BORGNE
NC
MC
PM
SC
RL
CM



A FRESHWATER DIVERSION PLAN FOR THE LOUISIANA COASTAL ZONE:
PHASE I - HYDROLOGIC UNITS I AND II

Lake Borgne

legend

PREDICTED HABITAT TYPES

- BALDCYPRESS - TUPELO SWAMP
- FRESH MARSH
- INTERMEDIATE MARSH
- LOW SALINITY BRACKISH MARSH
- HIGH SALINITY BRACKISH MARSH
- SALINE MARSH

PREDICTED ISOHALINES

(50% EXCEEDANCE - 1500 ft^2 CROSS SECTION AT BONNET CARRE)

- SPRING ISOHALINE (ppt)
- FALL ISOHALINE (ppt)
- 10.0 ★ 14.0 — MEAN SALINITY FOR MARCH, APRIL, MAY / MEAN SALINITY FOR SEPT., OCT., NOV.
- RL★ SALINITY STATION

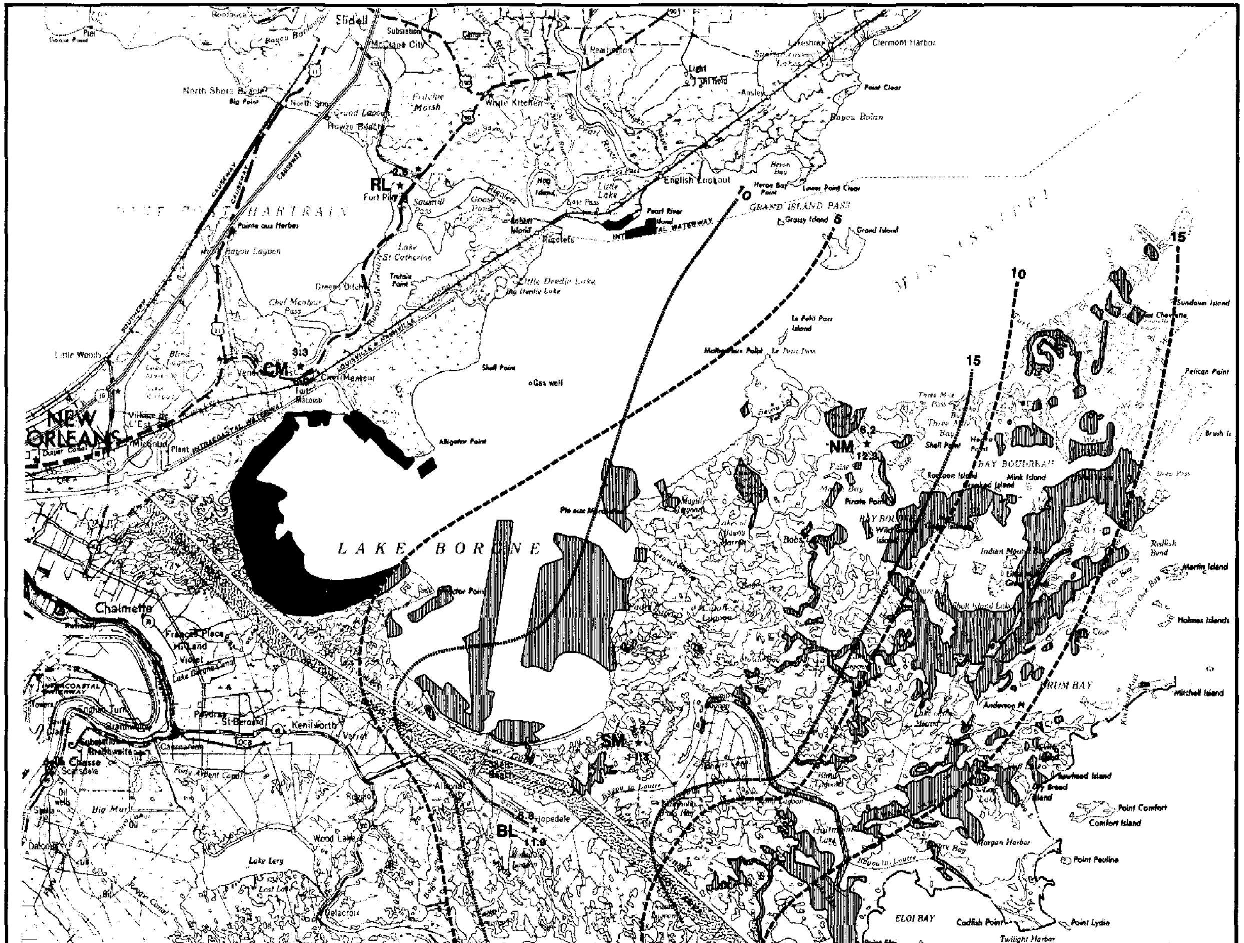
COASTAL ENVIRONMENTS, INC.

0 5 10 miles
0 5 10 kilometers

N

PREDICTED SALINITY REGIME (drought conditions) AND PREDICTED HABITAT TYPES

plate 5



A FRESHWATER DIVERSION PLAN
FOR THE
LOUISIANA COASTAL ZONE:
PHASE I -
HYDROLOGIC UNITS I AND II

Lake Borgne

legend

EXISTING OYSTER RESOURCES

BOUNDARY BETWEEN PRIVATE AND STATE PUBLIC OYSTER GROUNDS

LEASED OYSTER GROUNDS

POSSIBLE IMPACTS TO LEASED OYSTER GROUNDS

PREDICTED ISOHALINES
(60% EXCEEDANCE - 1600 ft² CROSS SECTION AT BONNET CARRE)

SPRING ISOHALINE (ppt)

FALL ISOHALINE (ppt)

10.0 MEAN SALINITY FOR MARCH, APRIL, MAY

14.0 MEAN SALINITY FOR SEPT., OCT., NOV.

RL★ SALINITY STATION

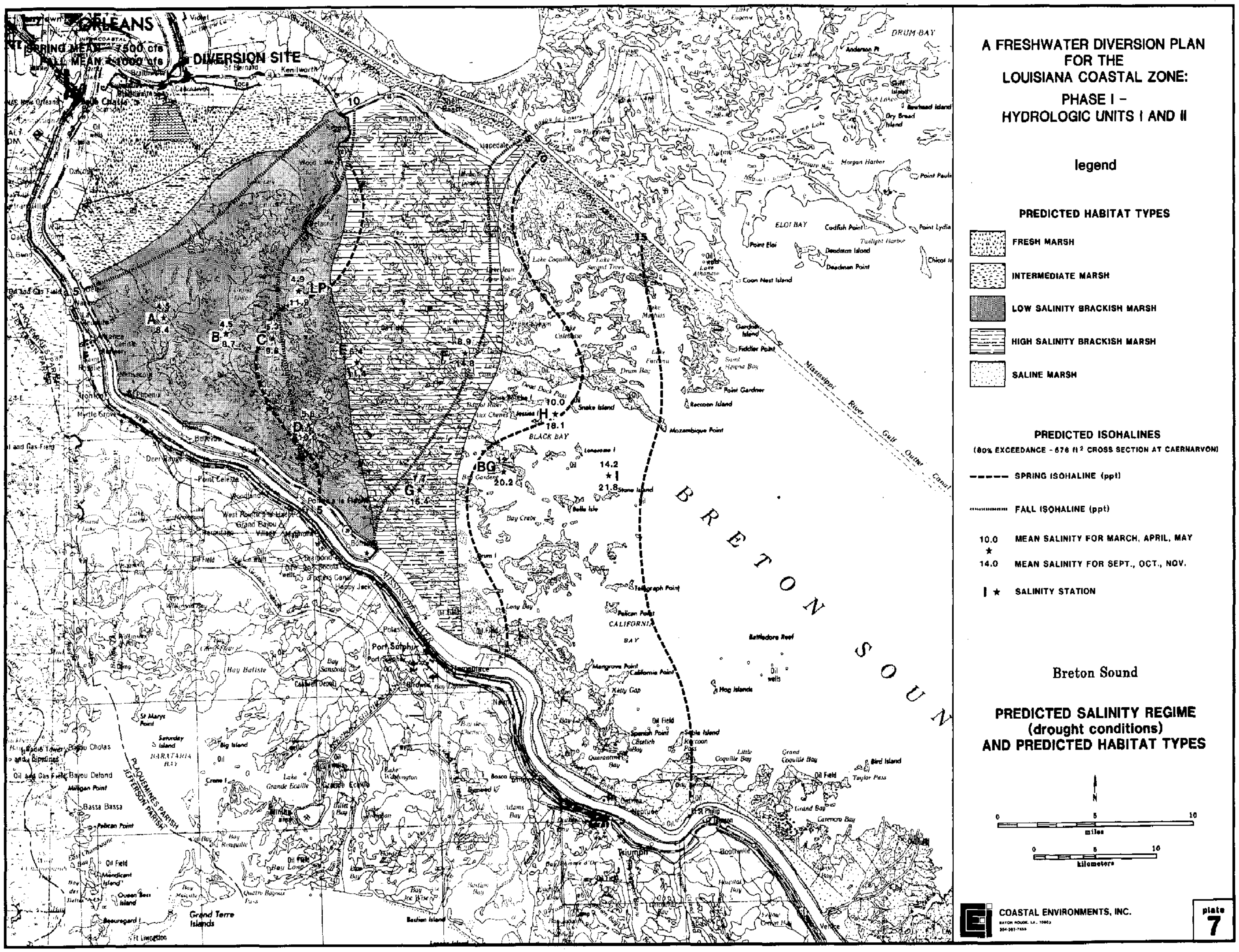
COASTAL ENVIRONMENTS, INC.

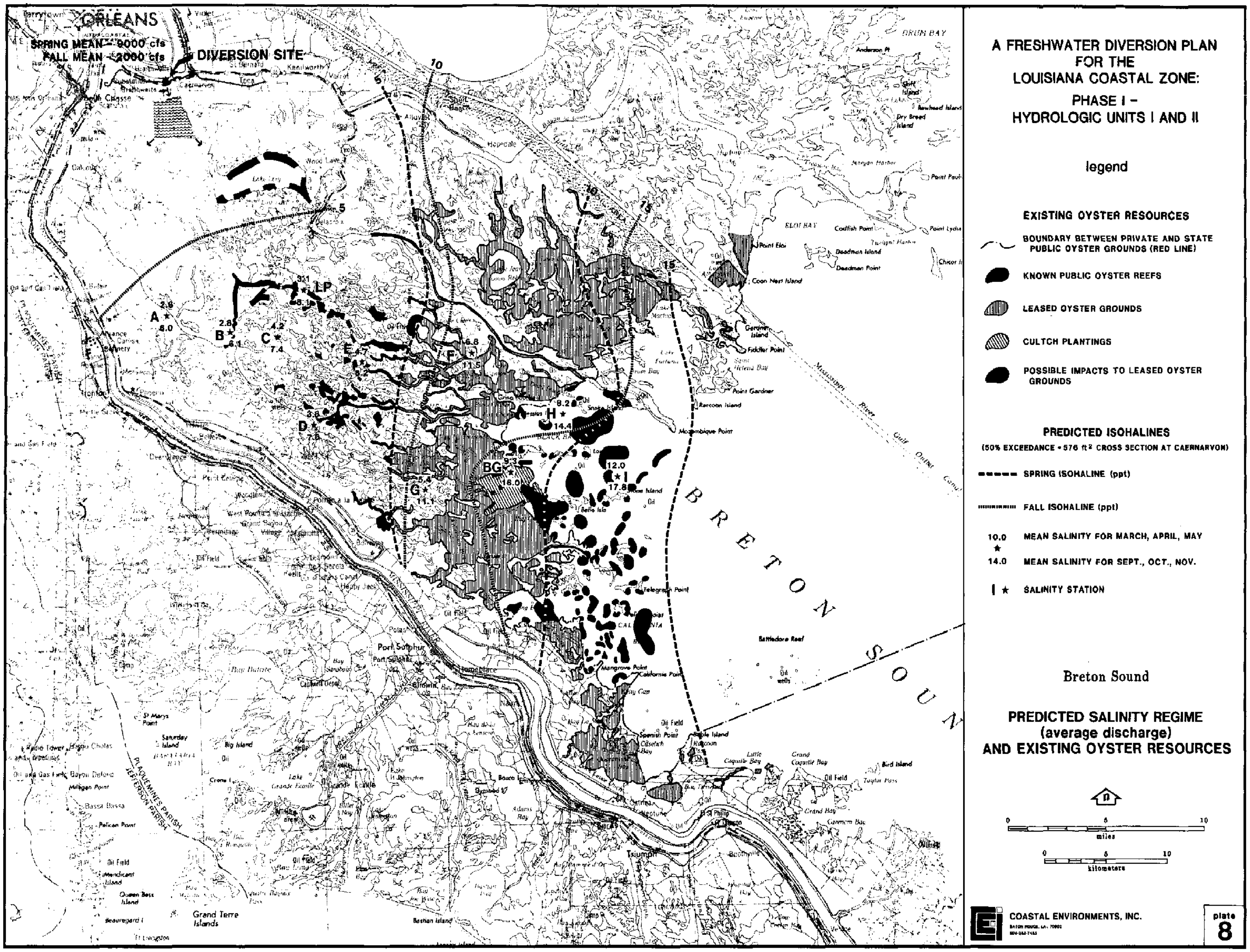
0 5 10 miles

0 5 10 kilometers

PREDICTED SALINITY REGIME (average discharge)
AND EXISTING OYSTER RESOURCES

plate 6


A FRESHWATER DIVERSION PLAN
FOR THE
LOUISIANA COASTAL ZONE:
PHASE I -
HYDROLOGIC UNITS I AND II
legend
PREDICTED HABITAT TYPES
FRESH MARSH
INTERMEDIATE MARSH
LOW SALINITY BRACKISH MARSH
HIGH SALINITY BRACKISH MARSH
SALINE MARSH
PREDICTED ISOHALINES
(80% EXCEEDANCE - 676 ft² CROSS SECTION AT CAERNARVON)
SPRING ISOHALINE (ppt)
FALL ISOHALINE (ppt)
10.0 MEAN SALINITY FOR MARCH, APRIL, MAY
14.0 MEAN SALINITY FOR SEPT., OCT., NOV.
SALINITY STATION
Breton Sound
PREDICTED SALINITY REGIME
(drought conditions)
AND PREDICTED HABITAT TYPES
miles
kilometers
COASTAL ENVIRONMENTS, INC.
plate
7
ORLEANS
SPRING MEAN - 7500 cfs
FALL MEAN - 4000 cfs
DIVERSION SITE
BRETON SOUND
ELOI BAY
BLACK BAY
CALIFORNIA BAY
DRUM BAY
BARATARIA BAY



A FRESHWATER DIVERSION PLAN FOR THE LOUISIANA COASTAL ZONE: PHASE I - HYDROLOGIC UNITS I AND II
legend
EXISTING OYSTER RESOURCES
BOUNDARY BETWEEN PRIVATE AND STATE PUBLIC OYSTER GROUNDS (RED LINE)
KNOWN PUBLIC OYSTER REEFS
LEASED OYSTER GROUNDS
CULTCH PLANTINGS
POSSIBLE IMPACTS TO LEASED OYSTER GROUNDS
PREDICTED ISOHALINES
(50% EXCEEDANCE = 576 ft² CROSS SECTION AT CAERNARVON)
SPRING ISOHALINE (ppt)
FALL ISOHALINE (ppt)
10.0 MEAN SALINITY FOR MARCH, APRIL, MAY
14.0 MEAN SALINITY FOR SEPT., OCT., NOV.
I ★ SALINITY STATION
Breton Sound
PREDICTED SALINITY REGIME (average discharge) AND EXISTING OYSTER RESOURCES
miles
kilometers
COASTAL ENVIRONMENTS, INC.
plate 8
ORLEANS
SPRING MEAN - 9000 cfs
FALL MEAN - 2000 cfs
DIVERSION SITE
BRETON SOUND