The MRGO Navigation Project: A Massive Human-Induced Environmental, Economic, and Storm Disaster

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ABSTRACT

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It is generally felt in the water resources community that the most significant twenty-first century public works projects will be those undertaken to correct environmental damage caused by twentieth century projects. A second axiom is that the switch from economic development to restoration and mitigation, what we call redemption, often will be precipitated by disaster. Finally, it must be expected that the repair project will cost far more than the initial public investment but also may have economic revitalization potential far exceeding anticipated environmental benefits. We examine this cycle for the federally funded Mississippi River Gulf Outlet (MRGO) navigation project east of New Orleans, beginning with its much heralded birth in 1963 as a 122 km long free-flowing tidal canal connecting New Orleans to the Gulf of Mexico and ending with its recent de-authorization and closure. We track the direct and indirect effects of the project through its commercial failure, and then on to the official denial, the pervasive environmental impacts, and finally exposure of its role in flooding New Orleans during Hurricane Betsy in 1965 and more seriously during Hurricane Katrina in 2005. Post de-authorization planning to curtail continuing environmental and economic damage now offers an opportunity to apply lessons that have been learned and to reinstate natural processes that were disrupted or interrupted by the MRGO during the half-century of its operation. One surprising outcome is that the restoration program may turn out to be more commercially successful than the original navigation project, which was conceived as an agent of economic transformation. The U.S. Army Core of Engineers still does not acknowledge, even in the face of compelling scientific evidence, that the MRGO project was a significant cause of early and catastrophic flooding of the Upper and Lower 9th Wards, St. Bernard Parish, and New Orleans East during Hurricane Katrina. A modeling effort that removed the MRGO from the landscape, and restored the cypress swamps and marshes killed by the MRGO, reduced flooding from Hurricane Katrina by 80%. We conclude that the MRGO spelled the difference between localized flooding, and the catastrophe that killed 1464 people and inflicted tens of billions of dollars of property damages. If the MRGO-caused economic damages associated with Hurricanes Betsy and Katrina are combined with those of construction, operation and maintenance, and wetlands destroyed, then the total economic cost of the MRGO is in the *hundreds of billions of dollars*.

ADDITIONAL INDEX WORDS: *Mississippi River Gulf Outlet, Hurricane Katrina, baldcypress, hurricane buffer, U.S. Army Corps of Engineers, environmental disaster, saltwater intrusion, dead zone, storm impacts.*

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INTRODUCTION

The Mississippi River Gulf Outlet (MRGO) is a 122 km long deep-draft shipping channel constructed in the early 1960s that connected thousands of hectares of storm-surge reducing baldcypress swamps and fresh marshes directly to the Gulf of Mexico. The navigation channel was constructed to shorten the travel time from the Gulf to the Port of New Orleans and its "levees" were originally thought to be suitable for economic development.

The primary purposes of this review are to demonstrate (1) that the environmental impacts brought on by the MRGO were known and ignored by the U.S. Army Corps of Engineers (USACE), prior to its construction, (2) that these impacts were indeed a direct or indirect result of the MRGO, and specifically, (3) that the MRGO was a substantial contributing factor to the destructive flooding in Orleans and St. Bernard parishes during Hurricanes Betsy and Katrina.

Development of the Mississippi Delta

An understanding of the formation and functioning of the Mississippi Delta is critical to appreciating the impacts of the MRGO. During the twentieth century, there was a massive loss of coastal wetlands, both marshes and forested wetlands, in the delta. Most research has focused on marsh loss (*i.e.*, Day *et al.,* 2000; 2007), but more attention has recently been focused on coastal forested wetland loss (Chambers *et al.,* 2005; Shaffer *et al.,* 2009). To understand the causes of this loss and plans for restoration, we will put these processes into a conceptual framework of deltaic ecosystem functioning. The Mississippi Delta formed over the past 5000 to 6000 years as a series of overlapping delta lobes nourished by distributary channels. Ridges associated with active and abandoned channels divide the coast into interdistributary basins (Day *et al.,* 2000, 2007; Roberts, 1997). These ridges prevent exchange between basins, but there was strong riverine input into the basins. Historically, wetland area increased in active deltaic lobes and decreased in abandoned lobes, but prior to the twentieth century there was generally a net increase in the area of wetlands over the past several thousand years (Day *et al.,* 2007; Shaffer, Hoeppner, and Gosselink, 2005). The delta network efficiently retained about 25% of sediment input (Kesel, Yodis, and McCraw, 1992; Tornquist *et al.,* 2007).

The MRGO study area (Figure 1) is part of the Pontchartrain Basin, which is located between the Mississippi and Pearl rivers with Pleistocene uplands north of Lakes Pontchartrain and Maurepas. The current Mississippi channel in southeastern Louisiana first formed as part of the St. Bernard delta complex between about 1000–3000 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.

A number of factors served to enhance the growth of the delta and retard its deterioration, including strong sediment and water input to the delta plain via functioning distributaries, overbank flooding, and crevasse splays. Significant parts of most delta lobes have been incorporated into the current delta as a system of overlapping and interwoven natural levee ridges and barrier islands that formed a skeletal framework within which the delta plain developed (Kesel, 1989; Kesel, Yodis, and McCraw, 1992). This framework was critically important in protecting baldcypress–water tupelo (*Taxodium distichum–Nyssa aquatica*) swamps and other freshwater wetlands in the study area from saltwater intrusion.

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 (for reviews of these issues, see Boesch *et al.,* 1994, 2006; Day *et al.,* 2000, 2007; Tornquist *et al.,* 2007). 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 in coastal Louisiana including flood-control levees and closure of most active distributaries that eliminated most riverine input to the delta plain (Boesch *et al.,* 1994; Day *et al.,* 2000, 2007). Most river sediments are lost to deep waters of the Gulf of Mexico. There also has been a reduction of at least 50% of the suspended sediment load in the river (Kesel, 1988, 1989; Meade, 1995). As a result of these activities, most wetlands of the Pontchartrain Basin have been cut off from the river since the early twentieth century.

Within the delta, about 15,000 km of canals led to pervasive alterations of hydrology (Day *et al.,* 2000; Turner, Costanza, and Schaife, 1982). Canal spoil banks interrupt sheet flow, impound water, and cause deterioration of wetlands. Long, deep navigation channels lessen freshwater retention time and allow greater inland penetration of salt water. The MRGO offers a textbook example of this destructive process.

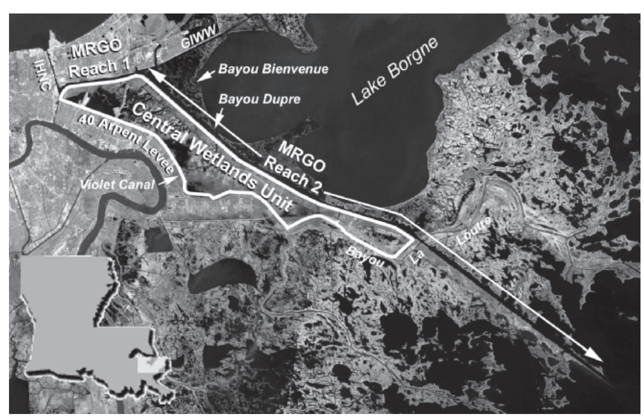

Figure 1. The MRGO Project from the IHNC lock in New Orleans to the Gulf of Mexico. Reach 1 extends from the IHNC to the turn southeast at the GIWW, and Reach 2 runs through the marsh southeast to the Gulf of Mexico. Other features include the CWU largely destroyed by the MRGO, the Bayou La Loutre and its ridge, the 40 Arpent levee, and Bayous Bienvenue and Dupres.

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 (Boesch *et al.,* 1994; Day and Templet, 1989; Day *et al.,* 1995, 1997; Turner and Cahoon, 1987). 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. In general, where deep straight navigation channels affect the local hydrology, accelerated land loss in freshwater wetlands is associated with dredging activities in the channel (Day *et al.,* 2000; Steyer *et al.,* 2008).

Coastal Basins and Vegetation Zones of the Mississippi Delta

Penfound and Hathaway (1938) studied wetland communities in the New Orleans vicinity and 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 vegetation in their classification and, with respect to baldcypress, they reported that "all available evidence points to salt water … as the destructive agent" for ghost forests in the Lake Pontchartrain–Lake Borgne region. Subsequently, a series of maps (Chabreck, Joanen, and Palmisano, 1968; Chabreck and Linscombe, 1978, 1988; Chabreck and Palmisano, 1973; O'Neil, 1949) classified coastal marshes into fresh, intermediate, brackish, and saline based generally on Penfound and Hathaway's descriptions. In general, plant species diversity increases from saline marshes to fresh marshes and swamps. More recently, Visser and colleagues have described these vegetation associations in more detail (Visser *et al.,* 1998, 1999, 2000, 2002).

Freshwater forested wetlands or swamps contain a variety of trees, shrubs, vines, and herbaceous species. Baldcypress (*Taxodium distichum*) and water tupelo (*Nyssa aquatic*) are two of the most common species. Although baldcypress occurs in freshwater forested wetlands, it can tolerate salinities less than 5 ppt (Chambers *et al.,* 2005; Penfold and Hathaway, 1938).

Both Chabreck (1970) and Palmisano (1970) stated that saltwater intrusion into fresh and brackish marshes resulted in maximum loss of marsh, and a subsequent study 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" (Coastal Environments, Inc., 1973). 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 affected by the MRGO includes the Central Wetlands Unit (CWU), wetlands around Lake Borgne, and north and south of the Bayou La Loutre (Figure 1) natural levee ridge. Before the MRGO, there were extensive baldcypress–water tupelo swamps in the CWU and adjacent to the Bayou La Loutre ridge. Water exchange between these freshwater areas and nearby brackish Lake Borgne occurred through shallow winding bayous. Local precipitation and runoff from adjacent uplands, combined with the semienclosed nature of the area (offered by the La Loutre ridge), maintained primarily fresh conditions in the CWU and a gradual salinity gradient to Lake Borgne. Aerial photographs taken by the USACE in the late 1950s and early 1960s during construction of the MRGO document thousands of hectares of baldcypress–water tupelo swamps, oaks, and other trees along bayous, and extensive expanses of dense, tall marsh vegetation, most likely characterized by roseaucane (*Phragmites australis*), giant cutgrass (*Zizaniopsis miliacea*), and big cordgrass (*Spartina cynosuroides*) (Penfound and Hathaway, 1938; Russel *et al.,* 1936). Although some wetland loss in the CWU would have occurred without construction of the MRGO, had the MRGO not been built, freshwater conditions, combined with sheet flow that selects for the previously mentioned marsh vegetation, would have been maintained.

Logging Old-Growth Baldcypress–Water Tupelo Swamps

Large-scale commercial logging of baldcypress–water tupelo swamps was driven by changes in legislation and technology. 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 began in 1889 with the invention of pullboat logging (Mancil, 1980; Perrin, 1983). Pullboats used cables and winches to winch logs to open water along logging "runs" spaced about 45 m apart. This carved logging runs approximately 2 m deep, leaving either parallel or wagon wheel–shaped markings that are still visible today. Most cutover swamps in coastal Louisiana, including those logged between 1912 and 1920 in the CWU (Figure 1) (Nuttall, 1950), regenerated in second-growth forests (Winters, Ward, and Eldredge, 1943).

Surge Buffering Effects of Wetlands

There was general knowledge prior to the construction of the MRGO that wetlands buffer storm surge as evidenced in a report of the Tidewater Channel Advisory Committee to the St. Bernard Police Jury:

> 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 (St. Bernard Police Jury, 1957).

Since the middle of the twentieth century, there has been an understanding that wetlands buffer storm surge. The USACE (1965) published a graph that showed that, on average, land lying between the coast and human inhabitants reduced storm surge by 6.9 cm/km (or 1 ft/2.75 miles). This regression is based on hurricanes hitting the Louisiana coast from 1909 to 1957.

Baldcypress–water tupelo swamps are far superior to most other wetland habitat types for storm-surge and wind-damage reduction. Only live oak (*Quercus virginica*) and palms (*Palmae*) are more resistant to wind throw (*i.e.,* blow down) than baldcypress and water tupelo (Williams *et al.,* 1999). Cypress–tupelo swamps fared far better than other forest types in Hurricanes Camille (Touliatos and Roth, 1971), Andrew (Doyle *et al.,* 1995), and Hugo (Gresham, Williams, and Lipscomb, 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 2) (Chambers *et al.,* 2007).

Emergent canopies, such as provided by forested wetlands, greatly diminish wind penetration, thereby reducing the wind stress available to generate surface waves as well as storm surge. Mangroves have been shown to reduce wave heights by 20% over distances of only 100 m (Mazda *et al.,* 1997, 2006) and 150 m of *Rhizophora*-dominated forest can dissipate wave energy by 50% (Brinkman *et al.,* 1997). More recently, Krauss *et al.* (2009) measured 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, there was an average of about 10 km of wetlands between Orleans and St. Bernard parishes and Lake Borgne. Therefore these wetlands had the capacity to reduce storm surge by about 1.35 m (4.5 ft). Because a considerable portion of these wetlands was baldcypress–water tupelo swamp, the reduction of storm surge would likely 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; van Heerden *et al.,* 2007).

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.

Effects of Saltwater Intrusion

The impacts of increasing salinity into fresh to low salinity wetlands, including baldcypress–water tupelo swamps, are threefold: direct osmotic imbalance, salt toxicity, and production in the soils of highly toxic sulfides. The lethal effects of salt water on freshwater wetland vegetation were known long before the initial construction of the MRGO (Penfound and Hathaway, 1938). Although baldcypress and water tupelo 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.,* 2009). Therefore, they require a reliable source of fresh water for system flushing following tropical storm events and during droughts. The MRGO led to increased salinity in the CWU and adjacent areas, which stressed and killed baldcypress and water tupelo.

Water budgets for southeastern Louisiana show that about one-third of rainfall remains after evaporation (Brantley, 2005; Shaffer and Day, 2007) (Figure 3). Thus, there was sufficient freshwater input to maintain the baldcypress–water tupelo swamps in the CWU because the system did not have a direct input of salt water. These swamps typically survived for centuries and certainly endured many periods of

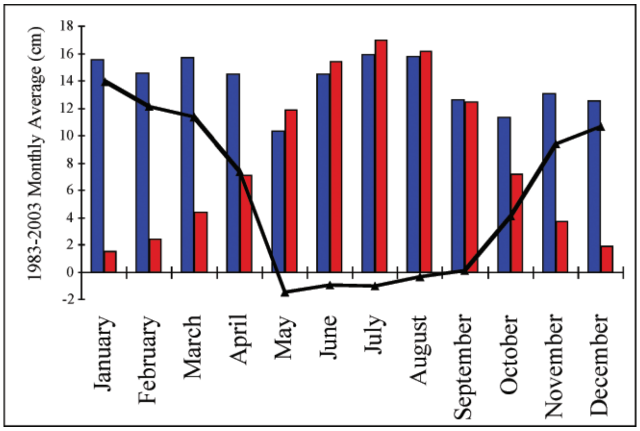

Figure 3. Average rainfall (blue), potential evapotranspiration (red), and net surplus and deficit (black line) for the western area of Lake Pontchartrain (from Shaffer and Day, 2007). Additional sources of freshwater (such as treated effluent, upland runoff, river water from the Industrial Canal lock or Violet diversion) can lower the impact of the summer freshwater deficit.

drought. Extensive mortality of swamps in the CWU and adjacent areas began shortly after the opening of the MRGO when the channel cut through the natural ridge at Bayou La Loutre and allowed saltwater intrusion into the CWU and adjacent areas (van Heerden *et al.,* 2007).

EVOLUTION OF UNDERSTANDING OF THE MRGO IMPACTS

Beginning prior to the construction of the MRGO and continuing up until the present, there has been a fairly detailed understanding of the impacts associated with its construction (Appendix I). In this section, we provide a brief history of concerns about the MRGO.

Both the U.S. Fish and Wildlife Service (USFWS) and the Louisiana Department of Wildlife and Fisheries warned the USACE that construction of the MRGO could have detrimental effects on the surrounding flora and fauna. "The Louisiana Wildlife Biologists Association predicted the project would create a 70-km long swath of destruction" (USFWS 1979 letter references the 1957 letter). In a report to the 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 hectares 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 the 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 (van Heerden *et al.,* 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 (van Heerden *et al.,* 2007). Furthermore, the USFWS (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 the construction that lead to massive wetlands destruction. After construction of the MRGO, the USACE failed to consider consistent warnings and suggestions that actions be taken to reverse the detrimental impacts of the channel (Appendix I).

ENVIRONMENTAL IMPACTS OF THE MRGO

The construction of the MRGO resulted in a number of pervasive and interacting environmental impacts ranging from physical disruption of the landscape, hydrological changes, and effects on the biota of the area. These impacts are summarized here.

Dredging

The construction of the MRGO resulted in a 122 km deep-water channel that directly connected offshore, high salinity waters of the Gulf of Mexico with low salinity and freshwater habitats in northern St. Bernard Parish and Orleans Parish. The channel cut through a number of natural ridges, most importantly that of Bayou La Loutre, that protected fresher habitats from direct saltwater intrusion.

The Louisiana Wildlife and Fisheries Commission (1957) detailed the predicted effects of the MRGO to the USACE. Furthermore, the USACE (1976) detailed the following effects in their own statements and reports:

(1) Initial loss of 16,183 acres of marshland for dredged material deposition
(2) Negative effects on aquatic species in the 17,600 acres of designated disposal areas
(3) Continued impacts with each dredge operation on 10,611 acres
(4) Increases in local water turbidity
(5) Deposition of dredged material over aquatic and terrestrial organisms
(6) Disturbance of bottom dwelling biota in the dredge operation
(7) Creation of disposal areas elevated above the adjacent marshlands, thus disturbing the natural flow of water in the wetlands
(8) Potential for resolubilization of chemicals causing local and neighboring biota exposure
(9) Effects that would cause plant species at disposal sites to remain in a pioneer stage of development

The USACE further stated:

> 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).

Operation and Maintenance

The federal government has spent approximately $115 million on only the low-maintenance dredging of the MRGO. 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 annually 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 the 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 restrict the ability of the parish to use the MRGO spoil bank for urban development.

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 (Figure 4) and dramatically increase sediment deposition on the channel bottom. This was due to the channel being originally dredged with 1 : 2 side slopes. The local substrate is not capable of supporting this slope, causing the sides to slump inward and erode, filling the bottom until an equilibrium is reached (the angle of repose). In areas such as the throat of Reach 1 (Figure 5), the channel eroded from approximately 200 m wide to over 900 m wide. Deteriorating wetlands were another major sediment source that was transported to the MRGO by tidal action, storms, and hurricanes. Thus, deteriorating wetlands, ship traffic on 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 as well as the public's economic investment.

Volume of Dredge Material

From 1965 to 1976, not including work associated with hurricanes, O&M dredging resulted in an average of 3,154,224 m^3 of material dredged from the inland section per year, and 2,745,131 m^3/y dredged from the offshore section of the MRGO. Records from the period further indicate that in actuality 12.8 million cubic meters per year (mcmy) were moved, including the material used for flood-works construction. The environmental statement for operations and maintenance (O&M) estimated that the overall annual volume of material dredged on the MRGO would be 9.2 mcmy (USACE, 1976). This material is disposed on land and in open water (USACE, 1976), smothering sessile organisms as well as resuspending toxins (see heavy metals section). This indicates that ongoing operation and maintenance of the channel continued to have detrimental effects on biota over the decades, up to 2006 when dredging ceased.

Figure 4. Widening of the MRGO channel from 1959 to 2008 near Bayou Mercier. Red dot marks the same location in both photographs.

Impacts of MRGO on 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 former Mississippi River distributaries: Bayou Savage, Bayou Terre aux Boufs, and Bayou La Loutre (Wicker *et al.,* 1982). The environment was 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. Furthermore, the Bayou La Loutre ridge helped to retain fresh water and prevent salt water intrusion from Breton Sound. In addition, salt water from Breton Sound was (and is) freshened by influences from the Pearl River and other local rivers that deliver fresh water through Lake Pontchartrain into Lake Borgne. Therefore, water levels and salinity changed very gradually with rainfall and tidal conditions.

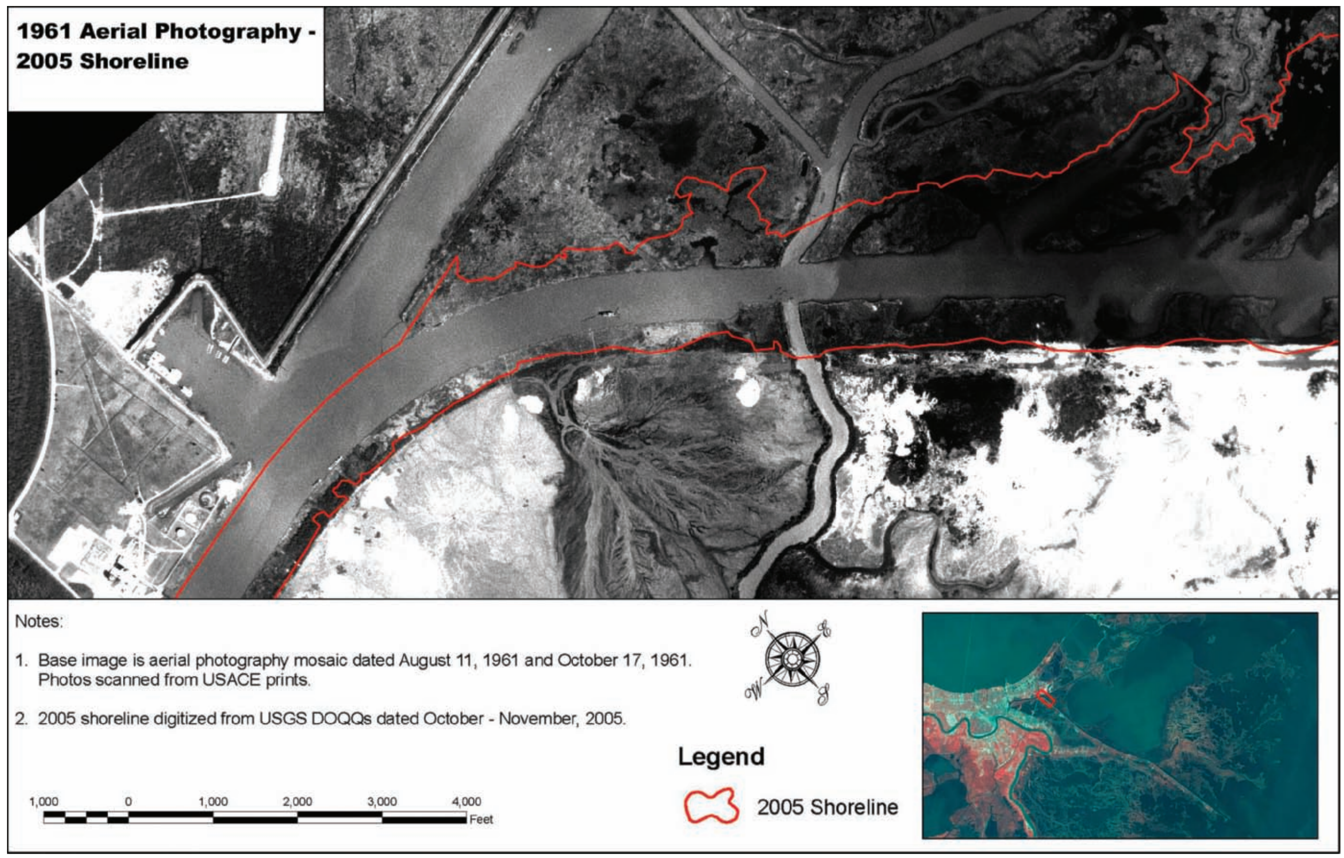

Figure 5. Widening of the MRGO near juncture of the GIWW and the MRGO from 1961 to 2005.

The USFWS determined, prior to construction, that detailed studies were needed to fully understand the effect of the planned MRGO on fish and wildlife resources (Appendix I and USFWS letters cited previously). The USFWS became the coordinating agency for extensive and detailed preproject 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 "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 interaction and exchange between subareas, existing variations in hydrology to enable forecasting of extremes in variation due to the planned project, and sampling of aquatic fauna and hydrology to consider the potential biological effects of environmental changes due to the project.

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 CWU, kept salinities low enough to allow the baldcypress–water tupelo swamps 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 the MRGO.

Salinity

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 changes in hydrology resulted in much more rapid water exchange allowing fresh water to drain quickly during low tide and be quickly replaced by saline waters at high tide (Figure 6) (Wicker *et al.,* 1982). As a result, there was increased salinity all the way up to the Gulf Intracoastal Waterway (GIWW) and Lake Pontchartrain (Table 1).

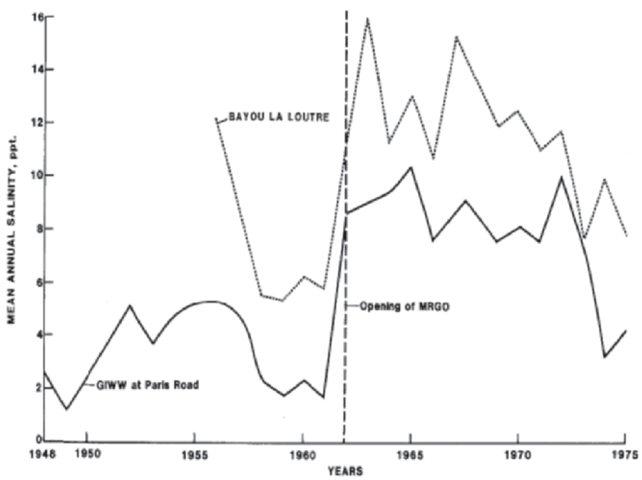

Figure 6. Mean annual salinity for the GIWW prior to, and after, the opening of the MRGO (Wicker *et al.,* 1982).

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). As a result, the USACE designed a gated structure at the junction of the Inner Harbor Navigation Canal (IHNC) and Lake Pontchartrain (USACE, 1963; Plate 34, p. 91). Had this structure been built, the impacts on Lake Pontchartrain described later could have been avoided.

Wetland Habitat Change and Loss Caused by MRGO Construction

In general, wetland loss in coastal Louisiana is a process where change takes place relatively gradually, but continually (Barras, Bourgeois, and Handley, 1994; Barras *et al.,* 2003). In contrast, wetland change in the CWU and adjacent areas was much more rapid after construction of the MRGO. Prior to construction of the MRGO, the CWU consisted primarily of baldcypress–water tupelo swamp and fresh marsh, transitioning to brackish marsh to the east (Figure 7, top; USGS topographic maps, O'Neal, 1949). Shortly following construction of the MRGO, swamp and fresh marsh habitats largely converted to intermediate and brackish marsh or were lost to open water or dredge spoil (Figure 7, middle; Chabreck, Joanen, and Palmisano, 1968). By the early twenty-first century, the swamps had essentially disappeared and open water habitat greatly increased (Figure 7, bottom; Barras *et al.,* 2003).

We estimate that construction of the MRGO directly caused the destruction of over 21,000 ha of wetlands and led to the indirect death of far more. The footprint of the channel and dredge spoil alone destroyed 10,000 ha (Coastal Environments, Inc., 1973; USACE, 1999; Wicker *et al.,* 1982). Channel widening from erosion destroyed another 2000 ha (Barras, 2008; FitzGerald *et al.,* 2008; USACE, 2007). 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 freshwater and low salinity wetlands, killing greater than 9000 ha in the CWU and Golden Triangle prior to 1978 (Barras, 2008; USACE, 1999). Salinity killed more than 4000 ha of baldcypress–water tupelo swamps in the CWU alone (FitzGerald *et al.,* 2008; USACE, 1999). In addition, the kill of greater than 3000 ha of baldcypress on the Manchac land bridge was primarily attributed to saltwater intrusion from the MRGO (USACE, 1999). As discussed, this salt kill was predicted by state and federal agency personnel prior to construction of the MRGO.

Table 1. *Comparison of mean salinities (ppt) before and after completion of MRGO. All available data collected prior to, and subsequent to, 1963 for each station have been included. Data from 1963 have been excluded.*

Station	Pre-MRGO	Post-MRGO	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

Data summarized from Amstutz, 1964; El-Sayed, 1961; Rounsefell, 1964; USACE, 1963.

There was a rapid wetland loss and change after construction of the MRGO, as demonstrated by the different mapping studies in the area cited previously and the habitat changes detailed in Figure 7. In summary, a number of factors indicate that the rapid die-off of baldcypress–water tupelo swamps was a result of saltwater intrusion caused by the MRGO.

- Salinity tolerances for baldcypress have been known since the 1930s (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 CWU before the opening of the MRGO were generally between fresh and 4 ppt. After the MRGO was opened, salinities in the CWU 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, and such dramatic increases were not experienced in areas more peripheral to the MRGO, such as the Manchac land bridge (Table 1) (Thomson, Shaffer, and McCorquodale, 2002).
- All habitat change mapping shows the loss of almost all baldcypress–water tupelo swamp and fresh marsh in the CWU after the MRGO was opened.
- There are a number of personal observations by local residents of baldcypress–water tupelo swamps dying after the MRGO was opened.

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

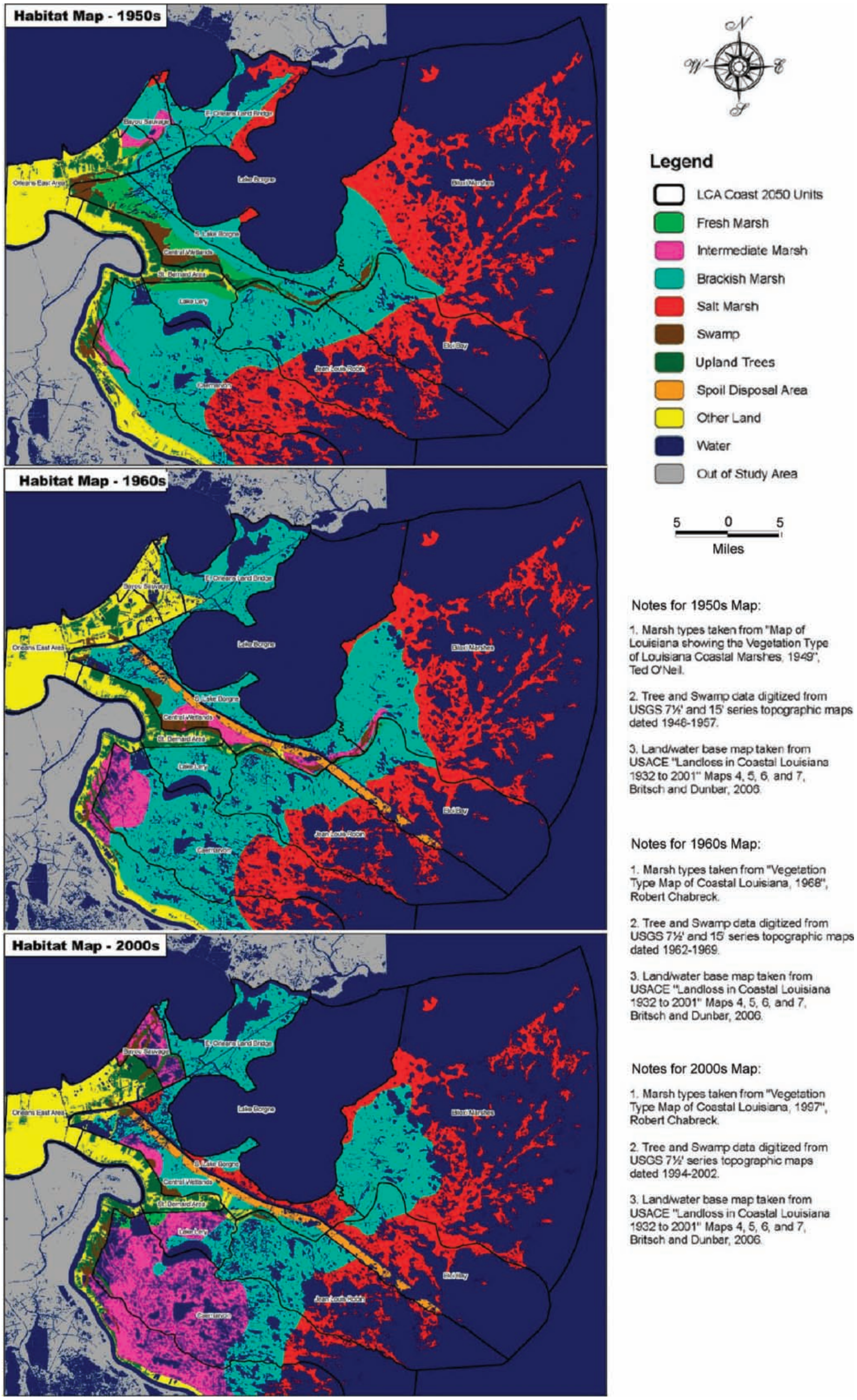

Figure 7. Habitat maps compiled for the CWU during the 1950s (top: constructed from USGS topographic maps and the vegetation map of O'Neal, 1949), the 1960s (middle: constructed from vegetation survey of Chabreck *et al.,* 1968), and the early 2000s (bottom: constructed from Barras *et al.,* 2003).

has had dramatic affects on both hydrology and salinity. By contrast, there is a relatively small area of other canals in the CWU and adjacent areas. For example, in 1955 there were only 22.7 ha of canals, and by 1978 this area had increased to only 27.5 ha, whereas the MRGO channel and spoil banks comprised about 8502 ha.

Estimates of Wetland Loss Related to MRGO

There were direct and indirect impacts of MRGO that resulted in high rates of habitat loss. The direct impacts affecting habitat loss include channel excavation, spoil disposal filling both wetlands and shallow water bodies, and wave erosion. Indirect effects that caused shifts in habitat type and increased wetland loss include salinity intrusion and hydrological changes caused by the MRGO. Numerous studies (Coast 2050, 1998; USACE, 1999; van Heerden *et al.,* 2007; Wicker *et al.,* 1982) detail that the MRGO caused land loss during different periods using various defined areas. All of the studies detail tens of thousands of hectares of land loss; however, the methods, periods, and defined areas differ, causing inconsistencies in the quantification.

The USACE (1999) reported that 6680 ha of marsh were filled or excavated during MRGO construction. In addition, 2308 ha of water were filled or deepened. In 1956, 4130 ha of baldcypress forest and 2308 ha of fresh and intermediate marsh existed. Both the baldcypress–water tupelo swamp and the fresh and intermediate marsh have been replaced with open water and brackish or saline marsh.

Impacts in Lake Pontchartrain

Lake Pontchartrain Dead Zone

Through its connection to the IHNC, the MRGO provides a direct link between the low salinity waters of Lake Pontchartrain and the high salinity waters of Breton Sound. The MRGO delivers salt water to the lake; the salt water sinks and causes the water column to stratify. Differences between mean surface and bottom water salinity can exceed 10 ppt (Junot, Poirrier, and Soniat, 1983; Poirrier, 1978) 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, Spalding, and Franze, 2009). Because of saltwater intrusion from the MRGO, roughly 259 km^2 (100 mi^2) of the lake's benthos is nearly devoid of life (Figure 8) (Abadie and Poirrier, 2001; Poirrier, Spalding, and Franze, 2009; Spalding, Walker, and Poirrier, 2006). The saline water from the MRGO causes hypoxic conditions to occur as far north as 24 km from the mouth of the IHNC (Spalding, Walker, and Poirrier, 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, Poirrier, and Yund, 1992) revealed that the effects of urban runoff were localized and the cause for episodic hypoxic and

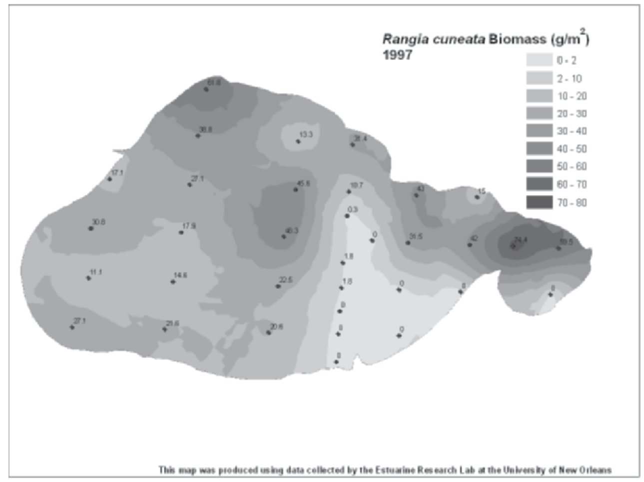

Figure 8. Density of *Rangia cuneata* in Lake Pontchartrain during 1997. Dead zone (lightest gray) is 250 km^2.

anoxic bottom waters in the larger dead zone could be attributed to saltwater intrusion from the MRGO.

Ecologically, the episodic anoxic bottom waters caused by the MRGO decimated populations of *R. cuneata,* which decreased the health of the entire aquatic ecosystem 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) helps to stabilize shorelines; *Rangia* add about 700,000 t of shell annually to bottom sediments (Spalding, Walker, and Poirrier, 2006). *Rangia cuneata* also serve as a food source for fish, crabs, and waterfowl (Spalding, Walker, and Poirrier, 2006). It is estimated that restoration of the hypoxic zone, through closure of the MRGO, could increase light penetration on the north shore of Lake Pontchartrain from 2.0 to 2.4 m and from 0.6 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 crippled by the MRGO.

The Louisiana Wild Life and Fisheries Commission (LWLFC) 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 the lakes' salinity:

> The proposed Seabrook Structure was designed for addition to the Mississippi River 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

Table 2. *Dredged material samples equal to or above proposed EPA criteria June 26, 1973.*

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).

the Lake. Excessive salinities in the upper part of the Lake, which were historically fresher, have caused considerable marsh deterioration and mortality of freshwater vegetation. The most spectacular evidence of this is the dead cypress trees visible from Interstate 10 (LWLFC, 1975).

Resuspension and Resolubilization of Heavy Metals in the Sediment

The USACE responded in their 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, 5 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 criterion* (Table 2) (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.

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 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. It is likely that there is potential for metals to accumulate in biota tissues and magnify up the food chain to larger more desirable game fish.

Effects of the MRGO on Storm-Surge Transmission

Levees and floodwalls adjacent to the MRGO failed catastrophically during Hurricane Katrina (ILIT, 2006; IPET, 2006; van Heerden *et al.,* 2007). To further address the relationship between the MRGO and levee failure, Kemp (2008) constructed models to quantify the impacts of the MRGO and associated features on the impacts of Hurricane Katrina. The models specifically included baldcypress–water tupelo swamps and marshes killed by saltwater intrusion from the MRGO. The models show that the widening of the MRGO, at the expense of adjacent wetlands, enhanced regeneration of waves from Lake Borgne that caused the earthen berm adjacent to it to breach earlier and more extensively. The presence of the ship channel, with its parallel embankment, increased discharge from the funnel area into the MRGO Reach 1 and the IHNC (Figure 1) that again led to an earlier and more extensive overtopping and failure of structures along both sides of the IHNC. This occurred without a significant increase in surge elevation within the channel system because surge height was determined by the mean crown elevation of the flood control structures, which changed as the sequence progressed. In other words, Kemp (2008) demonstrated that without breaches, the MRGO funnel was like a bathtub receiving water from Lake Borgne in excess of what could drain to Lake Pontchartrain. When the funnel was filled to the mean crown elevation of the flood control structures, excess surge poured into New Orleans in proportion to the rate of input, which was greatly enhanced by the presence of the MRGO channel, but peak surge was constrained by the height of the structures. The model predicted that peak surge input to the channels in the throat of the funnel was increased by 300% by the presence of the MRGO navigation project. Although modeling of an intact flood protection system explained the oceanography of the funnel and potential impacts of the MRGO project, actual flooding adjacent to the funnel was quite different because of structural failures. The sequence and severity of breaching was affected by local factors unique to each breach, which could not be effectively modeled, as well as by the combined surge and wave climate that could be modeled.

The model predicted that if the MRGO channel had not been built and operated to expand and cause wetland loss, and the Lake Pontchartrain and Vicinity (LPV) flood control structures were in place as they were before Hurricane Katrina, that the potential for overtopping would have been reduced by 80%, while wave energy experienced by the LPV embankments would drop by 66%. The combination of reduced overtopping and waves would have greatly diminished the risk of structural failure.

Enlargement of the GIWW to create the MRGO Reach 1 provided a much greater potential for conveyance of Lake Borgne surge into the IHNC, particularly after the forests in the throat of the funnel were destroyed by saltwater intrusion. The MRGO levee in Reach 2 enhanced flooding in Reach 1 by eliminating surge storage in the CWU and by allowing the surge level to build up further and drive added flow through the adjacent deep channel toward Reach 1, an interaction that would not have occurred if one or the other of these projects had not been built in the close conjunction that they were.

Even slight reductions in peak surge elevation, or delays in peak onset, could combine to significantly reduce overtopping of the LPV flood protection structures throughout the funnel. When all traces and effects of the MRGO project were removed from the landscape, but the LPV flood protection structures were retained in their pre-Katrina condition, Kemp (2008) predicted overtopping would have been reduced by about 80% for all of the three developed polders that experienced catastrophic flooding damage on August 29, 2005.

Summary of Impacts of the MRGO

Economic Disaster

From the beginning, the MRGO was never an economic success. The canal was built as an alternative shipping channel to the Mississippi River because it was a shorter route from the Gulf of Mexico to the Port of New Orleans and other ports. As explained previously, the banks of the channel were highly subject to erosion. For this reason, large ships had to go so slow, such that it was quicker to travel via the river. In addition, the locks between the IHNC and the Mississippi River are too small for large ships. The result of these limitations was that only one to four ships per day used the MRGO (carrying only about 3% of the New Orleans port-freight tonnage) compared with at least one order of magnitude more traveling the Mississippi River. While the economic benefits of the MRGO were small, the costs to maintain the channel through maintenance dredging and bank stabilization were large. Dredging and rock retention costs were about $10 million annually. These annual costs combined with emergency repairs associated with hurricanes yield a total maintenance cost over the life of the project of about $0.5 billion. If the MRGO-caused economic damages associated with Hurricanes Betsy and Katrina are combined with those of construction, operation and maintenance, and wetlands destroyed, then the total economic cost of the MRGO is in the *hundreds of billions of dollars*.

Environmental Disaster

We have reviewed in this paper the numerous environmental impacts of the MRGO. The initial dredging of the channel led to the direct destruction of tens of thousands of hectares of productive wetlands and estuarine water bodies by conversion to the deep navigation channel or by placement of spoil. The changes in hydrology due to the MRGO, most specifically the breaching of the Bayou La Loutre ridge, led to massive saltwater intrusion that killed tens of thousands of hectares of fresh and low salinity wetlands, most notably baldcypress–water tupelo swamps in the CWU and adjacent to the La Loutre ridge. Saltwater intrusion via the MRGO and IHNC also had an enormous detrimental impact on Lake Pontchartrain. Most severe was the creation of a large hypoxic zone that resulted in the widespread death of benthic organisms, especially the oligohaline clam, *Rangia cuneata*. Dredging also led to the resuspension and resolublization of heavy metals and other toxins. The cumulative effect of these impacts was a pervasive degradation of estuarine ecosystems in Lake Pontchartrain and Breton Sound.

Dr. T.B. Ford of the LWLFC 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 O&M activities, has led to one of the greatest human induced environmental disasters in human history. When the Bayou La Loutre ridge was cut in 1961, and the connectivity between the CWU and Breton Sound was increased through widening and deepening of the MRGO between 1961 and 1963, salinity abruptly increased in the CWU (Figure 6) 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 hectares of wetlands suffered conversion to open water or spoil banks. Hurricane protection offered by the baldcypress–water tupelo swamps and surrounding marshes was erased. In addition, a 259-km^2 dead zone was created in Lake Pontchartrain, and the indirect effects of that dead zone have negative impacts on the entire Lake Maurepas–Pontchartrain estuarine ecosystem. Furthermore, decades of maintenance dredging have negatively affected massive areas of wetland and aquatic ecosystems. These environmental impacts were foreseen before the MRGO was constructed.

Storm Disaster

The dredging of the MRGO set the stage for the dramatic disasters associated with Hurricanes Betsy and Katrina. The deep, straight channel, in combination with the funnel created by the MRGO spoil bank and levee, provided a path for hurricane surge. The funnel caused the amplification of the surge such that water levels were much higher, and were transmitted much sooner, than they would have been naturally. Indeed, the models of Kemp (2008) demonstrate that the MRGO functions like a major river during hurricanes, delivering massive volumes of water to the funnel, which is aimed directly at the city of New Orleans.

Saltwater intrusion via the MRGO killed thousands of hectares of baldcypress–water tupelo swamps and herbaceous wetlands that would have reduced both surge levels and the formation of waves on top of the surge. The dramatic flooding east of the INHC and in St. Bernard Parish would have been much less had the swamps still been alive and the channel not been dredged. The impacts of the MRGO on hurricane flooding had been predicted before the channel was constructed. Indeed, when the wetlands were put back into the landscape for the "neutral MRGO" modeling scenario (*i.e.*, scenario 2C in Kemp 2008), a fairly uniform reduction in overtopping volume of 80% to 85% occurred at points discharging into all three of the developed polders that experienced massive flood damage on August 29, 2005. In addition, overtopping of the Reach 2 spoil banks was reduced by 60% (Kemp, 2008).

ENVIRONMENTAL RESTORATION

Environmental restoration of the ecosystems degraded by the MRGO involves a variety of features and projects designed to return the area to a condition similar to that which existed prior to construction of the channel. The restoration includes closure of the MRGO, introduction of fresh water to the area, reestablishment of forested wetlands, and enhanced hurricane protection.

Closure of the MRGO

The passage of Hurricanes Katrina and Rita resulted in significant filling of the portion of the MRGO that passed through open waters of Breton Sound, and deep draft vessels were no longer able to use the channel. Because of this, a decision had to be made to either redredge or discontinue maintenance. Although there had been calls to close the MRGO beginning immediately after its construction, these calls rose to a crescendo after Hurricane Katrina. Most notably, a group of environmentalists and scientists prepared a report in the months after the storm that provided a detailed plan for closure of the channel (Lake Pontchartrain Basin Foundation *et al.,* 2006). Most important, the report called for a barrier to be constructed at the Bayou La Loutre ridge. Subsequently, the USACE produced a report that recommended closure. Language was included in the 2007 Water Resources Development Act directing the USACE to decommission and close the MRGO. As of July 2009, the MRGO has been plugged with a rock barrier at the LaLoutre ridge.

Freshwater Introduction via Diversions and Treated Effluent

With the reconstructed La Loutre ridge limiting saltwater intrusion, plans also are underway to introduce additional fresh water into the CWU and adjacent areas. One of the projects is to introduce treated municipal effluent from New Orleans and St. Bernard Parish to the CWU. Over the past several decades, wetlands have been used in Louisiana to assimilate municipal effluent. This was initially done to achieve water quality goals, but it has become clear that wetland assimilation also can result in wetland enhancement and restoration (Day *et al.,* 2004). Orleans and St. Bernard parishes together produce over 378,500 m^3/d of treated effluent. Before Hurricanes Katrina and Rita, New Orleans had plans for a small project to use treated effluent to create baldcypress–water tupelo wetlands. After the storm, this evolved into a plan to discharge treated effluent from the East Bank Sewage Treatment Plant of New Orleans and several plants in St. Bernard Parish to freshen the CWU to enable restoration of approximately 10,000 ha of baldcypress–water tupelo swamp.

In the summer of 2008, a feasibility analysis for the project was completed (Nelson, 2008). The State of Louisiana is providing $10 million as part of the Coastal Impact Assessment Program (CIAP) for the initial work on the project, and it is anticipated that the project will begin in 2009. The funds will be used for modifications at the treatment plants, construction of the distribution system for discharge of the treated effluent, filling deeper areas with dredge spoil, planting baldcypress and water tupelo seedlings, baseline ecological studies, and engineering fees. The total cost of the project is estimated at about $60 million. The cost of restoring the area comes to about $5300 per hectare, which is less expensive than most other coastal restoration projects in Louisiana (Lindquist and Martin, 2007)

In addition, there is a plan to enlarge a Mississippi River diversion at the Violet Canal (Figure 1) to provide fresh water to the Lake Borgne area to enhance oyster production and wetland health. This project is in the planning stages, and it is likely that it will not be finished for a number of years. When both the wetland assimilation and Violet diversions are operational, the area is expected to return to a condition similar to that which existed prior to construction of the MRGO, but with even greater hurricane protection.

Salinity Control

All of the previously discussed measures result in a greater control of saltwater intrusion by both keeping out salt water and supplementing fresh water. The importance of salinity control measures has been recognized since before construction of the MRGO (USACE, 1963).

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 the MRGO. Many of these measures were suggested prior to construction and post-MRGO opening, but the USACE never implemented them. In 1976, in response to the Environmental Protection Agency Region VI that had requested measures to mitigate salinity intrusion, the USACE indicated that the proposals for salinity control measures in the MRGO system would require authorization for "new construction features … which would require 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 prior to opening of the MRGO 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 the forests that were killed by saltwater intrusion.

The most obvious and significant measure that could have been implemented, either before or after MRGO construction, was adding a structure to the Bayou La Loutre ridge. A gated structure could have been opened for the few ships per day that used the MRGO, greatly reducing saltwater intrusion. To accommodate smaller vessels, such as shrimp boats, crew boats, and recreational craft, USACE could have constructed an ancillary structure. If complete control of water exchange at the La Loutre ridge was desired, then a lock could have been constructed. This would have largely eliminated water exchange at the ridge. These measures would have been expensive to implement, but much cheaper than environmental and flood damages due to the loss of the baldcypress–water tupelo forests and surrounding marshlands.

Salinity intrusion into the CWU could have been greatly reduced by placing water control structures at Bayou Bienvenue and Bayou Dupris (Figure 1). 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 completed, 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 become 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, introduction of fresh water 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 are overtopped. There are several sources of fresh water available to the CWU, including the Violet diversion structure, drainage water from uplands adjacent to the CWU, pumps that drain storm water from adjacent municipalities, and treated, disinfected municipal effluent as mentioned earlier.

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 and low salinity marshes 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 of the previously mentioned salinity control measures.

Baldcypress Restoration

It is clear that construction of the MRGO led to salinity intrusion that caused the death of thousands of hectares of forested wetlands. After the flooding caused by Hurricanes Katrina and Rita, there was a growing realization that the loss of the forested wetlands significantly contributed to the flooding. This has brought about the development of plans to restore the forested wetlands that existed prior to the MRGO. When the wetland assimilation project is underway, planting of baldcypress, water tupelo, and perhaps midstory species such as ash (*Fraxinus*) and maple (*Acer*), will be carried out to restore the forested wetlands to a greater area than existed before MRGO construction. The restoration of the area, in conjunction with flood protection works, will lead to enhanced hurricane protection for eastern New Orleans and St. Bernard Parish.

Conceptual Basis for Restoration

The sustainable restoration of ecosystems involves an understanding of how these ecosystems work and what sustainable management approaches will succeed. In general, the way ecosystems function should serve as the basis for their sustainable management (Day *et al.,* 1997, 2009). In this sense, restoration and management of the coastal-wetland ecosystem in upper Breton Sound and Lake Pontchartrain Basins involves two major actions that return the area to a more natural functioning. First, the channel that allowed both rapid draining of fresh water and the rapid inflow of salt water is to be closed. Second, freshwater reserves in the CWU and adjacent areas will be conserved and enhanced by additional sources of fresh water from treated effluent and a diversion of the Mississippi River.

This approach to management is called ecological engineering, which is the design of sustainable ecosystems that integrate human society with the natural environment for the benefit of both (Day *et al.,* 2009; Mitsch and Jorgensen, 2003). It combines basic and applied science for the restoration, design, construction, and sustainable use of aquatic and terrestrial ecosystems, and because it uses mainly natural energies, it is very energy efficient. The primary tools are self-designing ecosystems with the components being mostly biological species and processes. The goals of ecological engineering are:

(1) The restoration of ecosystems that have been substantially disturbed by humans.
(2) The development of new sustainable ecosystems that have both human and ecological value.
(3) Maximum use of natural energy and reduction of fossil energy.

In a time when fossil energies are becoming more expensive and scarce, greater use of natural energies such as winds, currents, and waves allows for more sustainable management (Day *et al.,* 2009).

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APPENDIX

A listing of comments, correspondence, and reports about the environmental impacts of the MRGO. Note that there was a considerable understanding of the impacts of the channel prior to its construction.

Reference	Date	Comment
United States Fish and Wildlife Service	1979	Association predicted the project would create a 44-mile-long swath of destruction.
*Wild Life and Fisheries Commission J.N. Gowanloch	12-19-1951	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.
Wild Life and Fisheries Commission L.D. Young Jr.	05-09-1956	Letter 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 to provide recommendations to USACE.
Wild Life and Fisheries Commission Correspondence Letter	05-29-1957	Letter 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, these processes would alter vegetation types and lead to land loss. WLFC made recommendations for alternative alignments that would have less negative effects on the environment and wildlife resources.
New Orleans State Newspaper, Times Picayune	06-04-1957 06-05-1957	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."
Secretary of Interior	09-23-1957	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.
New Orleans State Newspaper, Times Picayune Newspaper	09-26-1957 09-27-1957	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.

APPENDIX
Continued.

Reference	Date	Comment
Wild Life and Fisheries Commission T.B. Ford	1956-1957	Seventh Biennial Report, 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.
St. Bernard Parish Tidewater Channel Committee	12-06-1958	Requests assistance detailing predicted environmental effects of the MRGO from WLFC.
Wild Life and Fisheries Commission	03-24-1958	Letter cites adverse environmental effects of the proposed MRGO including saltwater intrusion, siltation, rapid fluctuation of water levels and salinities, turbidity increases, etc.
Times Picayune	12-12-1958	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."
Times Picayune	12-17-1959	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 Special Report on Fish and Wildlife Resources, Interim Report on Fish and Wildlife Resources and an Outline of Proposed Fish and Wildlife Studies	11-1957, 04-1957, 05-04-1959, 07-09-1959, 12-08-1960, 07-27-1960, 09-27-1960, 01-12-1961, 12-13-1961, 05-08-1962, 09-13-1962 09-28-1962, 01-26-1965, 02-24-1966	Coordinating agency on extensive and detailed pre-project hydrology and biological studies by several agencies.
Eighth Biennial Report of the Louisiana Wild Life and Fisheries Commission T.B. Ford	1958-1959	"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.
U.S. Fish and Wildlife Service Letter Report	07-27-1960	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.
Citizens Committee for Hurricane Flood Control	11-24-1965	Correspondence letter 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.
Wild Life and Fisheries Commission	3-11-1968	Meeting held with USACE and WLFC staff to discuss pre- and post-construction study results of the impacts of the MRGO.
Correspondence letters between Wild Life and Fisheries Commission and the Covington Daily News	8-16-1972	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.
St. Bernard Parish Planning Commission	9-28-1972	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.
Wild Life and Fisheries Commission	9-19-1973	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.
Wild Life and Fisheries Commission	12-10-1973	Correspondence memo from within WLFC expressing frustration with USACE on the Lake Pontchartrain and Vicinity Project.
Wild Life and Fisheries Commission	1-7-1975	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."

APPENDIX
Continued.

Reference	Date	Comment
U.S. Army Corps of Engineers	2-22-1975	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.
Wild Life and Fisheries Commission	7-1-1975	Louisiana Wild Life and Fisheries Commision letter to Colonel Heidberg from Director J. Burton Angelle. Angelle emphasizes that the Commision truthfully predicted 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.
U.S. Fish and Wildlife Service	5-31-1979	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.
St. Bernard Parish Council	12-15-1998	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.

* The Louisiana Wildlife and Fisheries Commission (WLFC) is the predecessor of the current Department of Wildlife and Fisheries.