- Expert Report -

Effects of the Mississippi River Gulf Outlet on Coastal Wetlands and Other Ecosystems in Southeastern Louisiana

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Submitted by:

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This Expert Report is submitted on behalf of the Plaintiffs in *Robinson v. United States*. We reserve the right to supplement this Expert Report upon receipt of any additional documents produced by the U.S. Army Corps of Engineers. We incorporate by reference into this report our Section 702c Expert Report. As detailed below, it is our opinion that (1) baldcypress – water tupelo (*Taxodium distichum – Nyssa aquatica*) swamps offer excellent hurricane protection, while the intermediate and brackish marshes, and open areas created by the Mississippi River-Gulf Outlet (MRGO) are much more inferior with regard to wind- and storm-surge reduction; (2) the construction of the MRGO, and the significant widening of the MRGO Reach 2 channel over nearly 50 years, the severing of the Bayou La Loutre Ridge, and the steady influx of salt water into the baldcypress – water tupelo swamps in Orleans and St. Bernard Parishes, quickly and directly killed much of this previously-thriving, extensive habitat; and (3) there was extensive understanding of the impacts of the MRGO both before and after construction and the Corps of Engineers consistently ignored recommendations for mitigation against detrimental impacts.

Qualifications

Dr. John Day is distinguished professor emeritus in the Department of Oceanography and Coastal Sciences at Louisiana State University who has worked on coastal wetland issues in Louisiana for the past 35 years. For the last 20 years, he has studied the complex mechanisms responsible for wetlands loss in coastal Louisiana as well as techniques to restore wetlands, including baldcypress – water tupelo swamps. The School of the Coast and Environment at LSU has an international reputation for the study and management of coastal and wetland ecosystems.

Dr. Day has published over 100 articles in the peer-reviewed scientific literature as well as several books. His curriculum vitae is attached.

Dr. Gary Shaffer is a professor in the Department of Biological Sciences at Southeastern Louisiana University. He has decades of research experience on wetland systems. Dr. Shaffer is the Department's biostatistician, was appointed as the initial Coastal Wetlands Planning Protection and Restoration Act (CWPPRA) Science Advisor for the Lake Pontchartrain Basin (currently re-appointed), and helped devise potential restoration projects for the Lake Pontchartrain Basin in CWPPRA, Coast 2050, and LCA programs. He also assisted The Nature Conservancy and the Lake Pontchartrain Basin Foundation in devising specific restoration programs for the Basin. Over the past eight years, his lab has been conducting a major study on the health and restoration of baldcypress – water tupelo swamps of the Lake Pontchartrain Basin. His curriculum vitae is attached.

Classification of Louisiana Coastal Wetlands

One of the most comprehensive and widely known books on wetlands is "Wetlands" by William Mitsch and James Gosselink (2007). These authors, among the most highly respected wetland experts in the world, list a number of definitions of wetlands. Wetland definitions often include three main components: 1) The presence of water either at the surface or in the root zone, 2) Unique soil conditions that differ from adjacent uplands, and 3) Wetlands support biota such as vegetation that are adapted to wet conditions (Mitsch and Gosselink 2007). Although there are a number definitions of wetlands, we will cite two definitions that are commonly used in the United States; one by the National Academy of Sciences and the second by the Army Corps of Engineers.

> The National Academy of Sciences (NRC 1995) definition is as follows: A wetland is an ecosystem that depends on constant or recurrent, shallow inundation or saturation at or near the surface of the substrate. The minimum essential characteristics of a wetland are recurrent, sustained inundation or saturation at or near the surface and the presence of physical, chemical, and biological features reflective of recurrent, sustained inundation or saturation. Common diagnostic features of wetlands are hydric soils and hydrophytic vegetation. These features will be present except where specific physiochemical, biotic, or anthropogenic factors have removed them or prevented their development.
>
> The Corps of Engineers is responsible for the dredge-and-fill permit system required by Section 404 of the 1977 Clean Water Act. Their definition is as follows: The term "wetlands" means those areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas (33 CFR 328.3(b); 1984).

Using the definitions above, and in fact almost any definition of wetlands, all of the marshes and swamps of coastal Louisiana, and specifically the swamps and marshes in the upper Breton Sound Basin and Central Wetlands Unit, are clearly wetlands.

Generally, in the U.S., a marsh refers to a wetland with herbaceous (grassy) vegetation and a swamp has woody vegetation. In the Central Wetlands Unit, the dominant vegetation of marshes is currently *Spartina patens* and *Spartina alterniflora*. The most characteristic swamp species in the Central Wetlands Unit before construction of the MRGO was baldcypress, *Taxiodium distichum.*

Because of the broad expanse of coastal wetlands and the variety of wetland habitat types in coastal Louisiana, a rather unique classification system for wetlands has evolved over time. To understand the nature of this classification, it is necessary to present a brief overview of the physiography of the coastal zone.

The Louisiana coast has often been described in terms of a series of hydrologic basins that are separated largely by current or abandoned distributary channels (Louisiana Wild Life

and Fisheries Commission 1971, Reed 1995, see figure below). Coastal wetlands of the Mississippi Delta consist of two physiographic units-- the Deltaic Plain to the east and the Chenier Plain to the west (Roberts 1997). Active deltaic lobe formation took place in the deltaic plain, which is divided into six hydrologic units. These are, from east to west, the Pontchartrain, Breton Sound, Birdfoot (Balize), Barataria, Terrebonne, and Atchafalaya Basins. The modern mouth of the Mississippi, the Birdfoot Delta, although not technically a basin, has been considered a separate hydrologic unit for most analyses of Louisiana coastal wetlands.

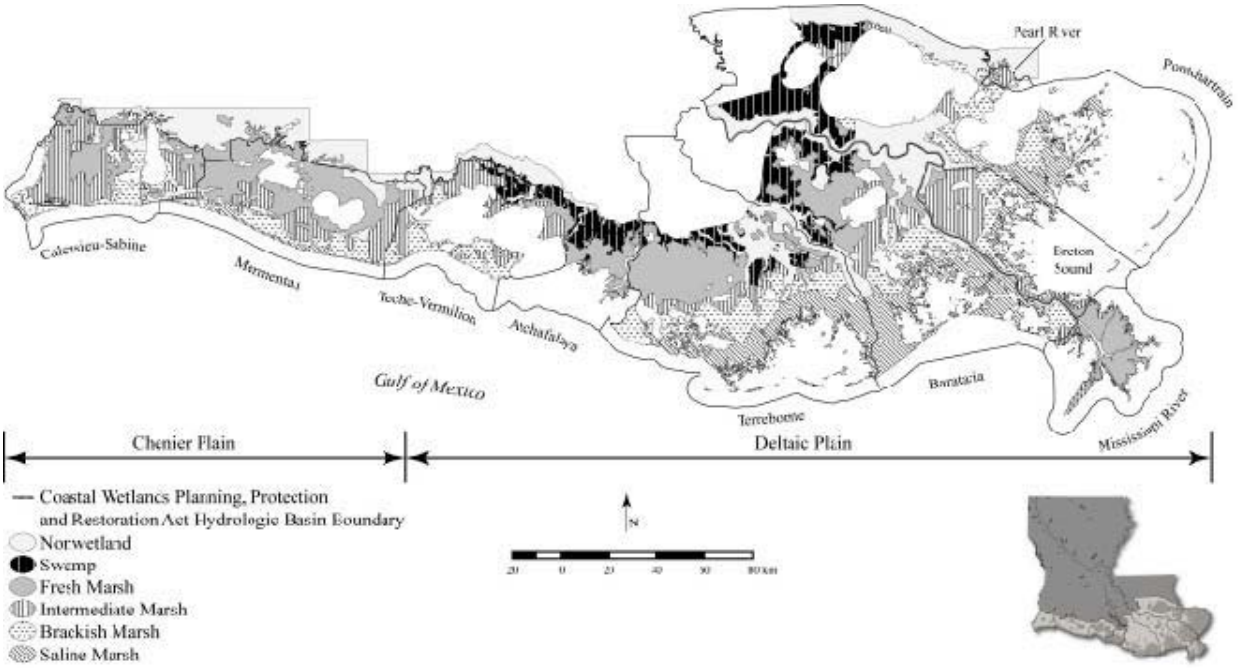


Figure 1. Map of hydrologic units of coastal Louisiana. Various wetland habitat types are delineated by different shading patterns.

The Chenier Plain was created by a series of beach ridges and mud flats formed by periods of westward down drift of sediments from the River. It is comprised of two hydrologic units, the Mermentau and Calcasieu/Sabine Basins. The coast also is characterized by a series of vegetation zones (saline, brackish and fresh marshes and freshwater forested wetlands, from the

coast inland) that run roughly parallel to the coast and are determined by salinity, hydrology, soil conditions, and other factors. Changes in these vegetation zones over much of the 20th century have been described in a series of papers and vegetation maps (Penfound and Hathaway 1938, O'Neil 1949, Chabreck et al. 1968, Chabreck and Palmisano 1973, Chabreck and Linscombe 1978, 1988, Visser et al. 1998, 1999, 2000, 2002).

Coastal Basins and Vegetation Zones of the Mississippi Delta

The first comprehensive treatment of vegetation classification of the Louisiana coastal zone was carried out by Penfound and Hathaway (1938) who studied wetland communities in the vicinity of New Orleans. They distinguished four communities based on salinity tolerance: strictly freshwater species, fresh or nearly freshwater species, brackish water species, and saltwater species. They included both swamp and marsh species in their classification and, with respect to baldcypress, they reported that "all available evidence points to salt water....as the destructive agency" for ghost forests in the Lake Pontchartrain-Lake Borgne region. O'Neil (1949) published the first map of major vegetation associations of the coastal marshes of Louisiana. This map was produced as part of a study of muskrat habitat in the coastal marshes. Chabreck et al. (1968) developed a map of coastal marshes based on a vegetation survey of more than 5000 stations throughout the coast. This and subsequent maps (Chabreck and Palmisano 1973, Chabreck and Linscombe 1978, 1988) classified the coastal marshes into four types, fresh, intermediate, brackish, and saline based generally on Penfound and Hathaway's (1938) descriptions. These four coastal marsh types are now commonly used to describe marsh vegetation associations in the coastal zone. More recently, Visser and colleagues have described these vegetation associations in more detail (Visser et al. 1998, 1999, 2000, 2002). It is interesting to note that after Penfound and Hathaway included swamp species in their

classification, subsequent work on vegetation classification has dealt mainly with marshes. Recently, however, forested wetlands were described in detail in terms of their distribution, sustainability, and factors affecting distribution and sustainability (Chambers et al. 2005; Shaffer et al. 2008).

A variety of wetland plant species occur in each of the vegetation types and there is some overlap. But each of the wetland types is often characterized by one to several species. The dominant species in saline marshes is *Spartina alterniflora*. Other important species include *Spartina patens*, *Distichlis spicata*, and *Juncus roemerianus*. The black mangrove, *Avicennia germinans*, is spreading in the saline marsh due to climate warming. The dominant species in the brackish marsh is *Spartina patens*, but a number of other species occur with less frequency including *Spartina alterniflora* and *Juncus roemerianus*.

Intermediate marsh is characterized by species tolerant of low salinities including *Spartina patens*, *Sagittaria lancifolia*, and *Schoenoplectus* spp.

Fresh marsh includes a diverse assemblage of freshwater wetland species with over 40 species reported. Common species include *Panicum hemitomon*, *Typha* spp., *Hydrocotyle umbelata*, *Schoenoplectus* spp., and *Sagittaria* spp.

Freshwater forested wetlands or swamps contain a variety of trees, shrubs, vines, and herbaceous species. Baldcypress, *Taxodium distichum*, and water tupelo, *Nyssa aquatica*, are two of the most common species. Although baldcypress occurs in freshwater forested wetlands, it can tolerate low salinities less than 5 ppt. In general, plant species diversity increases from saline marshes to fresh marshes and swamps.

Several studies of the vegetation of the MRGO vicinity have been conducted: Texas A&M 1958-1960, the U.S. Department of Interior in 1962, Valentine in 1968, Lemaire in 1961,

etc. Some of the more recent studies include Chabreck 1970, 1972, and 1973, Chabreck et al. 1968, and Palmisano, 1970. Other studies include those by Lloyd and Tracy 1901, Brown 1936, Penfound and Hathaway 1938, Humm 1956, and Chanberlain 1957. The table below provides salinity ranges of different marsh types from Penfound and Hathaway in 1938.

Salinity and Marsh Type

Salinity: Range, Mean Na Content and pH of Marsh Types			
Vegetation Type	Salinity Range (ppt)	Mean Na Content (ppt)	Mean pH
Saline	> 20	4.11	6.49
Brackish	10-20	3.26	5.71
Intermediate	5-10	1.51	5.54
Freshwater	< 5	0.62	5.42

Source: Penfound and Hathaway 1938

Salinity and Water Table Conditions in Various Vegetation Types in Vicinity of MRGO as Recorded Between 1958 and 1960.				
Vegetation Type	**Salinity Range in ppt**			
	Surface Water[1]	Average Bayou Water[2]	Average Soil Water[3]	Average Water Table[3]
Salt Marsh	1.5-26.2	Winter: 5.9-15.6 Growing Season: 9.2-18.2	Winter: 10.6-* Growing Season: 12.6-*	+4 in
Brackish Marsh	0.9-18.6	Winter: 4.2-5.9 Growing Season: 5.6-9.2	Winter: 5.8-10.6 Growing Season: 8.1-12.8	Highly Variable
Intermediate Marsh	0.6-5.9	Winter: 2.1-4.2 Growing Season: 1.5-5.6	Winter: 2.7-5.8 Growing Season: 2.1-8.1	+4 in to –4 in
Freshwater Marsh	0-1	N.D.	N.D.	0 in to +12 in
Arboreal: Swamp Bottomland Hardwoods	N.D. N.D.	N.D. N.D.	N.D. N.D.	+1 ft to +4 ft 0 ft to –5 ft

*Insufficient data.
N.D.: No Data

Sources: 1 Fruge 1980, personal communication (from data collected between 1958 and 1960)
2 Giles 1966, personal communication (from data collected between 1958 and 1960)
3 Giles 1966, personal communication (from data collected between 1958 and 1960)
Overall Source: (Wicker et al. 1982)

Both Chabreck (1970) and Palmisano (1970) stated that saltwater intrusion into fresh and brackish marshes resulted in maximum loss of marsh. Another study in 1973 on the MRGO that was prepared for the St. Bernard Parish Police Jury referred to the two previous studies but ultimately concluded that "when salinity is increased in areas underlain by thick organic sequences, instead of being replaced by saline grasses, the marshes simply break up and revert to open ponds and lakes" (Anon 1973).

Development of the Mississippi Delta

To understand the problems facing coastal forested wetlands and fresh and low salinity marshes in Louisiana, it is helpful to put these wetlands into the broader context of the entire Mississippi Delta. During the 20th century, there was a massive loss of coastal wetlands, mostly marshes, in the Mississippi Delta. Most research has focused on marsh loss (i.e., Day et al. 2000, 2007) but recently more attention has been given to the issue of coastal forested wetland loss (Chambers et al. 2005, Shaffer et al. 2008). At present, there are plans for a large-scale effort to restore the Delta, including forested wetlands. To do this, it is necessary to understand both the processes that formed the Delta as well as the forces that led to its deterioration. We will put these processes into a conceptual framework of deltaic ecosystem functioning. This framework is called the pulsing paradigm and will be discussed in more detail later.

The Mississippi Delta, like most deltas, is made up of several interdistributary hydrologic basins that are separated by current or abandoned river distributary channels (Day et al. 2007).

The Barataria Basin is a typical interdistributary basin located between the Mississippi River and Bayou Lafourche. The Pontchartrain Basin is located between the Mississippi and Pearl Rivers with Pleistocene uplands north of Lakes Pontchartrain and Maurepas. The study area is part of the larger Pontchartrain Basin. These river channels developed in several stages. The current Mississippi channel in southeastern Louisiana first formed as part of the St. Bernard delta complex between 1000-4000 BP. Remnant ridges of the St. Bernard complex occur in the New Orleans metropolitan area, eastern New Orleans, St. Bernard Parish, and the Lake Borgne area. The Plaquamines-Modern delta complex has been active over the last 1000 years. The Lafourche delta complex functioned from about 3500 years BP until colonial times. It was finally closed off from the Mississippi River at the beginning of the 20th century. The interdistributary ridges prevent almost all exchange between interdistributary basins, but until levee construction there was regular input of river water into the basins, including Pontchartrain and Barataria Basins.

The Mississippi Delta formed over the past 6,000-7,000 years as a series of overlapping delta lobes (Roberts 1997) as sea level stabilized at near its present level after rising more than 100 m from the low stand at the height of the last glacial period about 15,000 years ago. There was an increase in wetland area in active deltaic lobes and wetland loss in abandoned lobes, but there has been an overall net increase in the area of wetlands over the past several thousand years (Shaffer et al. 2005, Day et al. 2007; see also the dynamic graphic of the Times-Picayune at www.hurricane-**katrina**.org/2007/12/expert-louisian.html).

A number of factors served to enhance the growth of the Delta and retard its deterioration. With the exception of the first delta lobe (Maringouin), significant parts of all subsequent delta lobes have been incorporated into the current delta as a system of overlapping

and interwoven distributary systems. Functioning distributaries, overbank flooding, crevasse splays, and reworking of sands formed a skeletal framework of these natural levee ridges and barrier islands within which the Delta plain has formed (Kesel 1989, Kesel et al. 1992). This framework was critically important in protecting baldcypress – water tupelo swamps and other freshwater wetlands in the study area from saltwater intrusion.

Numerous crevasse splays (i.e., Bonnet Carre), minor (i.e., Bayou Manchac) and major (i.e., the Gentily and Metaerie) distributaries and beach ridges occur in the Pontchartrain Basin. Bayou Manchac was not always a minor stream. Today it is a shallow, dead end channel with low flow. But during historical periods, it carried steamboats between the Mississippi River and Lake Pontchartrain (Keddy et al. 2007). Kniffen (1935) described the upper Manchac as a raging torrent when fed by the Mississippi floodwaters. Furthermore, floodwaters created natural levees along the flanks of Bayou Manchac and caused a rise in base level of the local floodplain, drowning gullies with Mississippi River alluvium. Ecosystem functioning and sustainability of the Delta is controlled by interactions of the Mississippi River and marine processes (Day et al. 1997). The skeletal framework protected wetlands of the Deltaic plain from erosion and salinity intrusion and slowed interactions between fresh water and salt water parts of the Delta. This is especially important for wetlands of the upper Pontchartrain Basin, including the upper Breton Sound Basin.

Until modified by human activity, many of the distributaries continued functioning, delivering fresh water, sediments, and nutrients to large areas of the Delta plain. There also were many crevasses along the lower river. For example, numerous large crevasses into the Breton Sound Basin have occurred since European colonization of the lower river and delta. A number of crevasses occurred in the early 20th century. Crevasses occurred at Violet, White's Ditch, and

Bayou La Moque. In the early 20th century, crevasses occurred at Poydras in 1922, Mon Plaisir in 1920, Caernarvon in 1927, and at Cannon in 1912. These show that there was major riverine input to the area well into the 20th century.

Fresh water forms a buffer against salinity intrusion, and provides mineral sediments, nutrients, and other materials, such as iron, that sustain healthier, more productive wetlands. The distributary network was very efficient in sediment retention and about 25% of sediment flux was retained in the Delta (Kesel et al. 1992, Tornquist et al. 2007). Because of the widespread freshwater input and the protection afforded by the skeletal network, floating marsh and forested wetlands developed as common wetland types. Riverine input was important for coastal forested wetlands for several reasons. Freshwater input was a buffer against saltwater intrusion, nutrients increased productivity, mineral sediments strengthened soils and helped build up the elevation of the land, and iron detoxified sulfides, the byproducts of anaerobic metabolism.

Critical to understanding the formation and functioning of the Mississippi Delta is the role of geologic subsidence. There is continual, ongoing subsidence in the Delta due to the compaction, consolidation, and dewatering of sediments. The rate of subsidence is highest in the upper, surficial sediments, especially in the active growing root zone. The rate of subsidence for much of the coastal zone is between 0.5 and 1.0 cm/yr. In a coastal area experiencing relative sea-level rise (RSLR) due to a combination of subsidence plus eustatic sea-level rise, wetlands must grow vertically at a rate equal to the rate of RSLR if they are to survive in the long term. If there is an elevation or accretion deficit (surface elevation gain < RSLR), the site will become progressively more waterlogged and vegetation will become stressed and eventually die (Mendelssohn and Morris 2000). Saltwater intrusion exacerbates these conditions. All of the above factors lead to wetland loss which decreases the wetland storm buffer.

Delta Deterioration

An understanding of the causes of wetland loss is important not only for a scientific appreciation of the mechanisms involved, but also so that effective management plans can be developed to restore the Mississippi Delta (see Boesch et al. 1994, 2006, and Day et al. 2000, 2007, Tornquist et al. 2007 for reviews of these issues). In essence, human activity caused a reduction in the forces that lead to delta growth and an enhancement of forces that lead to delta deterioration. A number of factors led to the massive loss of wetlands.

- Flood-control levees along the Mississippi River resulted in the elimination of riverine input to most of the Delta (Boesch et al. 1994, Day et al. 2000, 2007).
- In addition to the flood-control levees, most active distributaries were closed (i.e., Bayou Lafourche in 1900 and Bayou Manchac much earlier), crevasses have been mostly eliminated, and the river mouth was made more efficient for navigation. This has resulted in the loss of most river sediments directly to deep waters of the Gulf of Mexico.
- There also has been a reduction of the suspended sediment load in the Mississippi River caused by dam construction upstream (Kesel 1988, 1989). The suspended sediment load carried by the Mississippi River decreased by about half since 1700 (Meade 1995, U.S. Geological Survey, Circula 1133, Figure 6A). The greatest decrease occurred after 1950 with the completion of large dams on the Missouri River and its tributaries.
- As a result of these activities, the forested wetlands of the Pontchartrain Basin have been cut off from river input for over a century.
- Within the Delta, pervasive altered wetland hydrology, mostly caused by canals and navigation channels like MRGO, is another important factor contributing to wetland loss. Canals, originally dredged for drainage and navigation, are now overwhelmingly linked

to the petroleum industry. Drilling access canals, pipeline canals, and deep-draft navigation channels have left a dense network of about 15,000 km of canals in the coastal wetlands of Louisiana. Although canals are estimated to comprise about 2.5 percent of the total coastal surface area, their destructive impact has been much greater (Turner et al. 1982, Turner 1997, Day et al. 2000).

- Spoil banks, composed of the material dredged from the canals, interrupt sheet flow, impound water, and cause deterioration of wetlands. Long, deep navigation channels—like the MRGO—that connect saline and freshwater areas tend to lessen freshwater retention time, and allow greater inland penetration of salt water. The MRGO is an infamous case of this destructive process. Spoil banks from dredging (as along South Slough just south of Ponchatoula as well as along the MRGO), highway embankments (as along I-55), access roads and drainage canals (e.g., South Slough, Reserve Relief Canal, Hope Canal) have caused much of the area to be semi-impounded with a greatly reduced overland flow hydrology (Shaffer and Day 2007).

In summary, there is a broad consensus that wetland loss is a complex interaction of a number of factors acting at different spatial and temporal scales (e.g., Turner and Cahoon 1987, Day and Templet 1989, Boesch et al. 1994, Day et al. 1995, 1997). Day et al. (2000, 2007) concluded that isolation of the Delta from the Mississippi River by levees was perhaps the most important factor for the Delta as a whole. More locally, in Orleans and St. Bernard Parishes devastated by Hurricane Katrina flooding, the MRGO greatly accelerated and contributed to the marsh and baldycypress – water tupelo swamp loss in the Pontchartrain and Breton Sound Basins by the introduction of salt water into this sensitive ecosystem.

Swamps for Hurricane Protection

In terms of storm-surge and wind-damage reduction, baldcypress – water tupelo swamps are far superior to most other wetland habitat types. Only live oak (*Quercus virginica*) and palms are more resistant to wind throw (i.e., blow down) than baldcypress and water tupelo (Williams et al. 1999). Cypress – tupelo swamps faired far better than other forest types in Hurricanes Camille (Touliatos and Roth 1971), Andrew (Doyle et al. 1995), and Hugo (Gresham et al. 1991, Putz and Sharitz 1991). In addition, fresh, intermediate, and brackish marshes suffered vastly greater loss in Hurricanes Katrina and Rita than did cypress – tupelo swamps (Barras 2006). Katrina caused wind throws of up to 80% of the bottomland hardwood forests of the Pearl River Basin, while contiguous swamps remained largely intact (Figure 1) (Chambers et al. 2007).

Emergent canopies, such as provided by forested wetlands, can greatly diminish wind penetration, thereby reducing the wind stress available to generate surface waves and storm surge. Mangroves have been shown to reduce wave heights by 20% over distances of only 100 m (Mazda et al. 1997) and 150 m of *Rhizophora*-dominated forest has been shown to dissipate wave energy by 50% (Brinkman et al. 1997). More recently, Krauss et al. (2008) used water-level recorders to measure storm surge reduction through a mixture of mangrove and marsh (but mostly marsh) and storm surge was decreased by 9.45 cm/km. Perhaps the best estimate to date of storm surge reduction by marsh comes from USGS water level data taken during Hurricane Rita. On average, the wetlands reduced storm surge by 13.5 cm/km (Kemp 2008). Prior to the construction of the MRGO, an average of about 10 km of the wetlands lied between Orleans and St. Bernard Parishes and Lake Borgne. Therefore these wetlands had the capacity to reduce storm surge by about 135 cm (4.5 feet). Because a considerable portion of these wetlands was

baldcypress – water tupelo swamp (> 10,000 acres), the reduction of storm surge likely would have been much greater.

The sheltering effect of forested wetlands also affects the fetch over which wave development takes place. Shallow water depths attenuate waves via bottom friction and breaking, while vegetation provides additional frictional drag and wave attenuation and also limits static wave setup. Extracting energy from waves either by breaking or increased drag in front of levees would reduce the destructive storm wave action on the levees themselves. Indeed, overtopped levees flanked by trees received little structural damage from Hurricane Katrina (IPET 2006, Team Louisiana 2007, Kemp 2008).



Figure 2. Aerial photograph of a forested area in the Pearl River Basin that was located near the eye wall of Hurricane Katrina. Brown areas depict fallen bottomland hardwood trees, such as

oaks and sweetgums. Green areas are contiguous baldcypress – water tupelo swamps that suffered relatively little damage.

Although baldcypress – water tupelo swamps are extremely resistant to wind throw and deep flooding, they are far less resistant to saltwater stress (Penfound and Hathaway 1938 and many later references), and to stressors coupled with salinity stress (Shaffer et al. 2008). Therefore, they require a reliable source of fresh water for system flushing following tropical storm events and during droughts. In stark contrast to this, the MRGO brought the swamps contiguous with Orleans and St. Bernard Parishes a steady influx of lethal salt water.

Prior to construction of the MRGO, the environmental setting for coastal wetlands in southeastern Louisiana was significantly different than at the present time. The area under consideration includes wetlands that are now deemed the Central Wetlands Unit (CWU), wetlands around Lake Borgne, and north and south of the Bayou La Loutre natural levee ridge. Prior to the construction of the MRGO, there were extensive baldcypress – water tupelo swamps in the CWU and adjacent to the Bayou La Loutre Ridge. The semi-enclosed and protected nature of this area—and the exclusion of deadly salt water— allowed the survival of these swamps (see historic photos in FitzGerald et al.(2008) report and Appendix E herein). Water budget analyses for southeastern Louisiana show that about one third of rainfall remains after evaporation (Brantley 2005, Shaffer and Day 2007). Thus, there was sufficient fresh water to maintain the baldcypress – water tupelo swamps in the CWU, so long as the system did not have a direct input of salt water. Greater than 12,000 acres of the swamps in the CWU and adjacent areas were killed shortly after the opening of the MRGO when the U.S. Army Corps cut through the natural ridge at Bayou La Loutre and allowed salt water to move unimpeded up the tidewater channel and into the Central Wetlands Unit and adjacent areas (Team Louisiana 2007, refer to

sections on Saltwater Intrusion, Vegetation Studies, and Land Loss herein). Tens of thousands of wetland acres were subsequently destroyed by the MRGO over the succeeding decades leading up to Hurricane Katrina (Team Louisiana 2007).

Surge Buffering Effects of Wetlands

There was general knowledge prior to the construction of the MRGO that wetlands buffer storm surge. This is evidenced in a 1957 report of the Tidewater Channel Advisory Committee to the St. Bernard Police Jury that was available to and is believed to have been received by the USACE. The report specifically details:

> The upper reaches of the Parish heretofore have been protected from excessive tidal waters due to the slowing down action of the outer marsh areas…However, with the existence of a channel 40 feet deep traversing the marsh lands from the Gulf to the upper Parish, the full fluctuation of the tide will be felt throughout the Parish. The tidal action will have adverse effects on the entire marsh area with consequent erosive action and the intrusion of high saline content water into areas normally fresh or only slightly brackish. During times of hurricane conditions, the existence of the channel will be an enormous danger to the heavily populated areas of the Parish due to the rapidity of the rising waters reaching the protected areas in full force through the avenue of this proposed channel. This danger is one that cannot be discounted. No matter how small a flood may be, or how small the area to which it is confined, to the families that have water in their houses, it is a major catastrophe (SBPJ, 1957).

One of the most cited studies depicting the surge buffering effects of wetlands is actually by the USACE (1965). The study indicated a consistent relationship between the maximum surge height and the distance inland from the coast (Figure 3). "This relationship exists independently of the speed of hurricane translation, wind speeds, or directions. The data indicate that the weighted mean decrease in surge heights inland is at the rate of 1.0 foot per 2.75 miles. This relationship remains true even in the western portion of Louisiana where relatively high chenieres, or wooded ridges, parallel the coast." (USACE 1963) The study based on hurricane

protection for Morgan City, Louisiana was published in 1965. However according to the original plate the specific analysis of storm surge reduction was performed in 1963. It is reasonable to believe that USACE employees were working on the study a year or two prior to 1963. Most likely the relationship would have been recognized within the time period of the first few storms used for calculation. Though the specific hurricanes used for calculation are not detailed in the 1965 report, it is stated that the calculation was derived from 7 hurricanes impacting south Louisiana from 1909-1957. Either way, there is no doubt that after the report, the USACE plainly recognized the need for salinity control and storm surge measures to decrease the deleterious impact that the MRGO has on the storm buffering wetlands.

Figure 3. Storm surge reduction by wetlands during hurricanes occurring between 1909 and 1957. This was Figure 5 in the USACE 1965 report.

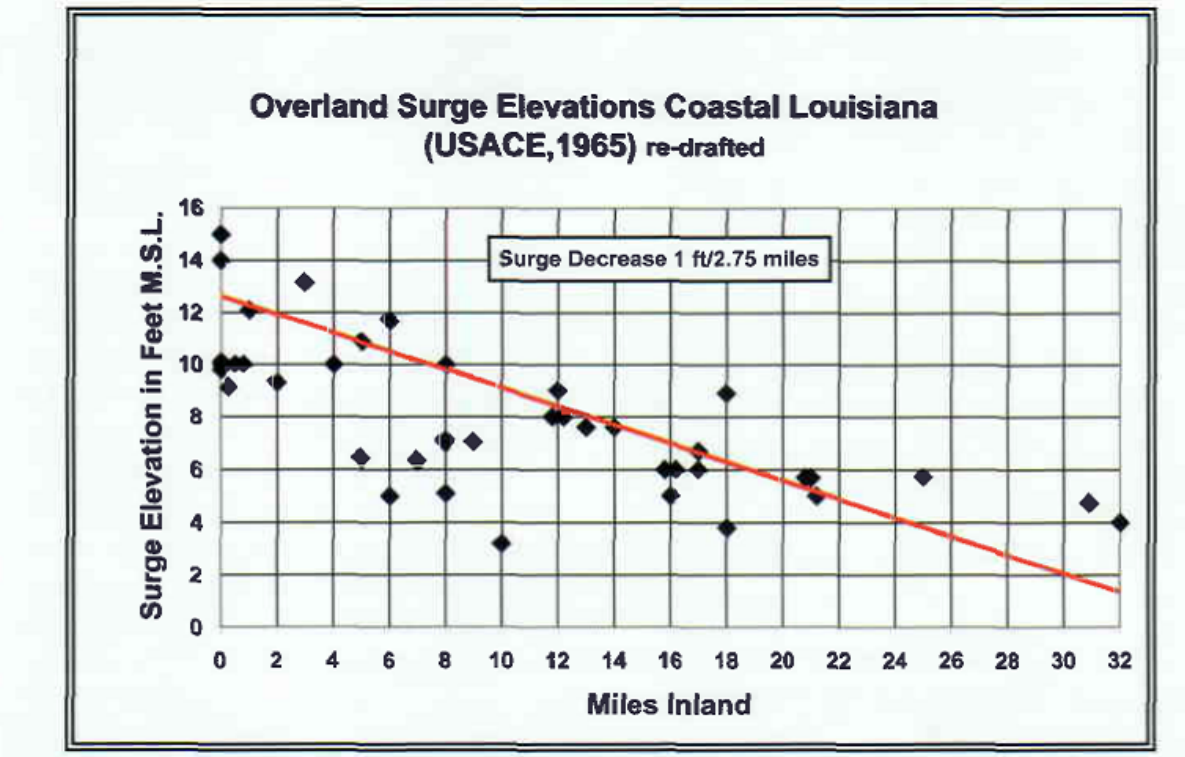


Figure 5. Observed storm surge elevation relative to the position inland for seven hurricanes impacting south Louisiana from 1909 to 1957 (re-drafted). Relationship implies coastal habitats can generally reduce surge by one foot for every 2.75 miles of coastal habitat (USACE, 1965).

Negative Effects of Saltwater Intrusion

The dangers of increasing salinity into a fresh to low salinity wetland, including baldcypress – water tupelo swamps, are three-fold: direct osmotic imbalance, salt toxicity, and production in the soils of highly toxic sulfides. Salt water contains sodium and chloride ions and when these reach concentrations higher than the solutes in plant cells, fresh water escapes from the plant through osmosis and uptake of fresh water ceases. In essence, the salt-intolerant vegetation is experiencing "drought" conditions (Mendelssohn and Burdick 1988). Plants also absorb ions such as sodium from salt water and these ions may be lethal when in high concentration. Finally, salt water contains a much higher concentration of sulfate than fresh water. In wetlands, the sulfate, through alternative anaerobic metabolic pathways of soil microbes (Mitsch and Gosselink 2007), becomes chemically reduced to deadly compounds such as hydrogen sulfide (Mendessohn et al. 1981). The lethal effects of salt water on freshwater wetland vegetation were known long before the initial construction of the MRGO (e.g., Penfound and Hathaway 1938). Both the U.S. Fish and Wildlife Service (USFWS) and the Louisiana Department of Wildlife and Fisheries warned the U.S. Army Corps of Engineers (USACE) that construction of the MRGO could have catastrophic effects on the surrounding flora and fauna. The Louisiana Wildlife Biologists Association predicted the project would create a 44-mile-long swath of destruction (USFWS 1979 letter). In a report to USACE (the April "1958 Interior Report"), the USFWS predicted that the MRGO construction "particularly by breaching the natural east-west ridges between fresh/brackish and salt water" such as the Bayou La Loutre Ridge, would introduce salt water into the wetlands and destroy tens of thousands of acres of marshes and mature baldcypress – water tupelo swamps. In a letter of September 23, 1957, Secretary Seaton of the Department of Interior made it clear that USACE had not followed the

protocol put forth in the Wildlife Coordination Act of August 14, 1946 (60 Stat. 1080), and requested funds to model potential impacts of the MRGO (Team Louisiana 2007). In the 1956-1957 Seventh Biennial Report of the Wild Life and Fisheries Commission, T.B. Ford expressed extreme frustration and disappointment at the dismissal of predicted environmental impacts of the MRGO and emphasized the importance of further study to assess trade-offs of the project. Modeling funds were not granted and, when the USACE finally modeled MRGO scenarios (USACE 1963), a salinity increase of 4-6 ppt (lethal to cypress – tupelo swamps) was found (Team Louisiana 2007). Furthermore, the USFWS (in their Interim Report on Fish and Wildlife Resources as Related to Mississippi River-Gulf Outlet Project, Louisiana and an Outline of Proposed Fish and Wildlife Studies 1958) recognized the wetlands of coastal Louisiana as "perhaps the densest and richest wild fauna in the world….[with a] flora [that] has narrow salinity range; therefore, desirable production must result from exacting conditions….[and] the 36-foot-deep cut will result in direct changes of salinity…." The USACE ignored their concerns and began construction, or perhaps better put, massive wetlands destruction.

There were numerous reports and letters detailing the predicted effects of the MRGO. A summary of these reports is detailed in Appendix A. Furthermore, the sources for Appendix A are provided.

Pre-MRGO Hydrology

Before major human induced physical alterations to the landscape, the Orleans and St. Bernard Parish wetlands were divided into three interdistributary basins formed by natural levee ridges of the former Mississippi River distributaries: Bayou Savage, Bayou Terre aux Boufs, and Bayou La Loutre (Wicker et al. 1982). The environment was considered stable because of a

general sheet flow of fresh water from rainfall, drainage pump stations, and other sources, which was slowed and stored by wetland vegetation (see section on Water Budget). Furthermore, the Bayou La Loutre Ridge helped to retain fresh water and prevent saltwater intrusion from Breton Sound. Therefore, water levels and salinity changed very gradually with rainfall and tidal conditions.

The U.S. Fish and Wildlife Service (USFWS) determined, prior to construction, that detailed studies were needed to fully understand the affect of the planned MRGO on fish and wildlife resources (see USFWS letter dates cited in May 31, 1979 letter, Appendix A). The USFWS became the coordinating agency for extensive and detailed pre-project hydrological and biological studies to facilitate meaningful discussions with the USACE to minimize channel effects on the environment and wildlife. Most of the hydrological studies were under contract with the Texas A&M Research Foundation. Some of the studies include the "Hydrological and Biological Studies of the Mississippi River-Gulf Outlet Project" by El-Sayed (1961) and "Analysis of the Salinity Regime of the Mississippi River-Gulf Outlet Channel" by Amstutz (1964). The studies addressed the following:

a) Interaction and exchange between sub-areas.
b) The existing variations in hydrology to enable forecasting of extremes in variation due to the planned project.
c) Samples of the aquatic fauna and hydrology to consider the potential biological effects of environmental changes due to the project.

Therefore, because of the extensive preconstruction studies, the effects of the MRGO can be clearly determined. The results of these studies were analyzed by Rounsefell (1964), a USFWS employee.

One of the most detailed hydrologic studies is the "Preconstruction Study of the Fisheries of the Estuarine Areas Traversed by the Mississippi River-Gulf Outlet Project." This study was

conducted from April 1959 to March 1961 to detail the pre-MRGO hydrology (Rounsefell 1964). Salinity, dissolved oxygen, water temperature, inorganic phosphate concentration, and turbidity were sampled several times a month throughout the area. The conclusion of the study was that very little saline water entered Lake Borgne from Breton Sound, specifically because of the Bayou La Loutre Ridge acting as a barrier between Lake Borgne and Breton Sound. This, in combination with the freshwater surplus of the area now occupied by the Central Wetlands Unit, kept salinities low enough to allow cypress to survive. Based on the Texas A&M studies, Rounsefell further concluded that changes in salinity patterns and population structure of estuarine organisms would result from the construction of MRGO.

Coastal Forested Wetlands of the Pontchartrain and Breton Sound Basins

Before construction of the MRGO, there were thousands of acres of healthy baldcypress – water tupelo swamp in the Central Wetlands Unit in Orleans and St. Bernard Parishes (Team Louisiana 2007, FitzGerald et al. 2008). It was sustained by a combination of freshwater surpluses and extensive wetlands and ridges that slowed or prevented saltwater intrusion from the Gulf of Mexico.

Although baldcypress – water tupelo swamps are extremely resistant to wind throw and deep flooding, they are far less resistant to saltwater intrusion and multiple stresses coupled with salinity stress (Shaffer et al. 2008). They therefore require a reliable source of fresh water for system flushing following tropical storm events and during droughts. The MRGO provided the exact opposite, causing extensive loss of the baldcypress – water tupelo swamps of the Central Wetlands Unit (CWU) by serving as a constant saltwater intrusion conduit for more than four decades.

Conditions Prior to MRGO Construction

Prior to the construction of the MRGO, the study area was starkly different than it is now. Wetlands were much more extensive than now and, in particular, there were, as noted, tens of thousands of acres of healthy baldcypress – water tupelo swamps and freshwater wetlands in the CWU and surrounding areas (see Figure 4).



Figure 4. Example of a healthy baldcypress – water tupelo swamp in southwestern Lake Maurepas. The area experiences little salinity stress, much like the swamps of the Central Wetlands Unit prior to construction of the MRGO.

The Bayou La Loutre Ridge and other minor ridges were mostly intact. The cypress – tupelo swamp grew in the entire wetland area bordering the developed areas of St. Bernard Parish and Orleans Parish east of the IHNC. And, unlike the MRGO, "the hurricane protection levee begun in the early 1950s appeared to have no impact on the vitality of the bottomland hard-woods and cypress swamps south of the levee" (Wicker et al. 1982, p. 43). This refers to the forty arpent levees.

Prior to the construction of the MRGO, the Bayou La Loutre Ridge was an effective natural barrier against saltwater intrusion. Rainfall in the area north of Bayou La Loutre (and inflow from the GIWW and from the uplands in St. Bernard Parish) provided a relatively constant source of fresh water that protected the baldcypress – water tupelo swamps from salt water. The condition and extent of wetlands in the study area—before and after the MRGO's construction—has been documented (FitzGerald et al. 2008). The nearly complete loss of baldcypress – water tupelo swamps due to saltwater intrusion is clearly evident.

Water Budget Before and After the MRGO

Locally generated fresh water in conjunction with an intact Bayou La Loutre Ridge maintained the conditions in the CWU and adjacent areas in a fresh to very low salinity regime, which allowed baldcypress – water tupelo and fresh marsh to survive there. An analysis of the water budget of the area prior to construction of the MRGO demonstrates why this was the case.

Coastal Louisiana generally has abundant rainfall throughout the year, without a distinct dry season. This rainfall maintains fresh or near-fresh conditions in the upper parts of coastal drainage basins. This was the case in the Pontchartrain and upper Breton Sound Basins prior to the constructions of the MRGO. However, the availability of fresh water varies considerably

over the year. A water budget demonstrates this seasonal availability of fresh water. A water budget analysis involves consideration of precipitation, evapotranspiration, and freshwater surplus/deficit. To prepare a water budget, monthly precipitation and mean temperature values are obtained from a National Climate Data Center near the study area, such as the one in New Orleans. Precipitation varies from year to year. For example, Hyfield et al. (2008) reported that precipitation in the upper Breton Sound Basin ranged between 1000 and 1870 mm/yr between 2000 and 2002 and that the 30-year average rainfall for the area was 1630 mm/yr. Using these data, potential evapotranspiration (PET) can be calculated using Thornwaite's equation. The water budget can be used to demonstrate the variability of climate during a year in the area and to show the impacts of additional water loading. The components of the water budget are discussed below.

Potential evapotranspiration for a typical year is higher during the warmer months with longer days and higher temperatures and lower during the winter months with shorter days and lower temperatures. The PET generally ranges from a low of about 0.5 cm in January to as high as 20 cm during the summer.

Seasonal and annual variations of rainfall give rise to variability in water surplus/deficit (P-PE). Although rainfall is normally greatest during the warm weather months, high evapotranspiration rates during these months often lead to a slight net water deficit. Rainfall is generally somewhat lower during cold weather months, but net water surpluses occur due to low evapotranspiration rates.

It is during the summer months when there is a water deficit and southerly winds that saltwater intrusion can be a potential problem, as it generally is during the fall due to tropical

storm activity. In the study area prior to construction of the MRGO, low salinity to fresh conditions were maintained as a result of the net surplus of fresh water from precipitation, runoff from the natural levees, some input of fresh water from the Industrial Canal Lock, the intact Bayou La Loutre Ridge and a greater area of wetlands than at present. The fresh to low salinity conditions are demonstrated by direct salinity measurements and the presence of extensive baldcypress – water tupelo swamps and fresh marshes (see below and Appendix C).

Figure 5 shows the average water budget for the western area of Lake Pontchartrain. This budget shows relatively high precipitation throughout the year, the strong seasonality of evapotranspiration, and the slight summer water deficit.

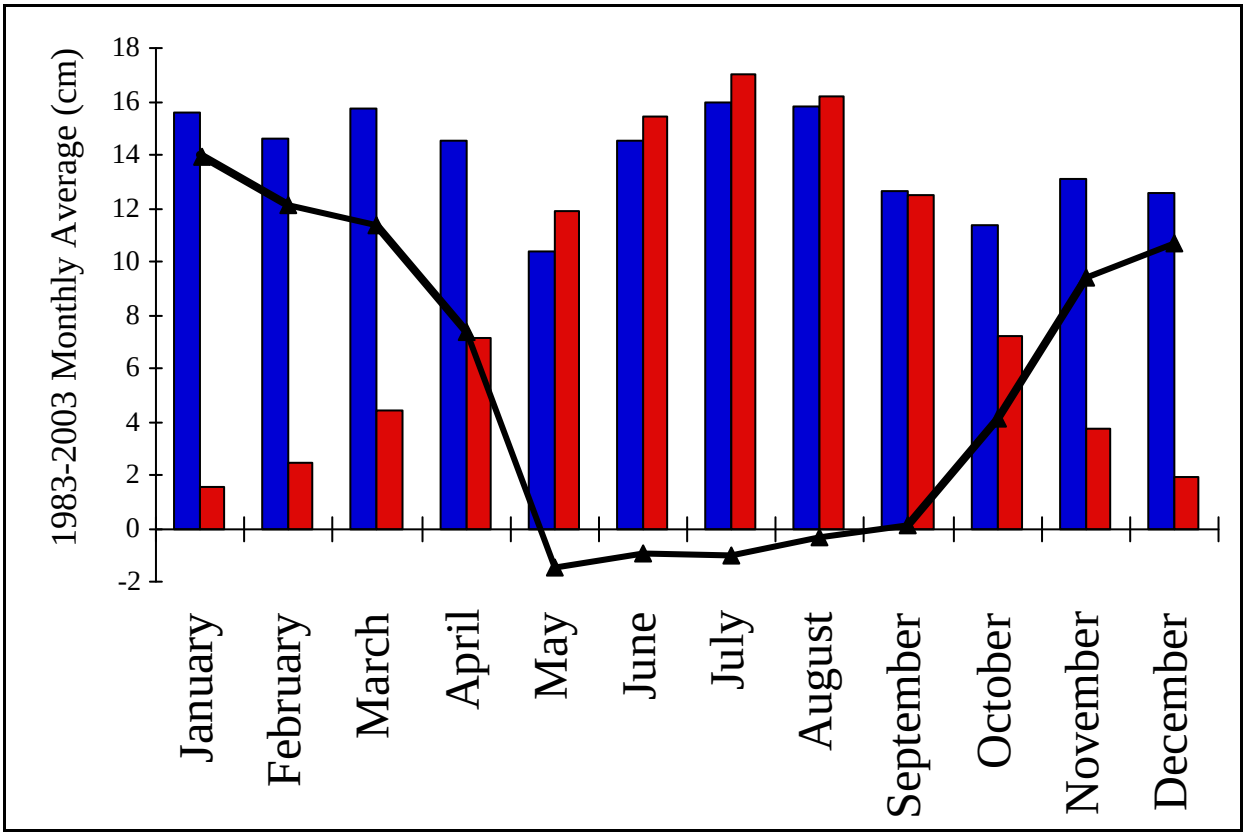


Figure 5. Average rainfall (blue), potential evapotranspiration (red) and net surplus/deficit (black line) for the western area of Lake Pontchartrain (from Shaffer and Day 2007). Additional

sources of fresh water (such as treated effluent, upland runoff, river water from the Industrial Canal lock or Violet diversion) can lower the impact of the summer freshwater deficit.

The water deficit during the summer months due to large rates of evapotranspiration was off-set by rainfall that fed into the St. Bernard storm water drainage system and discharged into the Central Wetlands Unit (CWU). These stations are detailed in the table below. Prior to the stations being built, storm drainage fed into the CWU via a series of canals. Furthermore, the Violet wastewater treatment plant provided fresh water and nutrients by discharging indirectly into the CWU until the 1980s when it was then converted to discharge into the Mississippi River.

St. Bernard Drainage Pump Stations Discharging to CWU

Station Number	**Capacity**	**Year Installed**
1	1100 cfs	Early 1970's
2	380,000 gpm	1950's
3	285,000 gpm	Mid 1950's
4	1,100 cfs	1970's
5	300,000 gpm	Unknown
6	1000 cfs	1991-1992
7	1000 cfs	1992
8	350,000gpm	Unknown

(Lake Borgne Basin Levee District, personal communication)

The Violet Canal was the precursor to the Industrial Canal used mainly for ship traffic utilizing a lock structure. In the late 1950's the lock was closed and a levee was built. In 1978 the Violet Siphon was initiated. The siphon was built in 1979 and operated until 1983 until St. Bernard could not afford the maintenance due to significant needs for dredging. The siphon was again brought into operation by LDNR beginning in 1990. The structure has a maximum

capacity of 500 cfs, however it normally operates between 100-300 cfs. At 200 cfs the siphon distributes more than 12 million cu ft of fresh water a day (Rasi and Steller 1993).

A total of five S&WB drainage pump stations discharge storm water run-off into either the IHNC, the Michoud Canal, the GIWW, or the MRGO with a total capacity of 3,352 cfs (6.7 percent of the total stormwater pumping capacity in 1976). All storm water pumps average 100 hours of operation a year.

The Pearl River discharges into Lake Borgne near the mouth of the Rigolets with a mean annual flow of about 10,000 cfs (USACE 2002). The freshwater flow into Lake Pontchartrain averages about 3,800 cfs (USACE 2002). Some additional fresh water enters the area via the Industrial Canal lock and GIWW.

Combined with rain water, the inputs of fresh water mentioned above were sufficient to sustain the healthy baldcypress – water tupelo swamps and fresh marshes of the CWU. This delicate balance was severed when the Bayou La Loutre Ridge was cut, during construction of the MRGO (for timeline of MRGO contruction, see Appendix D). Salt water carried by the MRGO overpowered freshwater inputs and the baldcypress – water tupelo swamps and fresh marshes rapidly succumbed.

Measurement of Salinity

Salinity is defined as "the total solids in the water, after carbonates have been converted to oxides, all bromide and iodide have been replaced by chlorine, and all organic material has been oxidized" (American Public Health Association, American Water Works Association, and Water Pollution Control Federation (APHA-AWWA-WPCF) 1975). There are three primary ways of measuring salinity, namely the electrical conductivity method, the hydrometric method, and the argentometric method.

Basically, pure water is a poor conductor of electricity and when ions (charged molecules) are present, water becomes a better conductor. As the concentration of ions increases, water's ability to conduct electricity increases. Therefore, the ability of water to conduct electricity can be used to measure salinity (or the "saltiness" of the water). Electrical conductivity also increases as temperature increases (by about 2% per degree C), so salinity measurements must be adjusted for temperature (APHA-AWWA-WPCF 1975).

As the concentration of ions increase in water, the water becomes more dense. Therefore, salinity also may be ascertained by using a hydrometer, which measures specific gravity. These measurements also are temperature dependent. Once specific gravity is corrected for temperature, it can be converted to salinity by means of published density-salinity tables (APHA-AWWA-WPCF 1975).

The argentometric method is more complicated, requiring titration. Chemicals required for the titration include: standardized seawater, silver nitrate solution, potassium chromate indicator solution, and standard sodium chloride. Following titration, chlorosity is converted to salinity using published conversion tables (APHA-AWWA-WPCF 1975). All studies of salinity of the area affected by MRGO were done using acceptable standard methods of measurement.

Salinity

Man-made modifications -- primarily cutting of the Bayou La Loutre Ridge during construction of the MRGO -- provided a direct, steady inflow of highly saline waters. Before construction of the MRGO, seasonal changes and rainfall peaks were not immediately reflected in salinity changes. After construction, the once stable hydrology of the area was changed to act as a conduit for tidal exchange, allowing fresh water to drain quickly during low tide and be quickly replaced by saline waters at high tide (Wicker et al. 1982). This explains the post-

MRGO drastic salinity ranges that occurred all the way up to the GIWW and Lake Pontchartrain. The figure and table below utilize the available salinity data collected from each station prior to and subsequent to 1963 (USACE 1963, Rounsefell 1964, El-Sayed 1961, Amstutz 1964; also see pre-and post-MRGO isohalines in Appendix C).

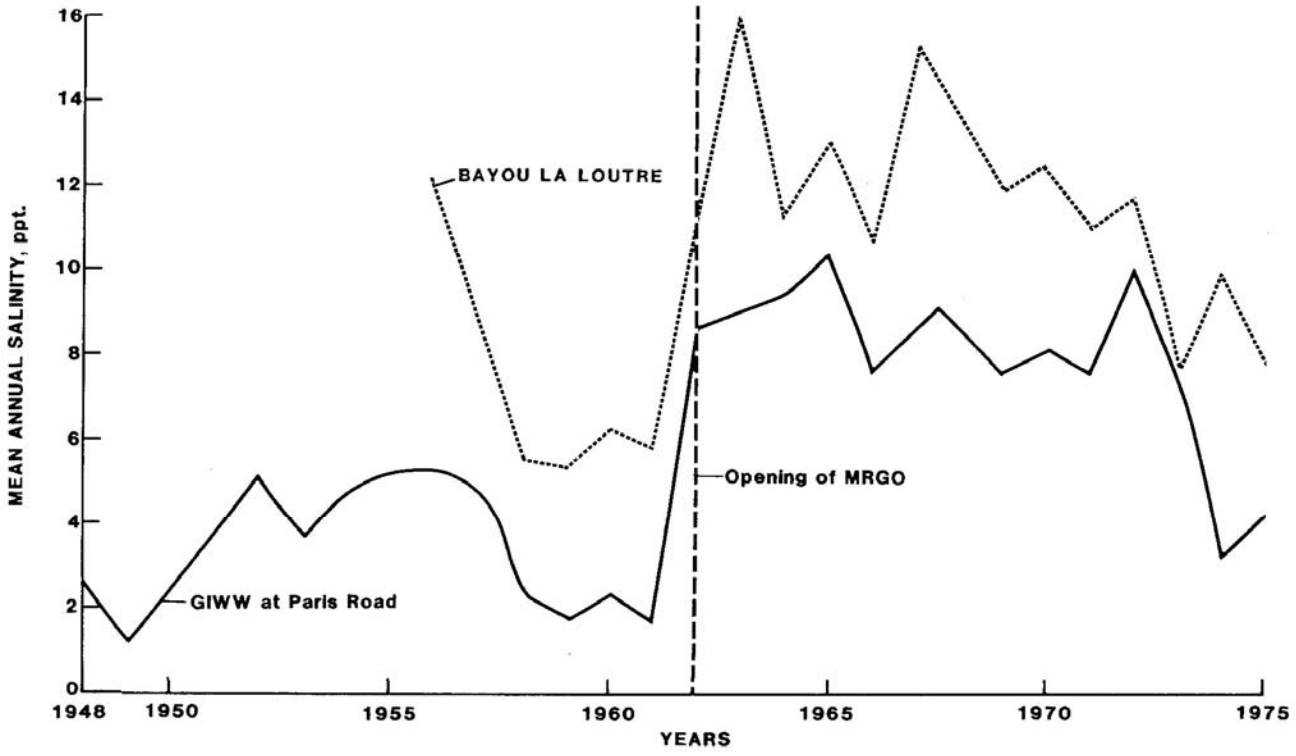


Figure 6. Mean annual salinity for GIWW at Paris Road Bridge and Bayou LaLoutre at Hopedale (Wicker et al. 1982).

Comparison of mean salinities (ppt) before and after completion of MR-GO. All available data collected prior to, and subsequent to, 1963 for each station have been included. Data from 1963 have been excluded.			
Station	Before 1963	After 1963	Increase
Chef Menteur	3.2	5.8	2.6
Rigolets	3.8	5.8	2.0
North Side	2.6	3.9	1.3
Little Woods	3.2	4.8	1.6
Pass Manchac	1.2	1.4	0.2

(Source: Environmental Sub-Committee Report, LPBF 1999.)

In the early 1960s, the USACE built a physical model to test salinity increases in Lake Pontchartrain, caused by the MRGO, and predicted salinities to increase on average by 5.0 ppt and 5.9 ppt for high and low precipitation years, respectively (USACE 1963). In that report they designed, and motivated the need for, a gated structure at the junction of the IHNC and Lake Pontchartrain (Plate 34, p. 91). Had this structure been built, the massive dead zone created in Lake Pontchartrain by the MRGO (discussed below under "Other Impacts of MRGO") may have been avoided.

Salinity Control Measures

A number of measures could have been taken to prevent salinity intrusion into the CWU and adjacent areas both before and after the opening of MRGO. Many of these measures were suggested prior to construction and post-MRGO opening, but the Corps never implemented any of them. Appendix B contains information of a request by EPA to include salinity mitigation measures. Also included in Appendix B is a statement from USACE to the Wild Life and Fisheries Commission detailing that salinity control measures "would require new construction features necessitating environmental and socio-economic investigation" which was deemed "not appropriate" for comments in relation to operation and maintenance of the channel. Unfortunately, the USACE repeatedly used the excuse that "salinity control measures were outside of the scope of work." If measures had been taken to prevent salinity intrusion during construction, much of the vegetation loss including baldcypress – water tupelo swamps could have been prevented. Measures taken after the opening of the MRGO would have made it possible to revegetate trees that were killed by saltwater intrusion. Without salinity control measures to freshen the area, a baldcypress – water tupelo planting is not feasible.

The most obvious and significant measure that could have been implemented, either before or after MRGO construction, was some sort of structure at the Bayou La Loutre Ridge. A gate at the Bayou La Loutre Ridge would need to be closed except for times when ships used the channel. Since large vessel traffic on the MRGO was generally one or two ships per day, the gate could have been kept closed for the majority of the time. To accommodate smaller vessels, such as shrimp boats, crew boats, and recreational craft, a smaller ancillary structure could have been constructed. If complete control of exchange of water at the La Loutre Ridge was desired, then a lock could have been constructed. This would have largely eliminated water exchange at the ridge. More recent technology includes inflatable barriers for deployment when there was no ship traffic. If any of these had been implemented during construction of the MRGO, saltwater intrusion into the CWU would have been much lower. These measures are expensive to implement, but much cheaper than environmental and flood damages due to the loss of the baldcypress – water tupelo forests.

Salinity intrusion into the CWU could have been greatly reduced by placing water control structures in openings in the spoil bank between the MRGO and the CWU. The major openings were at Bayou Bienvenue and Bayou Dupre. Such structures could have been built when the first phase of the MRGO channel was dredged so that they were in place by the time the channel cut through the La Loutre Ridge. This would have prevented the immediate introduction of salt water. Then as the succeeding dredging phases were done, the spoil banks could have been made higher and more secure. In this way, salt water could have been largely excluded. This option would have been very easy and economical to implement.

The massive widening of the MRGO channel through bank erosion also was preventable. The MRGO could have been armored at its authorized width to protect it from ship wakes. Had

this been done, the approximately 250 m area of dredge spoil between the channel bank and the toe of the "levee" would have vegetated in herbaceous plants, shrub-scrub, and trees, similar to the dredge spoil on the western side of the "levee," but perhaps with more salt-tolerant vegetation.

In addition to exclusion of salt water at the La Loutre Ridge and along the MRGO spoil bank, fresh water introduction into the CWU could have buffered any saltwater intrusion and flushed out salt. This is important in the case of hurricanes if the spoil banks were overtopped. There are several sources of freshwater available for the CWU. The Violet diversion structure easily could have been operated to put fresh water into the area. Variable operation of water control structures at Bayou Bienvenue and Bayou Dupre would have ensured wide distribution of fresh water in the CWU. For example, keeping the Bayou Dupre structure closed for longer periods than the Bayou Bienvenue structure would have forced fresh water towards the western part of the unit.

There also is freshwater generated from the uplands adjacent to the CWU that could have been used to reduce and buffer the CWU. Drainage pumps have discharged surface runoff into the CWU for decades. Before the construction of back levees for flood protection, surface runoff flowed directly into the CWU. Proper management of this freshwater source could have acted as a buffer against salt water. The pumps that drain the Lower Ninth Ward discharge directly into the upper end of Bayou Bienvenue and the fresh water flows directly out of the system. This drainage station could have been operated to discharge into the triangular wetland area of Bayou Bienvenue to increase freshwater retention within the area and to prevent saltwater intrusion.

Treated, disinfected municipal effluent is another steady source of fresh water. There are a number municipal systems currently in operation in south Louisiana that clearly demonstrate

the effectiveness of using treated wastewater for wetland assimilation and restoration. Wetland assimilation has been recognized for decades as an effective means of water quality improvement (Shaffer and Day 2007). The Riverbend oxidation pond in St. Bernard Parish is an example of a system that provided fresh water that prevented the death of cypress. The oxidation pond discharges into the forty arpent canal on the inside of the flood control levee and is pumped to the wetlands by the Gore pumping station located adjacent to the pond. The Gore station pumps out rainfall only when there is sufficient precipitation. However, it also pumps out the discharge from the oxidation pond. Thus, there is a nearly continuous supply of fresh water. The effectiveness of this methodology is evidenced by the nearly 100 acres of cypress that has been maintained in the area over the last four decades while the rest of the CWU converted to saline wetlands and open water due to the MRGO. The East Bank Sewage Treatment Plant (EBSTP) that treats all of the east bank wastewater of Orleans Parish, which is located within the CWU, is a source of fresh water that presently discharges to the River. This system is to be converted to provide an additional one hundred million gallons a day of fresh water into the CWU. The value of maintaining a freshwater system is evidenced by the project to use the discharge from the EBSTP to freshen the CWU so that the baldcypress – water tupelo forests killed by saltwater intrusion from the MRGO can be restored.

It is clear from this analysis that there were a suite of measures that could have been used, either individually or in concert, to prevent saltwater intrusion into the CWU and adjacent areas. These measures could have been implemented before or after the construction of the MRGO. If they were done before construction of MRGO, it is clear that the massive die off of baldcypress – water tupelo forests due to salinity intrusion could have been prevented. If the USACE had carried out a careful analysis of the problem of saltwater intrusion, either before or after

construction of MRGO, they would in all likelihood have identified most to of these salinity control measures.

Measuring Wetland Change

The basic approach to measuring wetland loss or gain is to use historical and recent data to assess trends. For a given area, this approach is accomplished by developing a "base map," often delineating habitat types from aerial data combined with "ground-truthing." Each pixel of the base map is assigned to a particular habitat type (e.g., baldcypress – water tupelo swamp, salt marsh, open water) and these habitat types form polygons of various size. For each habitat type the polygons are then summed. This methodology is used to create maps from subsequent time periods and these are overlain onto the base map; polygon differences are used to determine shifts in habitat types (Barras et al. 2003, Braud and Feng 1998, Britsch and Dunbar 1993, FitzGerald et al. 2008).

Habitat classification maps are constructed by using aerial photography, satellite imagery, ground surveys, or a combination of the three. For example, the wetland habitat change maps constructed for the Louisiana Coastal Area (LCA) restoration project used 1:65,000-scale, color-infrared aerial photographs (Cahoon and Groat 1990) combined with Landsat 5 and 7 Thematic Mapper (TM) satellite images (Barras et al. 2003). The Landsat 5 and 7 satellites are Earth-observing instruments designed for land surface monitoring and change detection, operated jointly by the U.S. Geological Survey (USGS), the National Oceanic and Atmospheric Administration (NOAA), and the National Aeronautics and Space Administration (NASA). These satellites fly over the same spot of the Earth every 16 days and each scene covers approximately 185 km by 180 km, with resolution of 30 m (Braud and Feng 1998, Barras et al. 2003).

There exist several reasons why habitat changes estimated by a particular team of investigators, over a specific period, do not necessarily exactly match those estimated by a different team. Discrepancies may arise from interpretation techniques, sampling resolution, or differences in environmental factors when scenes were obtained, such as differences in (a) the amount of floating aquatic vegetation present, (b) meteorological or astronomical tidal conditions, (c) management practices including the use of weirs to alter hydrologic conditions, or marsh burning, (d) multiple habitat types co-occupying individual cells, (e) vegetative vigor, or (f) seasonality (e.g., leaf-on vs. leaf-off) (Barras et al. 2003). To minimize error, investigators often interpret a number of scenes of a particular site to characterize a particular time period. In addition, a stratified (by habitat type) random sample of geographic points often are ground-truthed to assess classification accuracy. For example, the LCA wetland loss classification used 300 on-site inspections to estimate classification accuracy and determined it to be 92% or better (Barras et al. 2003). Thus, in the Central Wetlands Unit and adjacent areas there is some variation in reports of the areas of different wetland types at different times before and after construction of the MRGO. There is, however, a general consistency in the trends reported for this area.

Wetland Habitat Change and Loss Caused by MRGO Construction

At issue here is wetland habitat change and land loss in the Central Wetlands Unit (Figure 7) and adjacent areas and its relationship to the MRGO. In general, wetland loss in coastal Louisiana is a process where change takes place relatively gradually, but continually. The rate of wetland loss in the Louisiana coastal zone has ranged between 25 and 100 km^2 per year. Thus, rates of land change are generally gradual, but wetland change in the Central Wetland Unit and adjacent areas was much more rapid after construction of the MRGO.

O'Neil, in 1949, reported that 40% of the marsh of the CWU was fresh/intermediate marsh and the remainder was intermediate. Forested wetlands were not included in the study. Wicker et al. (1982) reported that in 1955, 23% was brackish marsh, 35% was fresh/intermediate marsh, and 38% was baldcypress – water tupelo swamp. Wright et al. (1960) reported that pre-MRGO wetlands were 50% intermediate marsh and 50% cypress – tupelo swamp. Chabreck et al. (1968) classified post-MRGO wetlands between Bayou Bienvenue and the Violet Canal/Bayou Dupre as brackish marsh and the area to the south as intermediate marsh. Valentine (1968) classified some marsh in the upper Bayou Bienvenue drainage as intermediate. Chabreck et al. (1978) classified the entire CWU as brackish marsh. Also in 1978, Wicker et al. classified wetlands near the pumping stations as intermediate marsh with dead or dying cypress, the majority of the area as brackish marsh, and the northeastern corner as saline marsh. In 1988, Chabreck reported only brackish marsh in the area. The variability in the classification as intermediate is due to the fact that not all investigators used the same species to characterize intermediate marsh. Several other studies of the vegetation of the MRGO vicinity have been conducted: Lloyd and Tracy 1901, Brown 1936, Penfound and Hathaway 1938, Humm 1956, and Chanberlain 1957, Texas A&M 1958-1960, the U.S. Department of Interior in 1962, Lemaire 1961, Chabreck 1970, 1972, and 1973, Palmisano 1970 and 1971, and USACE in 1999.



Figure 7. Aerial photograph of the Central Wetlands Unit, bounded on the west and north by development and on the east by the MRGO.

Canals have been implicated as a major cause of wetland loss in the Louisiana coastal zone. Although the MRGO is a canal, it is quantitatively and qualitatively different from smaller canals dredged mainly for oil and gas activity (access to drilling sites, pipelines). The MRGO is much larger than most other canals and connects high salinity Gulf water to fresher parts of the Pontchartrain Basin. Thus the MRGO has had dramatic affects on both hydrology and salinity. By contrast, there is a relatively small area of other canals in the Central Wetland Unit and adjacent areas. For example, in 1955, there were only 56 acres of canals and by 1978, this had increased to only 68 acres, whereas the MRGO channel and spoil banks comprised about 21,000 acres.

Construction of the MRGO directly caused the destruction of tens of thousands of acres of wetlands and led to the indirect death of tens of thousands of additional acres of wetlands.

Following the opening of the MRGO, there were significant increases in salinity in the area north of the Bayou La Loutre Ridge. This had a dramatic affect on fresh water and low salinity wetlands. Salinity killed thousands of acres of baldcypress – water tupelo swamps in the CWU alone. As discussed above, this salt kill was predicted by state and federal agency personnel prior to construction of the MRGO.

There was a rapid wetland loss and change after construction of the MRGO, as demonstrated by different mapping studies in the area and the detailed analysis in the expert report by FitzGerald et al. (2008). There is convincing evidence that a relatively rapid increase in salinity after the MRGO opened caused rapid mortality of baldcypress – water tupelo swamps and other wetland vegetation. There are several lines of evidence to support this conclusion.

In summary, a number of factors indicate that the rapid die-off of baldcypress – water tupelo swamps was a result of the MRGO.

- Salinity tolerances for baldcypress have been known since the 1930s (e.g., Penfound and Hathaway 1938). Baldcypress can tolerate salinities up to 3-4 ppt but sustained salinities higher than 5 ppt are lethal to cypress and other swamp tree species.
- Levels of salinity in the Central Wetlands Unit before the opening of the MRGO were generally between fresh and 4 ppt. After the MRGO was opened, salinities in the Central Wetlands Unit were consistently higher than 5 ppt and often higher than 10 ppt. A salinity record at Bayou Dupre showed a dramatic increase after the opening of the MRGO. There were no other significant activities that introduced salt water.

- All habitat change mapping shows the loss of almost all baldcypress – water tupelo swamp and fresh marsh in the Central Wetlands Unit after the MRGO was opened.
- There are a number of personal observations by residents of St. Bernard Parish of baldcypress – water tupelo swamps dying after the MRGO was opened.

Specific Estimates of Wetland Loss Related to MRGO

With a broad overview of wetland loss in the Mississippi Delta in mind, it is clear that there are direct and indirect impacts of the construction of the MRGO that resulted in extreme habitat loss. The direct impacts affecting habitat loss include channel excavation, spoil disposal filling both wetlands and shallow water bodies, and wave erosion. Indirect affects that caused shifts in habitat type and increased wetland loss include salinity intrusion and hydrological changes caused by the MRGO. Numerous studies detail that the MRGO caused land loss during different periods of time using various defined areas. All of the studies detail tens of thousands of acres of land loss, however the methods, time periods, and defined areas differ, causing inconsistencies in the quantification. Once the Coast 2050 sub-units were defined, the studies became more consistent. Below are the results of a few of these studies; however, for the purposes of this report, the results contained in the Expert Report of FitzGerald et al. (2008) are the most current, reliable, and consistent in relation to the studies listed below.

Gatien J. Livaudais of the St. Bernard Wetlands Foundation wrote in a report to the Environmental Sub-Committee that Sue Hawes of the USACE stated that 16,500 acres of marsh were filled or excavated during MRGO construction. In addition, 5,700 acres of water were filled or deepened. In 1956, 10,200 acres of cypress forest and 5,700 acres of fresh/intermediate

marsh existed. Both the baldcypress – water tupelo swamp and the fresh/intermediate marsh have been replaced with open water and brackish or saline marsh. The tables depicting habitat type in 1955, and 1978, are from a 1982 study performed by Wicker et al. (1982) for the St. Bernard Parish Police Jury. For this study, the wetlands of St. Bernard Parish are separated into environmental management units, which include the Central Wetlands, Lake Lery, Bayou Bienvenue, Proctor Point, and Lower Proctor Point (Wicker et al. 1982).

Habitat Type and Area of the Central Wetland Unit, in 1955 and 1978			
Habitat Type	**Habitat Area (in acres)**		**Change in Area**
	1955	**1978**	
Developments (houses, roads, etc.)	10	106	+96
Hurricane Protection Levee	70	296	+226
Canals (oil/gas/logging)	56	68	+12
MRGO Retention Levee/ Borrow Pit	0	254	+254
Open Water (channels/lakes etc.)	1,519	2,081	+562
Fresh to Intermediate Marsh	5,678	0	-5,678
Intermediate Marsh and Dead Cypress	0	540	+540
Intermediate Marsh and Stagnating Cypress	0	670	+670
Brackish Marsh	3,721	7,425	+3,704
Brackish Marsh and Dead Cypress	0	5,433	+5,433
Saline Marsh	0	1,198	+1,198
Cypress Swamp	7,050	0	-7,050
Spoil with Shrubs	0	33	+33
Total	**18,104**	**18,104**	

(Wicker et al. 1982)

Habitat Type and Area for Lake Leary, in 1955 and 1978			
Habitat Type	**Habitat Area (in acres)**		**Change in Area**
	1955	**1978**	
Fresh Marsh	4,175	101	-4,074
Intermediate to Brackish Marsh	12,309	1,677	-10,632
Brackish Marsh	0	12,206	-12,206
Bottomland Hardwoods	646	267	-379
Agriculture	173	0	-173
Hurricane Protection Levee	0	370	+370
Canals (oil,gas, borrow pit):			
Fresh	47	0	-47
Estuarine	195	270	+75
Open Water (channels/lakes etc.)			
Fresh	76	108	+32
Estuarine	2,756	5,378	+2,622
Total	**20,377**	**20,377**	

(Wicker et al. 1982)

Habitat Type and Area of Bayou Bienvenue, in 1955 and 1978			
Habitat Type	**Habitat Area (in acres)**		**Change in** Area
	1955	**1978**	
Brackish Marsh	3685	1286	-2399
Saline Marsh	0	638	+638
Spoil with Shrubs	6	9	+3
Natural Levee Forest	1	4	+3
Natural Levee/ Ridge with Shrubs	4	8	+4
Cypress Swamp	6	0	-6
Canals (Oil / Gas)	10	39	+29
Open Water (Channels/Lakes)	478	1377	+899
MRGO	0	829	+829
Total	**4,190**	**4,190**	

(Wicker et al. 1982)

Habitat Type and Area of Proctor Point, in 1955 and 1978			
Habitat Type	**Habitat Area (in acres)**		**Change in Area**
	1955	**1978**	
Brackish Marsh	10,338	5,286	-5,052
Saline Marsh	0	2,000	+2,000
Natural Levee Forest	5	3	-2
Natural Levee/ Ridge with Shrubs	5	10	+5
Spoil with Shrubs	2	4	+2
Canals (Oil / Gas)	0	11	+11
Open Water (Channels/Lakes)	0	1,288	+1,288
Total	**10,841**	**10,841**	

(Wicker et al. 1982)

Habitat Type and Area of Lower Proctor Point, in 1955 and 1978			
Habitat Type	**Habitat Area (in acres)**		**Change in Area**
	1955	**1978**	
Fresh to Intermediate Marsh	74	0	-74
Intermediate Marsh	193	0	-193
Brackish Marsh	6,590	2,961	-3,629
Open Water (channels/lakes etc.)	1,519	2,081	+562
Saline Marsh	0	2,414	+2,414
Natural Levee Forest	222	14	-208
Brackish Marsh	3,721	7,425	+3,704
Spoil with Shrubs	0	26	+26
Natural Levee/Ridge Shrubs	193	40	-153
Canals (oil, gas, navigation, etc.)	33	46	+13
Open Water Channels/Lakes etc.	1,561	2,491	+930
MRGO	0	898	+898
Developments (houses, roads)	34	10	-24
Total	**8,900**	**8,900**	

(Wicker et al. 1982)

The following tables are the results of an USACE study for the Environmental Subcommittee of the Technical Committee convened by EPA (1999) in response to the St. Bernard Parish Council Resolution 12-98 titled "Habitat Impacts of the Construction of the MRGO."

SUMMARY TABLE

Converted to Open Water (Acres)	
Fresh/intermediate Marsh	3,400
Brackish Marsh	10,300
Saline Marsh	4,200
Cypress swamp destroyed as disposal area	1,500
Shallow open water to deep water/ disposal area	4,800
Total Construction and Erosion Habitat Loss	**24,200**
Habitat Shifts	
Fresh/ intermediate marsh to brackish marsh	3,350
Cypress swamps to brackish marsh	8,000
Swamp to intermediate marsh	7,500
Brackish marsh/ swamp to saline marsh	19,170
Total Acreage Affected by Habitat Shifts	**38,020**
TOTAL ACREAGE AFFECTED BY THE MRGO	**62,220**

(compiled from USACE 1999)

Summary of Estimated Habitat Loss From MRGO Construction and Erosion by Mapping Unit					
Spoil	Fresh/ Intermediate Marsh	Brackish Marsh	Saline Marsh	Forest	Water
Central Wetlands	3080	5530		1110	1700
South Lake Borgne					
Eloi Bay		1880	1950	300	2220
Total Spoil	**3080**	**7410**	**1950**	**1410**	**3920**
Channel	Fresh/ Intermediate Marsh	Brackish Marsh	Saline Marsh	Forest	Water
Central Wetlands					
South Lake Borgne	290	1550	490	40	345
Eloi Bay		460	360	60	485
Total Channel	**290**	**2010**	**850**	**100**	**830**
Erosion (1990)	Fresh/ Intermediate Marsh	Brackish Marsh	Saline Marsh	Forest	Water
Central Wetlands					
South Lake Borgne		790	620		
Eloi Bay	0	100	790	0	0
Total Erosion	0	890	1410	0	0
Grand Total per Wetland type	**3370**	**10310**	**4210**	**1510**	**4750**
Grand Total of Habitat Loss					**24,150**

(USACE 1999)

Habitat types in 1956, 1978, and 1990 for the Central Wetlands, south Lake Borgne and Floi Bay (acres) (from LDNR digitized habitat maps). (USACE 1999)

Central Wetlands	**1956**	**1978**	**1990**
Fresh/Intermediate Marsh	11,620	1,520	620
Brackish Marsh	13,490	21,710	19,710
Saline Marsh	0	0	90
Cypress Forest	10,200	0	90
Forest	2,740	640	440
Bottomland scrub/shrub	0	0	1,180
MRGO spoil*	0	11,620	11,420
Developed/agricultural	520	100	790
Inert	0	200	0
Water	4,020	6,800	8,250
Total	**42,590**	**42,590**	**42,590**

*includes upland scrub/shrub (spoil), upland barren, and some ag/pasture, shore/flat, and inert. In 1988, the 620 acres of fresh marsh is on the MRGO spoil.

South Lake Borgne	**1956**	**1978**	**1990**
Fresh/Intermediate Marsh	540	340	0
Brackish Marsh	23,760	18,060	7,080
Saline Marsh	0	0	9,510
Forest	30	70	10
Swamp	2,740	640	440
Scrub/shrub	0	0	80
MRGO spoil*	10	260	120
Developed	30	60	0
Beach/Inert/shore/flat	0	10	50
Ag/pasture			150
Water	4,450	10,410	12,210
Total	**29,210**	**29,210**	**29,210**

*Spoil includes upland scrub/shrub in 1988

Eloi Bay	**1956**	**1978**	**1990**
Fresh/Intermediate Marsh	950	250	990
Brackish Marsh	18,000	7,800	5,320
Saline Marsh	14,710	18,150	19,160
Swamp	360	0	0
Forest	0	50	0
MRGO spoil*	40	5,710	4,970
Beach/inert/shore/flat	30	0	0
Water	63,850	65,980	67,500
Total	**97,940**	**97,940**	**97,940**

*Fresh marsh on MRGO spoil in 1978 and 1988

**spoil includes inert, ag/pasture, upland barren, developed and scrub shrub

Habitat types in 1956, 1978, and 1990 in Biloxi marshes and eastern Orleans land bridge (from LDNR digitized habitat maps). (USACE1999)

Biloxi Marshes	**1956**	**1978**	**1990**
Fresh/Intermediate Marsh	1,010	930	0
Brackish Marsh	40,850	47,980	36,060
Saline Marsh	59,310	42,070	50,950
Swamp	810	0	0
Forest	0	40	10
Scrub/shrub and spoil	0	610	750
Inert/Upland Barren	20	0	20
Beach/shore/flat	20	100	1,260
Water	264,410	274,700	277,380
Total	**366,430**	**366,430**	**366,430**

Eastern Orleans Land Bridge	**1956**	**1978**	**1990**
Brackish Marsh	30,580	26,670	25,460
Saline Marsh	0	0	0
Swamp	20	20	0
Forest	40	10	240
Scrub/shrub	20	270	1,070
Developed	860	1,520	810
Inert/Upland Barren	160	90	30
Beach/shore/flat	120	20	90
Ag/Pasture	0	0	20
Water	13,810	17,040	17,890
Total	**45,610**	**45,610**	**45,610**

(USACE 1999)

Habitat types in 1956, 1978, and 1990 in La Branche, eastern Manchac land bridge, and north shore marshes (from LDNR digitized habitat maps). (USACE 1999)

La Branche	**1956**	**1978**	**1990**
Fresh/Intermediate Marsh	4,100	3,590	3,510
Brackish Marsh	6,260	4,380	3,980
Saline Marsh			
Swamp	12,140	11,030	10,020
Forest	600	730	2,140
Scrub/shrub	390	220	250
Developed	480	880	220
Ag/Pasture	40	40	410
Water	580	3,720	4,060
Total	**24,590**	**24,590**	**24,590**

East Manchac Land Bridge	**1956**	**1978**	**1990**
Fresh Marsh	6,440	8,470	850
Fresh/intermediate	0	6,620	11,620
Brackish Marsh			
Saline Marsh			
Swamp	19,660	9,660	4,490
Forest	1,570	1,520	4,890
Scrub/shrub spoil	0	130	5,240
Developed	500	850	220
Ag/Pasture	270	130	170
Water	1,410	2,470	2,490
Total	**29,850**	**29,850**	**29,970**

North Shore Marshes	**1956**	**1978**	**1990**
Fresh/Intermediate Marsh	120	550	3,690
Brackish Marsh	12,250	9,290	5,750
Saline Marsh			
Swamp	40	50	
Forest	1,030	880	700
Scrub/shrub		40	90
Developed	70	170	180
Inert/beach	110	20	
Ag/Pasture			50
Water	670	3,250	3,830
Total	**14,290**	**14,250**	**14,290**

(USACE 1999)

Logging Old-Growth Baldcypress – Water Tupelo Swamps

The first advance towards large-scale commercial logging of baldcypress – water tupelo swamps was driven by changes in legislation. When the Homestead Act of 1866 was repealed and replaced by the Timber Act of 1876, swamps were declared unsuitable for cultivation (Norgress 1947). Large-scale logging of old-growth baldcypress, with trees greater than 1,000 years old and 30 m tall, began in 1889, with the invention of pullboat logging (Mancil 1980, Perrin 1983). Pullboats mechanized logging by using cables and winches to "ground skid" felled trees. The logs were winched to open water along logging "runs" spaced about 45 m apart. Ground skidding the giant trees carved the logging runs to approximately 2 m deep, leaving either parallel or wagon wheel-shaped markings that are still visible today. In many areas, these logging runs permanently altered the hydrology of the swamps. Despite the altered hydrology, most cutover swamps in coastal Louisiana, including those logged between 1912 and 1920 in the Central Wetlands Unit (Nuttall 1950), regenerated in second-growth baldcypress and water tupelo (Winters et al. 1943). For examples of direct destruction of second-growth cypress by the construction of the MRGO, see historic photographs in Appendix E.

Shortly after the Timber Act of 1876, large tracts were sold to timber companies at 25 to 50 cents per acre. Several large transactions took place during this era (Dranguet and Heleniak 1992). Between 1885 and 1892, Leonard Strader, for example, acquired greater than 2,834 ha of baldcypress – water tupelo swamp. Other timber barons of that era included Joseph Rathborne, Thomas Hume, and Charles Hackley. Clearcuts of baldcypress – water tupelo swamps reached a peak in the early 1900s (with the zenith occurring between 1910 and 1914), and by 1934 greater than 647,773 million hectares of swamp had been cutover (Norgress 1947). Most mills were abandoned, however, by 1925 (Mancil 1980).

Ghost Cypress

As mentioned in the section on hurricane protection, there are a number of characteristics that make baldcypress very resistant to being blown down during hurricanes. The aboveground parts of the trees are pliable and thus bend but do not generally break in high winds. This is the opposite of pines and most hardwoods, which snap off or blow over rather readily in high winds.

The root structure of baldcypress also contributes to its ability to withstand hurricanes. An individual tree can send out roots to distances greater than 30 m. In a normal baldcypress – water tupelo forest with average density (i.e., 1000 stems per hectare and basal area $\geq$ 40 m^2/ha), the roots of the trees form a dense, intertwined belowground tapestry. The knees sent up from the root mat increase friction on water flowing over the forest floor and also assist in resisting windthrow. Because of the intertwined nature of the root mat, the canopy trees also hold the midstory and herbaceous groundcover in place (Shaffer et al. 2008).

Even though baldcypress are highly resistant to hurricanes, they are very sensitive to salt water (see section on saltwater intrusion). When baldcypress are killed by salt water, the structure of the root system affects the way that they ultimately fall after they die. After a saltwater kill, a "ghost" forest of standing dead trunks is formed. These are unfortunately common in coastal Louisiana, because saltwater intrusion has been widespread. The saltwater intrusion caused by the MRGO is the most notable and widespread example of this.

The trees in ghost forests can stand for many decades. But they eventually fall. The structure of the root system and the decomposition of the trunk affect the way that most trees fall. Wood rot is most extensive at the water line (Figure 8), because this part of the tree is affected by wetting and drying and the action of organisms that attack and weaken the moist, but aerated, wood. The upper part of the trunk remains dryer and thus deteriorates more slowly. The

belowground root system occurs in anaerobic conditions where decomposition is much slower. This accelerated decomposition at the water line generally results in the trunk breaking at this point when the trunk is blown over. It is extremely rare for a dead baldcypress tree to pull up the root mat when it is finally blown down.



Figure 8. Examples of ghost cypress killed by logging (left) or by saltwater intrusion (right). Decomposition, decades after the trees are killed, occurs most extensively at the air-water interface, where the trunk is moist yet oxygenated (Photographs by Michaelyn Lombard).

In an area such as the Central Wetlands Unit where baldcypress was killed by saltwater intrusion from the MRGO, the process of trees dying and ultimately falling over affects what is

visible over time. Since the trees generally break off at the water line, there is little stump visible at the time the trunk falls. The trunk falls in soft mud and is partially covered at the time of falling. Continued subsidence results in at least partial burial of both stumps and trunks. In an area such as the Central Wetlands Unit where extensive and rapid tree mortality has occurred, the shallow subsurface is a dense network of roots, stumps, and trunks. Two of our team members (Day and van Heerden), have driven cores and pipes into the sediments of the Central Wetlands Unit. It was difficult to drive the cores and pipes into the ground because of the remaining dense woody underground matrix.

Dredging

The wetlands surrounding the MRGO were affected directly during construction by the initial dredging and also during operation and maintenance projects over the ensuing 40 years. The dredge operations literally smothered marshes in sediments and increased turbidity levels affecting primary producers. Dredge deposition areas created permanent high-ground on the west bank of the MRGO resulting in negative effects on the hydrology by semi-impounding natural areas and affecting biotic resources.

These effects were in fact predicted and presented to the USACE by the USFWS prior to construction. In 1957, the USFWS indicated that the 300 million cubic yards of dredge from the excavation would eliminate 6,200 acres of shallow open water and 17,400 acres of marsh. The USFWS urged the USACE to construct diked containment areas to prevent smothering of the surrounding waterways. The USFWS also recommended in a July 27, 1960 report to the USACE that openings be made in the spoil banks (Rounsefell 1964). The report detailed that uninterrupted spoil banks would alter current patterns resulting in shoaling and change salinity over a large area. The report further detailed the effects of impounding the wetlands that would

reduce the freshwater inputs from the Pearl River to the north and the Mississippi River to the south (Rounsefell 1964).

In a February 22, 1975 Interim Statement on the Pontchartrain Hurricane Protection Plan by the Louisiana Wildlife and Fisheries Commission (LWFC) provided to the USACE, the WLFC expressed environmental concerns in relation to dredging and containment of sediments and the length of the construction project (1975-1990) (LWFC 1975). The statement officially requested review involving state and federal fish and wildlife agencies be held at least every three or four years. It is unclear whether this was actually done.

Methods of Dredge Operation

The USACE actually detailed the methods of dredge operation that devastated the wetland areas in their 1976 Final Environmental Statement for Operation and Maintenance. There were multiple USACE dredging reports that reflect the understanding of the environmental impacts of construction and operation and maintenance activities. The following sections contain extended excerpts documenting this understanding.

> General: Dredging operations involve pumping the bottom sediments up to a dredge and simultaneously piping the material to the deposition area. A cutterhead pipeline dredge is used primarily for maintenance operations in the Lake Borgne vicinity. The cutterhead pipeline dredge pumps the liquid material to a shoreline area. Clay type material may contain 10 parts water for one part solids. Sand type material may contain 5 parts of water for one part solids. When necessary, a hopper dredge is used for maintenance of the channel in the Gulf of Mexico. The hopper dredge loads the dredged material, moves to deep water, and dumps the material through trap doors to the Gulf bottom.
>
> Mile 66 to Mile 23: A diked disposal area, 2,000 feet wide, is adjacent to the southwest side of the channel through the land area of the MRGO (Mile 66- Mile 23). Deposited material spreads over the existing vegetation with each dredging operation. As the material flows outward from the pipeline and dries, a flat, cone-like mound is created.

Mile 23 to 0: Beyond the land's end in Breton Sound (Mile 23), material is piped to an area 3,000 feet southwest of the MRGO channel centerline and the material settles to the bottom of the sound. Heavier particles settle out in the immediate area, but fine clay particles remain in suspension for considerable distances.

Mile 0 to Mile –9.38: In the Gulf of Mexico, beyond Breton and Grand Gosier Islands, a hopper dredge has been used in the past. Dredge material is carried and dumped on the right descending side, 2,000 feet from the MRGO centerline or is dumped into the deeper Gulf waters.

Total Land Deposition Area: During original construction, material was pumped to contained areas north and south of the east-west segment of the MRGO/Gulf Intracoastal waterway (Mile 66 to Mile 60). Material from the MRGO channel south of Mile 66 and west of Lake Borgne has been used for construction of hurricane protection levees. The total land area for dredged material deposition for original construction was a 4,000-foot wide strip of land (16,183 acres) on the southwest bank of the MRGO to Mile 23. (USACE 1976)

Operation and Maintenance

The ongoing operation and maintenance of the MRGO further exacerbated environmental damages by constantly disrupting bottom-dwelling biota and increasing turbidity. In general, when water velocity decreases in a navigation channel the sediment carrying capacity decreases, causing sediment deposition on the channel bottom. Furthermore, waves caused either by wind or shipping vessels cause the shoreline to erode and further dramatically increase sediment deposition on the channel bottom. This was due to the channel being originally dredged with one vertical to two horizontal feet side slopes, which cause the slopes to erode and fill near the bottom until an equilibrium is reached (the angle of repose). Deteriorating wetlands were another major sediment source that was transported to the MRGO by tidal action, storms, and hurricanes. Thus, deteriorating wetlands, ship traffic caused by the MRGO, and hurricanes exacerbated by the MRGO created a tremendous need for operation and maintenance, which increased dredging operations and therefore continued to increase environmental damages.

However, the USACE themselves document the environment damaging mechanisms of dredging in the report "Disposal of Dredge Spoil, Problem Identification, and Assessment, and Research Program Development," by the U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi (1972, cited in USACE 1976).

> "Much of the concern over the actual dredging process is related to the direct destruction of benthic (bottom-dwelling) organisms. Such organisms are known to play an important role in the aquatic ecosystem, and include commercially valuable species such as oysters and clams….In addition to the direct effects of dredging operations, concern also exists over the possible indirect effects on biological communities. The potential for indirect effects on biological communities is usually attributed to physical alterations of the environment such as changes in bottom geometry and bottom substrate which trigger subsequent alterations in water velocity and current patterns, salinity gradients, and the exchange of nutrients between bottom sediments and the overlying water.
>
> Most of the concern over the dredging-disposal process is directed toward the effects of open water disposal on water quality and aquatic organisms… One of the direct effects of open water disposal is sediment buildup, resulting in the smothering of benthic organisms, changes in spawning areas, reduced habitat diversity, changes in sediment/water chemical interchange, and reduced or changed vegetative cover. In addition, increased levels of turbidity reduce light penetration (thus altering biological productivity), decrease the availability of food, and alter the chemistry and temperature of the water. Finally, because most of the sediments in the nation's waters have become contaminated with chemical pollutants, there are grave concerns that man-induced resuspension of such sediments may increase the availability of these pollutants, thus directly affecting biological communities and, indirectly, man. Because of the poor understanding of the possible consequences of these changes and alterations, definitive research is needed to assess all aspects of the open water disposal of dredged sediments.
>
> Primarily because of the concern over the open water disposal of polluted sediments, a trend toward land disposal has developed….Land disposal often involves marshlands or other wetlands, which are among the most biologically productive areas on earth….One of the most intensive concerns involves the possible pollution of groundwater reservoirs and the subsequent effects on man. Land disposal also altered vegetation assemblages and local relief, thereby triggering changes in drainage patterns and wildlife migration. The relocation of sediments from one biotope to another (e.g., the ocean to the coastal plain) can be an alien intrusion that concerns many ecologists. Finally, as is always the case, each of these alterations can initiate further sequences of events, not only in the terrestrial regime, but the aquatic regime as well." (USACE 1972, cited in USACE 1976)

Volume of Dredge Material

A five-year average during the period from 1965 to 1976, not including work associated with hurricanes, resulted in 4,125,000 cubic yards of material dredged from the inland section per year, and 3,590,000 cubic yards per year dredged from the offshore section of the MRGO. Records from the time period further indicate that in actuality 16.7 million cubic yards (mcy) per year were moved including the material used for floodworks construction or 15.7 mcy if floodworks construction is not included. The environmental statement for operation and maintenance concluded that the overall annual volume of material dredged on the MRGO is about 12 million cubic yards (USACE 1976). This material is disposed on land and in open water (USACE 1976). This indicates that ongoing operation and maintenance of the channel continued to have detrimental effects due to the large volume of dredged sediments.

Location of Shoaling

From 1961 to May of 1974, the total volume of material dredged out of the MRGO during maintenance operations was 166.4 million cubic yards (mcy). Of the 166.4 mcy, 18.6% came from the Gulf section, 58.7% came from the Breton Sound section, and 22.7% came from the Land Cut section (USACE 1976). Of the 166.4 mcy, 19.5% was comprised of O&M work during the construction period prior to 1965. The following table shows the shoaling rates and frequency of dredging calculated from dredging contract records from 1965 to 1974.

Prediction of Shoaling Rates and Frequency of Dredging MR-GO 1965-1976		
Location	Shoaling Feet/Month	Dredging Frequency
Mile 66.0 to Mile 41.4	0.02	6 yrs.
Mile 41.4 to 24.3	0.03	4 yrs.
Mile 24.3 to 14.9	0.11	2 yrs.
Mile 14.9 to Mile 6.0	0.58	1 yr.
Mile 6.0 to Mile 0.0	0.14	2 yrs.
Mile 0.0 to Mile –9.4	0.28	1 yr.

Source: Corps of Engineers, based on data, 1965 to 1974 (USACE 1976)

This information details the location and frequency of dredge operations that continued to impact the environment. Furthermore, the correlated deterioration of wetlands provided additional sediments that increased shoaling. Additionally, the waters containing the dredged sediments that were pumped into the wetlands exacerbated the wetland deterioration, because the dredge waters were the brackish to saline waters of the MRGO. Thus dredge operations created a vicious cycle.

"Dredging after Hurricane Betsy in September of 1965 and Hurricane Camille in August 1969 required major efforts. In addition, the channel bottom west of Lake Borgne was used as a source of construction material for hurricane protection levees. The resulting 50-60 foot depths in some borrow areas will not fill to the 36-foot channel depth for some time. The largest volume of material originates from shoaling in open waters. Local storm action can sometimes shoal the channel in two or three days. This type of shoaling occurs most often in spring and midsummer with prevailing southeast winds. The shoaling problem in the sound is also being studied in conjunction with planning investigations for extension of the retention dikes all the way across the sound to the Chandeleur Island Arc." (USACE 1976)

Therefore, hurricanes further increased shoaling and the need for dredging operations. Lastly, the over dredging of the MRGO for floodworks increased the depths of the MRGO and hence increased the rate of saltwater intrusion.

Site Specific Effects

Each dredging operation has a variety of site specific effects including temporary turbidity affecting local and adjacent aquatic environments, the covering of vegetation, and increased elevation of adjacent land during disposal. The dredge itself destroys/removes the bottom dwelling biota and free-floating species which die when placed on land. The environmental damaging effects of dredge operations differ, depending on whether the operation utilizes open water disposal or land disposal.

Open Water Disposal Effects

The U.S. Army Corps concluded in the 1976 Environmental Impact Statement that the deposition of MRGO dredge material into open waters was harmful to the environment.

> "When material is deposited in open water, heavier material settles immediately to the bottom of Breton Sound. Bottom dwelling, non-mobile organisms that cannot escape the flow are covered. Approximately 27.5 square miles of open water disposal (about 17,600 acres) have been affected. The O&M work directly affects the immediate disposal site near the dredge within this 27.5 square mile area. About 40% of the dredged material can be expected to remain suspended in the water for four hours or more. Current velocities measured in Breton Sound indicate a range of 0.34 to 1.19 feet per second (Department of the Army 1964). In a four-hour period, sediment could be carried from about 0.9 to 3.2 miles… Suspended sediment reduces light availability to organisms. The amount of sediment taken in by fish and the small filter feeders increases. If sediments containing heavy metals which can be resolubilized are resuspended, metals may be taken in by biota, concentrated in tissues, and made available to other organisms in the food web (for example, oysters or large fish-eating birds)." (USACE 1976)

Land Disposal Effects

The Army Corps concluded in 1976 that land disposal of MRGO dredged materials had a direct, deleterious effect on vegetation, aquatic life, terrestrial animals and birds.

> "Direct effects on vegetation and elevation of the 10,617 acres of land disposal area are significant for the specific disposal sites.…Each time material is placed on the disposal area, the herbaceous plants and shrubs of that area are covered.…Terrestrial animals that cannot escape the dredged material are lost. Some individuals may also die from stress of overcrowding if they move to adjacent habitat which is already supporting its capacity of animals. Dredge operations might coincide with nesting times of birds and other animals. Nest disruption would be adverse to some populations. Secondary and cumulative effects follow direct impacts. As material is deposited on the land, the elevation of the diked areas increases, thus….providing or maintaining a barrier to water interchange." (USACE 1976)

Dredging Summary

Overall, the USACE was aware of the detrimental effects of dredge operations both in construction and during operation and maintenance. A May 29, 1957 Statement of Louisiana Wildlife and Fisheries Commission detailed the predicted effects to the USACE. Furthermore, the USACE detailed the following effects in their own statements/reports:

i) Initial loss of 16,183 acres of marshland for dredged material deposition,
ii) negative effects on aquatic species in the 17,600 acres of designated disposal areas,
iii) continued impacts with each dredge operation on 10,611 acres,
iv) increases in local water turbidity,
v) deposition of dredged material over aquatic and terrestrial organisms,
vi) disturbance of bottom dwelling biota in the dredge operation
vii) creation of disposal areas elevated above the adjacent marshlands thus disturbing the natural flow of water in the wetlands,
viii) potential for resolubilization of chemicals causing local and neighboring biota exposure, and
ix) effects that would cause plant species at disposal sites to remain in a pioneer stage of development (USACE 1976).

Furthermore, the following quotations taken from the 1976 report summarize the knowledge of the USACE of the detrimental environmental effects:

> "From the single perspective of preserving the marshland, effects of O&M could be classed as adverse human intrusions….O&M work is part of on-going change in the estuary environment. Preservation of resource quality essential for shellfish production, trapping, fishing etc. is more difficult with intrusion of O&M work….O&M work is a human intrusion into a sensitive estuarine environment. Presence of the dredged material disposal areas affects the northeast/southwest movement of water." (USACE 1976)

This portrays without question the understanding of the USACE of the detrimental environmental effects of construction, and continued operation and maintenance of the MRGO. Further comments from agency personnel and responses of the USACE may be found in Appendix B.

The federal government will have spent approximately 115 million dollars on only the low-maintenance dredging of the MRGO according to a document contained in LWLF materials that is cited in Appendix A. The 1998 St. Bernard Parish Council resolution to close the MRGO stated that Hurricane Georges cost $35 million in emergency dredging on top of the average annual dredging cost of $7-$10 million, and $3 million annual for rock retention. Citizens of St. Bernard were led to believe that dredge disposal areas would be suitable for urban development and thus economic development. The reality, known to USACE, was that dredged material settles and does not make good foundation material, thus limiting the usefulness for urban development. Furthermore, a lack of access to the area would constrict the ability of the parish to use the MRGO area for urban development.

Other Impacts of MRGO

Lake Pontchartrain Dead Zone

The "Dead Zone" in Lake Pontchartrain was caused by the opening of the MRGO to the Lake in 1963, via its connection to the Inner Harbor Navigation Canal (IHNC). Because of saltwater intrusion from the MRGO, roughly 250 km^2 (100 square miles) of the Lake's benthos is nearly devoid of life (Figure 9) (Abadie and Poirrier 2001a, b, Poirrier et al. 2008, Spalding et al. 2006). The MRGO delivers salt water to the Lake and it sinks and causes the water column to stratify. Differences between mean surface and bottom water salinity can exceed 10 ppt (Poirrier 1978, Junot et al. 1983) even though the average salinity of the Lake is only 3.9 ppt (Francis et al. 1994, Sikora and Kjerfve 1985). The stratification leads to episodic events of low dissolved oxygen (hypoxia and anoxia) that kill sessile creatures such as the clam *Rangia cuneata* (Poirrier et al. 2008). The saline water from the MRGO causes hypoxic conditions to occur as far north as

24 km from the mouth of the IHNC (Spalding et al. 2006). Earlier studies (Sikora and Sikora 1982) attributed the depauperate benthic community in the Dead Zone to chemical spills and urban runoff. Later investigations (Poirrier et al. 1984, Powers et al. 1992) revealed that the effects of outfall canals were localized and the cause for episodic hypoxic and anoxic bottom waters in the Dead Zone was, indeed, saltwater intrusion from the MRGO.

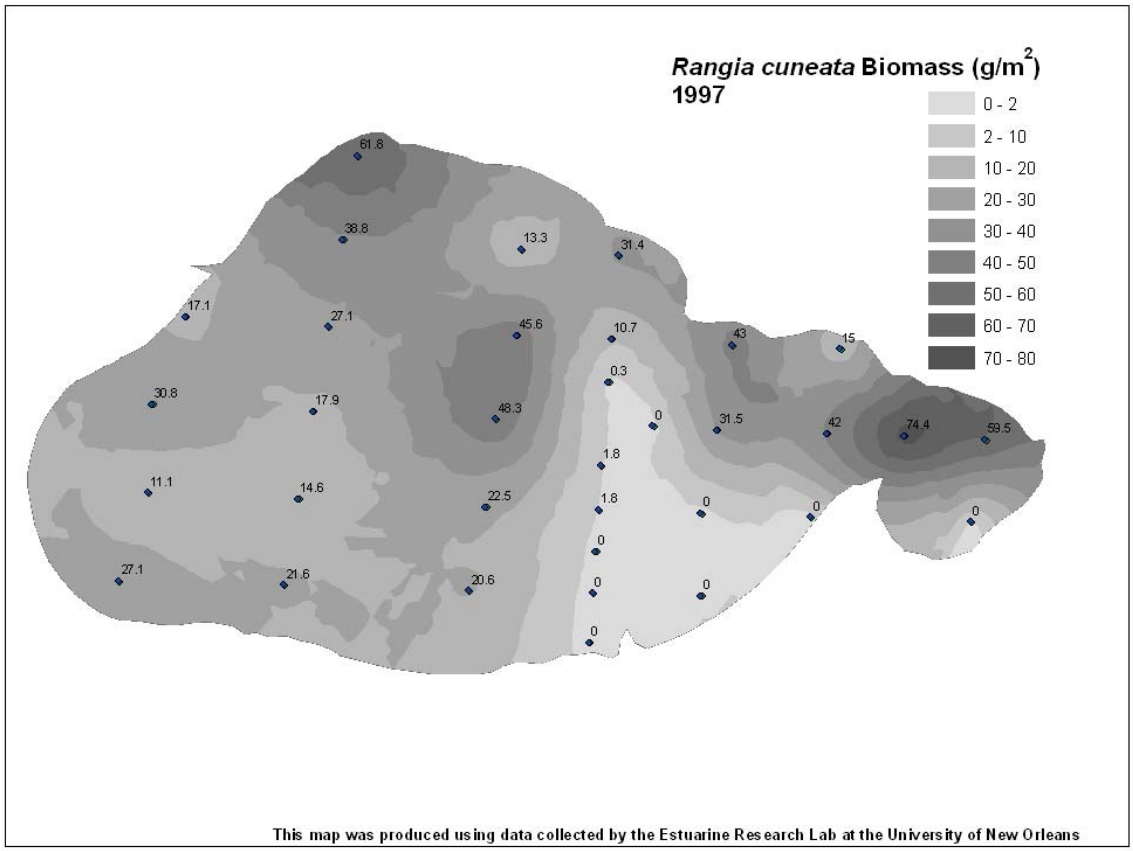


Figure 9. Density of *Rangia cuneata* in Lake Pontchartrain during 1997. Dead Zone (lightest gray) is 250 km^2.

Ecologically, the Dead Zone caused by MRGO is disastrous. By decimating populations of *R. cuneata*, the Dead Zone decreases the health of the entire aquatic ecosystems of Lakes Pontchartrain and Maurepas. *Rangia cuneata* filters silts, clays, algae, and bacteria from the water column, increasing water clarity. The shells of *R. cuneata* stabilize the benthos and the

shell hash (i.e., remnants) help to stabilize shorelines; Rangia add about 700,000 metric tons of shell annually to bottom sediments (Spalding et al. 2006). *R. cuneata* also serve as a food source for fish, crabs, and waterfowl (Spalding et al. 2006). It is estimated that restoration of the Dead Zone, through closure of the MRGO, could increase light penetration on the north shore of Lake Pontchartrain from 2.0 m to 2.4 m and from 0.6 m to 1.3 m on the south shore (Poirrier and Spalding 2004). As a result, submerged aquatic vegetation (SAV) would be expected to increase in aerial coverage by as much as 685 ha (Cho and Poirrier 2005, Poirrier and Spalding 2004). Submerged aquatic vegetation serve as refugia for breeding and juvenile fish, increase sedimentation and therefore water clarity, stabilize sediments, decrease wave energy, and provide food for waterfowl and detritivors. Combined, *Rangia cuneata* and SAVs provide a feedback loop of increased ecosystem health; this loop was and is crippled by the Dead Zone wrought on by the MRGO.

Lake Pontchartrain Salinity

In a report written by Steve Gorin of the Lake Pontchartrain Basin Foundation to the MRGO Task Force Environmental Sub-Committee, it is stated that the MRGO salinity increases in Lake Borgne also have affected salinities in Lake Pontchartrain. According to the report, seven percent of the water entering the Lake comes through the IHNC. "Thirty four percent enters through the Chef and sixty percent through the Rigolets. A significant twenty percent of the salt that enters the lake comes through the IHNC….A direct result of the MRGO" (Environmental Sub-Committee Report 1999). A USACE report detailed that the Lake Pontchartrain salinities increased directly after the 1963 construction of the MRGO by 2.1 ppt at Chef Menteur, 1.1 ppt at the North Shore, and 0.3 ppt at Pass Manchac (USACE 1997). These salinity increases vary in relation to the distance from the IHNC and are reflected by the size of

the Dead Zone shown in Figure 9. As mentioned previously, the USACE predicted that the MRGO would cause large salinity increases in Lake Pontchartrain (USACE 1963) and designed a gated structure at the junction of the IHNC and the Lake to prevent saltwater intrusion. Obviously, the structure was never built.

Resuspension and Resolubilization of Heavy Metals in the Sediment

The USACE responded in their own Operation and Maintenance Environmental Statement in 1976 that the contaminated dredge material was "considered potentially adverse from all perspectives." A sampling program was conducted in 1973 for the purposes of the Environmental Statement. According to the EPA criteria in 1973 for allowable concentrations of metals in material to be disposed of in open water, five of 27 sample locations did not exceed EPA criteria for at least one metal parameter, and only two of 27 sample locations did not exceed any EPA criteria. (USACE 1976). The report further concluded:

> "If a significant amount of metal is being resolubilized when sediment particles are resuspended during dredge operation, and are entering the food web, the effects would be considered adverse. Tests remain to be done. Effects upon biota are not presently determined." (USACE 1976)

It is unclear if mitigation measures were taken to protect wetland and estuarine biotic resources. There is only one statement in the report stating that the determination would be made in the future by those state and federal agencies involved. A past employee of the LDWLF stated that it is fair to assume that the sediments were dredged with no mitigation measure in place.

Dredged Material Samples Equal to or Above Proposed EPA Criteria 6/26/73	
Parameter	Number of Samples (Total = 27)
Percent Volatile Solids	17
Chemical Oxygen Demand	11
Total Kjeldahl Nitrogen	0
Lead	1

Mercury	6
Zinc	2
Arsenic	13
Cadmium	8
Chromium	0
Copper	0
Nickel	0

Source: Stanley Consultants and D.B. McDonald Research (USACE 1976)

One of the most important factors in dredging contaminated sediments is the potential for chemicals to become resolubilized. During dredge operations, the interface between bottom sediments and water is disturbed. Therefore, the redistribution of bottom sediments that were blanketed by overlying sediments become exposed to the direct sediment/water interface. The increase in the ratio of particle surface to water, increases the potential for resolubilization of chemicals in the water. The EPA bases the dredged material criteria maximum concentrations on the likely effects on biota, plus a safety factor. The potential is likely for metals to accumulate in biota tissues and magnify up the food chain to larger more desirable game fish.

The Louisiana Wild Life and Fisheries Commission (WLFC) prepared a written statement for the Lake Pontchartrain Hurricane Protection Plan public meeting (held February 22, 1975) and this statement was provided to the USACE. The following is an excerpt that relates to salinity:

> "The proposed Seabrook Structure was designed for addition to the Mississippi Gulf Outlet to partially correct the high salinities that are occasioned in the Lake by waters from that navigation channel. This structure will provide the capability for managing salinities within the Lake. Excessive salinities in the upper part of the Lake, which were historically fresher, have caused considerable marsh deterioration and mortality of fresh water vegetation. The most spectacular evidence of this is the dead cypress trees visible from Interstate 10." (WLFC 1975)

Conclusions

T.B. Ford of the WLFC wrote in the 1956-1957 Seventh Biennial Report in reference to the WLFC's repeatedly dismissed predictions of massive environmental degradation from the MRGO…."Unfortunately, some observations would indicate that many people do not have the ability to recognize or understand the difference between the short-term changes and long-term changes. This same principle appears to hold true for benefits associated with projects. These facts of life are unfortunate because generally the people of an area or of the country or its subdivisions are called upon to pay for the cost of the changes and then must live with them." Sadly everything that Mr. Ford fought so hard to bring to light before the construction of the MRGO became the current reality for those who experienced Hurricane Katrina.

In this report we have demonstrated that construction of the MRGO, in addition to Operations and Maintenance activities, has led to one of the greatest environmental disasters in human history. When the Bayou La Loutre Ridge was cut in 1963, lethal doses of salt water crept into the Central Wetlands Unit and surrounding areas including Lake Pontchartrain. The subsequent death of baldcypress – water tupelo swamps and fresh marshes was rapid, clearly pointing to the MRGO as the cause. Through both direct and indirect influences, tens of thousands of acres of wetlands suffered conversion to open water or spoil banks. Hurricane protection offered by the cypress – tupelo swamps and surrounding marshes was erased. In addition, a 100-square mile Dead Zone was created in Lake Pontchartrain, and the effects of that Dead Zone have negative impacts on the entire Lake Maurepas – Pontchartrain estuarine ecosystem. Furthermore, decades of maintenance dredging have negatively impacted massive areas of wetland and aquatic ecosystems.

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July 11, 2008

/s/ John W. Day Jr.__
Dr. John W. Day, Jr.

/s/_Gary P. Shaffer _
Dr. Gary P. Shaffer

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July 11, 2008

Dr. John W. Day, Jr.

Dr. Gary P. Shaffer

Appendix A

Correspondence Timeline

Louisiana Wildlife Biologists Association predicted the project would create a 44-mile-long swath of destruction (USFWS 1979 letter).

December 19, 1951 Internal letter of WLFC written by the Chief Biologist J.N. Gowanloch. The letter details the frustrations of WLFC trying to give input on the MRGO and being excluded from MRGO meetings where only oil and shipping representatives were included.

May 9, 1956 L.D. Young Jr. of WLFC writes to Louisiana Congressional Delegation emphasizing the important natural resources, predicting environmental damages including saltwater intrusion. The letter requested legislation and funds for a biological study in to provide recommendations to USACE.

May 29, 1957 correspondence letter from WLFC stated construction would lead to: increases in tidal action in marsh pond areas; higher average salinities with wider salinity ranges; increased turbidity; and the filling with spoil of numerous ponds attractive to waterfowl. Furthermore, WLFC predicted in the letter that these processes would alter vegetation types and lead to land loss. In this letter the WLFC made recommendations for alternative alignments that would have less negative effects on the environment and wildlife resources.

June 4, 1957 New Orleans State Newspaper and June 5, 1957 Times Picayune articles depict that St. Bernard Police Jury is in opposition to alternative alignments proposed by WLFC because it would throttle industrial development and the "St Bernard Parish's shrimping and fishing industry would be enhanced tremendously by access to a deep-water channel along the route planned by the engineers."

September 23, 1957 Secretary of Interior informed Secretary of the Army that the USACE had violated Fish and Wildlife Coordination Act of August 14, 1946, which required that all phases of project planning be brought into balance.

September 26, 1957 New Orleans State Newspaper and September 27, 1957 Times Picayune Newspaper articles detail that the Secretary of the Interior asked in a letter to the Secretary of the Army to modify the MRGO project to minimize effects on fish and wildlife resources.

1956-1957 Seventh Biennial Report of the Wild Life and Fisheries Commission. T.B. Ford author of the article titled "River Basin Studies" expresses extreme frustration and disappointment at the dismissal of environmental impacts of MRGO and emphasizes the importance of further study to assess trade-offs of the project.

January 6, 1958 Tidewater Channel Committee of St. Bernard Parish requests assistance detailing predicted environmental effects of the MRGO from WLFC.

March 24, 1958 letter written by WLFC citing adverse environmental effects of the proposed MRGO including saltwater intrusion, siltation, rapid fluctuation of water levels and salinities, turbidity increases, etc.

December 12, 1958 Times Picayune article on St. Bernard meeting for citizens to express views on the MRGO. William Lewis, planning coordinator for the Dock Board is quoted, "This parish and its people stand in the most favorable economic and industrial position of any locality in the United States."

January 17, 1959 Times Picayune article Col. Lewis is quoted, "The tidewater channel has the same economic significance for New Orleans and adjoining St. Bernard parish that the Houston ship channel had for Houston." The article went on to say that there would be no appreciable change in hurricane tides, and property owners will receive just compensation "including payment of damages, if any."

U.S. Fish and Wildlife Service (USFWS) coordinating agency on extensive and detailed pre-project hydrology and biological studies by several agencies including:
"Special Report on Fish and Wildlife Resources" November 1957;
"Interim Report on Fish and Wildlife Resources and an Outline of Proposed Fish and Wildlife Studies" April 1958;
Reports to USACE were written May 4, 1959; July 9, 1959; January 8, 1960; July 27, 1960; September 27, 1960; January 12, 1961; December 13, 1961; May 8, 1962; September 13, 1962; September 28,1962; January 26, 1965; and February 24, 1966.

1958-1959 Eighth Biennial Report of the Louisiana Wild Life and Fisheries Commission. T.B. Ford writes that "every effort was made to secure a modification in the channel alignment to minimize damages". He continued that the USACE denied the realignment due to increased construction and maintenance costs. It is further detailed that no benefit-cost study was performed to come to this conclusion, and that provisions for rehabilitation should be included in the project cost.

July 27, 1960 (Letter Report) USFWS predicted that spoil banks would alter current patterns and result in shoaling and salinity changes over a large area and reduce the freshening effects of the Pear and Mississippi Rivers.

November 24, 1965 correspondence letter from the Citizens Committee for Hurricane Flood Control to Colonel Bowen of USACE. The letter specifically details the levees forming "a funnel, channeling all hurricane surges and wind driven water into the Intracoastal Waterway and Industrial." The letter further details mitigation measures to prevent the funnel.

March 11, 1968 1:30 pm meeting held with USACE and WLFC staff to discuss pre- and post-construction study results of the impacts of the MRGO.

August 16, 1972 correspondence letters between WLFC and the Covington Daily News link the MRGO as a primary contributing factor to declined primary productivity, specifically white shrimp landings due to changes in hydrology, sedimentology, and consequently biology.

September 28, 1972 correspondence letter from St. Bernard Parish Planning Commission to WLFC requesting assistance in detailing effects of proposed ship channel between the MRGO and the Mississippi River.

August 19, 1973 WLFC to USACE disputing that all state agencies are in favor of expanding the MRGO, detailing exacerbated environmental damages due to widening, expanding, or deepening the MRGO.

December 10, 1973 correspondence memo from within WLFC expressing frustration with USACE on the Lake Pontchartrain and Vicinity Project.

January 7, 1975 WLFC internal memo discussing the MRGO effects on oysters. Ronald Dugas, Biologist III suggests operating Industrial Locks to allow fresh water to enter and USACE compensation to oyster fisherman. He also is quoted, "The Corp is correct in pointing out the salinity increases in Lake Borgne, but less willing to point out their responsibility in this matter….It is truly distorting, discouraging, and demoralizing to have lost both directly and indirectly this vast amount of valuable marsh. We won't ever retain any marsh if they continue to cost/benefit us to death, for they have not properly accessed the true value of the marsh. I have assumed a "militaristic" defeatus attitude in the past and conceded everything above the Intracoastal as lost to concentrate on estuarine problems, but the Corp in this supreme undertaking has lowered the Intracoastal on me several valuable miles. I believe this area needs a "Protection Barrier Plan" against the Corp of Engineers."

February 22, 1975 Lake Pontchartrain Hurricane Protection Plan Public Meeting, WLFC expresses concern on dredge disposal areas and the need for the Seabrook Structure to control increased salinities caused by the MRGO.

July 1, 1975 Louisiana Wild Life and Fisheries Commision letter to Colonel Heidberg from Director J. Burton Angelle. Angelle emphasizes that the Commision truthfully predicited the environmental impacts of the MRGO, while the USACE dismissed the predictions as speculation. Angelle further accuses the USACE of extortion and threatens to bring the information before the Governor, Legislators, and the press.

May 31, 1979 United States Department of the Interior Fish and Wildlife Service provides the St. Bernard Parish Planning Commission a detailed report of environmental impacts of the MRGO including details of correspondence warning USACE of impacts.

December 15, 1998 St. Bernard Parish Council adopts resolution # 1336-12-98 to close the MRGO. The resolution details the environmental damages of hydrology, salinity,

wetland loss and erosion leaving Plaquemines, St. Bernard, and Orleans more vulnerable to tropical storms.

Corresondence Sources

Sources are provided in a separate folder on the disk.

Appendix B

Agency Comments on Dredging

Environmental Protection Agency, Region VI

Comment: We suggest that the final statement include an analysis of the benefits and costs of the three proposed operation and maintenance projects. This analysis should contain sufficient information in order to compare and weigh equally the cost of project implementation with the beneficial and adverse impacts of each action. Inclusion of a benefit/cost ration would be helpful in better understanding the economic benefits of continued operation and maintenance on the project channels and the environmental trade-offs that could occur.

Response: Because the economic studies frequently are lengthy as well as costly, and due to the relatively minor role of operation and maintenance charges, it is not considered practicable to conduct current economic analysis on operation and maintenance projects.

Comment: In order to minimize the existing adverse and future long-term (secondary) impacts of the MRGO, we recommend that mitigative measures that could reduce salinity levels in the Lake Borgne-Pontchartrain System be incorporated into the operation and maintenance of the MRGO project.

Response: The proposals for salinity control measures in the MRGO system would require authorization for new construction features. Such new construction features would require environmental and socio-economic investigation and impact analysis. Consideration of these measures in this assessment of the impacts of the project operation and maintenance is not appropriate.

Comment: The statement should contain additional information in order to allow for complete assessment of the interrelated impacts of MRGO and other local, state, and Federal projects in southern Louisiana. An environmental evaluation of the adverse and beneficial effects of the interrelated projects in the vicinity of the MRGO should be included in the final statement (GIWW, Lake Pontchartrain, and Vicinity Hurricane Protection, MRGO, Michoud Canal).

Response: The MRGO, from Mile 23 out, is the only project of those mentioned requiring annual dredging operations. Maintenance dredging of the other projects is less frequent. Lack of availability of dredging equipment and contractors tends to limit activity during any one season or year. Dredged material from the GIWW and MRGO is used for the Hurricane Protection System.

U. S. Department of Commerce, the Assistant Secretary for Science and Technology

Comment: Another possible sediment source that should be included in Section I is the marsh material released by marsh deterioration in the project area as a result of saltwater intrusion. This material may be transported to the MRGO by tidal action, storms, and hurricanes.

Response: This information has been incorporated into the text, Section I, 1.05 a. (3).

Comment: Section VI – Alternatives, should contain a discussion of possible economic use of the dredge soil.

Response: The quality, location, and cost of transportation is a limiting factor in use of this material. Large volumes of dredged materials are being used for hurricane levee construction.

U.S. Department of the Interior, Office of the Secretary, Southwest Region

Comment: Page IV-12, paragraph 3: A brief synopsis of the published results of the effects of heavy metals on the biota in other areas could be referenced and discussed in this section as they may relate to the project area.

Response: Information on the effects of heavy metals on biota is referenced in "Annotated Bibliography on Biological Effects of Metals in Aquatic Environments," Ecological Research Studies, National Environmental Research Center, U.S. Environmental Protection Agency, February, 1973. The effects in the project area would probably be similar to those documented for areas that are characteristically similar.

Louisiana Wild Life and Fisheries Commission

Comment: Dredging can produce multiple adverse effects in marsh and estuarine environments: turbidity, siltation, silt accumulation on channel bottom unsuitable for most bottom dwelling species, and resuspension of pollutants.

Response: The adverse impacts of dredging are recognized and are included in Section IV of this EIS.

Comment: Adverse effects may be heightened during storms which can flush out large volumes of anaerobic and polluted sediment layers from dredged channels into adjacent waters causing a precipitous decline in water quality. The Waters of Breton Sound of Lake Borgne could well be affected in this manner by stormwater from the MRGO and associated bayous following dredging in these channels.

Response: We recognize the potential of hurricane derived forces to redistribute large volumes of material which affect water quality.

Comment: Saltwater intrusion into normally brackish or freshwater areas is a problem of considerable magnitude which is causing significant ecological changes in the marshlands and estuaries of south Louisiana. The MRGO has contributed to this process and implementation of the proposed project would enhance the adverse effects of this channel and result in further deterioration of high quality marsh and water bottoms.

Response: This EIS recognizes the continual changes resulting from previous actions. We know of no definitive evidence which indicates that discontinuation of dredging operations would restore the salinity levels to pre-1960 conditions. Salinity control measures would require new construction features necessitating environmental and socio-economic investigation and impact analysis. Consideration of these measures in this assessment of the impacts of project operation and maintenance is not appropriate.

Appendix C: Isohalines Pre- and Post Construction of the MRGO

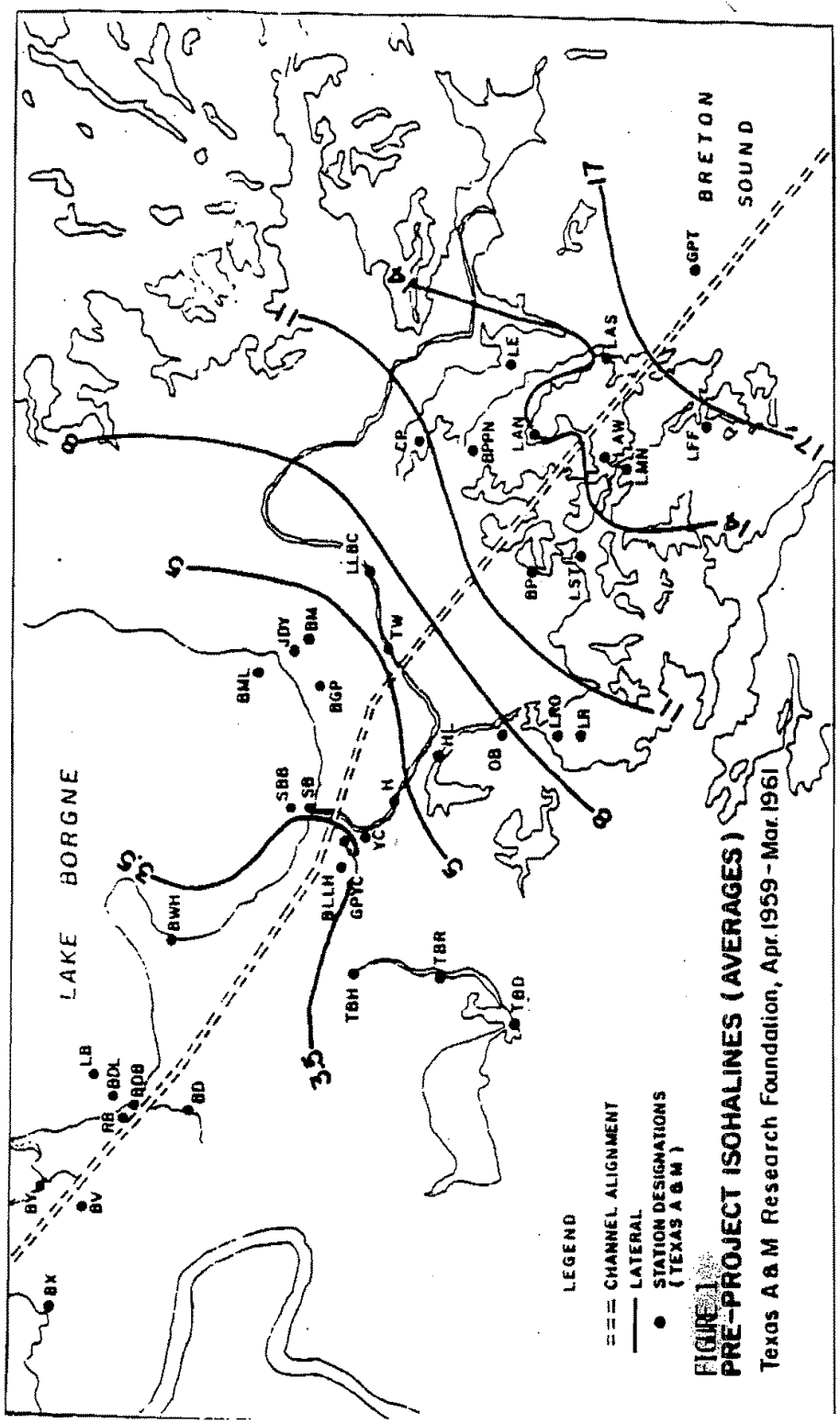


FIGURE 1
PRE-PROJECT ISOHALINES (AVERAGES)
Texas A & M Research Foundation, Apr. 1959 - Mar. 1961

LAKE BORGNE
BRETON SOUND
LEGEND
CHANNEL ALIGNMENT
LATERAL
CHANNEL
FIGURE 2
POST-PROJECT ISOHALINES (AVERAGES)
Bureau of Sport Fisheries and Wildlife, Sept. 1962–Sept. 1964
Louisiana Wild Life and Fisheries Commission, Sept. 1963–Sept. 1964

Appendix D

Mississippi River-Gulf Outlet Timeline

Work Item	**Date Completed**
Work authorized under the Act of 1956	
Work initiated	17 Mar 58
Access Channel (18 by 140 feet), GIWW to Breton Sound	27 Mar 61
Interim Channel (36 by 250 feet), Paris Road to Gulf of Mexico	5 Jul 63
Project Channel (36 by 500 feet)	
Inner Harbor Navigation Canal to Vicinity of Paris Road	7 May 59
Vicinity of Paris Road to Mile –9.4	14 Mar 65
Turning Basin (Vic. Mile 66.0) and appurtenant	
Work is physically complete	22 Jul 65
Plug at Paris Road removed (open for full operation)	20 Jan 68
High level bridge (Louisiana State Highway 47),	
initiated 1 June 1964, completed	14 Nov 67
Removal of pontoon bridge at Paris Road initiated	
24 July 1967, completed	22 Sep 67
Retention Dikes:	
Shell Core and Riprap (both dikes))	26 Aug 61
Capping (both dikes)) to Mile 20.2	29 Oct 62
Rockfacing (both dikes))	3 Nov 63
Extention of Southwest Dike to Mile 14.8 (Sta. 2700)	
1st phase, completed	
Extention of Southwest Dike to Mile 15.8 (Sta. 2650)	
2nd phase, completed	
Remaining dike across Breton Sound not yet started	
4 Prefabricated steel survey towers and 25 timber pile	
station markers	23 Jun 61
3 Concrete survey towers and 25 timber pile station	
markers	24 Jul 61

Source: Department of the Army, Condition of Improvement Report, 1973. (Full citing not found)

Appendix E

Note: Photos of construction of the MRGO from the NO Public Library including #57, #71, #109, #127, #133, #141, #163, and #266. These pictures are contained on the disk in a separate folder.



MRGO-PHOTOS-0000057



MRGO-PHOTOS-0000071



19 JAN 1959 U. S. ARMY ENGINEER DISTRICT, NEW ORLEANS. NO. 9850-10

MISSISSIPPI RIVER - GULF OUTLET

Dredging Mississippi River-Gulf Outlet 36' x 500' channel from Station 0+00 to Station 130+00. Under Contract No. DA-16-047-CIVENG-58-408 with Jahncke Service, Inc., New Orleans, La., dated 12 March 1958.

Dredging Bayou Bienvenue opposite approximately Station 160+00 on main channel.

MRGO-PHOTOS-0000109

MRGO-PHOTOS-0000127



9 JULY 1958

U. S. ARMY ENGINEER DISTRICT, NEW ORLEANS
MISSISSIPPI RIVER - GULF OUTLET

NO. 9773-13

Dredging Mississippi River-Gulf Outlet 36' x 500' channel from Station 0+00 to Station 130+00. Under Contract No. DA-16-047-CIVENG-58-408 with Jahncke Service, Inc., New Orleans, La., dated 12 March 1958.

Dredging in Bayou Bienvenue opposite vicinity Station 115+00 on main channel under construction.

MRGO-PHOTOS-0000133



9 JULY 1958

U. S. ARMY ENGINEER DISTRICT, NEW ORLEANS

NO. 9773-10

MISSISSIPPI RIVER - GULF OUTLET

Dredging Mississippi River-Gulf Outlet 36' x 500' channel from Station 0+00 to Station 130+00. Under Contract No. DA-16-047-CIVENG-58-408 with Jahncke Service, Inc., New Orleans, La., dated 12 March 1958.

View east vicinity Station 110+00. GIWW at right.

MRGO-PHOTOS-0000141



9 JULY 1958 U. S. ARMY ENGINEER DISTRICT, NEW ORLEANS NO. 9773-6

MISSISSIPPI RIVER - GULF OUTLET

Dredging Mississippi River-Gulf Outlet 36' x 500' channel from Station 0+00 to Station 130+00. Under Contract No. DA-16-047-CIVENG-58-408 with Jahncke Service, Inc., New Orleans, La., dated 12 March 1958.

View east vicinity Station 26+00. Dredge working in upper center. Spoil area for Item No. 1 at right.



24 JUNE 1958

U. S. ARMY ENGINEER DISTRICT, NEW ORLEANS

NO. 9771-10

MISSISSIPPI RIVER - GULF OUTLET

Dredging Mississippi River-Gulf Outlet 36' x 500' channel from Station 0+00 to Station 130+00. Under contract No. DA-16-047-CIVENG-58-408 with Jahncke Service, Inc., New Orleans, La., dated 12 March 1958.

Dredge PAUL F. JAHNCKE working vicinity Station 26+00.

MRGO-PHOTOS-0000163



MRGO-PHOTOS-0000266

RESEARCH AND PROFESSIONAL EXPERIENCE OF JOHN W. DAY, JR.

Recent Employment

1999-present, Distinguished Professor of Environmental Sciences, Department of Oceanography and Coastal Sciences, Louisiana State University

1980-present, Professor, Department of Oceanography and Coastal Sciences, Louisiana State University

Recent Teaching Experience

1995-present-Ecology and Management of Tropical Estuaries (in Mexico)

1995-present-Mangrove Ecology (taught irregularly)

Other Recent Experience

2000-2001, Visiting Scientist, Cambridge Coastal Research Unit, Dept. of Geography, University of Cambridge, Cambridge, UK.

1979-present, Adjunct Professor, Institute for Marine Sciences and Limnology, Universidad Nacional Autonoma de Mexico

CURRENT GRANT SUPPORT

A proposal to carry out monitoring and evaluate impacts of storm water discharge to coastal wetlands adjacent to the Pointe Aux Chiens pumping station, Terrebonne Parish, Louisiana. Barataria-Terrebonne National Estuary Program. $213,870. 9/01/02 – 8/31/04. J. Day and S. Faulkner.

Utilizing Mississippi River diversions for nutrient management in a Louisiana coastal watershed. US Dept. of Agriculture. $694,000. 8/01/02 – 7/31/05. J. Day, E. Reyes, J. Cable, and D. Justic.

RECENT EDUCATIONAL HONORS AND DISTINCTIONS

Received the 2000 Lipsey Award for Outstanding Contributions in Teaching and Professional Achievement

Editorial Board of Scientia Marina and Ecological Engineering

Co-chair, Modeling Subcommittee. Monitoring, Modeling, and Research Committee, Gulf of Mexico Program

Liaison from the NTRC to the National Academy of Sciences committee reviewing the coastal restoration program for the Mississippi delta.

J. W, Day. Invited Keynote Address. La gestion de los rios y la sostenibilidad de los deltas. Jornadas Cientificas: Del Ebro Al Segura: Planificacion Hidrologica Y Sostenibilidad. Tortosa, Spain. 22-24 March 2002

Member of the Estuarine Research Federation, Louisiana Academy of Sciences, Society of Wetland Scientists, International Society of Ecological Modeling, Society for Ecological Engineering

SELECTED RECENT PUBLICATIONS (2001-2003 IN CHRONOLIGICAL ORDER)

Reyes, E., M. White, J. Martin, P. Kemp, J. Day, and V. Aravamuthan. 2000. Landscape modeling of coastal habitat change in the Mississippi delta. Ecology. 81: 2331-2349.

Martin, J., M. White, E. Reyes, P. Kemp, H. Mashriqui, and J. Day. 2000. Evaluation of coastal management plans with a spatial model: Mississippi delta, Louisiana, USA. Environmental Management. 25: 117-129.

Day, J., G. Shaffer, L. Britsch, D. Reed, S. Hawes, and D. Cahoon. 2000. Pattern and process of land loss in the Mississippi delta: A spatial and temporal analysis of wetland habitat change. Estuaries. 23: 425-438.

Mitsch, W., J. Day, J Gilliam, P. Groffman, D. Hey, G. Randall, and N. Wang. 2001. Reducing nitrogen loading to the Gulf of Mexico from the Mississippi River basin: Strategies to counter a persistent problem. BioScience. 51(5):373-388.

Lane, R., J. Day, G. Kemp, and D. Demcheck. 2001. The 1994 experimental opening of the Bonnet Carre spillway to divert Mississippi River water into Lake Pontchartrain, Louisiana. Ecological Engineering. 17: 411-422.

Cardoch, J. W. Day, and C. Ibañez. 2002. Net primary productivity as indicator of sustainability in the Ebro and Mississippi Deltas. Ecological Applications. 12:1044-1055.

Lane, R., J. Day, G. Kemp, and B. Marx. 2002. Seasonal and spatial water quality changes in the outflow plume of the Atchafalaya River, Louisiana, USA. 2001. Estuaries. 25 (1): 30-42.

Martin, J., E. Reyes, P. Kemp, H. Mashriqui, and J. Day. 2002. Landscape modeling of the Mississippi delta. BioScience. 52: 357-365.

Poff, L., M. Brinson, and J. Day. 2002. Aquatic Ecosystems and Global Climate Change: Potential Impacts to Inland Freshwater and Coastal Wetland Ecosystems in the United States. Pew Center on Global Climate Change. Arlington, VA, 45 p.

Rybczyk, J., J. Day, and W. Conner. 2002. The impact of wastewater effluent on accretion and decomposition in a subsiding forested wetland. Wetlands. 22(1): 18-32.

Sutula, M., B. Perez, E. Reyes, D. Childers, S. Davis, J. Day, D. Rudnick, and F. Sklar. In press. Factors affecting spatial and temporal variability in material exchange between the Southeastern Everglades wetlands and Florida Bay (USA). Estuarine Coastal and Shelf Science.

Reyes E., J. F. Martin, J. W. Day, G. P. Kemp, H. Mashriqui. In Press. River forcing at work: watershed modeling of prograding and regressive deltas. Wetlands Ecology and Management.

Davis, S. E., D. L. Childers, J. W. Day, Jr., D. T. Rudnick, and F. H. Sklar. In press. Factors affecting the concentration and flux of materials in two southern Everglades mangrove wetlands. Marine Ecology Progress Series.

Reyes, E., J. F. Martin, M. L. White, J. W. day, G. P. Kemp. Habitat changes in the Mississippi Delta: future scenarios and alternatives. R. Costanza (ed.), Spatial Modeling in Coastal Environments. Island Press. Accepted.

Reyes E., J. F. Martin, M. L. White, J. W. Day, G. P. Kemp. In Press. Habitat changes in the Mississippi Delta: future scenarios and alternatives. Ch. 4. In: R. Costanza and A. Voinov (eds.). Spatially Explicit Landscape Simulation Modeling. Springer-Verlag.

* a complete publication list, including relevant publications before 1999, is available upon request*

EXPERT WITNESS (past 4 years)

Louisiana DOTD vs. Monteleone, et al., 2006-2007

Pontchartrain Levee District vs. Monteleone (case settled spring 2007)

Curriculum Vitae

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EDUCATION

University of California at Santa Barbara, B.A., Aquatic and Population Biology, June 1979
(G.P.A. 3.89 excluding freshman year)
University of California at Santa Barbara, M.A. Aquatic and Population Biology, June 1982 (G.P.A. 3.88)
Louisiana State University, Ph.D., Major: Marine Sciences (Mathematical Ecology),
Minor: Experimental Statistics, August 1986 (G.P.A. 3.77)

EXPERIENCE

1998- Director, Internet Laboratory of Biological Sciences, Contact Dr. Nick Norton, (504)549-3741.
1994- Director, Project CYPRESS, Systemic Initiatives Program, Contact Faimone Roberts, (504) 922-0690.
1993- Development Advisory Board, Global Wildlife Foundation. Contact Ken Matherne, (504) 624-WILD.
1992- Technical Advisor (Region 1 state university representative), evaluation of proposed projects under Breaux-Johnson Bill, Lake Pontchartrain Basin. Contact Dr. Jenneke Visser, (504) 388-6377.
1990- Associate Professor. Dept. of Biological Sciences, Southeastern Louisiana University. Contact Dr. W. Nick Norton, (504) 549-3741.
1987-90 Chief statistical consultant for 220 scientists at U.S.D.A. Southern Regional Research Center. Contact Dr. John A. Barkate (504) 286-4212.
1987-90 Assistant Professor, Dept. of Experimental Statistics and Coastal Ecology Institute, Louisiana State University. Contact Dr. J. G. Gosselink (504) 388-6379, or Dr. J. Geaghan (504) 388-8303.
1986-88 Seer Corporation, consulting, research and development of K-systems analysis software. Contact Dr. Bush Jones (504) 388-2191.
1986-88 Environmental Consultant, Pyburn and Odom. Contact Tim Tate (504) 766-6330.
1986 Post-doctoral Researcher, Coastal Ecology Institute. Contact Dr. J. G. Gosselink (504) 388-6379.
1985-86 Design of knowledge base for Expert System on Multivariate Statistics ("A Guide for Use in Statistical Technique Optimization" - GUSTO). Contact Dr. James Geaghan (504) 388-8303.
1977-82 Head of primary production study of aquatic macrophytes and microflora for California Wetlands Management Project. Contact Dr. Christopher P. Onuf (512) 888-3371.

AWARDS AND HONORS

Best Paper Award at the joint conference of the World Organization of Systems and Cyberntics and the International Institute of General Systems Studies. 2002
President's Award for Excellence in Research, 1996. SLU's annual career award for research productivity.
Faculty Research Award, presented for outstanding scientific manuscript at the annual meeting of the Association of Southeastern Biologists (ASB), 1993. Encompasses twelve states.
Named "Lead Ecologist" of Louisiana by the Ecological Society of America (>9,000 members) for their Ecology in Education Program, 1992.
Faculty Research Award, Association of Southeastern Biologists (ASB), 1988.
Full Member of Sigma Xi, 1987.
Graduate Student Awards: Joseph Lipsey, Sr. Memorial Scholarship, 1986; Eugene P. Odum Award, 1986; First Place Paper, Gulf Estuarine Research Society, 1986; Co-president Marine Environmental Researchers, 1983-84; Louisiana State Rockefeller Scholarship, 1983-1986; Alumni Federation Fellowship, LSU, 1982-1986; Sea Grant Fellowship, UCSB, 1980-1982.

PUBLICATIONS (Refereed Journals, Book Chapters)

Onuf, C. P., M. L. Quammen, **G. P. Shaffer**, C. H. Peterson, J. W. Chapman, J. Cermak, and R. W.Holmes. 1978. An analysis of the values of central and southern California coastal wetlands. In: Wetland Functions and Values: the State of Our Understanding, Eds. P. E. Greeson, J. R. Clark, and J. E. Clark. Amer. Water Res. Assoc., Minneapolis. 186-199.

Shaffer, G. P., and C. P. Onuf. 1983. An analysis of factors influencing the primary production of the benthic microflora in a southern California lagoon. Neth. J. Sea Res. 17(1):126-144.

Shaffer, G. P. 1984. The effect of sedimentation on the primary production of the benthic microflora. Estuaries. 7(4B):497-500.

Shaffer, G. P., and C. P. Onuf. 1985. Reducing the error in estimating annual production of benthic microflora: hourly to monthly rates, patchiness in space and time. Mar. Ecol. Prog. Ser. 26:221-231.

Shaffer, G. P., and P. Cahoon. 1987. Extracting information from ecological data containing high spatial and temporal variability. Int. J. Gen. Sys. 13:107-123.

Shaffer, G. P. 1988. K-systems analysis for determining the factors influencing benthic microfloral production in a Louisiana estuary, USA. Mar. Ecol. Prog. Ser. 43:43-54.

Shaffer, G. P. 1988. A comparison of benthic microfloral production on the west and gulf coasts of the United States: an introduction to the dynamic K-systems model. Mar. Ecol. Prog. Ser . 43:55-62.

Shaffer, G. P., and M. J. Sullivan. 1988. Water column productivity attributable to displaced benthic diatoms in well-mixed shallow estuaries J . Phycology. 24:132-140.

Delucca, A. J., **G. P. Shaffer**, and R. J. Berni. 1988. Analysis of epiphytic bacteria and endotoxin during cotton plant maturation. Am. Ind. Hyg. Assoc. J. 49:539-545.

Delucca, A. J., and **G. P. Shaffer**. 1989. A two year study of the factors influencing endotoxin levels on cotton grown in hot, humid, environments. British J. Indust. Med. 46:887-891.

Marshall, H. F., **G. P. Shaffer**, and E. J. Conkerton. 1989. An improved method for the measurement of free amino acids in peanut (Arachis hypogaea). Analytical Biochemistry. 189:2529-2534.

Ross, L. F., and **G. P. Shaffer**. 1989. The fermentation of carbohydrates by intestinal microflora from infants under aerobic and anaerobic conditions. J. Clin. Micro. 2529-2534.

Gosselink, J. G., **G. P. Shaffer**, L. C. Lee, D. M. Burdick, D. Childers, W. Conner, D. Cushman, S. Fields, S. Hamilton, M. Koch, N. Leibowitz, and J. Visser. 1990. Landscape conservation in a forested wetland watershed: can we manage cumulative impacts? BioScience 40:588-600.

Pitt, J. I., M. A. Klich, **G. P. Shaffer**, R. H. Cruickshank, J. C. Frisvad, E. G. Mullaney, A. H. S.Onions, R. A. Samson, and A. P. Williams. 1990. Differentiation of Penicellium glabrum from Penicellium spinulosum and other closely related species: an integrated taxonomic approach. System. Appl. Microbiol. 13:304-309.

Sasser, C. E., J. G. Gosselink, and **G. P. Shaffer**. 1991. Distribution of nitrogen and phosphorus in a Louisiana freshwater floating marsh. Aquatic Bot. 41:317-331.

Shaffer, G. P., D. M. Burdick, J. G. Gosselink, and L. C. Lee. 1992. A cumulative impact management plan for a forested wetland watershed in the Mississippi River Floodplain. Wetlands. Ecol. Manag.1(3):199-210.

Spanier, A.M., A.J. St. Angelo, and **G.P. Shaffer**. 1992. The response of beef flavor to oxygen depletion and a mixed antioxidant/chelator cocktail. J. Agric. Food Chem. 40(9):1656-1662.

Shaffer, G. P., C. E. Sasser, J. G. Gosselink, and M. Rejmanek. 1992. Vegetation dynamics in the emerging Atchafalaya Delta, Louisiana, USA. J. Ecology 80:677-687.

Bett, K., **G. P. Shaffer**, J.R. Vercellotti, T.H. Sanders, and P.D. Blankenship. 1993. Reducing the noise contained in descriptive sensory data. J. Sensory Studies 8:13-29.

Llewellyn, D. W., and **G. P. Shaffer**. 1993. Marsh restoration in the presence of intense herbivory: the role of Justicia lanceolata. Wetlands 13(3):176-184.

Myers, R. S, **G. P. Shaffer**, and D. W. Llewellyn. 1995. Baldcypress restoration in southeast Louisiana: the relative effects of herbivory, flooding, competition, and macronutrients. Wetlands 15(2):141-148.

Llewellyn, D. L., **Shaffer, G. P.**, N. J. Craig, D. Pashley, L.A. Creasman, and M. Swain. 1996. Restoration of the Mississippi River Alluvial Plain: a decision support system for prioritizing restoration sites. Conservation Biology 10(5):1446-1455.

Shaffer, G. P. 1997. K-systems analysis: an anti silver-bullet approach to ecosystems modeling. IIGSS. 32-39

Day, J.W. Jr. **G.P. Shaffer**, D. Britsch, D. Reed, S. Hawes, and D. Cahoon. 1999. Statistical version of Pattern and process of land loss in the Louisiana coastal zone: an analysis of spatial and temporal patterns of wetlands habitat change (published with permission of Estuaries and written by shafe). In: Recent research in coastal Louisiana: Natural system function and response to human influence. L.L. Rozas, J.A. Nyman, C. E. Proffitt, N.N. Rabalais, D.J. Reed, and R.E Turner (editors). Louisiana Sea Grant College Program, Baton Rouge, LA. p. 193-200.

Keddy, P.A. and **G.P. Shaffer**. 2000. Review of Status and Trends of the Nation's Biological Resources. (M.J. Mac, P.A. Opler, C.E. Puckett-Haecker, and P.D. Doran (eds.), 1998, U. S. Geological Survey, Department of the Interior.) Wetlands 20: 565-566.

Day, J.W., Jr., **G.P. Shaffer**, D. Britsch, D. Reed, S. Hawes, and D. Cahoon. 2000. Pattern and process of land loss in the Louisiana coastal zone: an analysis of spatial and temporal patterns of wetlands habitat change. Estuaries 23(4):425-438.

Dowty, R. A., **G.P. Shaffer**, M.W. Hester, G.W. Childers, F. M. Campo, and M.C. Greene. 2001. The phytoremediation of small-scale oil spills in fresh marsh environments: a mesocosm approach. Marine Environmental Research 52:195-211.

Souther, R.F., and **G.P. Shaffer**. 2000. The effects of submergence and light on two age classes of baldcypress (Taxodium distichum (L.) Richard) seedlings. Wetlands 20: 697-706.

Day, J.W., Jr., **G.P. Shaffer**, D. Britsch, D. Reed, S. Hawes, and D. Cahoon. 2001. Patterns and processes of land loss in coastal Louisiana are complex: a reply to Turner 2001. Estimating the indirect effects of hydrologic change on wetland loss: if the Earth is curved, then how would we know it?. Estuaries 24(4): 647-651.

Thomson, D.T., **G.P. Shaffer**, and J. A. McCorquodale. 2002. A potential interaction between sea-level rise and global warming: implications for coastal stability on the Mississippi River Deltaic Plain. Global Planetary Change 32:49-59.

Hoeppner, S.S., and **G.P Shaffer**. 2004. The K-systems glitch: granulation of predictor variables. Kybernetes: The International Journal of Systems and Cybernetics 33:962-972.

Visser, J. M., G. D. Steyer, **G. P. Shaffer**, S. S. Hoeppner, M. W. Hester, E. Reyes, P. A. Keddy I. A. Mendelsshon, C. H. Sasser, and C. Swarzenski. 2004. Habitat switching module. In: LCA Study – Main Report (Edited by Robert Twilley). US Army Corps of Engineers. New Orleans, LA.

Martin, S. B. and **G. P Shaffer**. 2005. Sagittaria biomass partitioning relative to salinity, hydrologica regime, and substrate type: implications for plant distribution patterns in coastal Louisiana, USA. Journal of Coastal Research 21(1):164-171.

Willis, J.M., M.W. Hester, and **G.P. Shaffer**. 2005. A mesocosm evaluation of processed drill cuttings for wetland restoration and creation. Ecological Engineering 25: 41-50.

Shaffer, G. P., S. S. Hoeppner, and J. G. Gosselink. 2005. The Mississippi River alluvial plain: characteriztion, degradation, and restoration. In: The World's Largest Wetlands. (Edited by L. H. Fraser and P. A. Keddy. Cambridge University Press. Pages 272-315.

Day, J.W., W.H. Conner, and **G.P. Shaffer**. 2006. The importance of pulsed physical events for sustainability of Louisana coastal forested wetlands. In: Hydrology and Management of Forested Wetlands Proceedings of the international Conference. American Society of Agricultural and Biological Engineers, St. Joseph, MI. Pages 158-166.

Keim, R.F., J.L. Chambers, M.S. Hughs, L.D. Dimov, W.H. Conner, **G.P. Shaffer**, E.S. Gardiner, and J.W. Day. (2006). Long-term success of stump sprouts in high-graded baldcypress-water tupelo swamps in the Mississippi Delta. Forest Ecology and Management 234:24-33.

Keim, R.F., J.L. Chambers, M.S. Hughes, J.A. Nyman, C.A. Miller, J.B. Amos, W.H. Conner, J.W. Day Jr., S.P. Faulkner, E.S. Gardiner, S.L. King, K.W. McLeod, and **G.P. Shaffer**. 2006. Ecological consequences of changing hydrological conditions in wetland forests of coastal Louisiana. P. 383-395 in: Coastal Environment and Water Quality, Y.J. Xu and V.P. Singh, eds. Challenges in Coastal Hydrology and Water Quality, Water Resource Publications, Highlands Ranch, Colo. 534 p.

Effler, R. S., **G.P. Shaffer**, S.S. Hoeppner, and R.A. Goyer. 2007. Ecology of the Maurepas Swamp: Effects of Salinity, Nutrients, and Insect Defoliation. In: Tidally Influenced Forested Wetlands, Eds. W.H. Conner, K.W. Kraus, and T.W. Doyle. Springer.

Faulkner, S.P., J.L. Chambers, W.H. Conner, R.F. Keim, J.W. Day, E.S. Gardiner, M.S. Hughs, , S.L. King, K.W. McLeod, C.A. Miller, J.A. Nyman, and **G.P. Shaffer**. 2007. Conservation and use of coastal wetland forests in Louisiana. In: Tidally Influenced Forested Wetlands, Edited by W.H. Conner and K.W. Kraus, and T.W. Doyle. Springer.

Keddy, P.A., D. Campbell, T. McFalls, **G.P. Shaffer**, R. Moreau, C. Dranguet, and R. Heleniak. 2007. The Wetlands of lakes Pontchartrain and Maurepas: origins, processes, and restoration. Environmental Reviews. 15:43-77.

Shaffer, G.P., Wood, W.B, Hoeppner, S.S, Perkins, T.E, Zoller, J.A, and Kandalepas, D. 2007. Degradation of Baldcypress – Water Tupelo Swamp to Marsh and Open Water in Southeastern Louisiana, USA: An Irreversible Trajectory? Journal of Coastal Research. In press.

Shaffer, G.P. and J. W. Day, Jr. 2007. Use of Freshwater Resources to Restore Baldcypress – Water Tupelo Swamps in the Upper Lake Pontchartrain Basin. White Paper. Louisiana Department of Wildlife and Fisheries.

TECHNICAL REPORTS, PROCEEDINGS (Twenty 28, available on request)

PRESENTATIONS

Invited presentations at: Gulf Coast Research Laboratory, Loyola University, Louisiana State University, University of Maryland, Mississippi State University, University of Rhode Island, Washington State University, National Wetlands Research Center, U.S. Corps. of Engineers, US Environmental Protection Agency, American Water Resources Association, LaCEPT, and conferences of the Ecological Society of America, the Estuarine Research Federation, the International Institute for System Studies, the Operations Research Society of America, Sigma Xi, the Association of Southeastern Biologists, the Society of Wetland Scientists, the World Organization of Systems and Cybernetics, and INTECOL. Present 2 to 4 papers per year at regional, national, and international conferences of the following societies: American Institute of Biological Sciences; Association of Southeastern Biologists; Ecological Society of America; Estuarine Research Federation; Gulf Estuarine Research Society; International Association for Landscape Ecology; Society of Wetland Scientists; Coastal and Estuarine Habitat restoration; World Organization of Systems and Cybernetics.

GRANTS AND CONTRACTS (*not* including University match)

Shaffer, G. P. 1987-1990. Statistical consulting. USDA, Southern Regional Research Center. $63,950.

Gosselink, J. G., **G. P. Shaffer**, and C. E. Sasser. 1990. Role of Herbivory in Controlling Plant Succession in an Emerging Coastal Delta. Sea Grant Project R/MPE-48/PD. $22,859.

Shaffer, G. P., and D. W. Llewellyn. 1991. A Landscape Restoration Plan for the Bottomland Hardwood Forests of the Lower Mississippi River Valley, U.S.A. The Louisiana Nature Conservancy. $62,558.

Shaffer, G. P. 1991. The Role of Nutria in Controlling Freshmarsh Vegetation Associations and the Potential for Utilizing Herbivore-resistant Vegetation in Marsh Restoration Efforts. Sea Grant Project R/MPE-61-PD. $13,660.

Shaffer, G. P. 1991-1998. **Fifteen** grants on cypress and marsh restoration. Southeastern Louisiana University Faculty Development Grant. $30,000.

Shaffer, G. P. 1992. Endotoxin in Cotton: A Multivariate Statistical Analysis. USDA. $3,500.

Shaffer, G. P. 1992-95. A Hierarchical Approach to Cypress and Marsh Restoration in the Manchac/Maurepas area: From Landscape Planning to Consideration of Local Herbivores. LEQSF Research and Development Program. $94,904.

Shaffer, G. P. 1993. Statistical and Ecological Consulting. USACE. $1,800. Lee Wilson & Assoc. $2,624.

Shaffer, G. P. 1993. Restoration of the "Prairie" in the Manchac Wildlife Management Area: Creation of Floating Marsh. Orr Memorial Research Grant.

Llewellyn, D. W., and **G. P. Shaffer**. 1994-95. Analyzing Global Change Through Dendrochronolgy Using Remote Sensing Techniques. U.S. Forest Service. $26,098.

Childers, G. W., Bancroft, K., and **G. P. Shaffer**. 1994-96. Bioremediation Protocol for Small-Scale Oil Spills in Louisiana Wetlands. OSRADP. $75,000.

Shaffer, G. P., and G. Purdy. 1994-95. Wetlands Creation for Science Education and Endangered Species Habitat at the Global Wildlife Center: Critical Manipulation of Water Levels. $4,837.

Shaffer, G. P. 1995-96. Discovering Science: An Experimental Arena for the Students of Southeastern. SLU Enhancement Funds. $25,000.

Shaffer, G. P., and Diana Hastings. 1996. Exploring Wetland and Estuarine Micro-Ecosystems in the Classroom: A Technique for Improving Science-Fair Projects. SLU Teacher/Researcher Prg. $2,000.

Llewellyn, D. W. and **G. P. Shaffer**. 1995-96. Adventitious root development, carbon dioxide enrichment, and natural regeneration of *Taxodium distichum* (baldcypress). U.S. Forest Service. $10,000.

Shaffer, G. P. 1995-96. Statistical and Ecological Consulting. LUMCON for CWPPRA. $6,500.

Shaffer, G. P. 1996-97. Statistical and Ecological Consulting. LUMCON for CWPPRA. $4,300.

Shaffer, G. P., M. W. Hester, and G. W. Childers. 1996-97. Use of Restored Drilled Cuttings for Marsh Creation: A Mesocosm Approach. Department of Energy (DOE). $50,000.

Shaffer, G. P., M. W. Hester, and G. W. Childers. 1997. Restored Drilled Cuttings for Marsh Creation: Extension and Expansion of a Mesocosm Approach to Emulate Field Conditions Under Varying Hydrologic Regimes. DOE. $24,998.

Shaffer, G. P., M. C. Greene, and M. White. 1997. A PerPetual Learning Environment (APPLE) for the Department of Biological Sciences at Southeastern Louisiana University. LEQSF. $51,000.

Clausen, S., **Shaffer, G. P.,** Childers, G. W., and R. Moffett. 1997. The Edward G. Schlieder Endowed Chair

of Environmental Studies. Edward G. Schlieder Foundation and LEQSF matching funds. $1,000,000.

Shaffer, G. P. and M. W. Hester. 1997-1998. Coast 2050 Consulting Team. LADNR. $30,620.

Shaffer, **G. P**., M. Hester, and G. W. Childers. 1998-2000. Use of Restored Drilled Cuttings for Marsh Creation: A Field Demonstration Study. DOE. $225,567.

Shaffer, G. P., and E. Simoneaux 1994-2001. Project CYPRESS: Using Wetlands Ecology as a Vehicle for Teaching Mathematics and Science in Louisiana. **Funded 7 times**. NSF (LaSIP). $1,153,000.

Shaffer, G. P. 1998-99. Regeneration of Baldcypress (Taxodium distichum (L.) Richard) Clearcuts and the effects of Submergence, Salinity Pulses, and Light Regime on Various Age Classes of Baldcypress Seedlings. US Forest Service. $11,600.

Souther, R. F., and **Shaffer, G. P.** 1998. Submergence Restrictions on Baldcypress Seedlings. OSCAR. $1,500.

Siccard, R., and **Shaffer, G. P.** 1998. Competition between Three Sagittarias Under Variable Levels of Flooding, Salinity, and Substrate Type. OSCAR. $1,500.

Shaffer, G. P. 1998-99. Statistical and Ecological Consulting for CWPPRA. LUMCON. $9,692.

Martin, G, G., and **G.P. Shaffer**. 1999-2000. Mitigation of 180 acres of balcypress swamp at Sawgrass Bayou and in the Lake Maurepas Basin. Wilprise Pipeline Co. $450,000.

Shaffer, G. P. 1999-2,000. Statistical and Ecological Consulting for CWPPRA: Science Advisor for Complex Projects. CWPPRA. $9,392.

Hester, M., and **G.P. Shaffer**. 1999-2000Analytical Assessment of Novel Substrates for Marsh Creation. Argonne National Laboratory. $43,000.

Shaffer, G.P., M.W. Hester, W.H. Conner, and P.A. Keddy. 2000. A Feasibility Study for a Freshwater Diversion into the Maurepas swamps. LUMCON (EPA, project sponsor). $127,000.

Keddy, P. A., M.W. Hester, **G. P. Shaffer**, W. Font, A. Cheek, P. Stouffer, R. Hastings, R, Moreau, D. Dardis, and W. Norton. 2001. Ecology and Restoration Potential of the Manchac Wetlands. EPA. $186,117 (Shaffer)

Keddy, P. A., M.W. Hester, **G. P. Shaffer**, G. W. Childers, G. Howard, B. Crother, and W. Norton. 2001. Ecology and Restoration Potential of the Manchac Area Wetlands, Phase II. EPA. $134,000 (Shaffer)

Shaffer, G.P. 2001. A Feasibility Study for a Freshwater Diversion into the Maurepas Swamps: Phase 0. LUMCON (EPA, project sponsor, CWPPRA funded). $56,000.

Hoeppner, S. S., and **G.P. Shaffer**. 2001. Lake Maurepas Freshwater Diversion Feasibility Study. EPA STAR Fellowship, $28,586.

Shaffer, G.P. and S.S. Hoeppner. 2001. A Feasibility Study for a Diversion into the Maurepas Swamps: Interim Study Period, April-December, 2001. EPA, $93,751.

Shaffer, G.P. and S. L. Howell. 2001. Studying Noctural Behavior Through the Use of Infra Red Photographic Technology. Student Technology Fee. $2,992.

Shaffer, G.P. and S.S. Hoeppner. 2002-03. Phase 1 Feasibility Study for a Diversion into the Maurepas Swamps. EPA, $108,075.

Shaffer, G.P. 2001-2002. Adaptive Management Team Statistical Consultant. DNR. $25,000.

Shaffer, G.P. 2002-2003. CWPPRA Science Advisor. LUMCON $13,600.

Shaffer, G.P. 2003-2005. Consultant and model builder for the LCA document. ULL and DNR. $28,852.

Shaffer, G.P. 2003. Expert Swamp Ecologist for Barataria Diversion. EPA. $11,436.

Shaffer, G.P. and T. Perkins. 2003. Technological Upgrade for the Wetlands Restoration Laboratory. SLU Student Technology Fee Large Projects Grant. $12, 277.

Shaffer, G.P. and J. Day 2003. Monitoring, Experimentation, and Modeling Environmental Stressors in the Swamps of Lake Maurepas. CREST. $54,742.

Shaffer, G.P. and P.A. Keddy. 2003. Habitat-State Change in the Wetlands of Lake Pontchartrain Basin: From Species Associations to Ecosystem Responses Under Different Diversion Scenarios. LPBRA, NOAA. $159,777.

Shaffer, G.P. 2003. A Whole-System Approach for Restoring the Wetlands of the Western Lake Pontchartrain Basin. EPA. $340,000.

Shaffer, G.P. 2004-. Ecological Consultant – CWPPRA Monitoring Program. DNR. $22,800.

Shaffer, G.P. and P.A. Keddy. 2004-2006. Habitat-State Change in the Wetlands of Lake Pontchartrain Basin: From Species Associations to Ecosystem Responses Under Different Diversion Scenarios. LPBRA,NOAA. $136,318.

Shaffer, G.P. 2006-2008. De-energizing Storms with Cypress/Tupelo Buffers: A Plan to Restore the Repressed Swamps of the Lake Pontchartrain Basin by Using Point and Nonpoint Sources of Freshwater. EPA (PBRP). $148,600.

Shaffer, G.P. 2006-2007. Habitat State Change and the Effects of Hurricanes Katrina and Rita on Aboveground

Turnover in the Manchac/Maurepas Wetlands Under Varying Restoration Scenarios. CREST $74,830.

Shaffer, G.P. 2006-2007. Reducing Hurricane-Damage in the Lake Pontchartrain Basin by Using Point Sources of Freshwater to Regenerate Cypress – Tupelo Swamps: A Demonstration Project. NOAA (PRP). $122,365.

Shaffer, G.P. 2007-2008. Restoring Baldcypress – Water Tupelo Swamps in Assimilation Wetlands and Locating Other Potential Sites by Creating the Basin-Wide Swamp Sustainability Map. $118,704.

TEACHING EXPERIENCE

Applied Biostatistics (undergraduate-graduate level (UG)); Botany (U); Biological Science for Teachers (G), Ecology (U); Ecological Methods (U); Estuarine Ecology (G); Experimental Design (G); Experimental Design for Teachers (G); Experimental Statistics for Agricultural Sciences - I, II (G); Foundations of Biology (U); Multivariate Statistics (G); Plant Ecology (UG); Simulation Modeling (UG); Statistical Techniques for Environmental Sciences - I, II (G); Science for Teachers (G); Wetlands Ecology (UG).

OTHER TEACHING INTERESTS

SAS Programming I, II; Geographic Information Systems; Landscape Ecology; Aquatic Ecology; Phycology.

REVIEWER

American Journal of Botany, Diatom Research, Estuaries, Journal of Experimental Botany, Journal of Experimental Marine Biology and Ecology, JGR Oceans, Journal of Phycology, Marine Ecology - Progress Series, WETLANDS, Mississippi-Alabama Sea Grant proposals, National Wetlands Research Center, National Oceanic and Atmospheric Administration proposal, Louisiana Agricultural Experiment Station proposals, many peer reviews for colleagues.

EXPERT WITNESS (past 4 years)

Louisiana DOTD vs. Monteleone, et al., 2006-2007

Pontchartrain Levee District vs. Monteleone (case settled spring 2007)