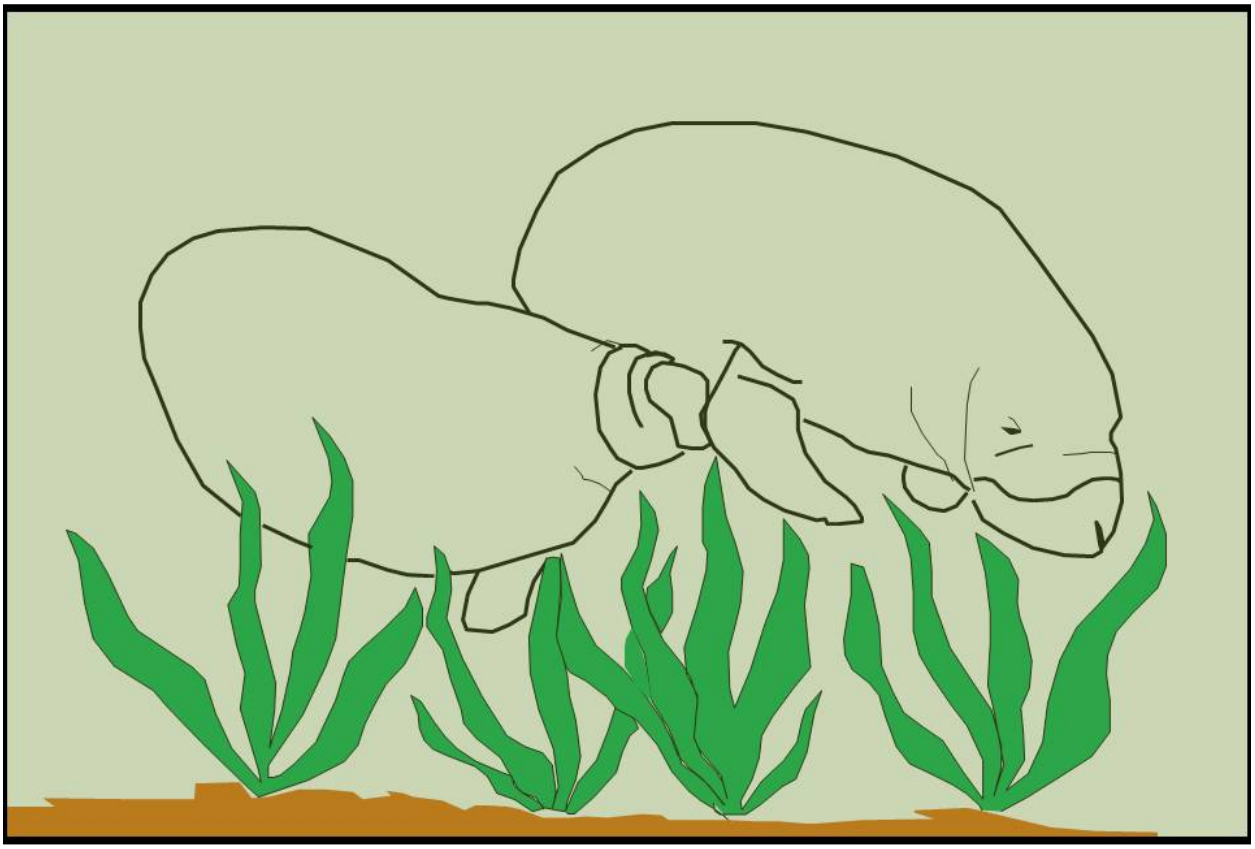
Framework for Environmental Assessment of Alternative Flood Control Structures on Chef Menteur and Rigolets Passes within the Lake Pontchartrain Estuary, Southeast Louisiana



Lake Pontchartrain Basin Foundation

saveourlake.org

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LAKE PONTCHARTRAIN BASIN FOUNDATION

SAVE OUR COAST SAVE OUR LAKE

Final Report June 2011

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Executive Summary

This report examines the potential environmental effects of various alternative flood control structures on the tidal passes into Lake Pontchartrain, originally conceived as a ”Barrier Plan” by the Corps of Engineers to protect the Greater New Orleans region. Specifically under investigation is the effect proposed flood control structures in the Rigolets and Chef Menteur Passes would have on the hydrodynamics, water quality, and ecology of the passes and the Lake Pontchartrain Basin estuary. Several flood control structure designs for the Orleans Land Bridge, which separates Lake Pontchartrain from the Gulf of Mexico, have been drafted since the early 1960's, but were never constructed. In lieu of a "Barrier Plan", a "High Level Plan" composed of levees and floodwalls was being constructed, but was incomplete when Hurricane Katrina struck in 2005. After severe storm surge flooding in the New Orleans, St. Bernard and St. Tammany Parishes from Hurricane Katrina, the flood control structures in the tidal passes have been reconsidered. The purpose of this report is to generally indicate possible harmful effects of implementing these structures as they are currently conceived, as well as to create a framework for future ecological and hydrological assessments. Three different structure design dimensions are described for each of the Rigolets and Chef Menteur Passes, including the original "Barrier Plan" designs, the Louisiana State Master Plan proposals, and the hydrologically determined designs based on University of New Orleans modeling. These designs must suffice for this framework assessment; until a more detailed design is conceived at which time these issues would be more thoroughly evaluated.

After several brutal hurricanes in 1955, Congress sanctioned the U.S. Army Corps of Engineers (USACE) to perform a series of studies to investigate hurricane protection options for areas along the eastern and southern U.S. coasts. One of these commissioned studies (authorized 1965) was the Lake Pontchartrain & Vicinity Hurricane Protection Project (LP&VHPP). As part of this project, a "Barrier Plan" was developed that would protect the Greater New Orleans area (St. Bernard, Orleans, Jefferson, and St. Charles Parishes). This plan consisted of levees along Lake Pontchartrain and flood control structures in the two natural tidal passes. Over the next 50 years, the designs and locations of the two proposed structures changed, including a switch over to a "High Level Plan" after an injunction in 1975. The "High Level Plan" consisted of higher levee heights along the Lake's south shore and the Orleans Land Bridge in lieu of the flood control structures in the tidal passes. The original "Barrier Plan" flood control structures were never built, although construction had begun on the bypass channels at Chef Menteur Pass. The "High Level Plan" was authorized and began construction, but was modified, under-designed, and incomplete when Hurricane Katrina struck in 2005.

After the intense flooding of the local communities during Hurricane Katrina in August of 2005, newer versions of a "Barrier Plan" type flood control structure designs were reconsidered for possible implementation. It appears that state and federal agencies have abandoned the original specific design. In 2007, the Louisiana State Master Plan included a conceptual alternative for flood control structures on Chef Menteur and Rigolets Passes. Also in 2007, the University of New Orleans (UNO) performed 3-D numerical modeling simulations with the proposed structures to estimate the effects of constrictions in the passes in order to predict the structure designs that would have the smallest effect on the tidal prism in Lake Pontchartrain and on the

velocities in the passes themselves . In 2009, the Corps released the Louisiana Coastal Protection and Restoration report (LACPR) which included some technical evaluation of the 2007 State Master Plan flood control structures, utilizing UNO's modeling work and extensive surge modeling. The LACPR report included alternative proposals for these flood control structures, but as a "barrier-weir", assuming there would be overtopping for a 100-year storm or higher level storms.

Incredibly, the original "Barrier Plan" did not include a flood control structure on the Mississippi River Gulf Outlet (MRGO) at the now infamous funnel (MRGO-GIWW confluence), and so storm surge moving through the MRGO and into the Inner Harbor Navigation Canal (IHNC) would have been dependent on "parallel protection" from floodwalls of these canals. Post-Katrina, two closures of the MRGO have been constructed that remedy this serious deficiency in the "Barrier Plan" and "High Level Plan" designs. In 2009, the USACE completed construction on the rock dam closure structure in the Mississippi River Gulf Outlet channel (MRGO) at Bayou la Loutre to control salinity and restore the hydrology. A second MRGO closure consists of a surge barrier structure at the Golden Triangle, which is currently completed with the exception of the navigation gates. The gates will allow barge traffic and smaller vessels access to the IHNC and the Port of New Orleans. These gates were completed by June of 2011. In addition, a flood control structure is being built on the Inner Harbor Navigation Canal at Lake Pontchartrain and should be completed by June 2012. Temporary protection here was provided by June 2011.

All of these flood control measures are within the 9,645-square mile Lake Pontchartrain Basin that includes the area east of the Mississippi River within Louisiana. It includes major cities such as New Orleans and Baton Rouge, and major population centers on both the north and south shores of Lake Pontchartrain, and has nearly 46% of the state's entire population. Approximately 5,800 square miles of the Pontchartrain Basin (60%) is estuarine including major tidal bays (Lakes) Borgne, Pontchartrain and Maurepas. All of these tidal bays and most adjacent wetlands are tidally connected. The 630-square mile Lake Pontchartrain is part of a larger estuary with tidal lakes that are inland and seaward of it.

The portion of the estuary that would be inland of the flood control structures includes approximately 630 square miles of wetlands, 730 square miles of tidal bays (lakes), and 8 rivers, bayous, or streams. The biology of the Lake Pontchartrain Basin estuary is typical of other Gulf Coast estuaries in Louisiana driven with strong influence of natural mixing of fresh water and sea water controlled by meteorological, and hydrological patterns. The resulting annual salinity variation and seasonal cycles drive estuarine migrations of almost all species of interest such as shrimp, blue crab, pogy, trout, red fish, etc. Any discussion of the alternative flood control structures on the natural passes into Lake Pontchartrain must consider effects on not just Lake Pontchartrain, but the entire estuary including the one fourth of the Pontchartrain Basin estuary (1,350 square miles) that would be inland of the flood control structures, and the three fourths that would be seaward (4,450 square miles).

The most prominent water body inland of the alternative flood control structures is Lake Pontchartrain. The Lake has numerous important aquatic species, including white and brown shrimp, blue crab, red drum, and white trout, which use the connection to the Gulf of Mexico via the tidal passes for spawning and migratory habits. These estuarine species, and some marine or anadromous riverine species, are the basis for robust commercial and recreational fisheries that have significant economic value and strong cultural traditions. For example, Lake Pontchartrain blue crabs and speckled trout fishing are renowned. Nearly all of the aquatic species that have social or economic value are somehow dependent on the tidal passes into Lake Pontchartrain. An examination of food webs for Lake Pontchartrain indicates 18 of 33 significant species could be directly affected by alteration to the tidal passes.

Louisiana is well known for being frequently attacked by moderate and severe hurricanes. The most memorable and catastrophic being Hurricane Katrina in 2005. This event is widely accepted as a man-made disaster due to the widespread failure of an under-designed and incomplete flood protection system. Hurricanes not only bring strong winds and storm surges, which cause damage to property and loss of life, but also affect the environment, the public economy, and the emotional state of its victims. Due to its proximity to the Gulf, the Lake is susceptible to these natural disasters. For these reasons, the highest density communities on the south shore of the Lake are included in the original Congressional authority for flood control for the region, and the Hurricane Storm Damage Risk Reduction System program (HSDRRS) is in the process of reconstructing this system to the new 100-year risk reduction standard. North shore communities represent an important area of growth for the region but do not have federally authorized hurricane flood control projects. The Corps' LACPR report did evaluate various structural and non-structural measures for the north shore communities. Slidell is probably the most vulnerable community on the north shore, and St. Tammany Parish is starting to build a local levee to protect Slidell.

The natural tidal passes, Pass Rigolets and Chef Menteur Pass, connect Lake Pontchartrain to Lake Borgne, which is then open to the Gulf. The passes undergo a diurnal tide, or both a high tide and a low tide within one day, with a mean tidal range of 0.36 ft . Pass Rigolets has a total length of 8.5 mi, an average depth of 33.8 ft, and an average cross-sectional area of 82,200 ft^2; and Chef Menteur Pass has a total length of 6.4 mi, an average depth of 41.0 ft, and an average cross-sectional area of 39,400 ft^2. The two passes have undergone significant scouring near the bridge piers and bends, which is believed to have been caused by the surge inflow combined with the receding flow from Hurricane Katrina.

Flood Control Structures – Closed Position during a Hurricane

If the proposed flood control structures were to be installed in the tidal passes, the gates across the channels would be closed in preparation for an incoming storm or hurricane in order to prevent the storm surge from entering the Lake. At this time, the water flow would be cut off in the passes and the incoming storm surge would encounter the barriers. With continued winds at the barriers, the surge height would amplify. Although dependent on the exact design, surge would also be forced to move laterally toward Mississippi and St. Bernard Parish. This lateral flow may occur already due to the presence of the CSX Railroad foundation, but would increase with additional flood control structures.

With closed flood control structures, water levels on the protected side of the flood control structures would also rise due to a combination of factors. The "Barrier Plan" flood control structures were designed at +12 feet elevation and would have major overtopping for even a 100-year event. The LACPR barrier-weir designs would have some overtopping of the structures, particularly for storms greater than 100-year. Additionally, rainfall within the approximately 5,000 square mile catchment basin that would be on the protected side of the flood control structure would not be able to drain from the lake and to the sea, including pumped storm water from New Orleans, Jefferson, St. Charles, and St. Bernard Parishes. With no outlet, the catchment basin would be a mega-retention basin of fixed storage capacity. The elevated water level in Lake Pontchartrain would also be subject to the wind driven phenomenon that forces high water to slosh from west to east during a typical hurricane event. Also, there could be initially a strong north to south setup. The greatest flood threat would be on the eastern side of Lake Pontchartrain, particularly Slidell. It is possible that the flood risk might actually be increased with flood control structures for some "protected" areas under certain combinations of conditions. The LACPR models suggest significant water levels could occur on the protected side with flood control structures in place.

With flood control structures closed during a hurricane, short term environmental impacts like freshening of the lake and reduced water quality would be increased. All aquatic species migration would cease, which for most species would only delay movement. However, migrations that might represent temporary shelter from a storm, such as for endangered West Indian manatee or fish, the temporary closure could increase mortality of any species seeking refuge.

Flood Control Structures – Open Position without a Hurricane Threat

If one of the alternative flood control structures were to be installed in the tidal passes, the gates across the channels would presumably be open during normal (non-storm) conditions in order to permit flow in and out of the estuary. All of the proposed designs for the structures include, to some extent, dams or embankments protruding into the channels, gates with piers, and sills above the mean sea floor elevation. In other words, even while "open", all of the alternative flood control structures evaluated include some permanent constriction of the natural channel's cross-sectional area and, therefore, none of the alternatives can be considered as completely hydrologically benign. For Rigolets Pass, with the structure open, channel reduction ranges from 77% to 29% of the cross sectional area. For Chef Menteur Pass, with the structure open, channel reduction ranges from 72% to 39% of the cross-sectional area. More recent alternatives have less constriction, but still represent a permanently reduced channel with the structure open.

These constrictions have at least three hydrologic effects including reduction in tidal prism, increase in channel velocity, and development of eddies. Defining the magnitude of these effects constitutes a critical hydrologic assessment that may demonstrate impacts that are unacceptable, but any hydrologic assessment alone cannot demonstrate acceptability from a complete ecologic perspective. That is, metrics such as change to the tidal prism are not a sufficient proxy to predict the impacts to subtle and complex influences on migration, predation, and habitat changes for diverse species ranging from large marine mammals to microscopic larvae.

Changes to the tidal prism for the UNO alternative flood control structures are less than 5%. "Barrier Plan" flood control structures were modeled by UNO and indicate a large change in the tidal prism that is much higher than what was suggested as an acceptable threshold (5%). Since all of the proposed flood control structures reduce the channel dimension while open, all of them increase the velocity of water passing through the open structure. This increase in velocity can create eddies on either bank and behind the gate piers, which can increase turbulence in the water column, as well as trap small fish in the currents. The proposed flood control structure designs presented in the 2007 UNO report would have the smallest effect on the cross-sectional area for both passes. Therefore, all of the proposed structures still cause modified flow in the passes.

In light of modern knowledge of ecology and of storm surge, it is clear that the original "Barrier Plan" had serious design flaws. Even assuming design engineering was reliable and that the "Barrier Plan" was actually completed as designed without a flood control structure on the MRGO, New Orleans would have been severely threatened. Furthermore, the significant changes to the hydrology of the Lake Pontchartrain estuary would have certainly been profound by restricting fish migration, altering habitats, and worsening water quality. Whether these flaws justify the decision not to build the "Barrier Plan" flood control structures, requires extensive forensic assessment of many other complex socioeconomic factors and are far beyond the scope of this report. Rather, this report attempts to frame at least the environmental issues in a modern scientific context so that further analyses can move constructively and efficiently forward to address regional flood protection.

A review of water quality processes suggests that water quality would be potentially impacted by reducing the natural tidal flushing of pollutants through tidal passes. Salinity would be expected to be lower due to constriction, even with the gates open. The wind-driven sloshing effect of high water levels in Lake Pontchartrain during a hurricane is critical to any flood protection measures in this region. The effect of storm surge pile-up on the west and then the east side of Lake Pontchartrain with a storm passage will occur with or without flood control structures on the passes. Flood control structures will stop or reduce the exit of storm surge out of Lake Pontchartrain and will exacerbate the pile–up process of storm surge. Modeling suggests that eastern Lake Pontchartrain is negatively affected the most by the sloshing and that this may offset the positive benefit of reduced storm surge volume entering the Lake with the presence of flood control structures on the passes.

A review of some representative species which utilize the passes to access Lake Pontchartrain leads to the conclusion that alterations to the hydrology by flood control structures must include species-specific analyses, and that assessment metrics that simply consider gross hydrologic changes, such as the tidal prism, are an inadequate proxy to predict the actual impact on all the aquatic species. Consideration of the Lake Pontchartrain food web, also suggests that a significant number of important species in the food web could be directly affected by flood control structures, which could have secondary effects on the food web. Many of these species are important recreational or commercial species.

This report is a compilation of possible adverse effects of the flood control structures in the Rigolets and Chef Menteur Passes. Many of the possible impacts need to be quantified to determine if they outweigh the benefits. The hydrodynamics of Lake Pontchartrain during the period that the gates are closed has not been completely analyzed considering the local wind shear, rainfall, bypassing flow and pumping; this should be completed before this flood control proposal goes forth. It is imperative that sound science and engineering is applied to these and other issues since there is much at stake economically, culturally, and environmentally. Although past authorities have favored the historically more populated south shore, economic changes and increased population of the North Shore must now be considered. Any future large federal project will likely require the broadest possible support to achieve authority and appropriations, and therefore it is in our best interest to think and work regionally.

Chapter 1: Introduction

Due to its proximity to the Gulf of Mexico, Louisiana is well known for being frequently attacked by moderate and severe hurricanes; the most memorable and catastrophic being Hurricane Katrina in August of 2005. Hurricanes not only bring strong winds and storm surges, which cause damage to property and loss of life, but also affect the environment, the public economy, and the emotional state of its victims. **Figure 1** shows a view of some of the severe hurricanes that have affected Louisiana, including Hurricanes Katrina, Rita, Camille, and Betsy, and their tracks and changes in intensity that occurred as they moved inland (NOAA, 2010). As shown in the figure, the hurricanes bring storm surge from the Gulf into Lake Borgne, which ultimately brings the storm surge into Lake Pontchartrain via the tidal passes – Pass Rigolets, Chef Menteur Pass, and formerly the Inner Harbor Navigational Canal (IHNC). This increase in water volume in the Lake can threaten the levee and floodwall system protecting New Orleans and the north shore. It should be noted that during Hurricane Katrina, the lakefront levees did not fail. According to the Corps of Engineers, the improvements to the levees currently under construction could be overtopped by a storm surge up to 1:500 year hurricane without breaching, which is more powerful than Hurricane Katrina (1:400 year storm). Nevertheless, if levees or floodwalls should fail, the storm surge could again inundate the low-lying portions of New Orleans. North shore areas also are susceptible to flooding. Slidell is currently building a levee that would provide new protection from storm surge from Lake Pontchartrain, but other north shore municipalities or communities do not have levees.

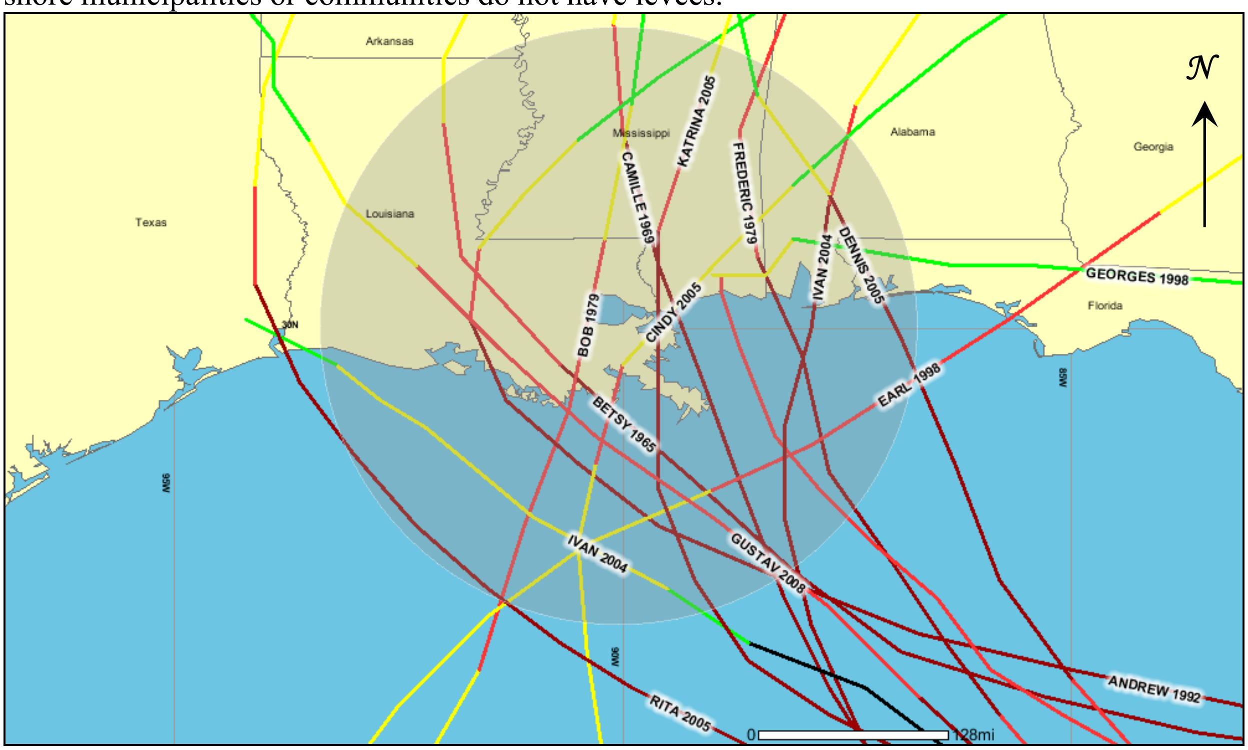

Figure 1: Map of Louisiana, including the hurricane tracks from some of the major hurricanes that significantly affected Louisiana (NOAA, 2010).

In the early 1960's, the U.S. Army Corps of Engineers designed a hurricane protection plan, termed the "Barrier Plan", which was designed to protect New Orleans from this high surge by building levees or "barriers" along the outer edges of the city and installing flood control structures in the two tidal passes (Pass Rigolets and Chef Menteur Pass). **Figure 2** shows a close-up view of the Louisiana coast, where the arrows indicate the Rigolets and Chef Menteur Passes, and the connection from Lake Borgne to Lake Pontchartrain can clearly be seen. These structures were expected to block the surge from entering Lake Pontchartrain, and thus, keep New Orleans safe from extensive flooding. Over the course of the years, this plan has changed and after an injunction in 1975, it was abandoned and replaced by the "High Level Plan" in 1985. This new plan eliminated the flood control structures in the passes and replaced them with higher levees along the Lake, even though construction had already begun for the "Barrier Plan". After Hurricane Katrina, the "Barrier Plan" was reconsidered, and studies were initiated to determine the effects of the plan's components on the Pontchartrain Basin.

Since Hurricane Katrina, it is often suggested that the region should emulate the Dutch style of storm surge management. The scale and design of the Dutch structures are marvels, but not without environmental consequences with near complete collapse of their estuarine functions (Heip, 1989). In many cases the Dutch have completely severed marine connection with now predictable consequences of collapse of fisheries and severe water quality problems. The Dutch are now trying to fix the widespread and deep environmental problems they have wrought, and in spite of their engineering prowess have only made meager gains. Coastal habitats once lost are not easy to replace.

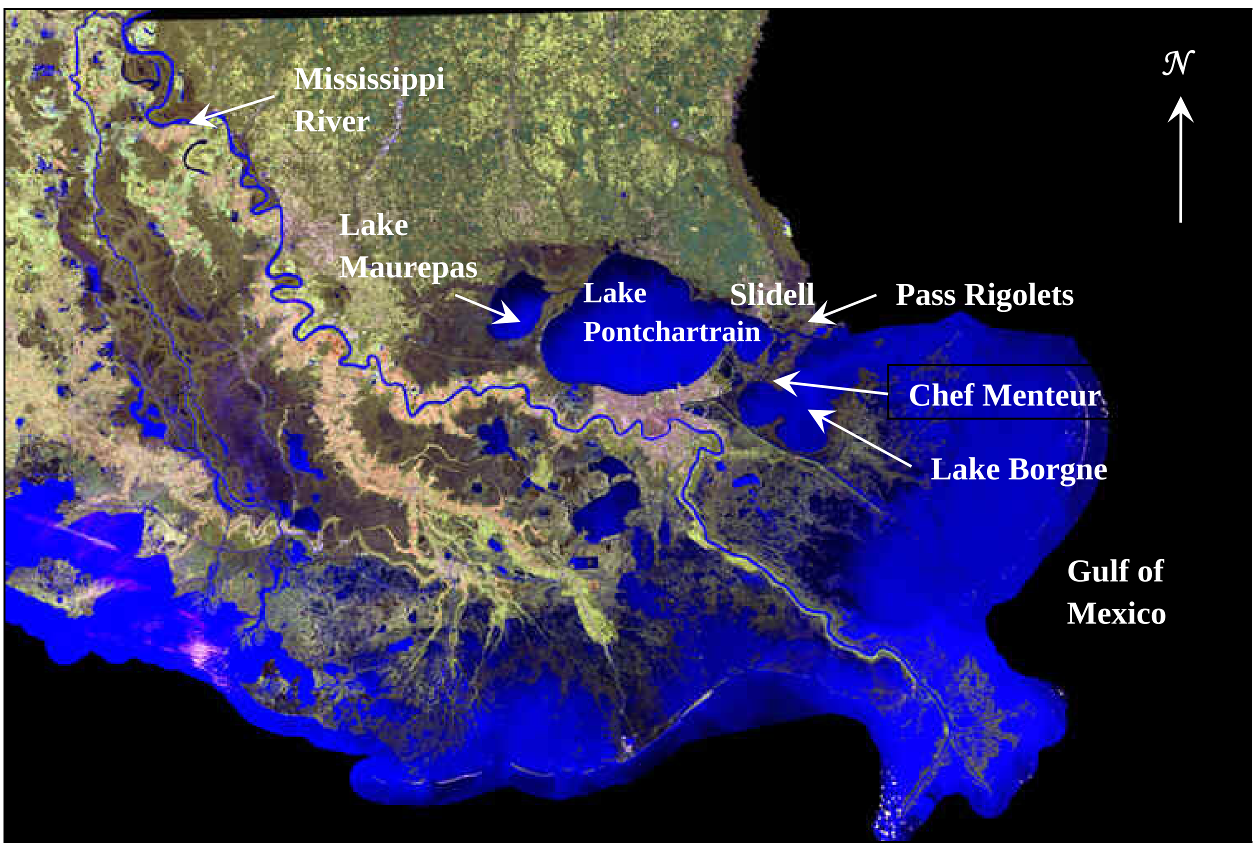

Figure 2: Southeastern Coast of Louisiana, including annotations for the water bodies and waterways discussed in this report.

The purpose of this report is to investigate previous studies dealing with the Pontchartrain Basin to determine what potential effects would need to be thoroughly investigated before implementing a "Barrier Plan" or some modified version of it. More specifically, this report addresses the potential issues that may arise due to the possible flood control structures being placed within the natural tidal channels (Pass Rigolets and Chef Menteur Pass), which are supposed to reduce the storm surge, and ultimately to reduce the threat to the local communities of the greater New Orleans region, caused by a hurricane or storm from the Gulf of Mexico. Some of the issues or parameters under investigation include, but are not limited to, the hydrodynamics of the tidal passes, salinity, water quality, currents, turbulence, fish migration, fish population density changes, and the tidal prism of Lake Pontchartrain. It should be noted that this report is by no means a comprehensive or final account of all of the potential effects that could occur due to the installation of these structures. This report should only be used as a guide or stepping-stone for further study of the designs of flood control structures in the Rigolets and Chef Menteur Passes.

Chapter 2: Lake Pontchartrain & Vicinity Authority

After several brutal hurricanes in 1955, Congress sanctioned the U.S. Army Corps of Engineers (USACE) to perform a series of studies to investigate hurricane protection options for areas along the eastern and southern U.S. coasts (Woolley & Shabman, 2008). One of these commissioned studies (authorized 1965) was the Lake Pontchartrain & Vicinity Hurricane Protection Project (LP&VHPP). As part of this project, a "Barrier Plan" was developed that would protect low-lying New Orleans from the Standard Project Hurricane (SPH) as well as the Probable Maximum Hurricane (PMH).

The wind speeds and coupled wave action during Hurricane Betsy in 1965 closely resembled the SPH; therefore, the New Orleans District was allowed to raise the proposed structure heights by 1 – 2 feet. A federal court injunction in 1975 halted progress, after construction had already begun on the project, due to insufficient evidence proving there would be a minimum environmental impact on Lake Pontchartrain due to the implementation of the project. In 1978, the court amended the injunction and removed the hold on any floodwalls and levees that did not directly affect the Lake; and in 1985, the Director of Civil Works authorized the implementation of the "High Level Plan," which required a higher lakefront levee in lieu of lower levees when the Rigolets and Chef Menteur Pass flood control structures were included (a.k.a the "Barrier Plan"). **Figure 3** shows the 1962 design map for both the "Barrier Plan" and the "High Level Plan". The figure shows that some of the design components are the same, but others, such as the levee heights or flood control structures in the passes, are different.

"Barrier Plan" – Levees along New Orleans and flood control structures in the Rigolets and Chef Passes.

"High Level Plan" – Higher levees along Lake Pontchartrain to replace the flood control structures in the Rigolets and Chef Passes.

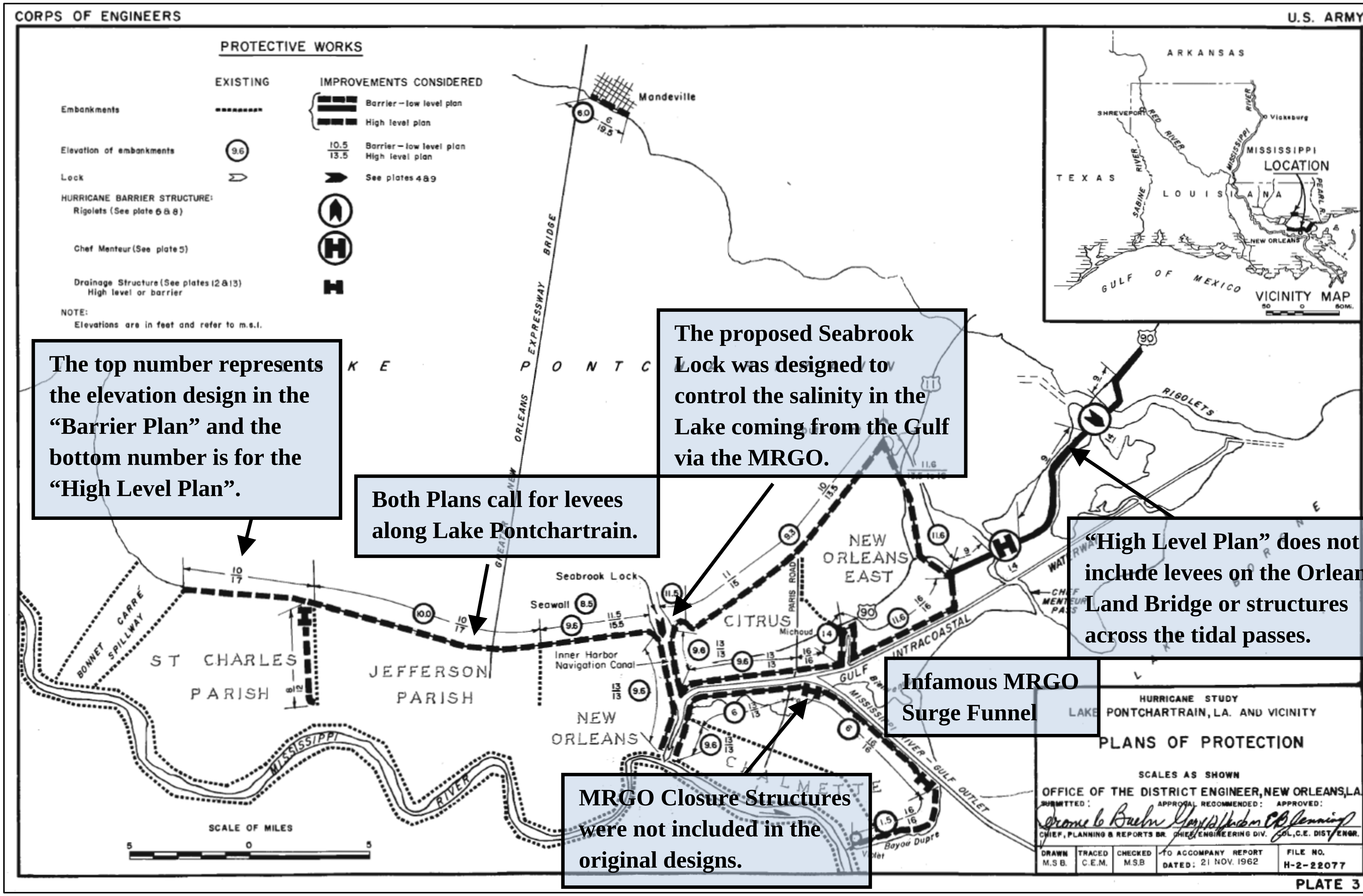

Figure 3: Lake Pontchartrain and Vicinity 1962 Plans for Hurricane Protection. Both the "Barrier Plan" and the "High Level Plan" were considered (USACE, 1962; blue text boxes added by author). The dashed lines indicate the proposed levees for both plans with the fraction representing the respective design elevations (Top number for the "Barrier Plan" and bottom number for the "High Level Plan".) The solid line represents the additional elements included in the "Barrier Plan". (Text boxes added)

Hurricane Katrina

In August 2005, Hurricane Katrina struck southeastern Louisiana and brought with it a significant storm surge that overtopped or breached levees in St. Bernard Parish. These levees were common to both the "High Level Plan" and "Barrier Plan." Immediately following the storm, the USACE developed Task Force Guardian, which was authorized to repair the damages to the LP&VHPP caused by the storm and to restore the area to pre-Katrina conditions (USACE, 2010a). St. Bernard levees were repaired, and failed floodwalls along New Orleans' storm water canals were addressed by protecting the ends of the canals as originally designed in the "High Level Plan." As of June 1, 2006, which was the start of the 2006 Hurricane Season, all of the repairs and restorations were completed (USACE, 2006a). **Figure 4** shows the repairs and restorations performed by Task Force Guardian. (See the Appendix for the Final Report).

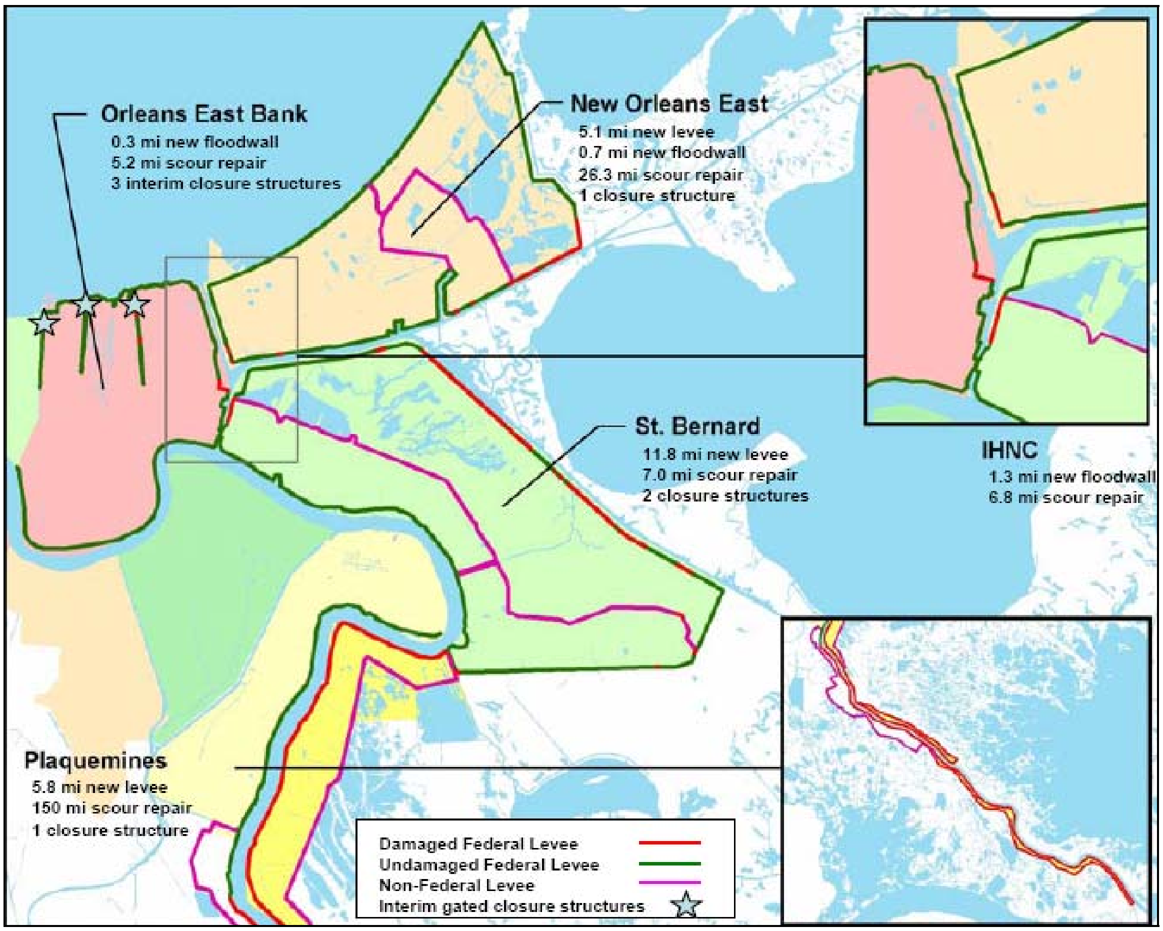

Figure 4: Task Force Guardian Hurricane Protection System Restoration Program Map. The red lines indicate the federal levees that were damaged, the green lines show the federal levees that were not damaged, and the pink lines show the non-federal levees that were damaged. The light blue stars represent the interim control structures that were installed in the New Orleans outfall canals (USACE, 2006a).

It has been casually suggested by some that, if the "Barrier Plan" had been built, that the Hurricane Katrina disaster would have been averted. It is impossible to draw a conclusion from a hypothetical alternative history that would be replete with dubious assumptions. It is fair to point out that the three catastrophic failures of the flood protection system during Hurricane

Katrina (St. Bernard Levee, IHNC floodwalls, storm water canal floodwall failures), were attributed to design failure, incomplete construction, and variation of design from the "High Level Plan" (IPET, 2006). For example, the St. Bernard levees were common to both plans and under the "Barrier Plan" would have had an even higher surge during Hurricane Katrina. Since the "Barrier Plan" did not include a flood control structure on the MRGO at the funnel, the IHNC would have also had higher surge, and therefore, the floodwalls would have been even more threatened and with greater consequences of failure. Along the lakefront, the storm water canal floodwall failures were due to surge being allowed to enter into the canals, which was not a significant departure from the "High level Plan". The "High Level Plan" had a continuous line of protection along the lakefront, and did not include the risky "parallel protection" that was actually constructed before Hurricane Katrina. The lakefront levees did not fail during Hurricane Katrina and have been significantly elevated and made more resilient post-Katrina.

Immediately following Hurricane Katrina, the USACE also established Task Force Hope, which was authorized to oversee Task Force Guardian, as well as to supervise the work on the levees and floodwalls, the removal of debris, and all other emergency response efforts that the USACE was requested to complete (USACE, 2006b).

Also, in 2005, several agencies began investigating the causes and effects of the failures of the 2005 Hurricane Protection System (HPS). Many questions were raised:

How did the levees fail?

Why were I-walls used instead of T-walls?

Could this man-made failure have been prevented?

One of the studies commissioned by the USACE was designed to answer some of these questions and to investigate how the HPS performed during the storm. This study was led by the Interagency Performance Evaluation Task Force (IPET), which consisted of over 150 national and international experts from various agencies, firms, and institutions (USACE, 2007). Another study was commissioned by the USACE to investigate why the 2005 HPS was in use at the time of the storm. This study was called the Hurricane Protection Decision Chronology, and it outlines a complete record of the decisions and events leading up to the design and implementation of the 2005 HPS, including decisions from Congress and design modifications based on impacts from severe hurricanes like Hurricane Betsy. The report was completed in 2008 by Douglas Woolley and Leonard Shabman for the Institute for Water Resources (IWR). **Figure 5** is taken from this report, and it shows the 50-yr timeline of the significant congressional, judicial, and headquarters' decisions that were made for the LP&VHPP. **Figure 6** is also from this report, and it shows the 50-yr timeline of the hurricane performance decisions that were made for the project.

Several important conclusions can be drawn from these important post-Katrina investigations. Significant departures from the "High Level Plan" levee designs were made which compromised flood protection, such as the choice of parallel protection along the outfall canals. The "High Level Plan" was not designed to the actual authorized storm level (~ Category 3). The "High Level Plan" levees and floodwalls were not properly engineered, such as soil engineering. Finally, the "High Level Plan" was not complete when Hurricane Katrina struck. In spite of these deficiencies, it is noteworthy that the central element of protection for Lake Pontchartrain was the lakefront levees which did not fail even with a storm of greater strength than their design criteria. There is near unanimous consensus that the Hurricane Katrina disaster was a manmade disaster due to the execution of the "High Level Plan" not to inherent flaws in the "High Level Plan".

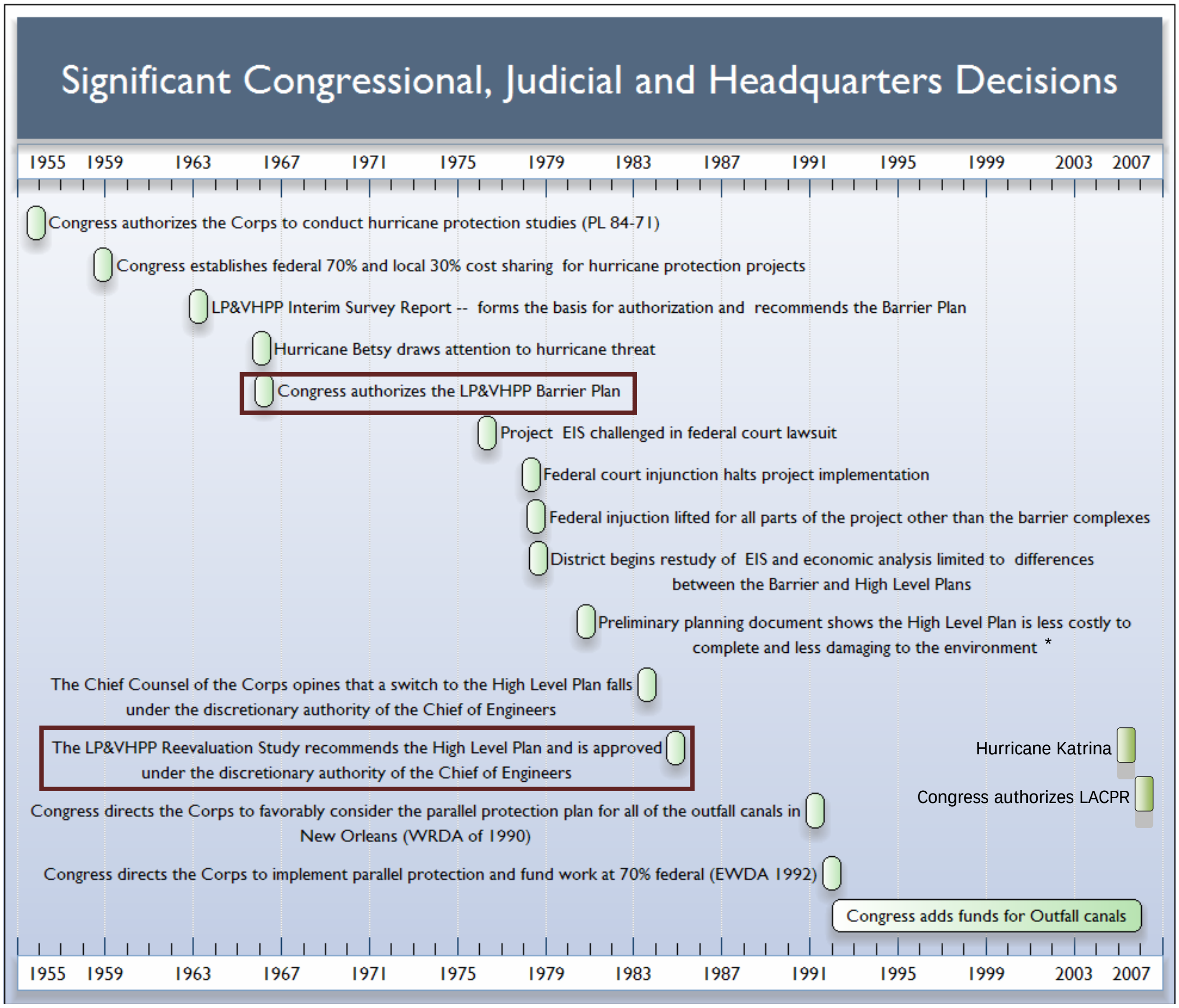

Figure 5: 50-yr Timeline of Significant Congressional, Judicial, and Headquarters Decisions. Construction had begun for the "High Level Plan" after the switch in 1985, but was not complete when Hurricane Katrina struck in 2005. The two units most affected by Hurricane Katrina were the Chalmette and New Orleans East Units, which were reported as 98 and 92% complete, respectively, as of 2005 (Woolley & Shabman, 2008 with minor edits by M. Davis).

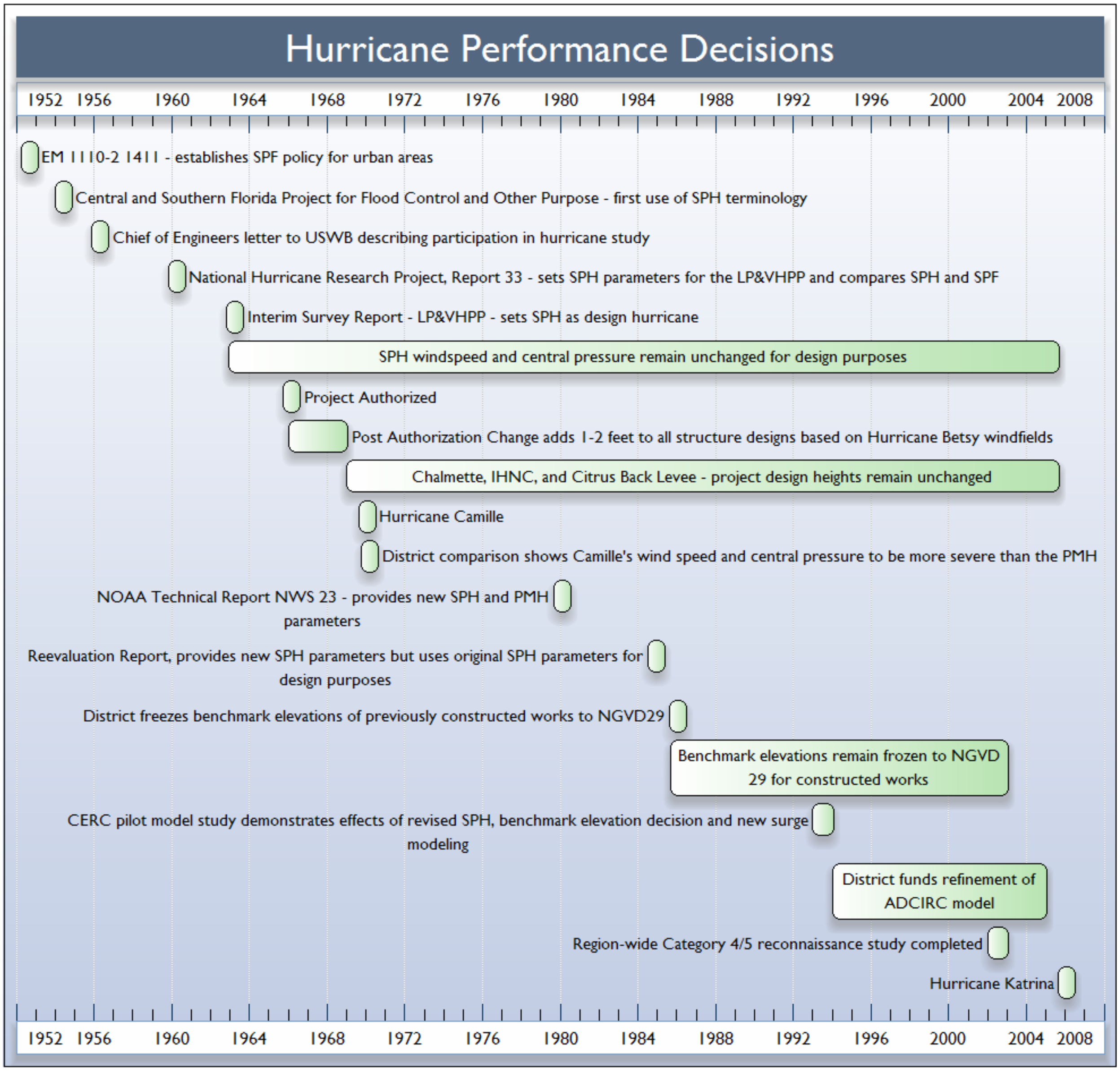

Figure 6: 50-yr Timeline of Significant Hurricane Performance Decisions (Woolley & Shabman, 2008).

In October 2005, the Louisiana Department of Transportation and Development (LDOTD) commissioned Louisiana State University to organize a team of local forensic experts from both academic institutions and private industries to investigate the failure of the New Orleans levee system. This group was called “Team Louisiana”, and they presented their findings in 2007 after the USACE presented its IPET report. There were two important findings from Team Louisiana: First, most historical Hurricane Protection System designs did not account for subsidence and marsh degradation which impacts the amount of storm surge that gets dissipated before making landfall. Second, the original LP&VHPP focused on protecting New Orleans from high surges in Lake Pontchartrain, when the highest historical storm surges came instead from Lake Borgne (LDOTD, 2007).

In 2006, the Lake Pontchartrain Basin Foundation (LPBF) presented a planning methodology for combining natural and man-made storm protection with coastal restoration. This methodology was coined the Multiple Lines of Defense Strategy (MLODS) (Lopez, 2006); and it has been adopted by several agencies in their efforts to protect and sustain coastal Louisiana, such as the Coastal Protection and Restoration Authority (CPRA) and the Louisiana Coastal Protection and Restoration Team (LACPR) (LPBF, 2008).

In 2007, CPRA released *Louisiana's Comprehensive Master Plan for a Sustainable Coast* (A.K.A. the State Master Plan), which is a comprehensive plan that identifies measures for protection against storms and restoration of Louisiana's coast (CPRA, 2010a). As mentioned previously, the State Master Plan adopted the MLODS, which combines storm protection with coastal restoration. The plan includes some guidance for design of possible flood control structures on Chef Menteur and the Rigolets Passes. The CPRA is currently working on the 2012 State Master Plan, which builds upon the 2007 State Master Plan, as well as other planning efforts (CPRA, 2010b).

Under Task Force Hope, the USACE is re-designing and re-constructing the "High Level Plan" hurricane protection system around the Greater New Orleans region. The new system is the Hurricane and Storm Damage Risk Reduction System (HSDRRS), which uses elevation design for a 100-year level of protection using the latest storm surge modeling, sea level rise, and subsidence information. In addition, the HSDRRS is being designed to withstand a 500-year storm event without failure, i.e., breaching. The purpose of this system is to limit the amount of damage associated with hurricanes in southeast Louisiana, at a cost of $14.7 B. The design consists of reinforced levees, T-wall floodwalls, surge barriers, pump stations, and floodgates. As of August 2010, the 100-yr level construction is expected to be completed by June 2011 (USACE, 2010b). (See the Appendix for the HSDRRS 100-yr design elevation map).

In 2008, LPBF and the Coalition to Restore Coastal Louisiana released a report, which applied the Multiple Lines of Defense Strategy (MLODS) throughout southeast Louisiana. The report has numerous recommendations for protection and restoration projects, including projects in the Pontchartrain Basin (LPBF & CRCL, 2008). The report recommends using a combination of measures to enhance flood protection around the Lake Pontchartrain region including home elevation both inside and outside of levee protection. Since 2006, LPBF has endorsed ten coastal restoration projects referred to as the Pontchartrain Coastal Lines of Defense because they are ecologically significant and because they provide storm surge benefits (see SaveOurLake.org).

In 2009, the Corps released the LACPR Technical report, which evaluated numerous alternatives including alternatives from the State's Master Plan to achieve protection levels to protect against a storm similar to Hurricane Katrina (1:400). This technical report presented several alternatives for flood control measures for Lake Pontchartrain and Vicinity that were similar to the original 1965 authorization "Barrier Plan" and the "High Level Plan", as well as measures that combined the effects of natural and man-made protection. The report also incorporates the MLODS by modeling surge with both structural measures, non-structural and coastal restoration. Since this was a technical report, no specific recommendations were made for future enhancement of hurricane protection.

Chapter 3: Lake Pontchartrain Basin Estuary

The Lake Pontchartrain Basin includes the area east of the Mississippi River that is within Louisiana and is 9,645 square miles (**Figure 7**) (Lopez, 2003). Approximately 5,800 square miles of the Basin is estuarine, and this includes lakes Borgne, Pontchartrain, and Maurepas (Figure 7, white shaded area). The estuary is shown in the white shaded area on **Figure 7**. All of these tidal bays (lakes) and most of the adjacent wetlands are tidally connected (LPBF, 2006). This means that the 630 square mile Lake Pontchartrain is part of a larger estuary with tidal bays (lakes) that are inland and seaward of it. The portion of the estuary inland of the Chef Menteur and Rigolets Passes (location of the alternative flood control structures Figure 7) includes approximately 630 square miles of wetlands, 720 square miles of tidal bays (lakes), and 8 rivers, bayous, or streams on the protected side of flood control structures. An excellent overview of the tidal bays can be found in *The Lakes of Pontchartrain* (Hastings, 2009). Any discussion of the alternative flood control structures on the Chef and Rigolets passes into Lake Pontchartrain must consider effects on not just Lake Pontchartrain, but the entire Pontchartrain Basin estuary of which one fourth of the estuary (1,350 square miles) would be inland of the flood control structures, and three fourths would be seaward (4,450 square miles).

Figure 7: Lake Pontchartrain Basin (red outline), and the estuary sub-basins. Shaded area is approximate area of the estuary. Alternative Flood Control structures at the tidal passes would be positioned with ¼ of the estuary on the protected side and ¾ of the estuary on the flood side.

The relationship of potential flood control structures to the larger estuary can be seen on **Figure 7** from the Lake Pontchartrain Basin Foundation's *Comprehensive Habitat Management Plan* in which the Upper Sub-Basin and Middle Sub-basin (estuary) are located inland of tidal passes and the Lower Sub-basin is located seaward. The flood control structures have the potential to alter estuarine functions between the Lower Sub-basin and the Upper-Middle Sub-basins.

Figure 8 shows a close up view of the bays (lakes) and some of the channels, tributaries, and water bodies connecting to them. From the figure, the western-most bay is Lake Maurepas, which is connected to Lake Pontchartrain via Pass Manchac. The eastern-most bay (lake) is Lake Borgne and is connected to Lake Pontchartrain via two tidal passes: Rigolets and Chef Menteur. The tidal passes will be discussed in a later section. The IHNC connects the Mississippi River with the use of a lock to Lake Pontchartrain and to the Gulf Intracoastal Waterway (GIWW) through the Mississippi River Gulf Outlet Channel (MRGO). **Table 1** shows some significant features of the Pontchartrain Basin and its components (Roblin, 2008). It should be noted that the MRGO was closed in July 2009 with a rock structure near Bayou la Loutré; and a storm surge barrier structure is now constructed near the Golden Triangle. (Both of these locations are shown in **Figures 8 and 9**).

Figure 8: Close-up view of Lakes Pontchartrain, Maurepas, and Borgne and the Rigolets and Chef Menteur Passes, including an arrow to indicate the typical direction of the storm surge (Roblin, 2008 with edits by M. Davis).

Table 1: Important features of the Lakes and channels in the Pontchartrain Basin, including average depth and surface areas of the lakes, and average depths, average cross-sectional areas, and total lengths of the channels (Roblin, 2008 with edits by M. Davis).

Lake/Channel	Parameter	SI Units	US Units
Lake Pontchartrain	Average Depth	3.7 m	12.1 ft
	North-South Axis	40.2 km	25 mi
	East-West Axis	64.4 km	40 mi
	Surface Area	1632 km^2	630 sq. mi
	Mean Tidal Range	0.11 m	0.36 ft
	Tidal Prism	$1.6x10^8$ m^3	$5.6x10^9$ ft^3
Lake Maurepas	Average Depth	3.0 m	9.8 ft
	Surface Area	233 km^2	90 sq. mi
Lake Borgne	Average Depth	2.7 m	8.9 ft
	Surface Area	550 km^2	212 sq. mi
IHNC-MRGO	Total Length	30 km	18.6 mi
	Average Depth	7.5 m	24.6 ft
	Average Cross-sectional Area	1125 m^2	12,100 ft^2
Pass Manchac	Total Length	15 km	9.3 mi
	Average Depth	8.0 m	26.2 ft
	Average Cross-sectional Area	2924 m^2	31,500 ft^2
Pass Rigolets	Total Length	13.7 km	8.5 mi
	Average Depth	10.3 m	33.8 ft
	Average Cross-sectional Area	7,630 m^2	82,200 ft^2
Chef Menteur Pass	Total Length	10.4 km	6.4 mi
	Average Depth	12.5 m	41.0 ft
	Average Cross-sectional Area	3,660 m^2	39,400 ft^2

Lake Maurepas is a tidal estuarine bay (lake), which is predominately fresh because it receives freshwater from the Amite, Tickfaw, and Natalbany Rivers. Lake Pontchartrain receives freshwater directly from the Tangipahoa and Tchefuncte Rivers, Pass Manchac, the New Orleans outfall canals, the East and West Pearl Rivers (through the Rigolets Pass) ; and the occasional leakage or spillway opening flow from the Bonnet Carré Spillway, It receives seawater from Lake Borgne through the Rigolets and Chef Menteur Passes and the IHNC.

Because Lake Pontchartrain is shallow, it is typically well mixed except for seasonal stratification which often covers $1/6^{th}$ of the lake bottom due to high salinity water introduced from the IHNC (Poirrier, 1978: Georgiou, 2002). According to Georgiou (2002), Lake Pontchartrain's salinity distribution is controlled by freshwater contributions from the tributaries and diversions listed above, precipitation, and thermal evaporation. Lake Pontchartrain is classified as a "brackish" estuarine lake, where the salinity approaches 6 ppt[1] (PSU) in the east

[1] PPT stands for parts per thousand and is a measurement of the concentration of a substance.

near Lake Borgne and 1 ppt in the west near Lake Maurepas (McCorquodale et al. 2009). Due to the lake being wide and shallow, the evaporation rate is almost the same as the average annual precipitation rate, which is approximately 4.6 ft (1.4 m) (McCorquodale et al. 2001).

Typically, Lake Pontchartrain also receives saltwater from the IHNC, but the IHNC opening to Lake Pontchartrain is temporarily closed. The saltwater would come from the Gulf of Mexico via the Mississippi River Gulf Outlet channel (MRGO) and its connection to the IHNC. The MRGO extends from the IHNC to the Gulf of Mexico and was completed in 1968; its purpose was to create a shorter navigation route from the Port of New Orleans to the Gulf of Mexico (USACE, 2008). **Figure 9** (to the right) shows the MRGO channel and its connection to the Gulf of Mexico (USACE, 2010c).

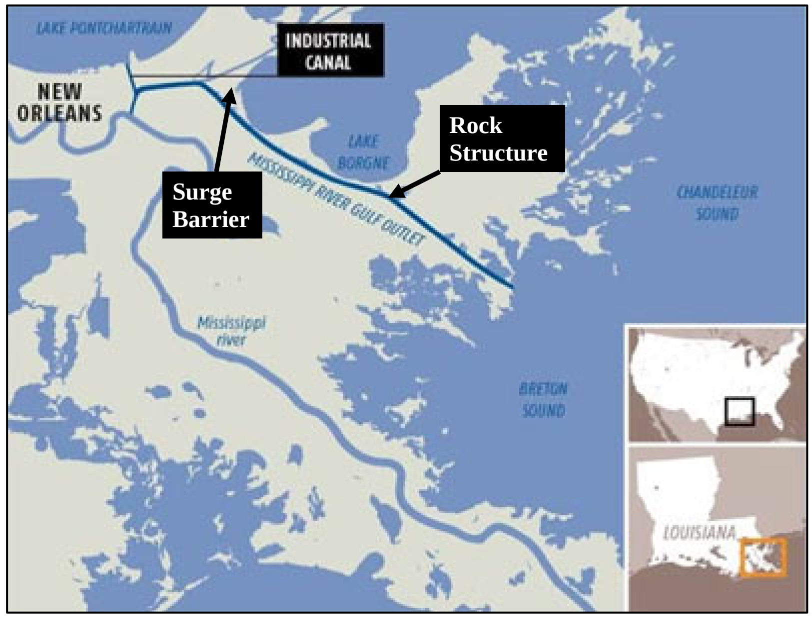

Figure 9: Mississippi River Gulf Outlet Channel. The channel extends from the IHNC to the Gulf of Mexico (USACE, 2010c with edits by M. Davis).

At the time it was constructed, approximately 4.9 square miles (3,150 acres) of marsh, 0.16 square miles (100 acres) of wetland forest, and 1.3 square miles (830 acres) of shallow open water were converted to the MRGO channel (USACE, 2008). Over the years, designs were proposed for the Seabrook Lock structure in the IHNC at Lake Pontchartrain in order to control the saltwater concentrations entering the Lake. This structure was never implemented. During Hurricane Katrina, severe shoaling occurred in the MRGO channel; and as a result of this shoaling, as well as the flooding of St. Bernard Parish and other local communities, Congress authorized the USACE to repair or de-authorize the MRGO depending on the necessary measures needed to "protect, restore or increase wetlands, to prevent saltwater intrusion or storm surge" (USACE, 2008). Based on the 2008 Deep-Draft De-authorization Report (USACE, 2008), the closure of the MRGO was authorized by Congress (USACE, 2010c). The current closure comprises of two structures: a rock structure across the channel near Bayou la Loutré and a surge barrier structure, consisting of a dam with navigation gates, across the Golden Triangle. **Figure 9** also shows the locations of the two closure structures. It should be noted that the barrier structure is currently complete with the exception of the navigation gates, which was completed by June 2011. A gate structure on the IHNC at Seabrook will be completed by June 2012.

Chapter 4: Hurricane Surge Dynamics of Lake Pontchartrain

During hurricanes, the combination of low pressure and high winds creates a large wave or surge of water emanating from the Gulf of Mexico. As this storm surge moves inland, it can cause extensive damage. All regions of the coast undergo the same general patterns of wind field and tidal surge, but each storm has unique characteristics. Just as important is that each area of the coast has different influences on the wind and surge patterns. This is particularly true for Lake Pontchartrain, which has a well known sloshing or seiche effect during storm passages.

Under historical conditions with the natural passes open and before closures of the MRGO or IHNC, a pattern of surge movement into the lake is well understood locally but not well documented in the literature. The IPET report on Hurricane Katrina mentions the tilting of the lake surface due to wind and the IPET models demonstrate this pattern of surge movement (IPET, 2006). It is noteworthy that all surge modeling of Hurricane Katrina, and actual observed high water document that the maximum surge in Lake Pontchartrain is on the northeast side near Slidell after passage of the storm center. That is, the highest surge is associated with passage of the weaker quadrants of the storm. This paradox is due to local hydrology and is demonstrated in the modeled and observed slosh effect of the lake by storm passage (**Figure 10**).

Surge Model of Hurricane Katrina in one hour increments (upper left to lower right)
IPET, Volume The Storm Appendices

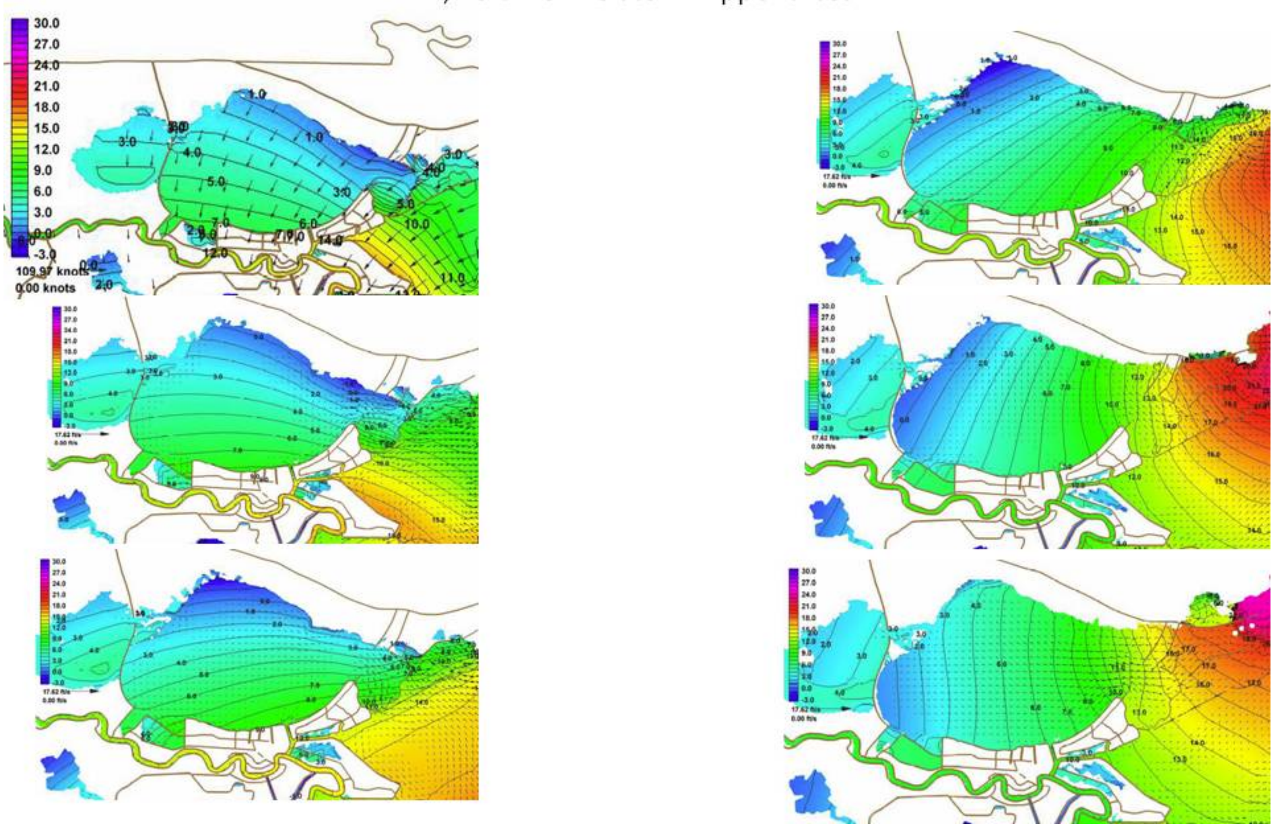

Figure 10: Surge model for Hurricane Katrina in one hour increments. Note the rotation of surge on the perimeter of the lake from southwest, to south and then east toward the passes. The Lake near Rigolets has extremely rapid rise in surge of 11 feet in just six hours.

An approaching storm has east winds pushing water into Lake Pontchartrain but also toward the west or southwest quadrant of the lake. This often begins 2-3 days in advance of the actual hurricane landfall. Once there is landfall, and the eye passes north of the lake, winds quickly rotate to north and then west pushing water southward and then eastward toward the passes and out of the lake. However, the rate of water exiting through the passes and with overland flow across the Orleans land bridge is not sufficient to accommodate the rapid transfer of water from the west to south and then to the east side of the lake. Surge transfer across the open lake by hurricane wind requires hours; whereas, draining the surge out of the lake requires 1 to 3 days. Therefore, as the storm moves inland and winds shift to the west surge elevates on the east side of the lake to levels higher than the storm's initial passage.

It is vital to recognize that the sloshing effect of Lake Pontchartrain is a wind driven phenomenon, and therefore, sloshing occurs even with closed flood control structures. The magnitude of surge on the protected side is not necessarily less with closed flood control structures on the passes. The reason is the closed flood control structures do not influence the wind field, but also that lake still water levels will be elevated due to rainfall, stream water discharge, barrier overtopping, and pumped storm water during the storm event. The lake will be storing all of this water since there is no outlet. That is, flood control structures also reduce draining of the lake. Any elevated still water level will be influenced by the sloshing effect of the wind field but with the added problem that less water will be allowed to escape during the period of wind reversal. It is unlikely flood control structures could be opened rapidly and predictably enough during the hurricane to allow the immediate release of surge from Lake Pontchartrain. The compounding effects of a flooding lake reduced outflow with the wind driven slosh against a barrier may still create serious flood conditions that under the right scenario may be worse than a lake without flood control structures.

Under the current condition without flood control structures on the Passes into Lake Pontchartrain, the Lake does create significant storage which to a point does not create a flood threat. This natural storage of hurricane surge allows surge to be spread over a larger area and therefore keeps surge levels lower in general. The LACPR report indicates that surge levels in Mississippi are elevated with flood control structures in place on passes into Lake Pontchartrain. Obviously, the hydrodynamics of the storage and sloshing effects in Lake Pontchartrain would be a critical flood issue to evaluate for any alternative flood control structures on the passes into Lake Pontchartrain.

Chapter 5: Physical Description of Pass Rigolets & Chef Menteur Pass

The Rigolets and Chef Menteur Passes connect Lake Pontchartrain to the Gulf of Mexico via Lake Borgne. The passes undergo a diurnal tide, or both a high tide and a low tide within one day, with a mean tidal range of 0.36 ft (0.11 m) (Roblin, 2008). **Figure 11** shows an image of the Rigolets and Chef Menteur Passes from Google Earth, as well as a close-up view of the connection from Lake Borgne to Lake Pontchartrain. Pass Rigolets has a total length of 8.5 mi (13.7 km), an average depth of 33.8 ft (10.3 m), and an average cross-sectional area of 82,200 ft^2 (7,630 m^2); and Chef Menteur Pass has a total length of 6.4 mi (10.4 km), an average depth of 41.0 ft (12.5 m), and an average cross-sectional area of 39,400 ft^2 (3,660 m^2).

Figure 11 Google Earth Image of the Rigolets and Chef Menteur Passes showing the connections from Lake Borgne to Lake Pontchartrain.

According to McCorquodale et al. (2007), the two passes underwent significant scouring near the bridge piers and bends, which is believed to be caused by the surge inflow combined with the receding flow from Hurricane Katrina. **Figure 12** shows the scour patterns in Chef Menteur Pass near the Railroad Bridge (McCorquodale et al. 2007). The darker areas represent the deeper bathymetry of the pass. At this location, depths reached beyond -100 ft. The mid-grey areas represent depths from 60 – 75 ft, and the light grey areas represent depths less than 50 ft (McCorquodale et al. 2007).

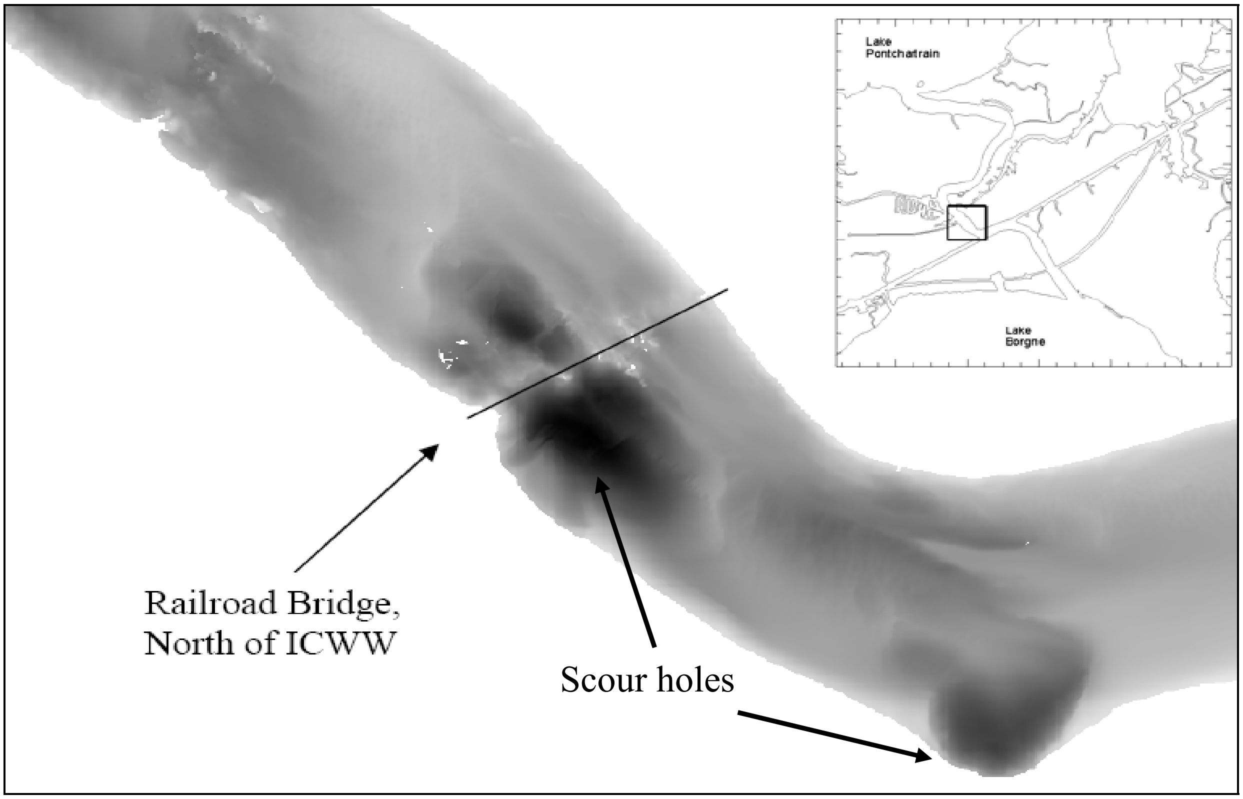

Figure 12: Scour Patterns in Chef Menteur Pass Following Hurricane Katrina. The dark grey areas represent depths beyond 100 ft; the mid-grey areas represent depths from 60 – 75 ft; and the light grey areas represent depths less than 50 ft (McCorquodale et al. 2007).

Multi-beam bathymetry data taken after Hurricane Katrina were used to estimate the cross-sectional areas of the two passes. **Figure 13** shows the cross-sectional area histogram for Pass Rigolets; and **Figure 14** shows the histogram for Chef Menteur Pass. The blue and red bars indicate the percent of the cross-sections in that pass that have an area in the corresponding range of thousands of square feet. Cross-sections were extracted from a Tecplot file and were spaced every 1,000 ft.

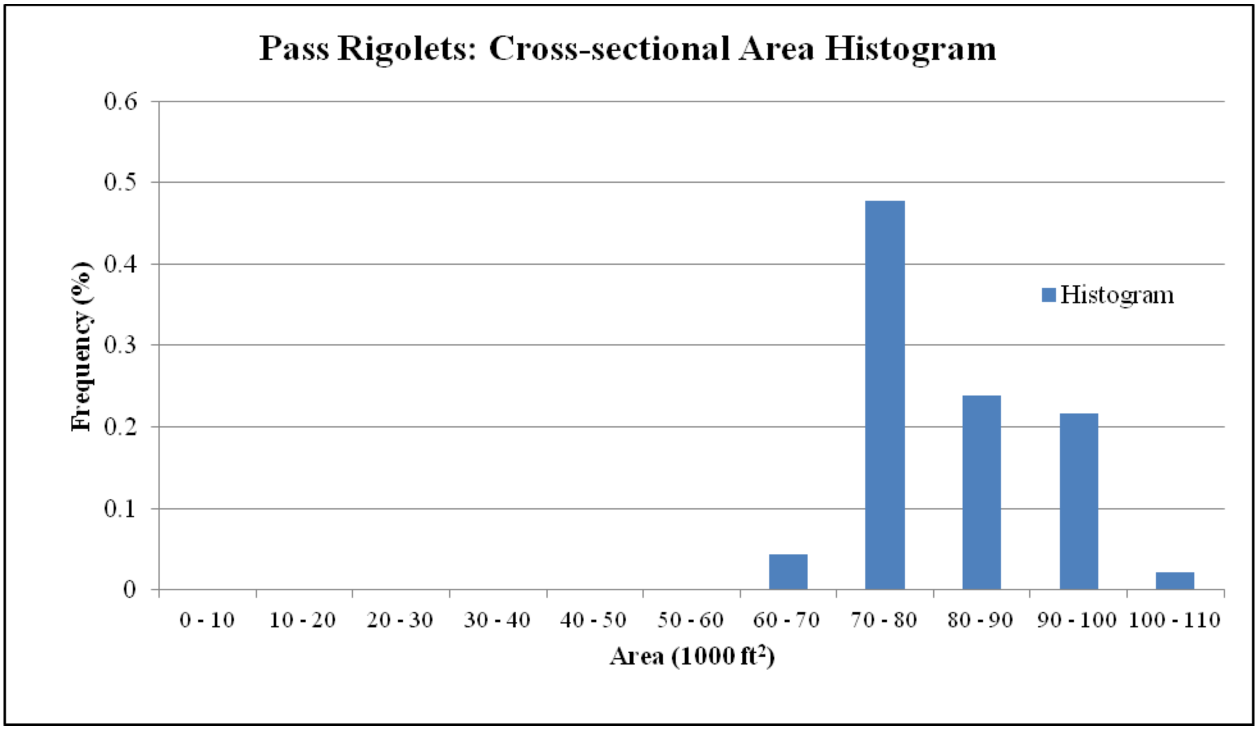

Figure 13: Cross-sectional area histogram for Pass Rigolets. Over 45% of Pass Rigolets has a cross-sectional area between 70,000 – 80,000 ft^2, over 20% has a cross-sectional area between 80,000 – 90,000 ft^2, and over 20% has a cross-sectional area between 90,000 – 100,000 ft^2.

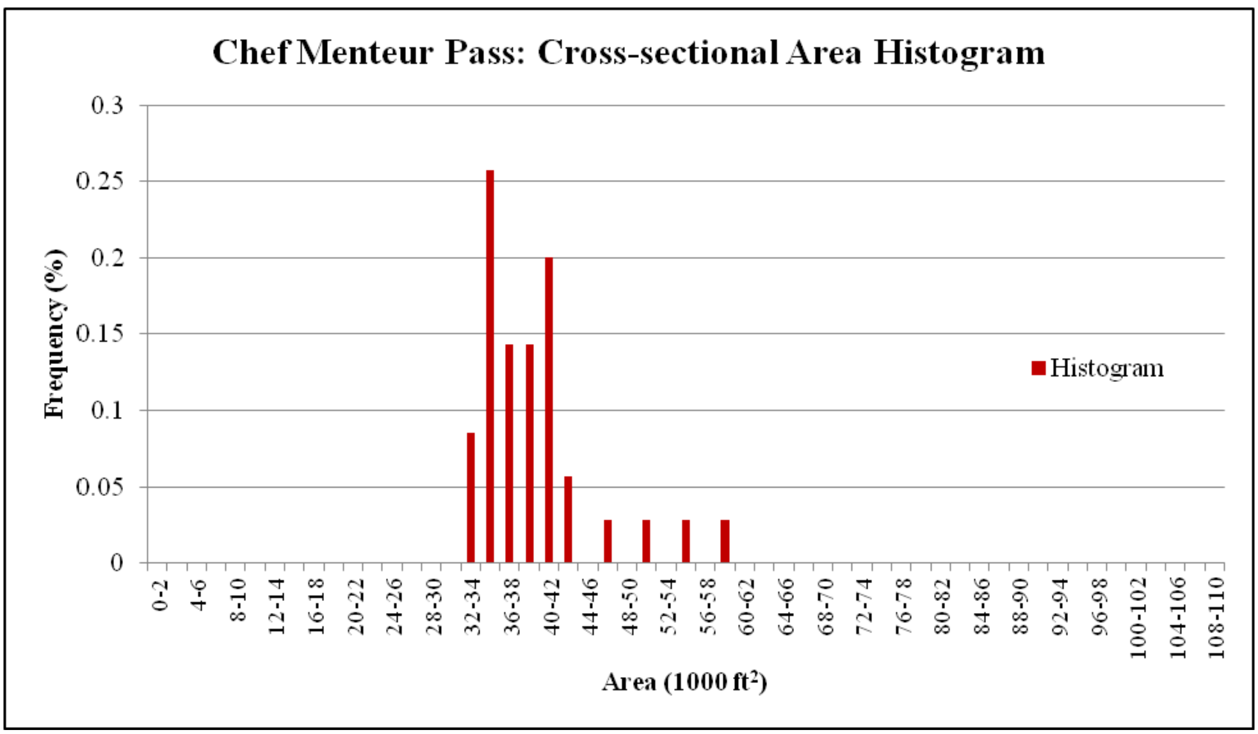

Figure 14: Cross-sectional area histogram for Chef Menteur Pass. Over 25% of Chef Menteur Pass has a cross-sectional area between 34,000 – 36,000 ft^2 and almost 20% has a cross-sectional area between 40,000 – 42,000 ft^2.

The Tecplot file mentioned above was also used to determine the thalweg of the two passes. A thalweg is a line from one end of the pass to the other end that connects the deepest points of the pass. **Figure 15** shows the thalweg profile for the two passes. It should be noted that although Chef Menteur Pass (red line) appears deeper, Pass Rigolets (blue line) is in fact the larger pass in length, as well as width. This can also be seen in the cross-sectional area histograms from **Figures 13** and **14**, where over 45% of Pass Rigolets is in the 70,000 – 80,000 ft^2 range and over 25% of Chef Menteur Pass is in the 34,000 – 36,000 ft^2 range.

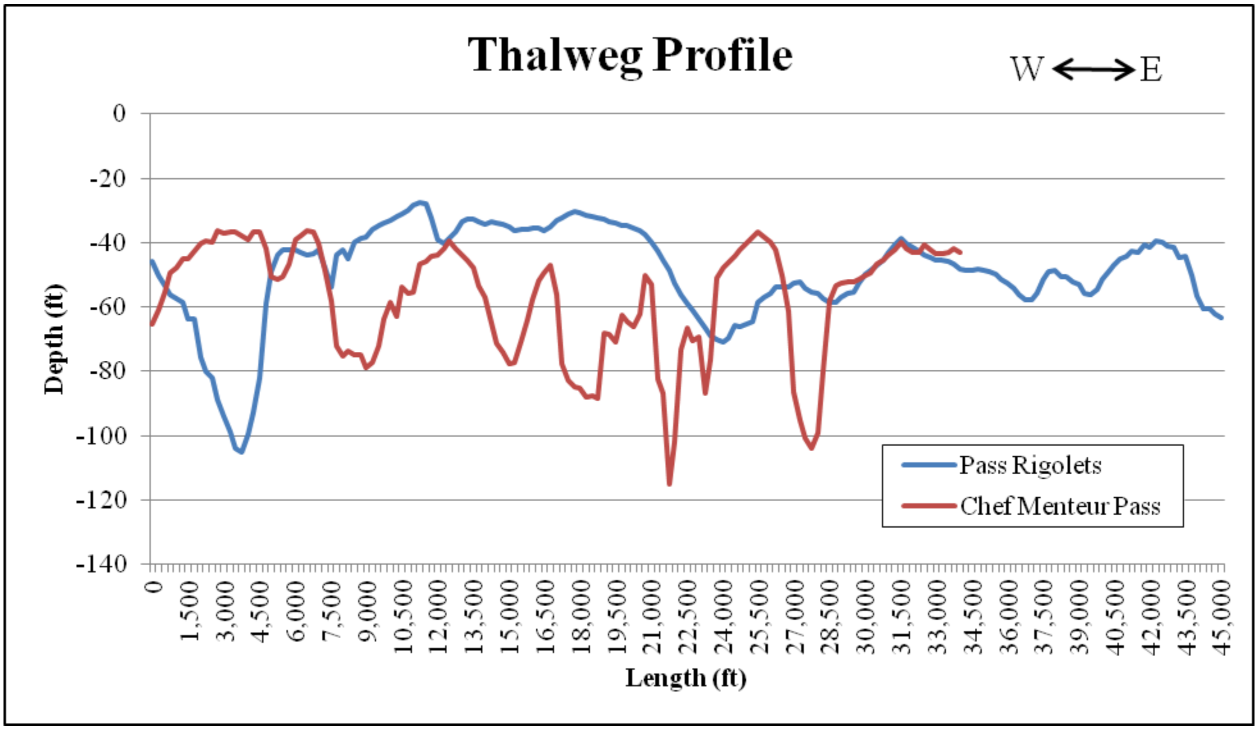

Figure 15: Thalweg profiles for Rigolets and Chef Menteur Passes. A thalweg is a line from one end of the pass to the other end that connects the deepest points of the pass. Chef Menteur Pass is smaller than Pass Rigolets, but it is deeper in some places. (See **Figures 13** and **14** for a cross-sectional area comparison). The water depth in Pass Rigolets gets shallower near Lake Borgne (East) as shown in the figure. This could be caused by the presence of the Pearl River, which brings with it sediment-laden freshwater that can cause shoaling of the pass.

Chapter 6: Description of Alternative Flood Control Structures

The original “Barrier Plan” for the LP&VHPP included levees along New Orleans, as well as flood control structures in the Rigolets and Chef Menteur Passes. These structures would be closed during storm events in order to prevent high surges from inundating Lake Pontchartrain and overtopping the surrounding levees. From the 1963 U.S. Army Corps of Engineers Technical Report, the design of the Rigolets structure consisted of a flood control structure with sill elevation and top elevation at -20 ft and +12 ft (1963 MSL), respectively, and a closure dam on the north side of the pass; the closure dam would stretch across the channel from the north bank to the control structure. The Chef Menteur Pass structure design consisted of a closure dam in the pass and a dredged bypass channel including a control structure with sill elevation and top elevation at -25 ft and +12 ft (1963 MSL), respectively. Plan and section views of these two designs are shown on Plates 32 and 33 in the Appendix (USACE, 1963). The 1965 proposed design and location of the flood control structures have changed over the years. **Figures 16 and 17** show some of the different proposed locations for the structures.

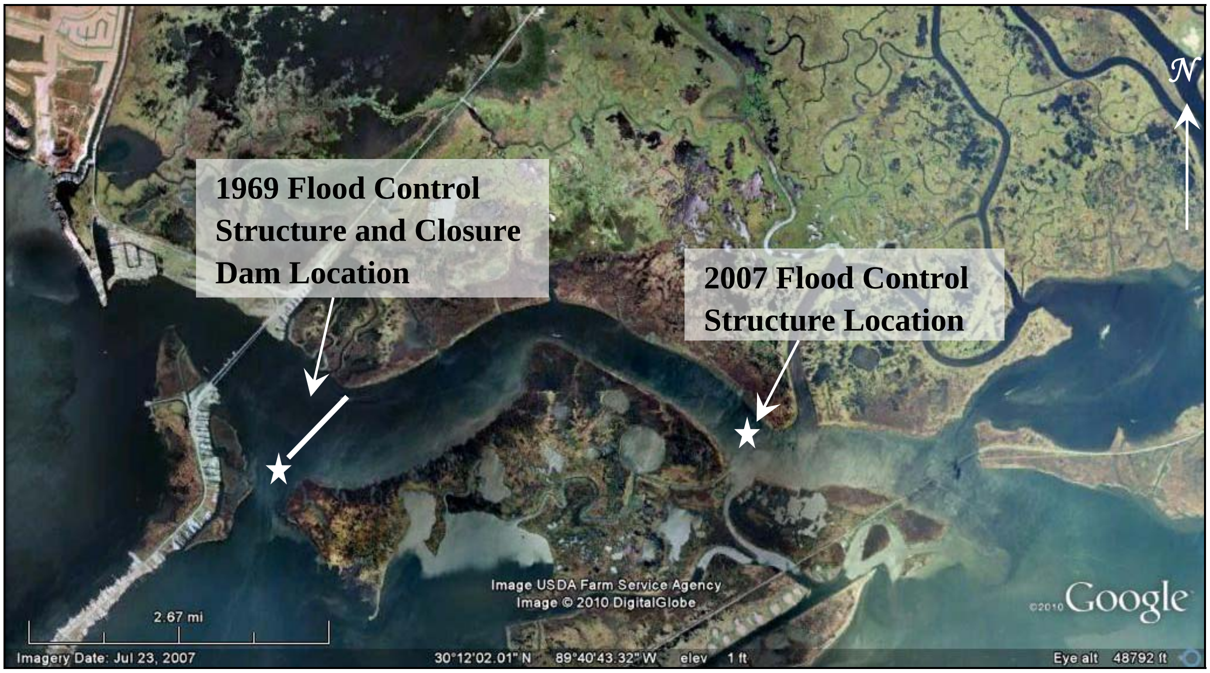

Figure 16: Google Earth Image showing the 1969 and 2007 proposed flood control structures and closure dam locations for Pass Rigolets.

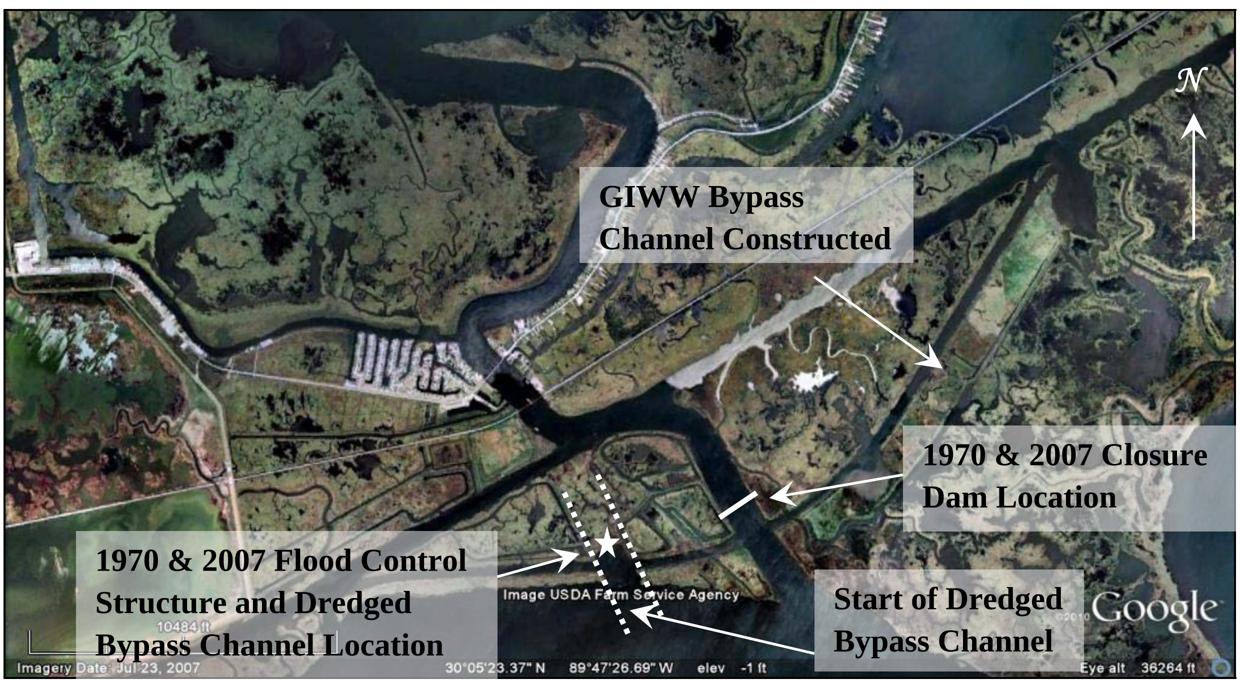

Figure 17: Google Earth Image showing the 1970 and 2007 proposed flood control structures, bypass channel, and closure dam locations for Chef Menteur Pass. As part of the 1965 design, dredging of the bypass channel had begun, but it was halted after the injunction in 1975.

In 2007, the LACPR published a technical report based on flood protection measures outlined in the State Master Plan. From the LACPR technical report, the Team recommends a 1,900 ft wide structure in Pass Rigolets and a 750 ft wide structure in Chef Menteur Pass. The design of the Rigolets structure consists of fifteen 63 ft wide tainter gates and one butterfly gate, each with a sill elevation of -30 ft. The design of the Chef Menteur Pass structure consists of twelve 63 ft wide tainter gates with a sill elevation of -25 ft (LACPR, 2010).

Also, in 2007, UNO was funded by the USACE to complete a study on the hydrodynamics of the Rigolets and Chef Menteur Passes. In this report, McCorquodale et al. prepared two 3-D numerical models to investigate the effects of constrictions in the Rigolets and Chef Menteur Passes. The models tested various clear openings of the structures to minimize the effects of the constrictions on the velocity and change in water surface elevation. **Table 2** is taken from this report and shows the recommended design components based on the model results (McCorquodale et al. 2007).

Table 2: Rigolets and Chef Menteur Passes flood control structure design dimensions based on model results from the June 2007 UNO Report, where the total width is from bank to bank, the sill elevation is the elevation of the bottom of the structure, the bays allow water to pass through, the piers are obstructions in the flow that connect the bays to each other, and the open width is the width available for water to pass through. NAVD 88 is the vertical datum used to reference structure elevations (McCorquodale et al. 2007).

Parameter	Pass Rigolets Structure	Chef Menteur Pass Structure
Total Width (ft)	1,950	790
Sill Elevation (ft) (NAVD 88)	-30	-30
Number of Bays	28	11
Width of Bays (ft)	60	60
Width of Piers (ft)	9	9
Open Width (ft)	1,700	700

As a part of the LDOTD study, Team Louisiana performed modeling of the 1965 flood control structures with the surge and wind conditions of Hurricane Katrina to estimate what would have happened if the 1965 flood control structures had been installed in the tidal passes. The model results indicated that the proposed structures would not have greatly reduced the surge height for the south shore of Lake Pontchartrain, as it was assumed (LDOTD, 2007). This is presumably due to the MRGO being open to the IHNC and Lake Pontchartrain (**see Figure 3**), rainfall, overtopping of the 12 foot high barriers (**Figure 16**), and the sloshing effect of storm water in Lake Pontchartrain (see Chapter 4).

Chapter 7: Potential Effects of Alternative Flood Control Structures – Closed Position

In the event that a hurricane or strong storm were to move inland on Louisiana, the flood control structures in the tidal passes would be closed to prevent the storm surge from entering Lake Pontchartrain. At the structures themselves, the surge would hit the flood control structure and with the continued winds would amplify in magnitude. The extent of the increased surge height was modeled for the LACPR report and was estimated for Pass Rigolets and Chef Menteur Pass, respectively, as 25 ft and 26 ft on the Gulf side of the structures. On the Lake side of the structures, the surge height was modeled as approximately 16 ft and 18 ft for Pass Rigolets and Chef Menteur Pass, respectively. The model included the proposed "Barrier Plan" structure designs for the tidal passes using the 100-yr design storm elevations (12 ft above MSL) (LACPR, 2009). (See the Appendix for the LACPR contour maps). As with the DOTD Team Louisiana Report's modeling of the original "Barrier Plan" (prior section), the surge reduction on the protected side is not as great as might have been anticipated due to the overtopping of the barrier, rainfall, and sloshing effect of Lake Pontchartrain even with the closure of the MRGO. It should be noted that the LACPR modeling also demonstrates that with flood control structures on the Lake Pontchartrain passes there is an increase in surge on the Mississippi coast, and so this would need to be carefully estimated and assessed.

Inside the Lake, there would be a build-up of water from the connecting rivers and diversions, from precipitation and runoff from the storm, and from the possible dewatering of New Orleans through the outfall canals, which would normally exit through the passes once the winds and surge dissipated. Again, the extent to which the water surface would increase for any given storm could be determined through numerical modeling.

During a storm, the gates of the flood control structures could be expected to close for approximately 2 – 3 days. If the average peak discharge through Rigolets and Chef Menteur Passes for both flood and ebb tide are 290,000 and 85,000 cfs, respectively (McCorquodale, et. al. 2007), then the amount of water that would no longer flow through the passes during a 2 – 3 day storm would equal $5.01 \times 10^{10} - 7.52 \times 10^{10}$ ft^3 and $1.47 \times 10^{10} - 2.20 \times 10^{10}$ ft^3, respectively.

Meanwhile in the Lake, water from the connecting rivers, as well as precipitation from the storm will be added to the volume of water in the Lake. Using the average summer (May – October) values for the tributaries and diversions listed in **Table 3** (excluding Pearl rivers) along with the recorded precipitation value at the Lakefront Airport during Hurricane Katrina (7.2 in) and the surface area of Lake Pontchartrain (630 sq. mi) and the neighboring city (115 sq. mi), the volume of water entering the Lake from these inputs would be 1.25×10^{10} ft^3 per day (144,000 cfs). Rainfall events can easily exceed the rainfall recorded for Hurricane Katrina (7.2 in) and would raise lake levels even higher. For the duration of a storm (2 – 3 days), the water level in Lake Pontchartrain could easily be raised 2-3 feet since the flood control structure would not allow the excess water to drain from the lake. Overtopping of flood control structures and the sloshing effect in Lake Pontchartrain would raise water levels higher.

Table 3: Estimated discharge values for the rivers and tributaries that flow into the Pontchartrain Basin. The rivers' discharges were averaged from U.S.G.S. summer (May – October) data for 2006. The IHNC value was derived from the peak flood and ebb tide values for the passes (Pass Rigolets, Chef Menteur Pass, Pass Manchac, and IHNC), where the IHNC accounts for 5% of the total (Roblin, 2008).

Tributary/Diversion	Discharge (cfs)	Daily Volume (ft^3)
Amite River	980	$8.47x10^7$
Tickfaw River	148	$1.28x10^7$
Natalbany River	26	$2.25x10^6$
East Pearl River	4,800	$4.15x10^8$
West Pearl River	1,100	$9.50x10^7$
Tangipahoa River	540	$4.67x10^7$
Tchefuncte River	64	$5.53x10^6$
IHNC (Tidal flow)	15,500	$1.34x10^9$

With the Lake cut off from the Gulf, several reactions may take place that could affect the water quality of the Lake. With the right mixture of sunlight, water temperature, lack of salinity, and other factors, algae will proliferate due to excess nutrients that are not being flushed out of the Lake and algal blooms may develop. These so called Harmful Algal Blooms (HAB) have occurred in the Lake associated with the opening of the Bonnet Carre Spillway. HABs lead to hypoxic or anoxic conditions in the water column (due to bacterial decomposition of dead algae). This can lead to fish kills. They also increase turbidity or cloudiness in the water column, which causes limited sunlight access for the bottom dwellers that need the solar radiation to create food and survive. Of greatest concern would be cyanobacteria or blue-green algae which can be toxic to the skin or if ingested.

Another issue with the water quality may arise from the discharge from the outfall canals. Aside from typical storm water pollution such as hydrocarbons, oil and grease, and household chemicals, the outfall canals have been cross-contaminated with sewage from sanitary sewers over the years (Chilmakuri, 2005). This fluid mixture entering the Lake could be high in fecal concentrations (as evidenced by fecal coliform concentrations). Flood control structures on the passes, would temporarily interrupt the normal tidal exchange of the lake, and therefore, would allow a build-up of unwanted pollution in the lake. Depending on the actual rates, duration and concentrations the suspension of flushing of these pollutants out of the lake may trigger secondary problems such as algal blooms, low oxygen, fish kills etc.

Considering these changes in the water column, there are also several biological changes that can occur with the structures closed. The proposed flood control structures could have deleterious effects on the organisms that utilize both the Rigolets and Chef Menteur Passes to move between Lake Pontchartrain and the Gulf of Mexico.

Figure 18: Two graphical depictions of a generalized food web for Lake Pontchartrain (Davis, 2009). Red circles indicate eighteen species, which are dependent on migration through tidal passes in Lake Pontchartrain and would be directly affected. Upper food web levels indicates potential secondary effects due to food availability.

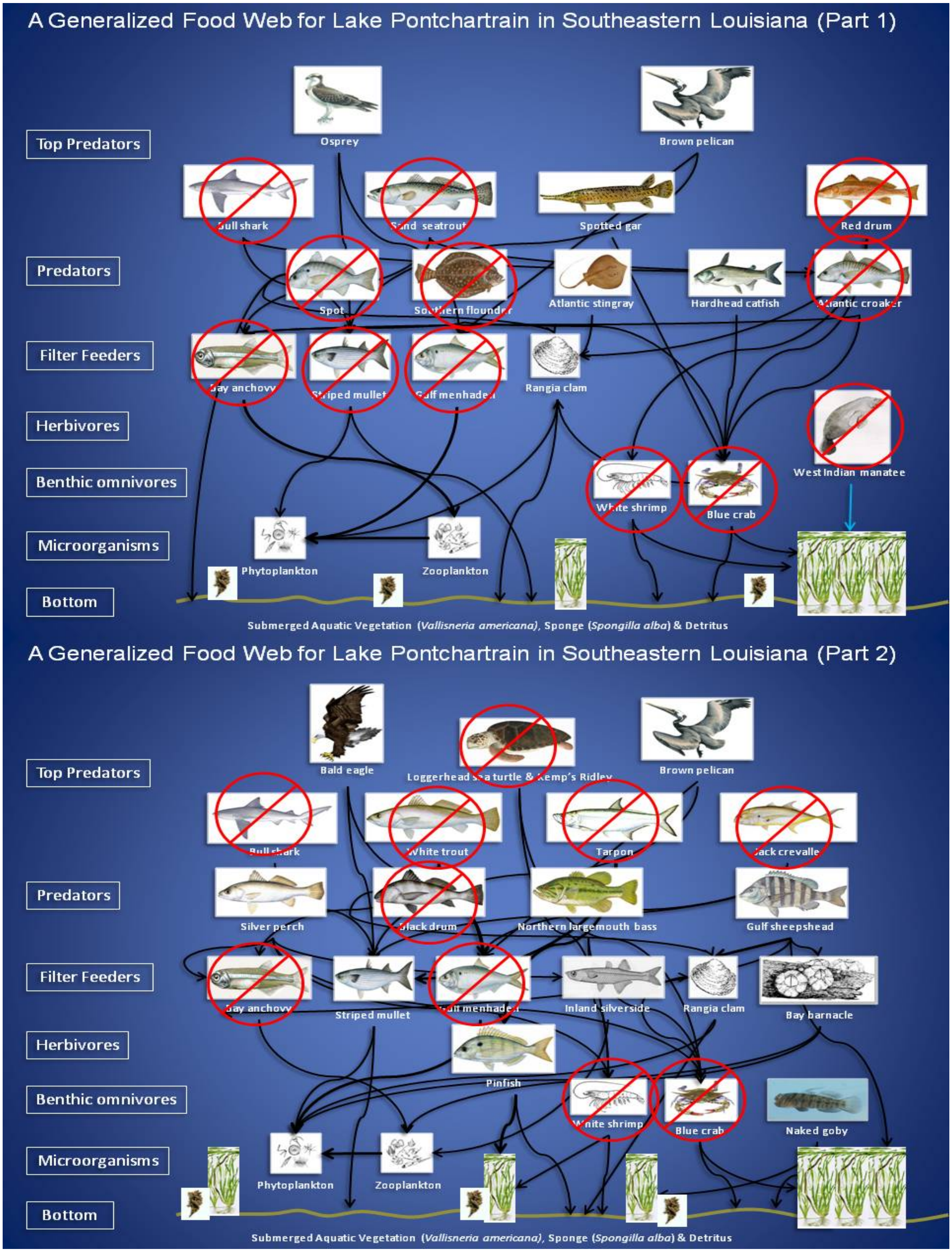

Table 4 on the right is a brief list of some of the significant migratory fish species that have been known to move through Pass Rigolets and Chef Menteur Pass. It should be noted that this list does not include all species that live in the Lake, but it is merely a composite list of prominent species that have utilized the Lake at some time.

Table 4: Some Species that Utilize Rigolets & Chef Menteur Passes. Underlined are listed as federally threatened or endangered species. Bold are commercially or recreationally significant species.

Atlantic Croaker (*Micropogonias undulatus*)
Bay Anchovy (*Anchoa mitchilli*)
Black Drum (*Pogonias cromis*)
Blue Crab (*Callinectes sapidus*)
Brown Shrimp (*Farfantepenaeus aztecus*)
Bull Shark (*Carcharhinus leucas*)
Crevalle Jack (*Caranx hippos*)
Gulf Sturgeon (*Acipenser oxyrinchus desotoi*)
Gulf Menhaden (*Brevoortia patronus*)
Loggerhead Sea Turtle (*Caretta caretta*)
Kemp's Ridley Sea Turtle (*Lepidochelys kempii)*
Red Drum (*Sciaenops ocellatus*)
Sand Seatrout (White) Trout (*Cynoscion arenarius*)
Southern flounder (*Paralichthys lethostigma*)
Spot (*Leiostomus xanthurus*)
Spotted (Speckled) seatrout (*Cynoscion nebulosus*)
Striped Mullet (*Mugil cephalus*)
Tarpon (*Megalops atlanticus*)
West Indian Manatee (*Trichechus manatus*)
White shrimp (*Penaeus setiferus*)

Types of organisms relying on the passes include: both adult and larval stages of estuarine-dependent species, marine transient species that enter Lake Pontchartrain to feed, riverine (anadromous) species and sensitive species (threatened or endangered) that move through Lake Pontchartrain en route to associated freshwater rivers. Also important are migratory mammals such as West Indian manatee. **Figure 18** illustrates a generalized food web for Lake Pontchartrain and twenty species potentially directly impacted by flood control structures. Four species are federally listed as threatened or endangered. Twelve species are considered significant for commercial or recreational harvests. Indirect impacts would be on species that prey on other species that would be directly inhibited from migration through the passes. For example, brown pelicans which consume striped mullet or Gulf menhaden, may find less food availability if these species were inhibited from migrating into Lake Pontchartrain.

Estuarine-dependent species are those that utilize the estuary (Lake Pontchartrain) for part of their life cycle. From the species list above (**Table 4**), these include the blue crab, brown and white shrimp, Gulf menhaden, red drum, spot, white trout, striped mullet, and Atlantic croakers. All of these species move out of Lake Pontchartrain through the passes and into the saltier waters of the Gulf of Mexico to spawn. Some of the adults move back into the Lake, while others remain offshore. For all of the species listed, however, the larvae move back into the estuary by utilizing the currents and tides, after which they mature within the Lake.

Most of the time, estuarine organism migrations are driven by typical astronomical tides. However, it is known that a severe tide drive by storm surge can also be extremely important in moving estuarine organisms into the estuary. In 2008, a very good white shrimp harvest in Lake

Pontchartrain may have been influenced by the effective timing of Hurricanes Gustav and Ike to carry juvenile shrimp into Lake Pontchartrain. With flood control structures closed storm driven migration into Lake Pontchartrain would be drastically reduced.

The passes are an essential migration corridor, and timing is of the utmost importance. Adult crabs, shrimp, and fishes would not be able to move out of the Lake and into the Gulf of Mexico if they encounter closed flood control structures on their migration route. They would therefore be unable to spawn, resulting in a decreased population size. Should the larvae encounter the closed flood control structures upon entering either Chef Menteur Pass or Pass Rigolets, then the large majority of them will suffer mortality. It is possible that some may find their way into the marsh along the edges of the passes, but this is unlikely for most. Considered nekton, organisms that move with waves, currents, and tides, the swimming ability of larval fish and invertebrates is limited, and with the high energy environment within the passes their ability to direct their movement may become even more restricted. While they are able to orient themselves vertically in the water column to a certain extent, many species are not capable of swimming horizontally to move from within the pass into the edge habitat. Most of the new larval population for all of the listed species would be entering or exiting the Lake during the summer and fall, the time which coincides with the highest probability of flood gate closure due to hurricane activity. Therefore, gate closure also represents a possible source of extensive larval mortality which may result in decreased fisheries within the Lake.

The marine transient species that enter the Lake to feed include crevalle jack, bull sharks, and sea turtles. Both Loggerhead and Kemp's Ridley sea turtles have been found in Lake Pontchartrain. Although rare in recent times, their numbers have been diminished by other cumulative impacts to these species gulf wide and locally. Both are federally listed as endangered. These marine transient species enter the Lake year-round and as top-level predators are an important part of the Lake Pontchartrain food web. Their inability to enter the Lake due to flood gate closure has the potential to alter food web dynamics which can have negative consequences for the estuary. In an absence of predators, species lower on the food chain increase in numbers and therefore increase predation pressure on their preferred prey items. This can lead to trophic imbalance of the Lake ecosystem.

The two other species listed, the Gulf sturgeon and the West Indian manatee, are species of special concern that also utilize Lake Pontchartrain. The federally threatened Gulf sturgeon moves through the Lake on its way to north shore rivers where it spawns. As with the estuarine-dependent species that move offshore to spawn, the passes are an essential part of their migration corridor. The closure of the flood gates during September and November would limit the ability of adult Gulf sturgeon to exit north shore rivers and Lake Pontchartrain, and therefore, possibly subjecting them to cooler conditions than they may tolerate. The West Indian manatee is a federally endangered species that utilizes the north shore rivers to feed, particularly during the summer months. There have been increased sightings of manatees in the rivers in recent years, and the closure of the flood gates would keep the species from entering the Lake. In 2005, just two weeks prior to Hurricane Katrina, a NOAA Stranding Survey of Lake Pontchartrain reported approximately two-hundred manatees in the Lake. Had these individuals been kept from entering the Lake due to closed flood gates in the passes, they may have been caught in transit in

Mississippi Sound, and possibly suffered high mortality during the hurricane or thereafter. **Table 5** is a summary of the potential effects a closure would have on the Lake Pontchartrain fishes and invertebrates.

Table 5: Summary of Potential Impacts to Fishes and Invertebrates due to the Closure of the Rigolets and Chef Menteur Passes Flood Control Structures.

Parameter	Potential Impact
Lake Pontchartrain Salinity	Reduced Salinity
Hydrology	No Water Exchange
Turbidity	Uncertain
Adult Fish & Invertebrate Migrations	Unable to Complete Migrations
Larval Fish & Invertebrate Recruitment	Unable to Complete Migrations
Food Web Dynamics	Changes Likely
SAV Growth	Uncertain
Juvenile Settling Habitat (Shrimp & Crab)	N/A
Sensitive Species (Turtles, Manatee, & Sturgeon) Entering or leaving Lake Pontchartrain	Unable to Enter or leave Lake Pontchartrain

Recent studies have indicated that in south Louisiana significant sediment deposition may occur during hurricanes and benefit marsh (Turner, et. al. 2006). Strom surges are high energy events that re-suspend sediment and may carry sediment for many miles into marsh that are otherwise devoid of a source of mineral sediment. The marsh on the north shore of Lake Pontchartrain are considered relatively stable in the respect that their vertical accretion can keep pace with subsidence and sea level rise, and these marshes do receive sediment derived from hurricanes (Reed, et. al., 2009). With flood control structures closed during storm events, introduction of mineral sediment into marsh or swamp may be reduced either because sediment is not allowed to enter into the Lake in the first place, or because reduced surge elevation and wave energy within Lake Pontchartrain may not have the same capacity to re-distribute sediment into interior marsh areas. With reduced sediment input, these marshes may be less stable.

Chapter 8: Potential Effects of Alternative Flood Control Structures – Open Position

During typical daily conditions (no storm), the flood control structures in the Rigolets and Chef Menteur Passes would be open to permit flow in and out of Lake Pontchartrain. The passes are subjected to diurnal tides, which means they experience a flood and an ebb tide once a day. The flood tide occurs when water enters the passes from the Gulf via Lake Borgne; and the ebb tide occurs when the water recedes from Lake Pontchartrain into Lake Borgne.

The original design of the Rigolets flood control structure involved permanent closure of a large cross-section of that pass. We estimate 77% of the cross-section would have been permanently blocked off by a closure dam and the water would be forced to flow through a relatively small operable flood control structure on the southern end of the cross-section. (See **Figure 20** and

Plate 32 in the Appendix for specific details of the design proposal). The Corps report estimated a 75% reduction in cross-sectional area. Either case represents an enormous change to the hydrology of the Pass and consequently to Lake Pontchartrain.

Figure 19 illustrates a computed general relationship between reduction in channel and a corresponding reduction in tidal prism. The "Barrier Plan" constrictions have a large reduction in tidal prism that actually projects beyond the limit of the graph. The La. State Master Plan dimensions affect is smaller, but still probably unacceptably large according to the UNO analysis. The UNO proposed channel dimensions have the least reduction in the lake's tidal prism and are suggested by the authors to be within an acceptable range using the 5% threshold as a proxy for the overall biologic effects, but which we question the comprehensive application of this metric.

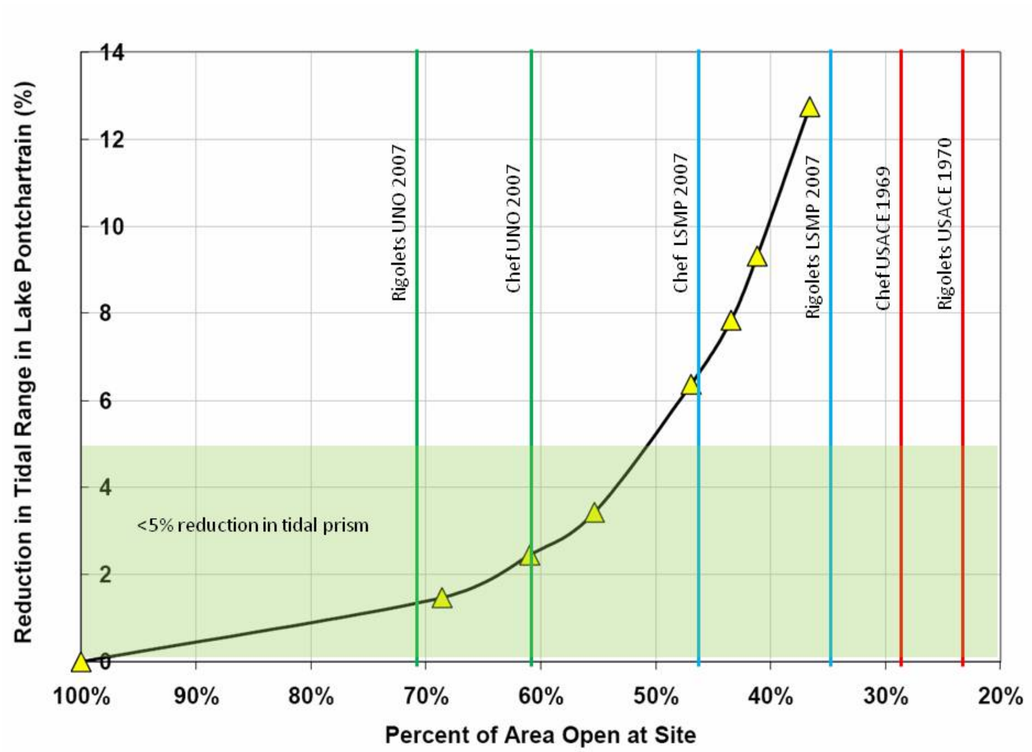

Figure 19: Relationship between change to tidal prism and constriction of passes (modified from McCorquodale et al, 2007b). Note that the original "Barrier Plan" structures would have had an enormous reduction in tidal prism (red bars). The State Master Plan has less of an impact but is probably unacceptably high.

Modeling by UNO also indicates that with the early "Barrier Plan" structures that velocities would be increased as much as 280% (McCorquodale, 2007a). Since the eddies are a function of the section of the channel permanently closed, a smaller opening has a larger permanent closure, and therefore, larger eddies. Extremely large eddies would have formed behind these structures which would induce scour and have biological impacts.

This major reduction in cross-sectional area would significantly increase the velocity immediately downstream of the structure. Over the years, this design has changed. For instance, the structure position was relocated to a smaller cross-section nearer to Lake Borgne, and in 2007, it was suggested that the structure be increased in width to closer resemble the natural conditions of the pass. (See **Figure 16** for some of the different proposed Rigolets structure locations). **Figures 20** and **21** show the 1970 USACE and the 2007 UNO (McCorquodale et al. 2007a) structure designs, in order to compare the differences in available cross-sectional area. It should be noted that these figures are estimates and should only be used as a guide for understanding the effects of constricted flow in a natural channel.

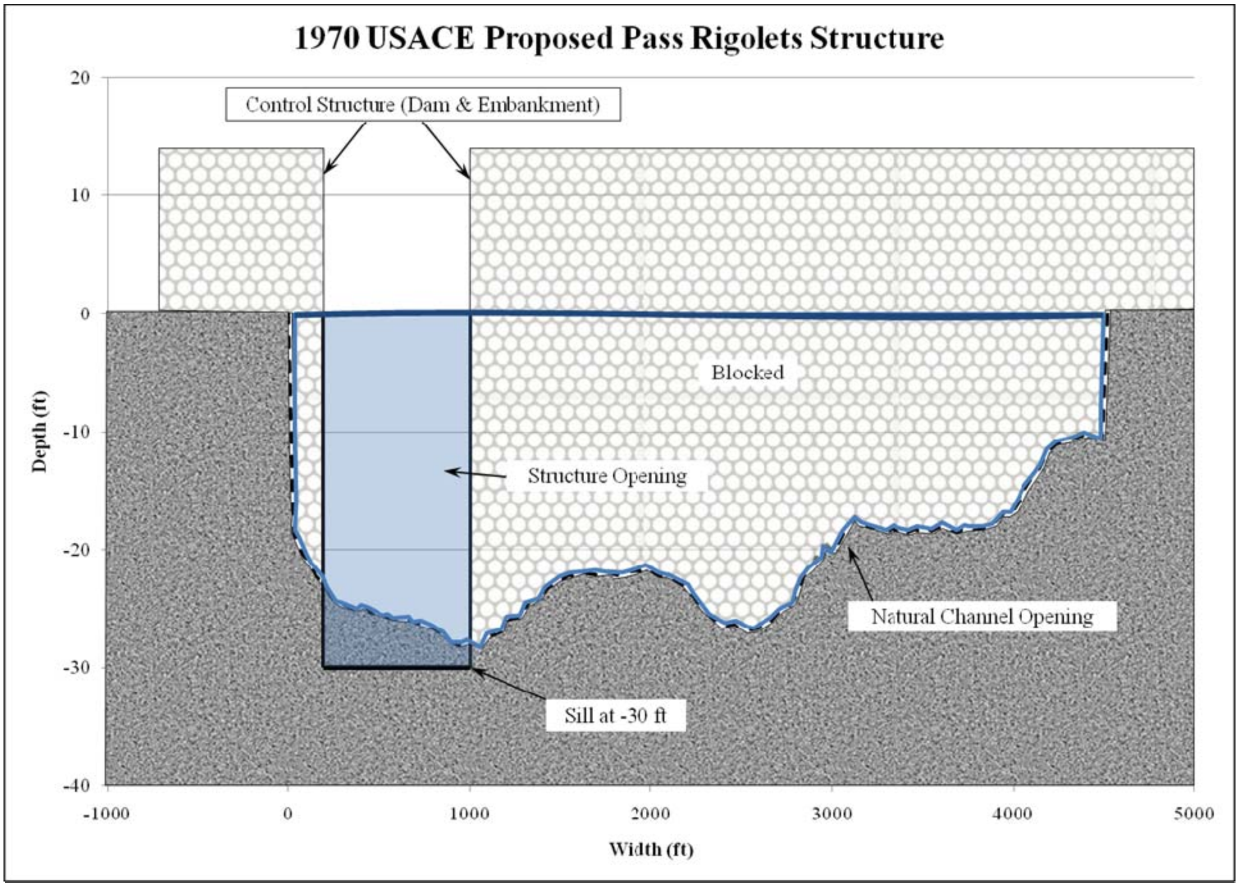

Figure 20: The old 1970 USACE Rigolets flood control structure diagram. The black dashed line represents the existing natural channel cross-section. The gray stone pattern indicates the dams and embankments of the proposed structure that would not allow water to flow through. The light blue square shows the structure opening where the water would generally be allowed to flow through (open position). They are not shown here, but this proposed design includes several gates, which would also constrict the flow within the blue area. Also, the gate piers would interrupt the flow and could cause local turbulence and eddies. As shown, the 1970 USACE structure significantly reduces the natural channel's cross-sectional flow area.

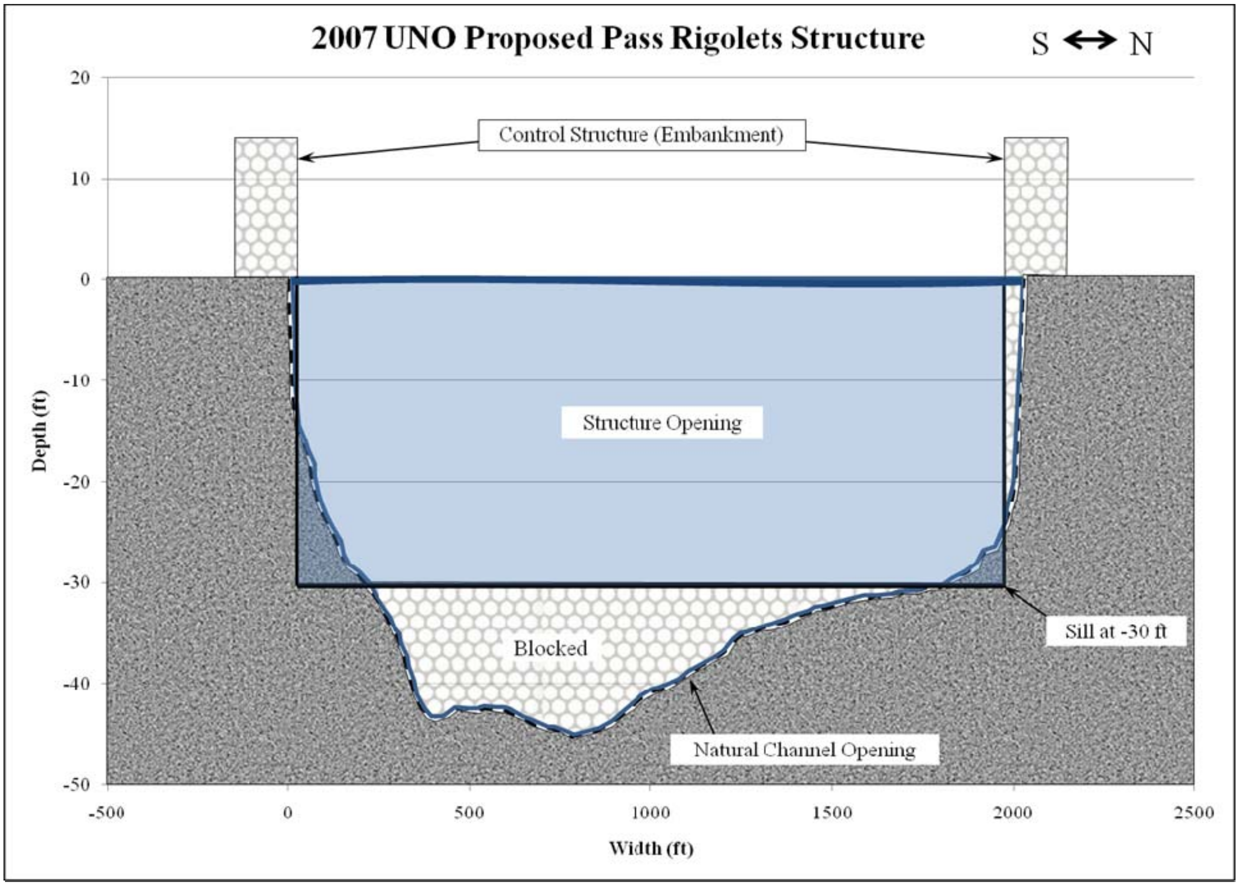

Figure 21: The new 2007 UNO Rigolets flood control structure diagram. The black dashed line represents the existing natural channel cross-section. The gray stone pattern indicates the proposed embankments that would not allow water to flow through. The light blue square shows structure opening where the water would be allowed to flow through (open position). They are not shown here, but this proposed design includes several gates, which would also constrict the flow within the blue area. Also, the gate piers would interrupt the flow and could cause local turbulence and eddies. As shown, the 2007 UNO structure more closely resembles the natural channel's cross-sectional flow area.

From **Figures 20** and **21**, it can be seen that the newer flood control structure (2007 UNO) would more closely resemble the natural Rigolets channel and would allow more water to flow through. However, even with the structure completely open, the sill, embankments, and gate piers will increase the velocity through the structure because of the reduction in cross-sectional area. This can be shown by the relationship between discharge and velocity:

$$Q = vA \tag{1}$$

where:
Q = discharge (cfs or cms)
v = velocity (ft/s or m/s)
A = cross-sectional area (ft^2 or m^2)

This equation (1) states that in order for equilibrium to exist, the velocity must increase when the cross-sectional area decreases. In 2009, Ischen modeled the effects of a constriction in Pass Rigolets; the results of this study indicated that the peak velocity leaving the opening of the flood control structure could reach over 8.5 ft/s (5.8 MPH), and 400 – 1000 ft eddies could develop upstream or downstream of the structure on either side of the pass for either flow direction (flood or ebb tide) (Ischen, 2009). It should be noted that an eddy is the swirling or filling in of a fluid that occurs behind obstructions or breaks in the flow. **Figure 22** shows a graphical representation of **Equation 1**, as well as the eddies that can be introduced due to the constricted flow.

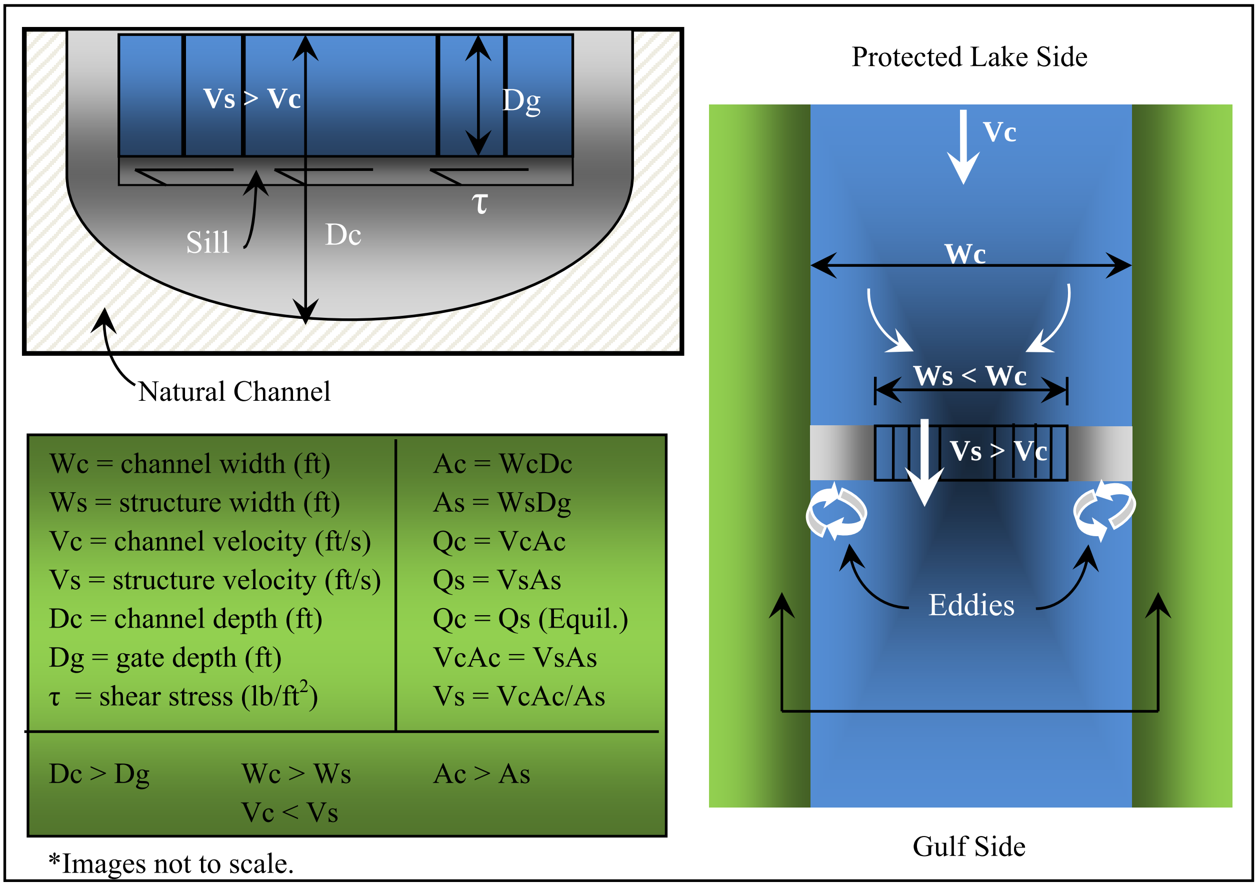

Figure 22: Graphical representation of falling tide with flood control structure in an open position applying **Equation 1**. The figure on the right is a bird's eye view of a generic channel. It should be noted that when the flow is reversed the eddies caused by the channel constriction and gate piers will switch to the other side of the structure. The figure in the upper left-hand corner is a section view of the generic channel looking upstream at the control structure. From this figure, it is seen that the area of the channel is significantly reduced by the flood control structure. The box in the bottom left-hand corner shows the definitions of the terms used in the other figures, as well as the relationships involved. (The white arrows indicate the direction of flow).

From **Figure 22**, water flows from the wide channel through the smaller structure (black box) and back into the wider channel; therefore, the cross-sectional area decreases and the velocity increases through the structure. **Table 6** shows the actual area values of the proposed control structures for the 1970 USACE design, the 2007 UNO design (McCorquodale et al. 2007), and the 2007 Louisiana State Master Plan design. **Figure 23** shows the cross-sectional area histogram shown previously for Pass Rigolets, but with the three proposed structures' areas included, and **Figure 24** shows cross-sectional areas every 1,000 ft along Pass Rigolets.

Table 6: Comparison of the cross-sectional areas of the 1970 USACE, 2007 UNO, and 2007 LA State Master Plan flood control structure designs for Pass Rigolets.

Design	Cross-Sectional Area of Natural Channel (ft^2)	Cross-Sectional Area of Open Structure (ft^2)	% of Open Structure to the Natural Channel
1970 (USACE)	97,000	22,000	23%
2007 (UNO)	70,900	50,400	71%
2007 (LSMP)	70,900	24,900	35%

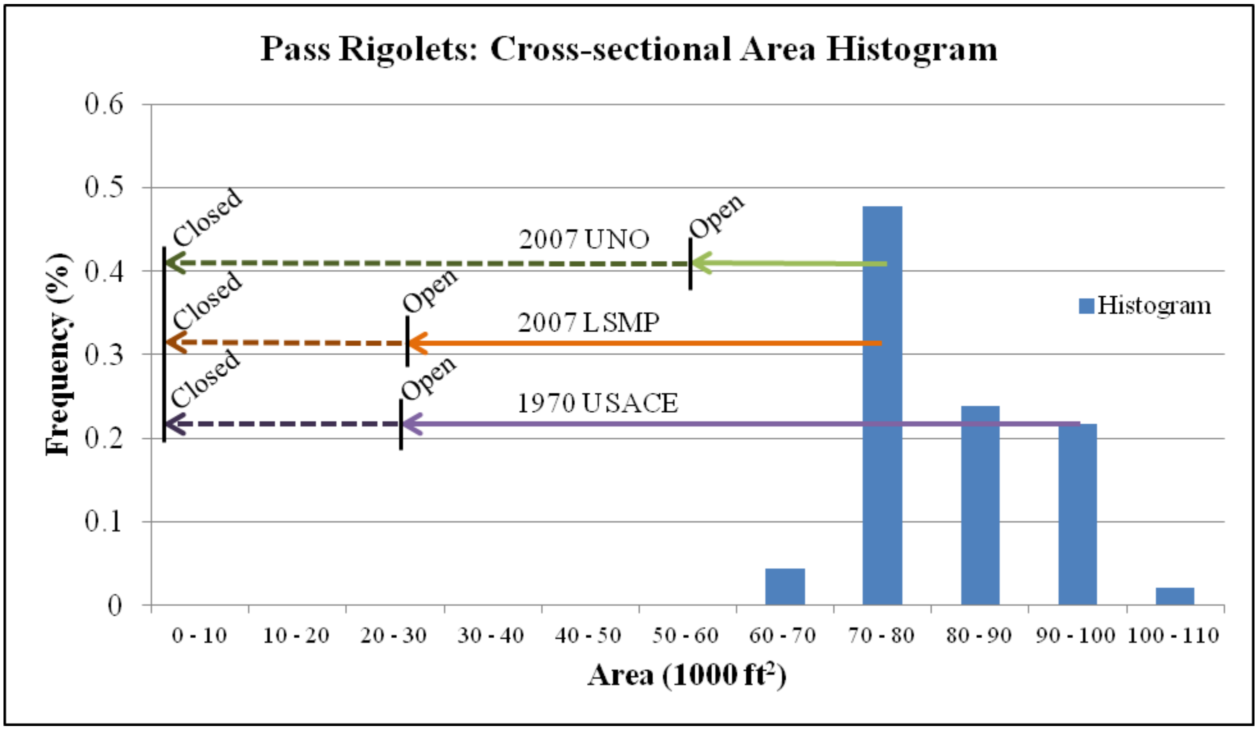

Figure 23: Cross-sectional area histogram for Pass Rigolets with several of the proposed flood control structure designs. The solid arrows correspond to the open position and the dashed arrows correspond to the closed position. The 1970 USACE design (solid purple line) occupies a cross-section in the 90,000 – 100,000 ft^2 range and constricts it to the 20,000 – 30,000 ft^2 range in the open position. The 2007 UNO design (solid green line) occupies a cross-section in the 70,000 – 80,000 ft^2 range and constricts it to the 50,000 – 60,000 ft^2 range in the open position. The 2007 LSMP design (orange line) occupies the 70,000 – 80,000 ft^2 range and constricts it to the 20,000 – 30,000 ft^2 range in the open position. As shown, the 2007 UNO design causes the least amount of cross-sectional area reduction of the three designs.

Figure 24: Cross-sectional areas for Pass Rigolets every 1,000 ft.

As shown by **Table 6** and **Figure 19**, the 2007 UNO design causes the least amount of reduction in the cross-sectional area. For either of these designs, however, the cross-section will be reduced and the velocity will be increased through the structure. As a result, the shear stress along the bottom of the channel will increase, as well as the turbulence in the water column. Both of these factors can cause scouring of the channel bed near the structure. Also, as the high velocity jet leaves the structure and enters the slower receiving water downstream of the structure, the slower water becomes entrained in a swirling pattern, which is called an eddy. The size of an eddy is dependent on the viscosity and velocity of the water. The final design of this structure should minimize the exiting velocity in order to prevent scouring of the channel bed.

The design of the Chef Menteur Pass flood control structure is very different from the Pass Rigolets structure in the sense that the structure itself will not be placed in the natural channel. All designs of the Chef Menteur Pass control structure consisted of placing a closure dam in the natural channel and dredging a new bypass channel to place the structure in. (See **Figure 17** for the location of the closure dam, dredged channel, and flood control structure. See the Appendix for the original design.) **Figures 25** and **26** show the 1969 USACE and the 2007 UNO (McCorquodale et al. 2007) structure designs, in order to compare the differences in available cross-sectional area. Again, it should be noted that these figures are estimates and should only be used as a guide for understanding the effects of constricted flow in a natural channel.

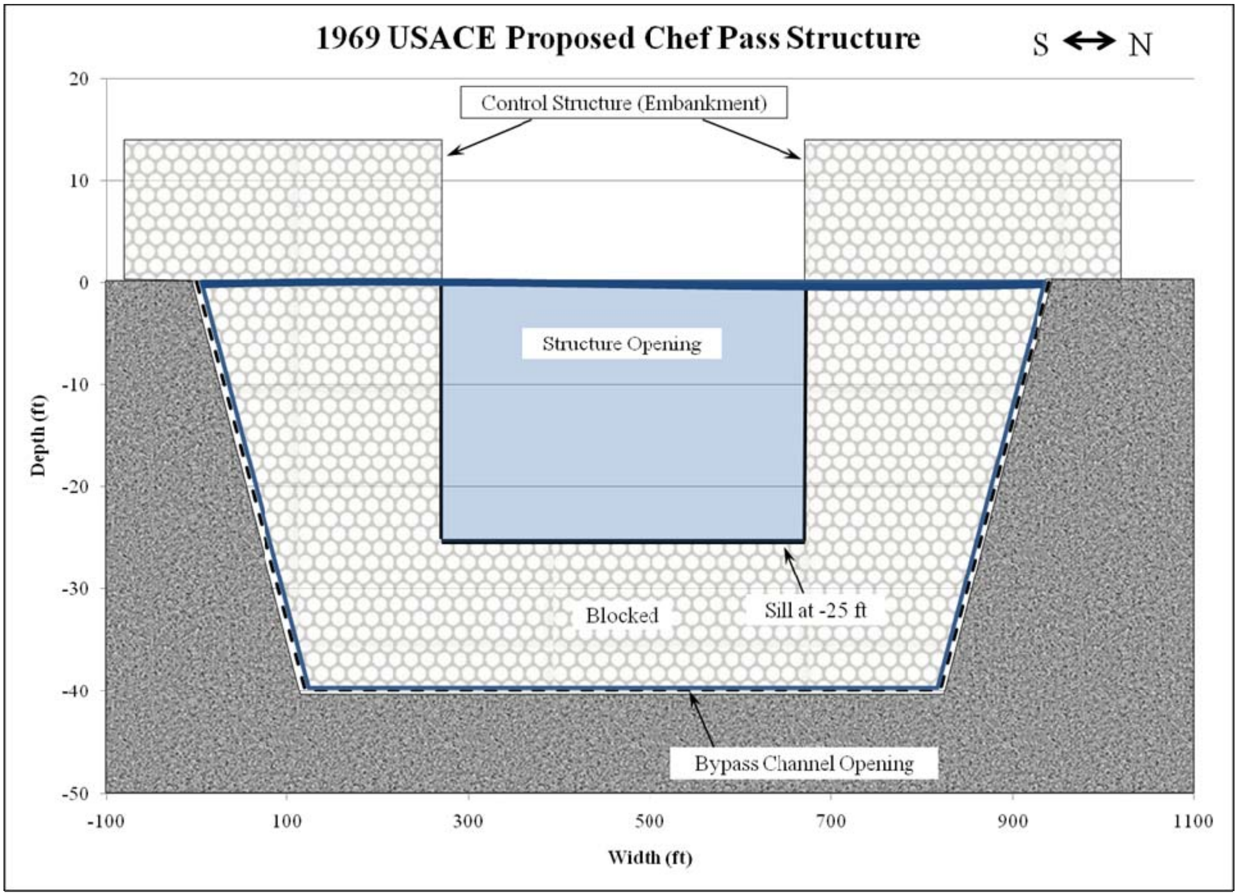

Figure 25: The 1969 USACE Chef Menteur Pass flood control structure diagram. The black dashed line represents the proposed bypass channel cross-section. The gray stone pattern indicates the dams and embankments of the proposed structure that would not allow water to flow through. The light blue square shows the structure opening where the water would be allowed to flow through. They are not shown here, but this proposed design includes several gates, which would also constrict the flow. Also, the gate piers would interrupt the flow and could cause local turbulence and eddies. As shown, the 1969 USACE structure significantly reduces the bypass channel's cross-sectional flow area.

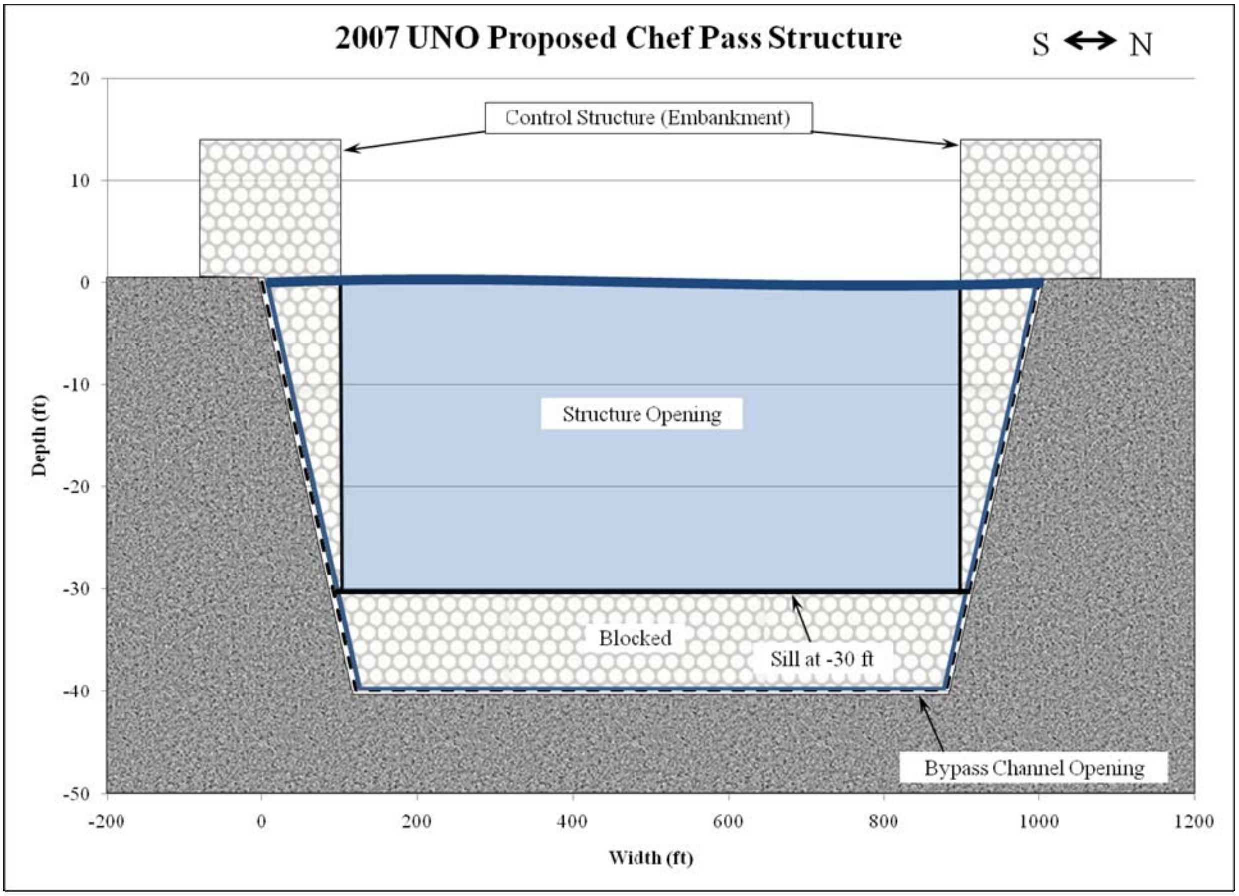

Figure 26: The new 2007 UNO Chef Menteur Pass flood control structure diagram. The black dashed line represents the proposed bypass channel cross-section. The gray stone pattern indicates the proposed embankments that would not allow water to flow through. The light blue square shows structure opening where the water would be allowed to flow through. They are not shown here, but this proposed design includes several gates, which would also constrict the flow. Also, the gate piers would interrupt the flow and could cause local turbulence and eddies. As shown, the 2007 UNO structure more closely resembles the bypass channel's cross-sectional flow area.

From **Figures 25** and **26**, it can be seen that the newer flood control structure (2007 UNO) would allow more water to flow through. However, even with the structure completely open, the sill, embankments, and the gate piers will increase the velocity through the structure because of the reduction in cross-sectional area. **Equation 1** is also used here to identify the relationship between cross-sectional area and velocity; similarly, **Figure 22** can also be used to demonstrate this relationship. **Table 7** shows the actual area values of the proposed control structures for the 1969 USACE design, the 2007 UNO design (McCorquodale et al. 2007), and the 2007 Louisiana State Master Plan design. **Figure 27** shows the cross-sectional area histogram shown previously for Chef Menteur Pass, but with the three proposed structures' areas included, and **Figure 28** shows cross-sectional areas every 1,000 ft along Chef Menteur Pass.

Table 7: Comparison of the cross-sectional areas of the 1969 USACE, 2007 UNO, and 2007 LA State Master Plan flood control structure designs for Chef Menteur Pass. (For the natural channel, the cross-section used was located at the site of the proposed closure dam).

Design	Cross-Sectional Area of Bypass Channel (ft²)	Cross-Sectional Area of Open Structure (ft²)	% of Open Structure to Bypass Channel	% of Open Structure to Dammed Natural Channel
1969 (USACE)	32,800	9,200	28%	28%
2007 (UNO)	35,200	19,800	56%	61%
2007 (LSMP)	35,200	15,300	43%	47%

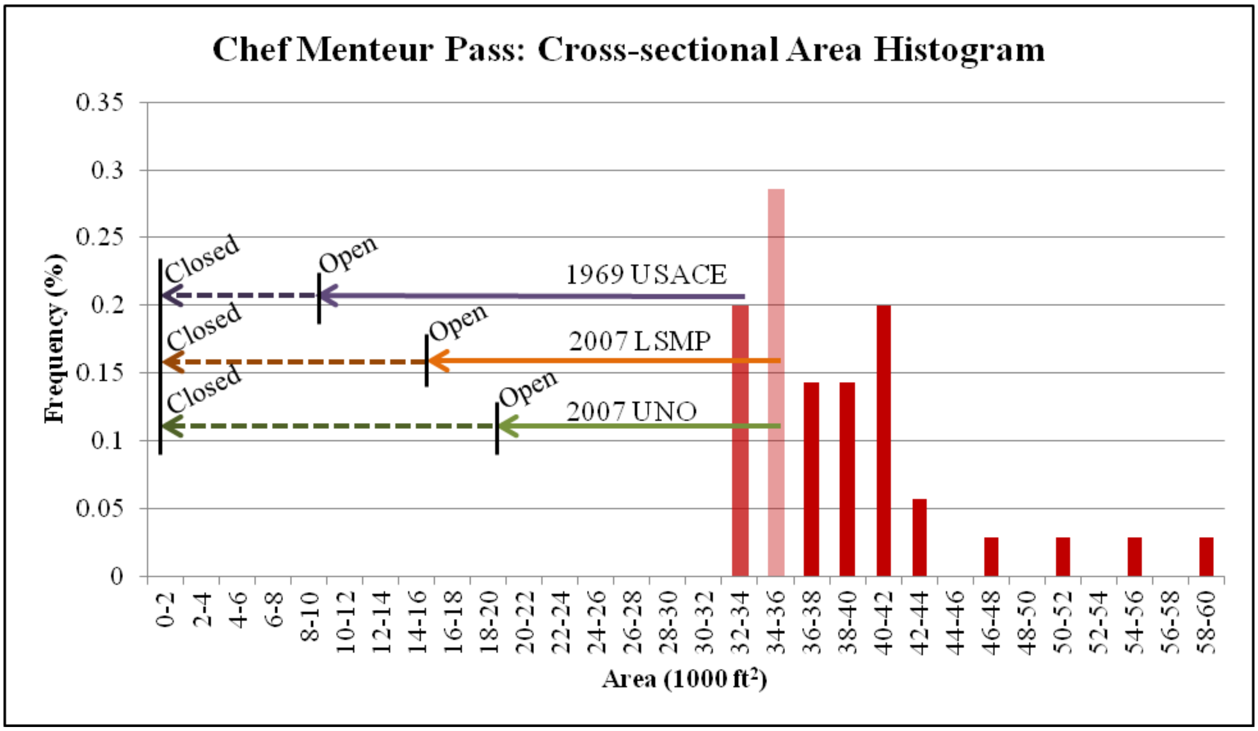

Figure 27: Cross-sectional area histogram for Chef Menteur Pass with several of the proposed structure designs. The solid arrows correspond to the open position and the dashed arrows correspond to the closed position. The proposed bypass channel will account for 14% of the entire pass. Therefore, the 14% of the natural channel near Lake Borgne that would be dammed off was added to the 32,000 – 34,000 ft^2 range bar (medium red), which comes from the 1969 USACE proposed bypass channel dimensions. Another 14% was added to the 34,000 – 36,000 ft^2 range bar (light red), which comes from the 2007 UNO and LSMP proposed bypass dimensions. The 1969 USACE design (solid purple line) occupies a cross-section in the 32,000 – 34,000 ft^2 range and constricts it to the 8,000 – 10,000 ft^2 range in the open position. The 2007 UNO design (solid green line) occupies a cross-section in the 34,000 – 36,000 ft^2 range and constricts it to the 18,000 – 20,000 ft^2 range in the open position. The 2007 LSMP design (solid orange line) occupies the 34,000 – 36,000 ft^2 range and constricts it to the 14,000 – 16,000 ft^2 range in the open position. As shown, the 2007 UNO design causes the least amount of cross-sectional area reduction of the three designs.

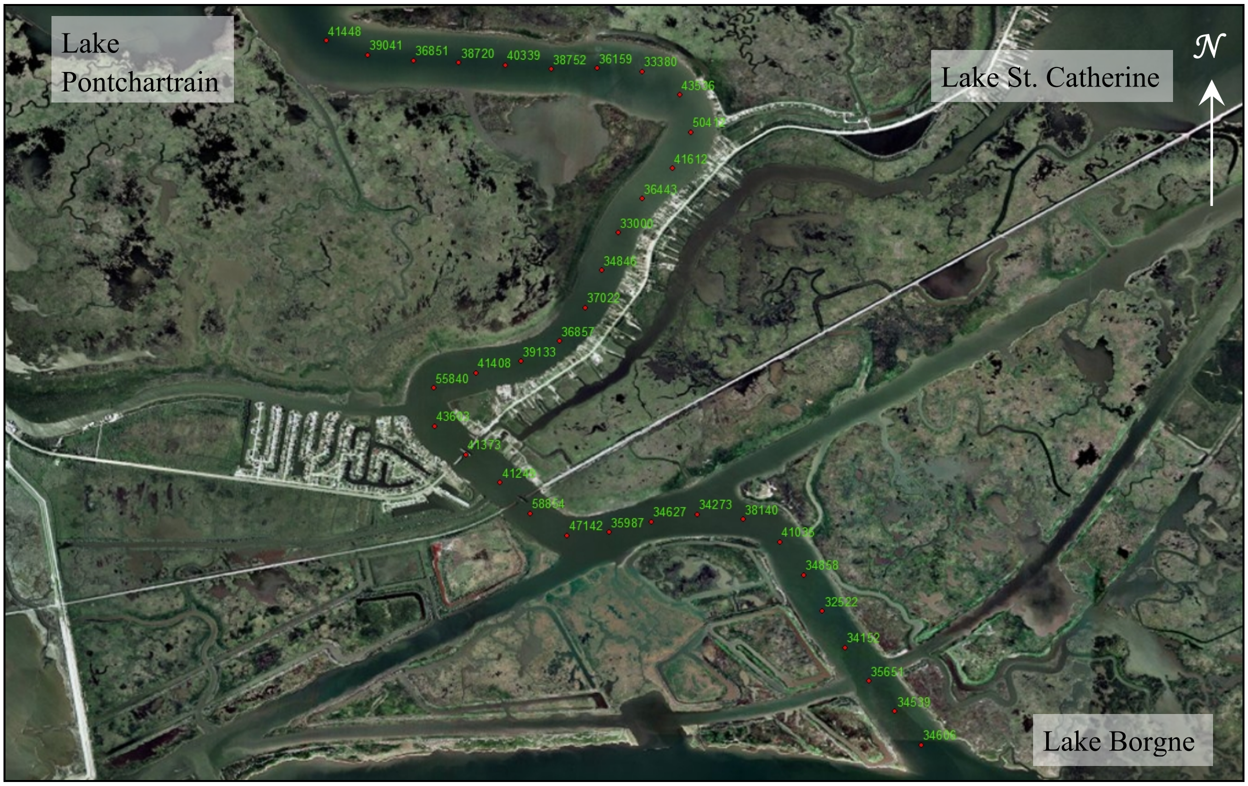

Figure 28: Cross-sectional areas for Chef Menteur Pass every 1,000 ft.

As shown by **Table 7** and **Figure 27**, the 2007 UNO design causes the least amount of reduction in the cross-sectional area. For either of these designs, however, the cross-section will be reduced and the velocity will be increased through the structure. As a result, the shear stress along the bottom of the channel will increase, as well as the turbulence in the water column. Both of these factors can cause scouring of the channel bed near the structure. Also, as the high velocity jet leaves the structure and enters the slower receiving water downstream of the structure, the slower water becomes entrained in a swirling pattern, which is called an eddy. The size of an eddy is dependent on the viscosity and velocity of the water. The final design of this structure should minimize the exiting velocity in order to prevent scouring of the channel bed.

With the gates open for the 1969/1970 flood control structures, the significant constrictions from the sills, embankments, dams, and piers will reduce the volume of water that can get through the passes at a time. This reduction could enhance the "freshening" effect mentioned earlier, in that the saltwater will have a harder time getting to Lake Pontchartrain. The constrictions will also affect the water quality in the Lake because it will be more difficult for the nutrients to get flushed out of the Lake; and with the right combination of sunlight, water temperature, salinity, and nutrients, algal blooms could develop near rivers or diversions, which is detrimental for the ecosystem as mentioned previously. For the UNO proposed 2007 flood control structures, the constrictions from the sills, piers, and embankments are significantly smaller and will only slightly reduce the volume of water that can get through the passes at a time. This reduction would have only a slight effect on the "freshening" of the Lake and would only slightly increase the possibility of algal blooms developing. Overall, additional designs should be investigated to completely minimize the constrictions in the passes in order to minimize the effects on the hydrology and water quality of the Lake.

Following Hurricane Katrina and extending after Hurricane Rita, the U.S. Army Corps of Engineers began de-watering, or pumping out, the flood waters that had inundated New Orleans. The constituents in this water included oil, precipitation, surge water from the Gulf, household chemicals, refuse, and anything else that was swept up by the storm surge. All of these components, consisting of 200 billion gallons, were pumped into Lake Pontchartrain over the course of 43 days (Roper et al. 2006). Several steps were taken by the Environmental Protection Agency (EPA) and the USACE to minimize the environmental impact of pumping this contaminated mixture into the Lake. Water quality sampling after the de-watering indicated that the Lake had not been contaminated by the mixture; this is believed to be caused by dilution by the surge water and precipitation, as well as settling of contaminated particles (Roper et al. 2006).

During normal conditions, the residence time, or the time it takes for one drop of water to flow from the outermost section of the lake to the outlet, in Lake Pontchartrain and Lake Maurepas can last anywhere from 6 months to 1 year, depending on the amount of input from the rivers and diversions (A. McCorquodale personal communication). During high flood years in the Mississippi River, when the Bonnet Carré Spillway is opened, the response time is on the order of weeks; and after Hurricane Katrina had passed the Lake, the response time for the surge water to recede and for the Lake to return to normal water surface elevation was 2 – 3 days (McCorquodale personal communication). Therefore, with the flood control structures in the Rigolets and Chef Menteur Passes closed during a storm, once opened the surge could recede in several days, depending on the surge height, the amount of precipitation, the input, if any, from the outfall canals, as well as the amount of constriction caused by the structures themselves. The water quality in the Lake, however, may not return to base conditions for up to several weeks, assuming a high discharge rate, dilution of the contaminants, and settling of the larger particles, such as sewage solids. Additional studies should be performed in order to give adequate estimates of response time and residence time of Lake Pontchartrain.

Similar to the closed condition, the proposed flood control structures could also have negative biological effects in the open position. See **Table 4** for a brief list of the current and/or past fish species that inhabited Lake Pontchartrain. Again, it should be noted that this list does not include every single species that live in the Lake, but it is merely a composite list of known species that have been identified in the Lake at some time.

While there is not the issue of a physical barrier to movement through the passes as in the closed position, the ability of some organisms to efficiently move through the modified passes could be impeded. The construction of the flood control structures will reduce the width of the passes and this constriction will result in increased water velocity. This increased water velocity may inhibit both adult and larval fishes and invertebrates from moving through the passes. Some adult species are sensitive to changes in water velocity, and would be dissuaded from entering the passes. Some of the species that utilize the passes are also fairly small and therefore do not possess great swimming ability, which would leave them unable to swim efficiently through the passes under altered hydrological regimes.

The increased water velocity would be of particular concern for the larval fishes and invertebrates migrating back into the Lake from the Gulf of Mexico. These larvae do not have the ability to move horizontally in the water column, but are able to position themselves vertically enabling them to utilize the tidal cycles to make their way into the estuary. This process, called selective tidal stream transport (STST) is described in greater detail in the species overview section. With increased water velocities, the larvae may not be able to move into the Lake through the passes. Some larvae that do make it into the passes may get caught up in the eddies that are predicted to form in the direct vicinity of the flood control structures. This would further increase the larval mortality resulting from flood gate construction. This decreased larval abundance can result in declining fisheries production in Lake Pontchartrain.

The altered hydrological conditions may also lead to a decrease in suitable nursery habitat along the edges of the passes and at the entrance to the Lake. The increased water velocities may cause scouring of the edge habitat that many organisms utilize as nursery habitat. With the changes in water velocity, the turbidity of the water may also increase. This will result in a decline in the submersed aquatic vegetation (SAV) that is a highly productive nursery habitat for both juvenile fishes and invertebrates. Without sufficient SAV, the larvae that are able to make it into the Lake will not have suitable habitat to settle in and mature, contributing to a further decline in fisheries production.

Additionally, in the open position the increased water velocities may dissuade sensitive species such as the Gulf sturgeon, West Indian manatee, and loggerhead sea turtle from entering the Lake. **Table 8** is a summary of the potential effects an open structure would have on the Lake Pontchartrain fishes and invertebrates. **Figure 29** shows a simplified diagram of a representative structure in order to illustrate how the proposed flood control structures would affect the migratory habits of the fishes and invertebrates that utilize the tidal passes.

Table 8: Summary of Potential Impacts to Fishes and Invertebrates due to the Open Rigolets and Chef Menteur Passes Flood Control Structures.

Parameter	Potential Impact
Lake Pontchartrain Salinity	Reduced Salinity
Hydrology	Water Velocity Increased
Turbidity	Increased
Adult Fish & Invertebrate Migrations	Impeded (Some species more than others)
Larval Fish & Invertebrate Recruitment	Significantly Impaired
Food Web Dynamics	Changes Possible
SAV Growth	Decreased (Due to turbidity)
Juvenile Settling Habitat (Shrimp & Crab)	Decreased (Due to scouring & loss of SAV)
Sensitive Species (Turtles, Manatee, & Sturgeon) Entering Lake Pontchartrain	Impeded or Stopped

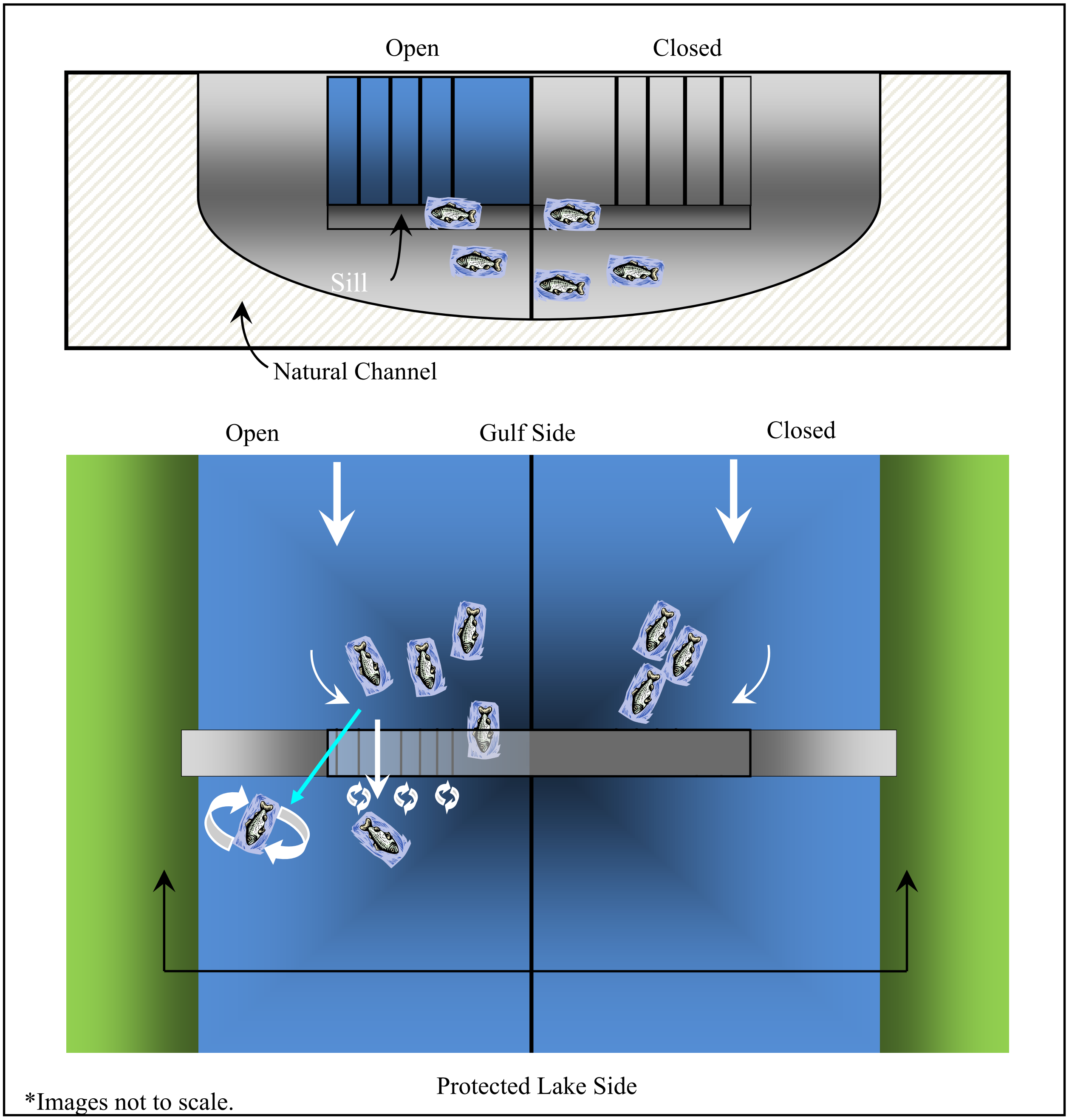

Figure 29: Representative Flood Control Structure hydraulics. The figure on the top is a section view of a generic channel looking upstream at the control structure. The figure on the bottom is a bird's eye view of the generic channel. For both figures, the left side corresponds to the "Open" position and the right side corresponds to the "Closed" position. In the "Open" position, fishes and invertebrates can swim through the flood, but they may encounter fast-moving eddies caused by the constrictions from the gate piers and embankments, which could kill the smaller species that cannot fight the currents. In the "Closed" position, the fishes and invertebrates cannot swim through the structure to get back to the Lake, and as a result, some of the species could die. It should be noted that when the flow is reversed the eddies caused by the channel constriction and gate piers will switch to the other side of the structure. (The white arrows indicate the direction of flow and the bright blue arrow indicates the movement of the fishes and invertebrates).

Chapter 9: Description of Individual, Representative Aquatic Species Potentially Affected for Flood Control Structures

This chapter includes a brief summary of each of the ecologically and commercially important aquatic species known to inhabit Lake Pontchartrain that were mentioned previously. Each summary provides a physical description and graphic of the species, a short explanation of their natural migratory and spawning habits, and some of the possible factors that could impact the species if the proposed flood control structures were to be installed, including impacts for both the open and closed positions.

Blue Crab (*Callinectes sapidus*)

The blue crab (*Callinectes sapidus*) is an ecologically and commercially important species to Lake Pontchartrain. It is an estuarine-dependent species that lives out most of its life cycle in the estuary where it serves as an important link in the Lake Pontchartrain food web (**Figure 30**). While larval blue crabs, called zoea (**Figures 31 and 32**), feed on other plankton, post-larval forms are omnivorous scavengers (Darnell, 1959). They are, however, also a prey item for many fish species, thereby serving as a means of energy transfer in the system (Hill et al., 1989). After mating, females move offshore to spawn in the saltier waters of the Gulf of Mexico. The zoea and the female crabs then make their way back toward shore. The Lake Pontchartrain blue crab fishery is reliant on the natural tidal passes to bring the crabs back into the lake. The larvae respond to chemical cues, such as salinity, which stimulate the transition from zoea to megolopae, the settling stage. The megalopae settle out in the marshy edges which serve as important nursery habitats.

Figure 30: Adult Blue Crab (*Callinectes sapidus*)

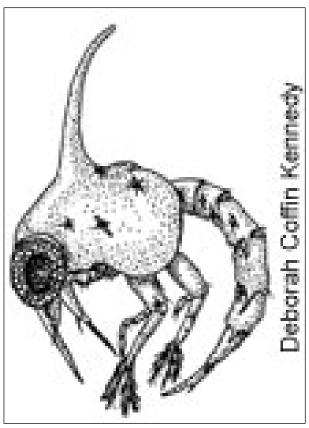

Figure 31: Larval Blue Crab (*Callinectes sapidus*)

While larval crabs are more or less at the mercy of the tides and currents, they do exhibit locomotion which enables them to regulate their vertical position in the water column. By moving up and down in the water column, blue crab larvae ensure their transport into the estuary with the tides. This is a behavior known as "selective tidal stream transport" (STST). During the flood tides, the crabs position themselves in the upper portion of the water column, thereby moving into the estuary. During ebb tides, they move down towards the bottom where the water is still moving inland. Ovigerous female blue crabs similarly utilize STST to make their way out of the estuary toward the Gulf of Mexico to spawn and then to return (Forward et al., 2003).

Figure 32: Larval Blue Crab (*Callinectes sapidus*)

In the open position, the proposed flood gates across the Rigolets and Chef Menteur Passes have the potential to affect larval recruitment to Lake Pontchartrain by altering hydrological regimes within the passes. By constricting the flow of water through the passes, the flood control structures have the potential to increase the water velocity. Studies have shown that the increased water velocities resulting from flood control structures inhibit the ability of crabs as well as fishes to move through the passageway (Rulifson & Wall, 2006). The ability of the crabs to orient themselves vertically in the water column may be thwarted, thus inhibiting STST. Moreover, by increasing the water velocity, turbidity may also increase. The coupling of these two effects could lead to a decrease in healthy edge habitat, as soft sediments may be scoured out and growth of local submersed aquatic vegetation (SAV) communities is hindered due to a lack of sunlight penetration. The crabs that do make it into Lake Pontchartrain may be forced to settle out in locations that do not offer good nursery habitat. Additionally, the increase in water velocity could result in larval crabs being pushed farther into the lake with the faster moving water. This may also lead to settlement in undesirable locations. While larval forms would experience the effect of increased water velocity in the passes the most, the ability of adult females trying to migrate out of the estuary to spawn could also be hindered.

In the closed position, the proposed flood gates would act as a physical, unavoidable barrier to crabs moving in and out of Lake Pontchartrain. The 2006 study by Rulifson and Wall on flood control structures between Lake Mattamuskeet and Pamlico Sound in North Carolina showed that the closure of the structure during certain times could cut off blue crab passage into the estuary and thus lead to a population collapse of the crab and other estuarine-dependent species. With regard to Lake Pontchartrain, pulses of blue crab larvae coming into the Lake have been found during the spring and fall (Lyncker, 2008). The pulses coincide with the busiest times for storm activity, and thus with the most probable times for closure of the flood gates across the Rigolets and Chef Menteur Passes. In the closed position, therefore, floodgates would effectively cut off a significant population of larval recruits into the Lake. The barrier would also prevent the re-entry of adult females into the Lake. This has the potential to decimate the Lake Pontchartrain blue crab fishery.

Brown Shrimp (*Farfantepenaeus aztecus*) and White Shrimp (*Litopenaeus setiferus*)

The brown shrimp (*Farfantepenaeus aztecus*, **Figure 33**) and the white shrimp (*Litopenaeus setiferus*) make up an important Gulf of Mexico fishery, with the brown shrimp representing 58% of the catch. The Gulf of Mexico fishery makes up 70% of the entire US shrimp fishery (Saoud & Davis, 2003). At first glance, the two species look remarkably similar, but they do have distinctive characteristics. The brown shrimp is brownish in color, has medium-length antennae, and has grooves running down either side of the spine on the head and on the tail. The white shrimp is more grayish in color, has very long antennae, and does not have any grooves on the head nor the tail. Brown shrimp are most abundant in the spring and early summer, while white shrimp are more abundant in the summer and early fall.

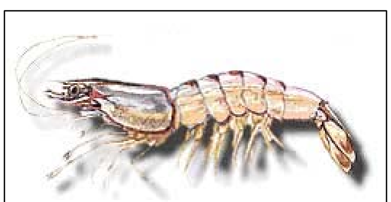

Figure 33: Brown Shrimp (*Farfantepenaeus aztecus*)

Aside from their commercial importance, the shrimp play an important role in the ecosystem. They are a prey item for many different species of fishes, particularly larval and juvenile shrimp. The shrimp themselves feed on organic matter and microorganisms in the sediments, thereby recycling important nutrients in the ecosystem.

Brown and white shrimp spawn in the saltier waters of the Gulf of Mexico, and then the larvae move back into the estuaries. White shrimp are known to begin spawning in late April or early May, and continue spawning as late as October (NOAA, 2010). Brown shrimp are thought to spawn throughout the year, but with a peak from September through November (Lee & Clark, 2005). It has been noted that brown shrimp have two major migrations into the estuaries; August to September and late February through March (McTigue & Zimmerman, 1991). They stay in the estuaries until they reach the juvenile stage, and then they move offshore where they grow and reproduce.

In the open position of the proposed flood control structures, the increase in water velocity through the Rigolets and Chef Menteur Passes due to the constriction of the natural channel could affect both larval transport into Lake Pontchartrain and juvenile migration out of the Lake. While they do have some swimming ability, the larval forms in particular would have a difficult time negotiating artificially altered hydrological conditions. Like blue crabs, both white and brown shrimp utilize selective tidal stream transport (STST) to move into the estuary.

The time of year with the highest potential for flood gate closure is hurricane season (late summer to early fall) and this coincides with one of the peak migration periods for shrimp. The estuarine part of the life cycle is vital for the survival of the entire population, and thus a closure which does not allow a large population of larval and post-larval shrimp into Lake Pontchartrain could prove to be detrimental to the fishery.

Gulf Menhaden (*Brevoortia patronus*)

Gulf menhaden, more commonly referred to as “pogies”, are the third most common fish in Lake Pontchartrain (**Figure 34**). Their scientific name is *Brevoortia patronus*; “patronus” meaning patron, due to the high incidence of copepod parasites they carry in their mouths. Gulf menhaden support the largest commercial fishery in the United States by weight (Shaw et al. 1985), with copious amounts of the relatively small fish being utilized for various types of feed, including aquaculture feed, and lesser amounts used as bait fish (Vaughn, 2007).

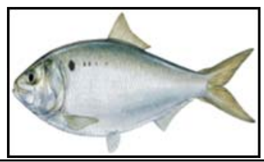

Figure 34: Gulf Menhaden (*Brevoortia patronus*)

The Gulf menhaden has a laterally-flattened, silver body and yellowish green coloration on its fins. It is distinguishable by the dark shoulder spot, which is followed by a row of smaller dark spots. It usually grows up to ten inches, but in rare instances, it can grow up to a foot in length. Gulf menhaden is a filter-feeder that consumes phytoplankton in surface waters, while it in turn is an important prey item for various game fish. It therefore serves as an important link between phytoplankton (primary producers) and higher trophic levels.

Adults spawn offshore during the fall and winter; the eggs and larvae are transported inshore by prevailing currents and then with the tides into the estuary via the tidal passes (Shaw et al., 1985). Movement into estuaries occurs from September through May (Lassuy, 1983).

One study by Wilkens and Lewis in 1971 found that larval menhaden were able to maintain their position in the water column with a water velocity up to 10 cm/sec. Above this threshold, the larvae were swept away with the current. From this, it is possible to say that with increased water velocities in the open position of the proposed flood control structures, the floodgates have the potential to impede the movement of menhaden larvae into Lake Pontchartrain by inhibiting their ability to control their vertical position in the water column. This, in turn, could have devastating impacts to its population numbers.

If the gates were closed, larvae would not be able to enter the Lake at all, and adults would not be able to move out to spawn in the Gulf of Mexico. The probable times of closure (i.e. during the fall) could coincide with the outward migration of large numbers of the species. Also, pogies are especially sensitive to drops in dissolved oxygen, even short-term drops. There have been numerous pogie kills in Lake Pontchartrain corresponding to still water with low dissolved oxygen levels in the summer months. One such fish kill occurred the summer of 2006, and resulted in an estimated 4-million pogies killed. Closing the passes, and thereby stopping the flow is likely to increase still, low dissolved oxygen water and lead to pogie kills.

Red Drum (*Sciaenops ocellatus*)

Figure 35: Red Drum (*Sciaenops ocellatus*)

The red drum (*Sciaenops ocellatus*, **Figure 35**), more commonly called redfish, and are an estuarine-dependent species commonly found in the waters of Lake Pontchartrain. The red drum fishery is a large commercial and recreational fishery in Louisiana. Interestingly, population crashes followed soon after the rise of blackened redfish as a staple menu item. Fishing restrictions, however, have resulted in a rise in numbers.

The average adult is 28 inches long and around 15 pounds. They are a rather long-lived species, known to live up to 50 years. Adults live offshore, where they spawn from August to November, with peaks in September or October (Comyns et al., 1991 & Matlock, 1987). Eggs are carried in surface waters by the winds and currents toward inshore waters, where a drop in salinity to less than 25 PSU (practical salinity units) induces sinking (Buckley, 1984). The larvae then make their way into lower salinity estuaries such as Lake Pontchartrain through the tidal passes. The young remain in the Lake until about three years of age, or near sexual maturity, when they move offshore. Several studies have noted the importance of bay-gulf passes in connecting estuarine nurseries with spawning grounds in the Gulf of Mexico (Matlock, 1987).

Larval red drum have been found to adjust their vertical position in the water column in response to flood and ebb tides to ensure transport into estuaries. Once in the estuary, they similarly change their position in the water column to remain in the estuary (Holt & Holt, 2000). As with other estuarine-depended organisms, the increased water velocities associated with the open position of the proposed flood gates could lead to an inability of red drum larvae to enter Lake Pontchartrain due to a failure to change and/or maintain vertical position in the water column. Additionally, if a larva were to settle in the edge habitat near the pass opening, the increased water velocity of the tidal prism flowing out of the lake could be too much for it to maintain its position and it could be swept out with the tide.

Once again, a flood gate closure would create a physical barrier to all movement into and out of Lake Pontchartrain. Red drum need to enter the Lake to feed, and the closure of the gates could prevent them. Larval forms would also be kept from moving into the estuary during periods of gate closures.

Spot (*Leiostomus xanthurus*)

The spot (*Leiostomus xanthurus*, **Figure 36**) is a member of the drum family. It is distinguishable from other drum species by its half-moon shaped tail and prominent dark spot behind its gills. A relatively small fish, it only grows to about 14 inches. They can live as long as six years, although this is uncommon; they typically only live to be four years old. The spot is a common recreational fish species, found along both the Atlantic and Gulf coasts of the United States. As a bottom-dwelling organism, they eat small crustaceans, worms, and organic detritus. In Lake Pontchartrain, *Rangia* clams (*Rangia cuneata*) comprise a large portion of their diet.

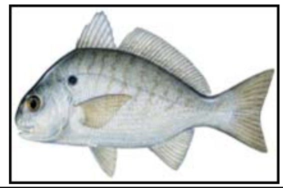

Figure 36: Spot (*Leiostomus xanthurus*)

The spot is an estuarine-dependent fish. As such, it makes seasonal spawning migrations between the estuary and offshore waters, starting when they reach sexual maturity which is between two and three years of age. They spawn offshore from November to February (Fruge & Truesdale, 1978).

In the open position, spot may have a hard time leaving or entering the Lake through the Rigolets and Chef Menteur Passes during their spawning migrations. As a relatively small fish, the water velocity may surpass their threshold for being able to swim competently through the passes.

In the closed position, the physical barrier of the floodgates would not allow for migration either into or out of the Lake. Fortunately, the most likely closure time during hurricane season would not interfere with annual spawning activity. It is possible, however, that the gates could be closed at different times of year for various reasons. In this case, it is possible that spawning migrations could be impacted as well as larval recruitment to Lake Pontchartrain.

Sand Seatrout or White Trout (*Cynoscion arenarius)*

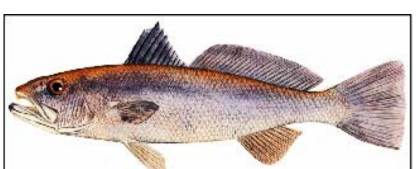

Figure 37: Sand Seatrout or White Trout (*Cynoscion arenarius)*

The Sand Seatrout (*Cynoscion arenarius*, **Figure 37**) is one of the most abundant sciaenid fishes found in estuaries of the northern Gulf of Mexico (Rakocinski et al., 2002). They are also commonly referred to as sand trout. This species does not have any truly distinguishing markings, but is silver with yellowish brown coloring on its dorsal surface and fins. Its mouth is filled with teeth, and usually there are two larger, pronounced teeth in the upper jaw, similar to canine teeth. It can grow up to 2 feet and 5 pounds, but the average weight within the estuary is less than one pound. It has been estimated that the sand seatrout can live up to three years. It feeds primarily on small fishes and shrimp. The sand seatrout is a member of the drum family, and utilizes the muscle of the air bladder to make a noise similar to purring during courtship and spawning.

Sand seatrout become sexually mature at twelve months of age (Ditty et al., 1991), and spawn offshore in the Gulf of Mexico in the winter and in the spring. After hatching, the larvae move back toward the estuary, a process that can take 30-94 days (Shaw et al., 1988). Larvae appear to remain mostly in the water surface as they migrate toward the estuary (Cowan & Shaw, 1988).

In the open position, the water flow through the passes could make it difficult for larvae to enter the Lake. As discussed with other species, larval forms have little swimming ability except for positioning themselves in the water column. Even this could be made impossible if water velocities were too fast, which would lead to a decrease in the number of larvae making it into the Lake. This, in turn, would affect the sand seatrout population size in Lake Pontchartrain.

In the closed position, adults would be inhibited from migrating in and out of the estuary. Larvae would also be prevented from entering the Lake. If spawning takes place in the spring and it takes up to ninety days for the larvae to make it back to the estuary, this would coincide with hurricane season and probable closure times of the flood gates.

Striped Mullet (*Mugil cephalus*)

The striped mullet (*Mugil cephalus*, **Figure 38**) is a widely distributed fish, found worldwide in tropical and subtropical estuaries and coastal waters. It is a filter-feeder, living off zooplankton in the water column and benthic detritus. While striped mullet can grow as large as 3 feet, individuals are generally less than 20 inches. The name "striped mullet" comes from the dark spots found at the base of each individual scale that give the impression of stripes. Another identifying feature is a dark spot on the axillary area of the pectoral fin.

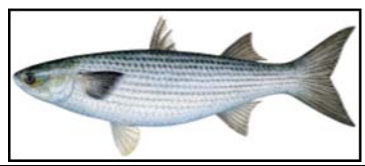

Figure 38: Striped Mullet (*Mugil cephalus*)

Within Lake Pontchartrain, the striped mullet is an important prey species for top level predators, such as the crevalle jack and bull sharks. Mullet are commonly seen jumping out of the water. This could be a means of predator avoidance, but is actually thought to be an activity aimed at dislodging external parasites.

Striped mullet is another commercially important estuarine-dependent fish species found in Lake Pontchartrain. The roe of striped mullet is harvested just prior to spawning, and is then exported to Asia. Aside from the roe fishery, mullet is not utilized much in Louisiana, except as bait for crabs and crawfish (Render et al., 1995). In other states, however, people do consume mullet.

Striped mullet spawns from October through mid-January in offshore waters, with a peak spawning period in late November to early December (Anderson, 1958). Therefore, those individuals living within estuaries must migrate to saltier waters for the spawning season. The striped mullet found in Lake Pontchartrain utilize the Rigolets and Chef Menteur Passes for their spawning migration. After hatching, larval forms remain offshore until they reach a length of 18-28 millimeters. They then make their way back towards shore, generally appearing in estuaries in January (Anderson, 1958).

In the closed position, with the most likely closure period falling during the late summer and early fall, the proposed flood gates could act as a barrier to striped mullet migrating out of Lake Pontchartrain to the Gulf of Mexico for the spawning season. The gates would most likely be open upon their return to the Lake, however the change in water velocity could affect their movement. Depending on the effect the gates have on water velocity through the passes, if the increase is very large this could decrease the numbers of fish actually making it back into the Lake. The larger potential for deleterious effects is with the larval population finding its way into Lake Pontchartrain. As discussed with other species, the ability to utilize the flood and ebb tides to move into the Lake could be negatively impacted, as an increase in water velocity could impede the ability of the larvae to orient themselves correctly in the water column. Therefore, the number of larval striped mullet making it through the passes and into the Lake could be greatly decreased, with those making it in based solely on chance.

Atlantic Croaker (*Micropogonias undulatus*)

The Atlantic croaker (*Micropogonias undulatus*, **Figure 39)** is the second most abundant fish in Lake Pontchartrain, as well as one of the most abundant fishes throughout the coastal waters of North America. It averages about 12 inches long and 2 pounds, but can grow as large as 20 inches and 4 pounds. The identifying features of the Atlantic croaker are the three to five pairs of barbels found on its chin, brown vertical stripes on the sides of its body, and a lateral line that extends onto the caudal fin. The barbels are indicative of the fact that this is a demersal species, living and feeding in the bottom of the water column. It eats small worms, mollusks, and crustaceans found in the bottom sediments, as well as detritus. It, in turn, is eaten by large fishes, such as flounder and spotted seatrout. The extended lateral line helps the Atlantic croaker to orient itself and locate food in the turbid bottom waters. It is a member of the drum family, so called because of the sounds they are capable of making by vibrating their air bladder. This is used mostly as an attractant for females during spawning.

Figure 39: Atlantic Croaker (*Micropogonias undulatus*)

The croaker is important both recreationally and commercially. Small individuals are used mostly as fishing bait, while larger organisms are often consumed by humans. In the United States, millions of pounds of Atlantic croaker are harvested every year and exported to foreign countries. Nationwide, populations have declined in recent years as a result of overfishing. In Lake Pontchartrain, its numbers have decreased in the last fifty years due to shell dredging. As a demersal organism, its juvenal habitat was heavily impacted by the practice.

Atlantic croaker in the Gulf of Mexico reach sexual maturity at approximately one year of age. As with other Lake Pontchartrain estuarine-dependent fishes, croakers migrate out of the estuary to spawn in the higher salinity waters of the Gulf of Mexico. The peak spawning period for Atlantic croakers is August to October, during which time females release anywhere between 100,000 and 2 million eggs (Cowan, 1988). The adults then travel back into the Lake, while the larvae drift towards the estuary with the currents. Individuals can live up to eight years, but most die much sooner due to heavy predation.

Due to their spawning period, the Lake Pontchartrain population of Atlantic croakers could be greatly affected by the closure of the proposed flood gates across the Rigolets and Chef Menteur Passes. The highest potential for closure of the gates coincides with the fall migration of sexually mature adults out of the Lake towards the Gulf of Mexico. By impeding this movement, the size of the new larval population making its way back into the estuary could be greatly decreased. In the case of the Atlantic croaker, this could be particularly detrimental due to extremely high annual mortality rates of the population as a whole.

In the open position, movement of both adult and larval croakers through the passes could be affected. Larval forms could be inhibited from proper positioning in the water column to ensure transport into the estuary, as with other species discussed here. Also, due to their relatively small size, increased water velocity through the passes due to the construction of the proposed flood gates could impede adult Atlantic croaker movement through the passes. This could be particularly relevant when trying to make their return to the estuary.

Crevalle Jack (*Caranx hippos*)

The crevalle jack (*Caranx hippos*, **Figure 40**) is a pelagic, schooling fish that is often found in Lake Pontchartrain feeding on striped mullet (*Mugil cephalus*) and Gulf menhaden (B*revoortia patronus*). In Lake Pontchartrain, it lies at the top of the food chain. Adults usually stay offshore, but juveniles are often found in brackish bays such as Lake Pontchartrain. Individuals can grow to 3 feet in length and weigh up to 30 pounds. Most often, however, they fall between 1 and 2 feet. Jacks are a common sport fish in many parts of the world.

Figure 40: Crevalle Jack (*Caranx hippos*)

In the open position, the crevalle jack would probably not be affected. It is a powerful swimmer, and so would not be inhibited from swimming through the passes with the increased water velocity.

In the closed position, it would not be able to enter the Lake. As a top-level predator, this could have cascade effects on lower-level species that it feeds on. In an absence of predators, species lower on the food chain increase in numbers, and therefore, increase predation pressure on their preferred prey items. This can lead to trophic imbalances.

Gulf Sturgeon (*Acipenser oxyrinchus desotoi*)

Figure 41: Gulf Sturgeon (*Acipenser oxyrinchus desotoi*)

The Gulf sturgeon (*Acipenser oxyrinchus desotoi*, **Figure 41***)* is a large, long-lived species that has been historically found throughout the northern Gulf of Mexico. It can grow up to 3 meters in length and has an average lifespan of 25 years. The Gulf sturgeon is an anadromous species that spends the winter months in the Gulf but migrates into freshwater for the larger part of the year. While residing in freshwater, the sturgeon rarely feeds. Rather, migration out to coastal and estuarine areas is linked to feeding (Ross et al., 2009). The species was listed as a federally threatened species in 1991.This is due to various factors such as overfishing for commercial sale of meat and caviar, and habitat degradation and alterations, including dam construction which cuts off accessibility to spawning grounds (Flowers et al., 2009).

The Gulf sturgeon has historically been found in the Pearl River, which represents the eastern boundary of the Pontchartrain Basin. Present day numbers are low due to the Pearl River Navigation Project that has impeded migration to spawning grounds. In 1935, the U.S. Army Corps of Engineers (USACE) authorized the project, which provided a navigation channel from Bogalusa to the mouth of the West Pearl River at Pass Rigolets. As part of the project, three locks were constructed in the river. In the 1950's, underwater concrete sills were added to help control water levels in the channel. These have prevented the Gulf sturgeon from successfully moving upstream to its spawning habitat. While rare in Lake Pontchartrain and its associated rivers, these are still considered essential habitat for the species. This includes the Lake (a migration corridor to spawning habitat), and the Tangipahoa, Tchefuncte, Tickfaw. and Amite Rivers on the north shore of Lake Pontchartrain (Rogillio et al., 2007).

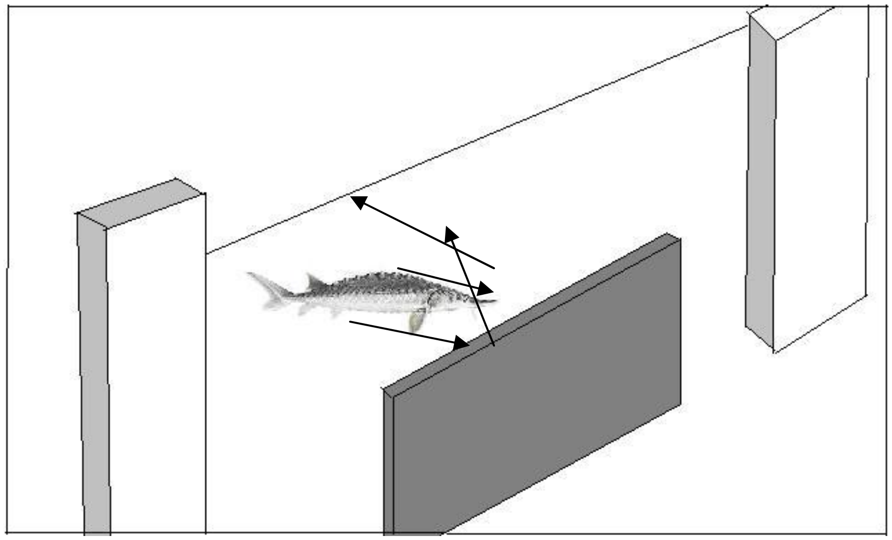

Figure 42: Gulf Sturgeon (*Acipenser oxyrinchus desotoi*) with an illustrated barrier sill

Gulf sturgeon are known to be present in Chef Menteur and Rigolets passes, and their dwindling populations could be further impacted by flood control structures. Certainly, in the closed position the proposed flood gates would impede movement from marine waters into Lake Pontchartrain during spawning season and then out again (Figure 42). Gulf sturgeon have been found to be very sensitive to altered water flow regimes (Flowers et al., 2009), so even in the open position they could be dissuaded from entering Lake Pontchartrain.

Bull Shark (*Carcharhinus leucas*)

The bull shark (*Carcharhinus leucas*, **Figure 43**) is common worldwide in warm, shallow coastal waters. They also are frequently found in rivers and associated lakes, due to their ability to tolerate freshwater. Bull sharks can grow up to 10 feet (3.5 meters) long and weigh up to 500 pounds. They are gray on the top of their body and white underneath, with two black-tipped dorsal fins. Their body shape is unique from other sharks in that it is wider than other sharks of comparable length. Its snout is also wider than it is long.

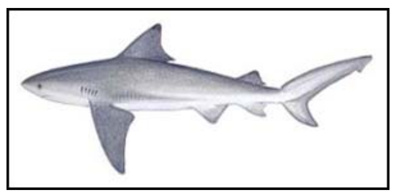

Figure 43: Bull Shark (*Carcharhinus leucas*)

The bull shark is an apex predator in Lake Pontchartrain. Juvenile bull sharks are mostly found in the Lake, particularly in areas with submersed aquatic vegetation (SAV) that are utilized by bull sharks as nursery habitat (i.e., the north shore of the lake). Adults do enter the Lake, though, particularly during the summer months (O'Connell et al., 2007). It has been observed that in the warmer months, larger bull sharks follow schools of catfish and other prey items into Lake Pontchartrain.

In the last fifty years, Lake Pontchartrain has experienced a decline in bull sharks due to anthropogenic disturbances that have led to the environmental degradation of the Lake. These include shell dredging, shoreline changes, hydrological changes, and overfishing among others. The loss of such an apex predator from an ecosystem can throw off the entire balance, resulting in a cascade effect throughout the food chain. Being at the top of the food chain, apex predators such as the bull shark, affect the population dynamics of prey species. By losing the top-down controls exerted by apex predators, organisms lower in the trophic pyramid may actually be negatively affected (O'Connell et al., 2007). The removal of large apex predators may result in the increase in numbers of smaller predators, which in turn may lead to a decline in prey populations. By having a healthy apex predator population, these smaller "mesopredators" are kept in check and important prey populations remain abundant. In very recent times, there does seem to be an increase in the amount of bull sharks coming into Lake Pontchartrain. This is a good sign of the upward turn of habitat and water quality in the Lake.

The construction of the proposed flood control structures across the Rigolets and Chef Menteur Passes could lead to a decrease in the number of sharks coming into Lake Pontchartrain. It has previously been noted that "[t]he construction of barriers that impede the movement of both freshwater and marine predator species into estuaries (e.g. dams on rivers, surge-control structures in tidal passes) poses a significant threat to the local trophic structure. Without the biotic control offered by multiple apex predators, the restoration of degraded estuarine ecosystems such as Lake Pontchartrain will continue to be problematic" (O'Connell et al., 2007).

In the closed position, the proposed flood gates will keep sharks from traveling in and out of Lake Pontchartrain. The increased likelihood of closure of the gates during the warmer months coincides with the most activity by bull sharks in the Lake. The closure could also prevent the movement of juveniles out of the Lake through the tidal passes.

In the open position, adult bull sharks would likely be unaffected by changing hydrological conditions (i.e. increased water velocity). Juvenile sharks, however, could be kept from entering and/or leaving the Lake.

West Indian Manatee (*Trichechus manatus*)

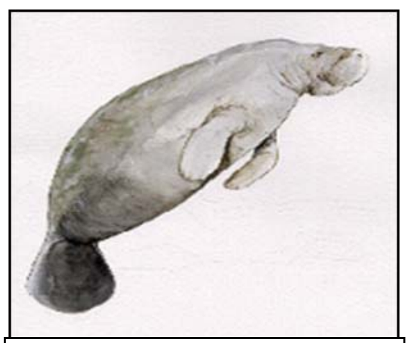

Figure 44: West Indian Manatee (*Trichechus manatus*)

The West Indian manatee (*Trichechus manatus*, **Figure 44**) is a large, gray aquatic mammal. They have two flippers and a paddle-shaped tail. Their terrestrial counterpart is the elephant, to which they are very closely related. The average adult is about 10 feet (3.5 meters) long and between 800 and 1,200 pounds. It is a long-lived species, thought to have a potential lifespan greater than sixty years.

The manatee inhabits calm, shallow rivers, as well as estuaries, canals, bays, and along coastal areas. As a very docile creature, it spends its time eating, sleeping, and swimming slowly. They are a herbivorous mammal, able to consume as much as 15% of their body mass in plant material daily.

While they have no known natural enemies, West Indian manatee populations are in decline. They are currently listed as a federallly-protected endangered species. Current studies indicate that there are only 3,800 individuals left in the United States. This is mostly related to anthropogenic causes, including boat collisions, fishing line and crab trap entanglement, ingestion of fish hooks, and being crushed by or drowning in canal locks and other flood control structures. The largest human-caused factor related to their decline, however, is habitat loss.

West Indian manatees are known to migrate from Florida and enter Lake Pontchartrain every year, typically during the summer (Fertl et. Al., 2004) and USFWS at http://ecos.fws.gov/speciesProfile/profile/speciesProfile.action?spcode=A007 . They travel through the Lake to rivers and canals on the north shore proably grazing on submerged aqautic vegetation and seeking sources of fresh water. In late July 2005 just prior to Hurricane Katrina, there were reports of a rather large group of manatees in the Lake (40 to 200). This unusually large number was first reported from a NOAA aerial stranding survey, and may indicate larger numbers of manatee may be present in the Lake than previously thought, since manatee documentation is dependent on incidental observations by the public or officals and reliance on their reporting. It has been observed that prior to a large storm, they will move from coastal areas into more protected areas such as rivers. Though manatee's signicance to the lake's ecology has not been investgated, manatees are a precious resource that needs protection (**Figures 45 and 46**).

In the open position, manatees could be disuaded from entering the Lake due to the increased water velocities through the passes. They prefer to live in low-velocity environments, and would probably avoid the altered current regimes presented by the construction of the proposed flood gates.

In the closed position, manatees would not be able to enter or exit the Lake at all. They are usually sighted during the summer during the hurricane season. It is possble that closed gates on the passes might prevent manatee from successfully seeking refuge inland, and therefore suffer higher mortality during a strom.

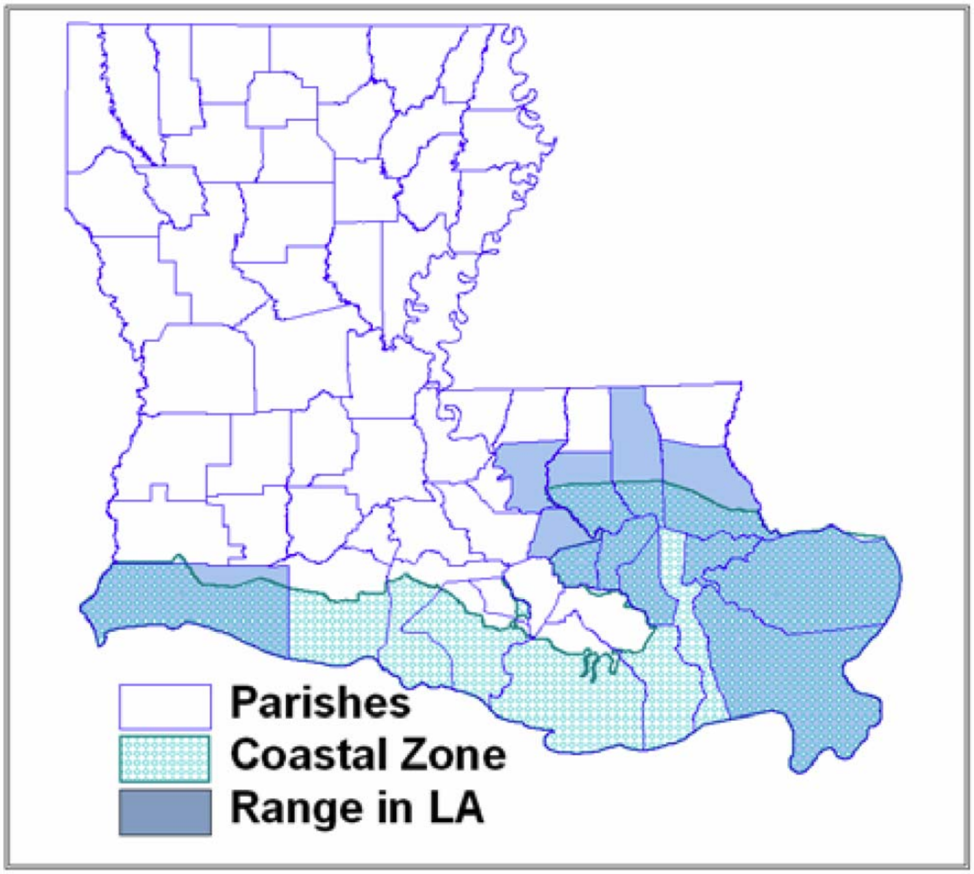

Figure 45: West Indian Manatee Range in Louisina based on historicalsightings
Source: Louisiana Depratment of Wildlfie and Fisheries – Natural Hertage program
http://www.wlf.louisiana.gov/wildlife/rare-animals-fact-sheets

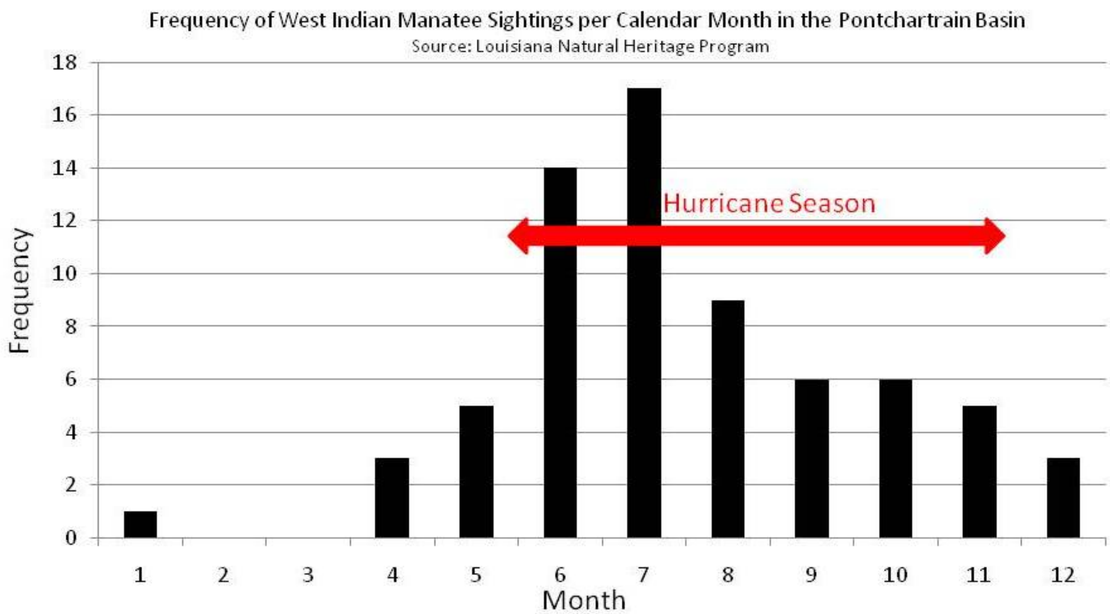

Figure 46: West Indian Manatee Frequency of presence in the the Pontchartrain Basin in Louisina based on historical sightings Source: Louisiana Depratment of Wildlfie and Fisheries – Natural Hertage program

Loggerhead Sea Turtle (*Caretta caretta*)

Figure 47: Loggerhead Sea Turtle (*Caretta caretta*)

The loggerhead sea turtle (*Caretta caretta*, **Figure 47**) is the largest hard-shelled sea turtle, with its reddish-brown shell reaching up to 84 inches in length. It is found in the temperate and tropical regions of the Atlantic, Pacific, and Indian Oceans, as well as in the Mediterranean Sea. In the Atlantic Ocean, the largest numbers have been recorded in the Gulf of Mexico and the southeastern coast of North America (Spotila, 2004). Nesting sites are most concentrated from Virginia to Alabama with additional sites along the shores of the northern and western Gulf of Mexico. Hatchlings first migrate offshore and are frequently associated with Sargassum mats, where they remain through the juvenile stage. As they mature, they migrate back toward nearshore environments (Wynn & Schwartz, 1999).

The loggerhead has been listed as a federally endangered species since 1978. The largest threat is fishing gear, such as longlines and gillnets in which the turtles become entangled, and trawl nets in which they can be trapped. They are also affected by the amount of plastic materials dumped in to the ocean. The turtles often times mistake plastics for prey items, such as jellyfish, and can suffocate or pass toxins onto their young by ingesting these materials. The accumulation of toxins found in plastics has been found to result in thinner eggshells, tissue damage, and behavioral changes. Other human-caused impacts include habitat loss, due to destructive development and increased human population densities in coastal areas. A deleterious factor associated with this is the use of artificial lighting, which can discourage females from coming ashore to nest, and also cause hatchlings to become disoriented and move from the nest toward the light instead of to the ocean (Miller, et al., 2000).

While sightings in Lake Pontchartrain are rare, loggerhead and other sea turtles do enter the lake from time to time. In 1998, the US Coast Guard discovered a Kemps Ridley sea turtle on a shrimp trawler in Lake Pontchartrain. They likely come into the Lake most often during the summer when salinity is higher. In the open position, the water flow through the constricted passes could keep the turtles from entering the Lake. While they are good swimmers, they do not often encounter high-velocity water in the coastal environment. Sea turtles have declined regionally, and flood control structures may inhibit their recovery.

In the closed position, sea turtles would not be able to enter or exit the Lake at all. It is possble that closed gates on the passes might prevent sea turtles from successfully seeking refuge inland, and therefore suffer higher mortality during a storm.

Phytoplankton

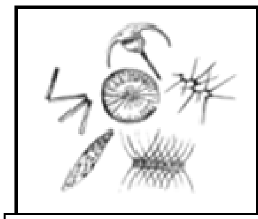

Figure 48: Phytoplankton

Phytoplankton are microscopic, photosynthetic organisms that live in the water column in both fresh and saltwater (**Figure 48**). The name comes from the Greek "phyto" meaning plant and "plankton" meaning to wander or drift. The phytoplankton is made up of a very diverse group of organisms including cyanobacteria, diatoms, dinoflagellates, and green algae. All of these organisms contain chlorophyll which is used to capture sunlight and convert it into energy. As primary producers, the phytoplankton make up the base of the food web in aquatic and marine environments. Their growth depends on the availability of sunlight, carbon dioxide, and nutrients, such as nitrogen and phosphorous. When these nutrients are available in excess, eutrophication, or "over-fertilization" can lead to large phytoplankton blooms. If large enough, such a bloom can lead to oxygen depletion or even anoxia in the water column as the algae die and decompose. This often leads to fish kills in the associated body of water. At times, the phytoplankton themselves can be toxic, such as cyanobacteria, also known as blue-green algae.

During a closure of the proposed flood gates, the Lake could become fresher due to increased rainwater input, riverine input from the north shore, as well as from storm water discharge from the city of New Orleans. Under normal conditions, the Lake might experience some freshening, but this would be diluted with the natural exchange of saltwater through the Rigolets and Chef Menteur Passes. In the closed position, the proposed flood gates would not allow for this natural exchange, leading to much reduced salinity in the Lake. This freshening, along with the increase in nutrient availability from storm water could lead to phytoplankton blooms in the Lake. These blooms, in turn, could lead to fish kills. Such phenomena have been observed during the openings of the Bonnet Carré Spillway when an excess of nutrients from the Mississippi River is introduced into the Lake. This effect is likely to be mild or transient unless for some reason the flood control structure were closed more than a few days. In the open position, the phytoplankton balance in the Lake should not be affected.

Chapter 4: Conclusions

1. Past environmental considerations for construction of flood control structures on the Rigolets and Chef Menteur Passes are inadequate, and any future project must comprehensively re-evaluate the potential environmental impact of flood control structures on the passes into Lake Pontchartrain.

2. Recent "Barrier Plan" designs are conceptual and so do not allow for a specific environmental impact. In lieu of that, this report attempts to provide a framework for future design work and the potential environmental analyses. Since science and knowledge do change, this report cannot be taken as the singular and definitive formula on how to analyze and avert environmental impacts of future projects.

3. All of the "Barrier Plan" concepts propose overtopping weirs, and would still allow storm surge to flow into Lake Pontchartrain depending on the size and duration of the hurricane.

4. The Corps' "Barrier Plan", as originally conceived more than 50 years ago, would have likely caused significant and long-lasting environmental damage to Lake Pontchartrain and the estuary.

5. Hurricane Katrina flooding in New Orleans was caused by an under-designed, incomplete, and modified "High Level Plan" flood protection system, not because of an inherent flaw of the "High Level Plan" design, except for the need to close the MRGO channel (a weakness also common to the "Barrier Plan"). If the "Barrier Plan" had been built as designed and somehow adequately funded to be completed before Hurricane Katrina, New Orleans would have very likely still had disastrous flooding, possibly worse.

6. All "Barrier Plan" designs reduce storm surge storage in Lake Pontchartrain and displace surge upward, but also laterally toward the Mississippi or southward toward St. Bernard Parish. The consequences of increased flood risk must be evaluated.

7. During the passage of a hurricane, Lake Pontchartrain undergoes a "sloshing" effect such that storm surge piles-up first on the west side of the Lake, then the south side and then the east side. This is predominately a wind driven phenomenon that will occur even with flood control structures on the passes. Also during a hurricane, when the gates are closed, Lake Pontchartrain and all of the surrounding drainage becomes, in effect a regional retention reservoir of finite capacity, which would receive hurricane rainfall, runoff and pumped storm water. With flood control structures in place and closed, the sloshing effect pushes water eastward toward the passes but water cannot escape as quickly, compounding the storm surge elevation. Any new flood protection measure, including structures on the passes, must consider the retention water levels, the reduced capacity for water to exit Lake Pontchartrain and the sloshing effect of Lake Pontchartrain.

8. Past flood protection authorities are biased toward the historic population and economy of the south shore. New federally authorized flood protection projects must consider the shifting of population and economics to the north shore and the entire Lake rim.

9. Although the three generations of "Barrier Plan" type designs that were evaluated show a trend toward reducing the hydrologic impacts, all of them would have some environmental impact.

10. In the open position, the flood control structures previously proposed would reduce the passes' channel dimensions, and thereby, increase velocity and turbulence. Both of these changes could

inhibit migration of some species or create some new vulnerability by ingress/egress, predation, physical stress, habitat change, hydroperiod, etc. The reduced tidal prism in Lake Pontchartrain would likely reduce salinity and increase chances for concentration of nutrients or pollutants, which could result in harmful algal blooms, fish kills, reduction in water quality, etc.

11. In the closed position, the flood control structures previously proposed would prevent any astronomically driven tidal exchange, and most storm surge. Assuming closure for storms are infrequent (1 /year) and of short duration (2-3) days, the reduced tidal exchange would likely slightly reduce salinity and increase chances for concentration of nutrients or pollutants, which could result in harmful algal blooms. These effects should recover quickly once structures are re-opened. However, there is a risk that some species such as West Indian Manatee may seek refuge in inland waters during a storm when the structures might be closed. The closed structure may increase risk of mortality of fish or marine mammals that may use Lake Pontchartrain as refuge during hurricanes.

12. North shore marsh accretion appears to be dependent on vertical accretion that occurs during storm surge events, and therefore, reduced storm surge sedimentation due to flood control structures may accelerate wetland loss on the north shore of Lake Pontchartrain.

13. Consideration of the Lake Pontchartrain food web, suggests that a significant number of important species in the food web could be directly affected by flood control structures, which could have secondary effects on the food web. Many of these species are important recreational or commercial species.

14. A review of some representative species which utilize the passes to access Lake Pontchartrain leads to the conclusion that alterations to the hydrology by flood control structures must include species-specific analyses, and that assessment metrics that simply consider gross hydrologic (physical) changes, such as the tidal prism, are an inadequate proxy to predict the actual biological impact on all the aquatic species.

15. Future environmental impact investigation of flood control structures on the passes into Lake Pontchartrain must recognize the enormous hydrologic function of the passes to regulate salinity, species migration, residence time, nutrient distribution, pollutant loading, etc, within a entire 5,800 square mile estuary, and therefore, potential effects are may occur on the protected and flood side of the floods control structures.

Acronym List

CPRA – Coastal Protection and Restoration Authority
EPA – Environmental Protection Agency
FEMA – Federal Emergency Management Agency
GIWW – Gulf Intracoastal Waterway
HPS – Hurricane Protection System
HSDRRS – Hurricane Storm Damage Risk Reduction System
IHNC – Inner Harbor Navigational Canal
IPET – Interagency Performance Evaluation Task Force
IWR – Institute for Water Resources
LACPR – Louisiana Coastal Protection and Restoration
LDOTD – Louisiana Department of Transportation and Development
LPBF – Lake Pontchartrain Basin Foundation
LP&VHPP – Lake Pontchartrain and Vicinity Hurricane Protection Project
LSMP – Louisiana State Master Plan
MLODS – Multiple Lines of Defense Strategy
MRGO – Mississippi River Gulf Outlet
MSL – Mean Sea Level
NOAA – National Oceanic and Atmospheric Association
PMH – Probable Maximum Hurricane
SPH – Standard Project Hurricane
UNO – University of New Orleans
USACE – United States Army Corps of Engineers

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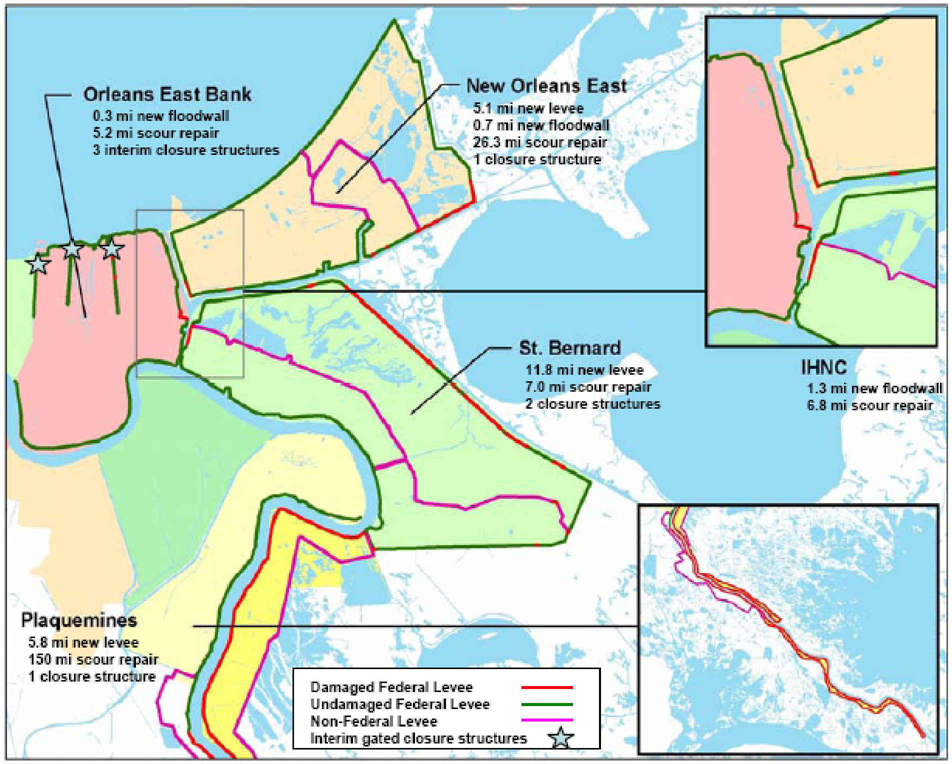
Appendix

TASK FORCE **GUARDIAN**

Hurricane Protection System Restoration Program Summary

Final Report
As of 8 June 2006



Protection Restored Schedule
- Restore pre-Katrina protection by 1 Jun 06
- 100% complete towards pre-Katrina Protection Restored
- All construction complete end of November 06

Program Facts
- Repaired system
  - 2.3 mi new floodwall
  - 22.7 mi new levee
  - 195.3 mi scour repair (98 mi MRL completed 17 Mar)
  - 3 interim gated closure structures (IGCS)
  - 4 closure structure repairs
- Fully funded at $800.5M
- Construction
  - 59 projects by 26 Contractors
  - 90% of work by local contractors - 38% by HZ/8(a)
  - $557M in construction activity
- Supply
  - Two supply contracts – clay and temporary pumps
  - 1,566,000 cy of clay supplied to date @ 47.1M
  - 34 IGCS pumps purchased @ $35.3M
- Real Estate
  - 894 acres commandeered
  - 404 ownerships anticipated
  - $63M anticipated property value
- 155 vessels removed from levee

Better and Stronger
- Interim gated closure structures stop surge at Lake
- New levees constructed with erosion resistant clay
- New floodwalls more stable – T/L wall versus I wall
- New erosion protection
  - at damaged overtopped floodwalls
  - at wall/levee transitions
  - at utility crossings

6/16/2006

Figure A-1: Task Force Guardian Hurricane Protection System Restoration Program Summary: Final Report (USACE, 2006a).

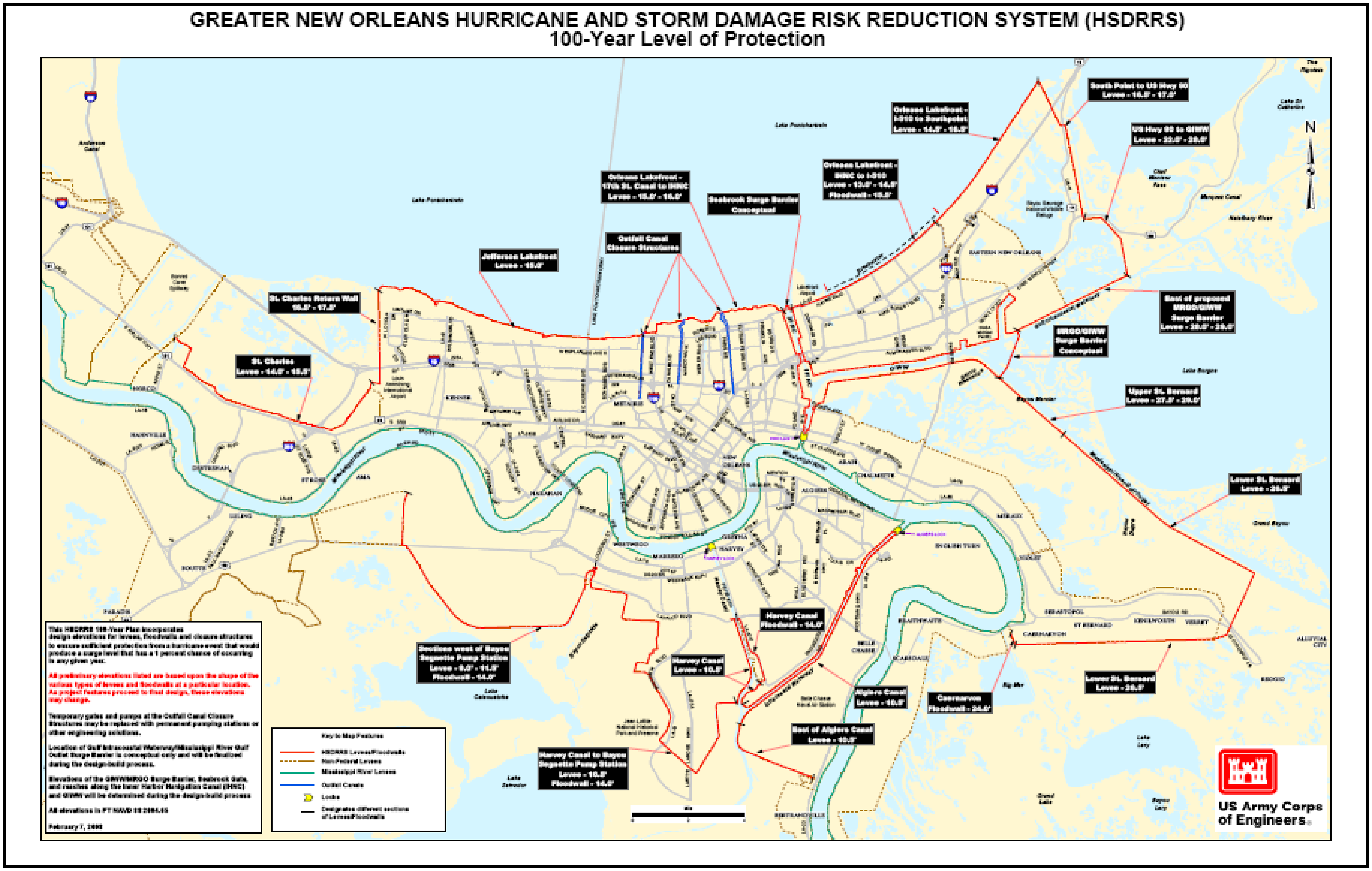


Figure A-2: Hurricane and Storm Damage Risk Reduction System (HSDRRS) 100-Yr Level of Protection Map (USACE, 2010b).

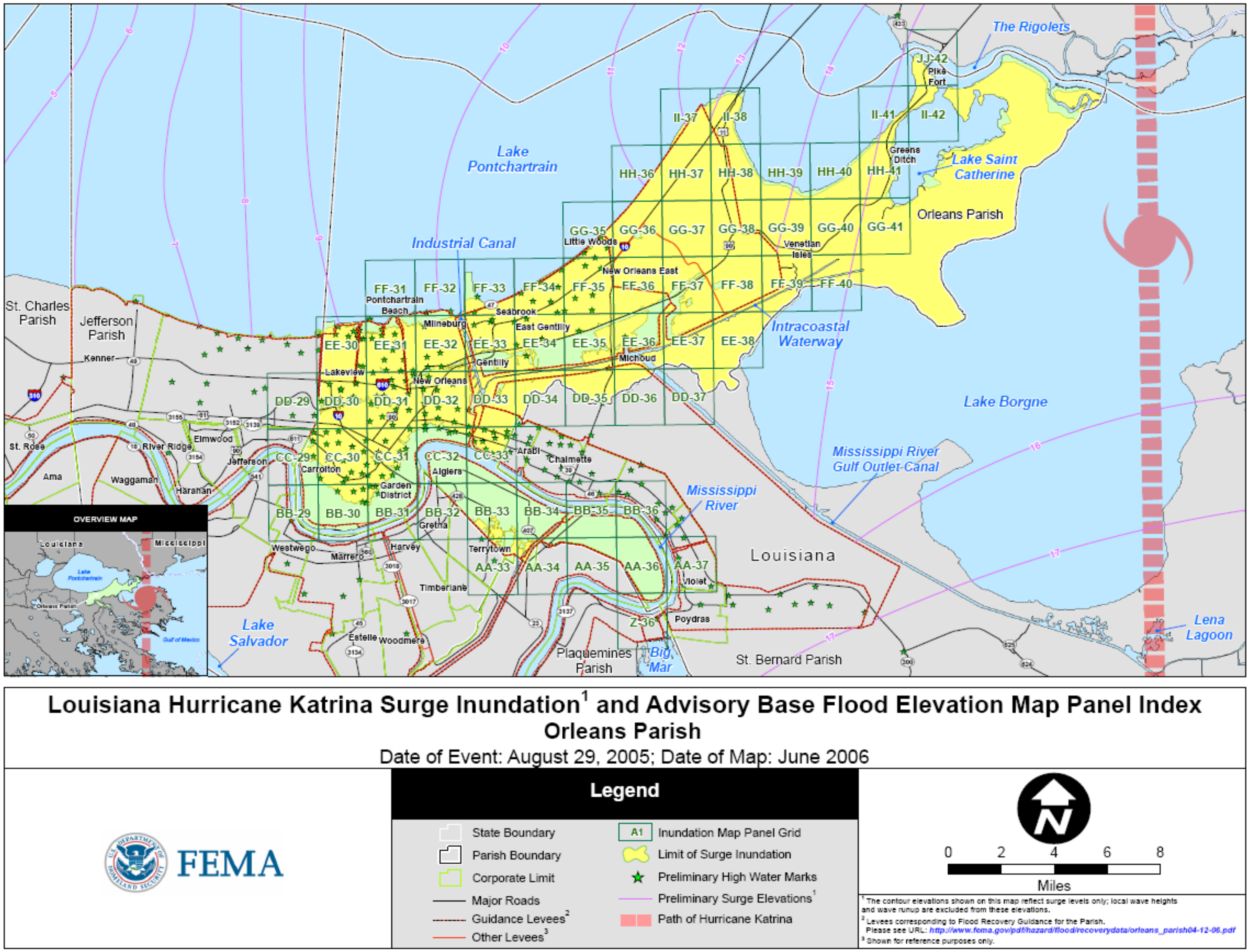


Figure A-3: Louisiana Hurricane Katrina Surge Inundation and Advisory Base Flood Elevation Map Panel Index (FEMA, 2006).

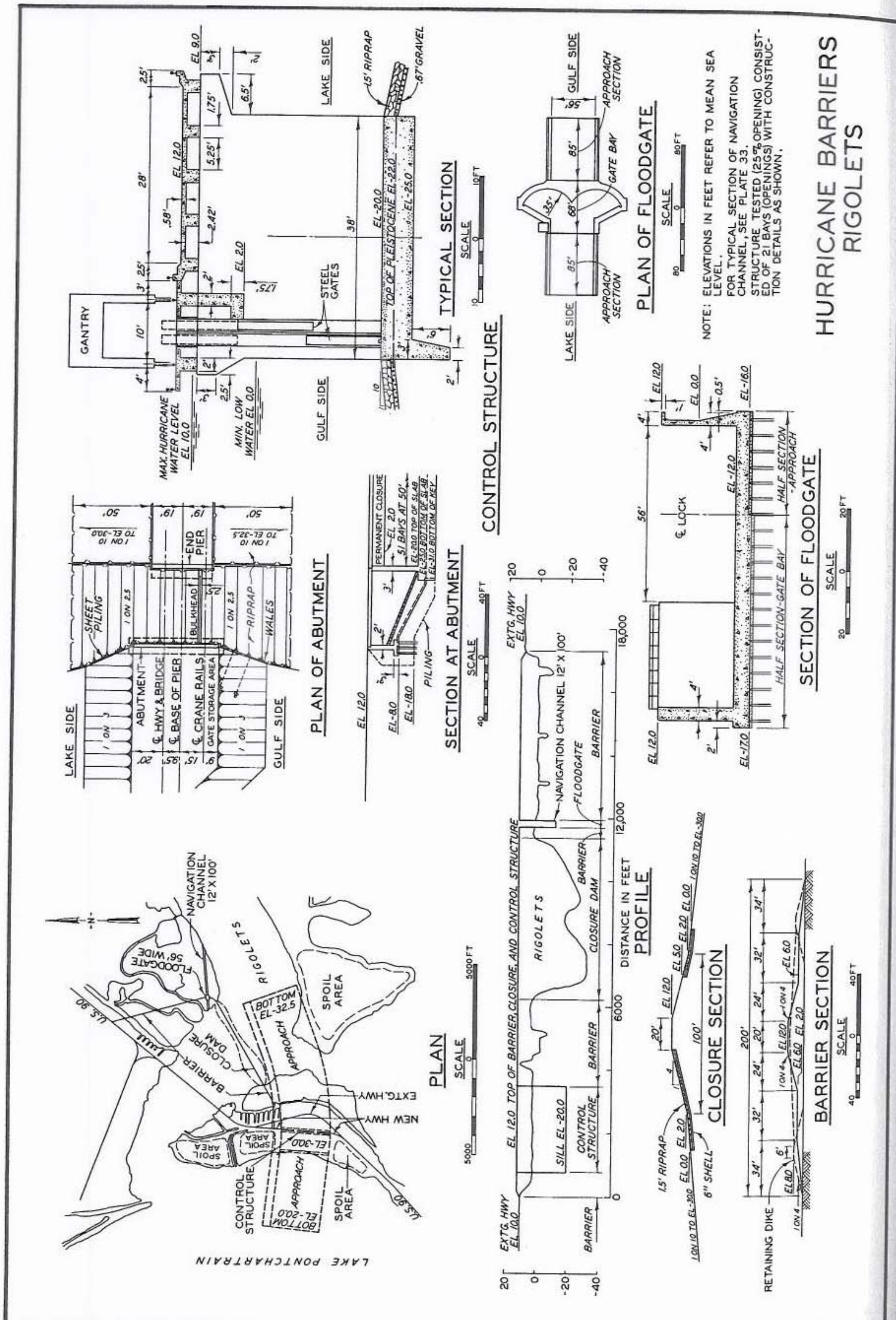

HURRICANE BARRIERS
RIGOLETS
PLAN
PROFILE
CLOSURE SECTION
BARRIER SECTION
PLAN OF ABUTMENT
SECTION AT ABUTMENT
CONTROL STRUCTURE
TYPICAL SECTION
PLAN OF FLOODGATE
SECTION OF FLOODGATE
LAKE PONTCHARTRAIN
NOTE: ELEVATIONS IN FEET REFER TO MEAN SEA LEVEL.
FOR TYPICAL SECTION OF NAVIGATION CHANNEL, SEE PLATE 33.
STRUCTURE TESTED (25% OPENING) CONSISTED OF 21 BAYS (OPENINGS) WITH CONSTRUCTION DETAILS AS SHOWN.

PLATE 32

Figure A-4: 1963 Plan and Section Views of the Hurricane Barriers in Pass Rigolets (USACE, 1963).

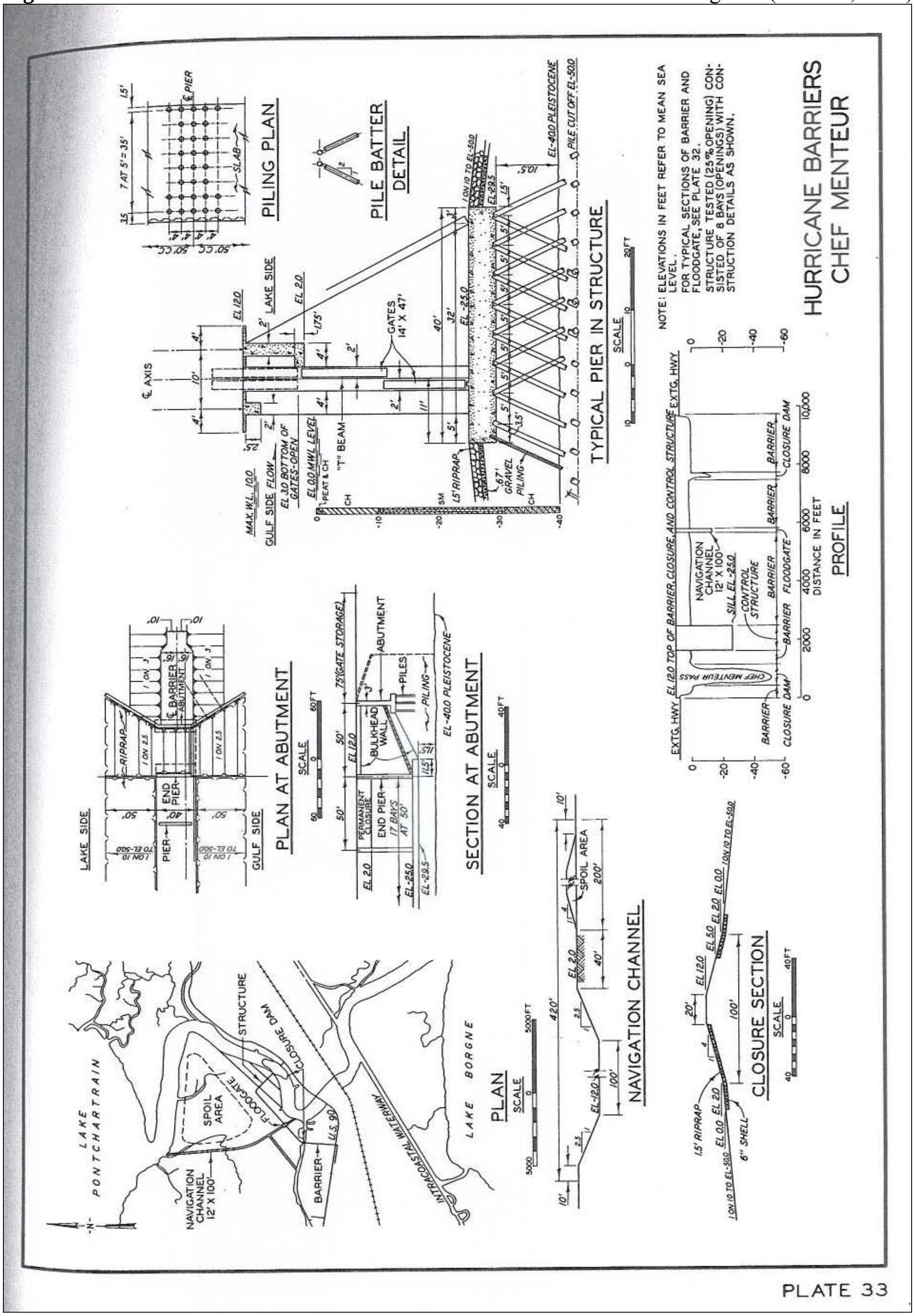


Figure A-5: 1963 Plan and Section Views of the Hurricane Barriers in Chef Menteur Pass (USACE, 1963).

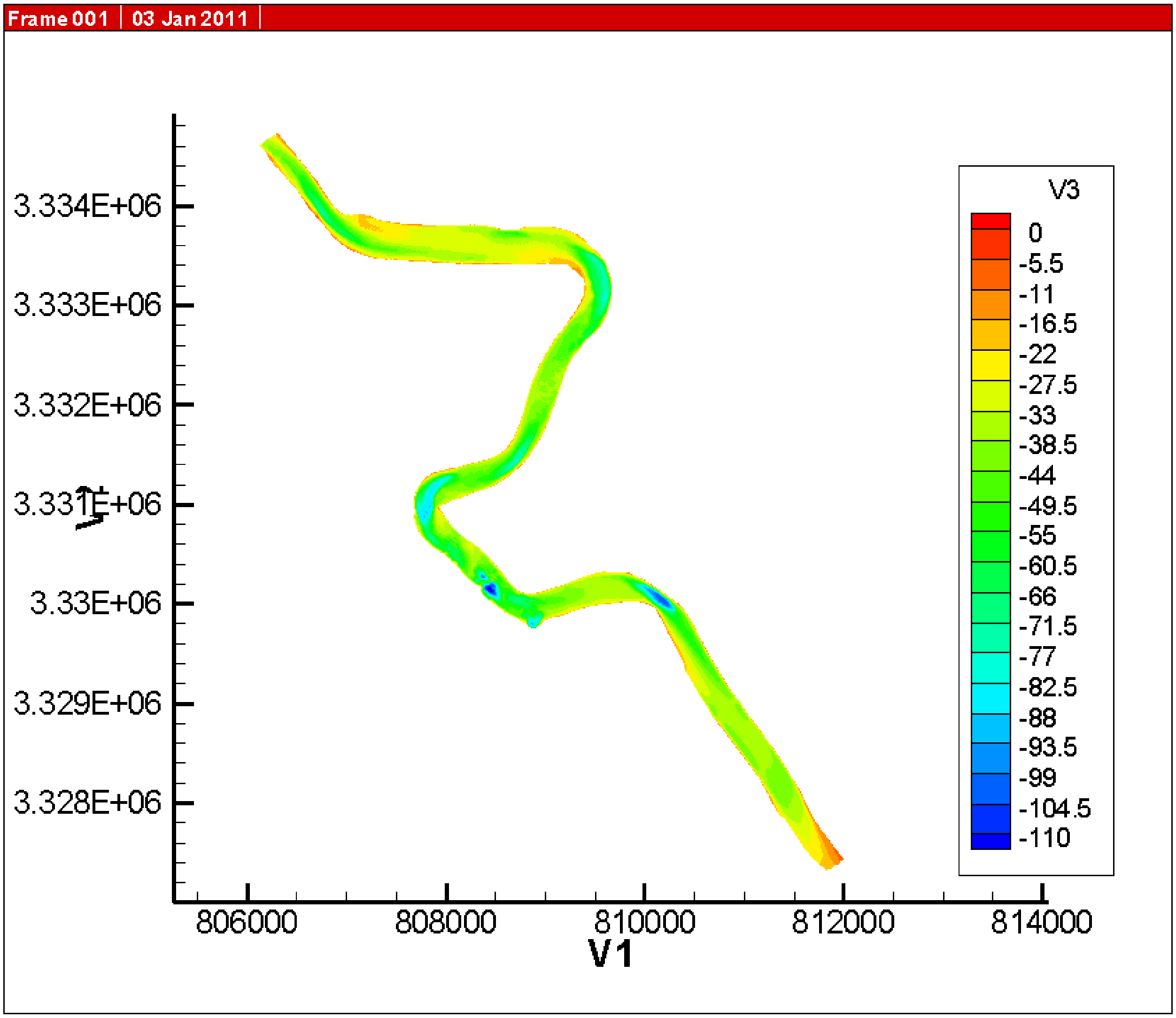


Figure A-6: Tecplot Image of Chef Menteur Pass. The variables V1 and V2 along the graph's axes represent the horizontal coordinates in UTM (Zone 15) with units of meters. The variable V3 represents the vertical coordinate or depth and is in units of feet. It should be noted that the image extends beyond the length of the actual pass into both Lakes Pontchartrain and Borgne.

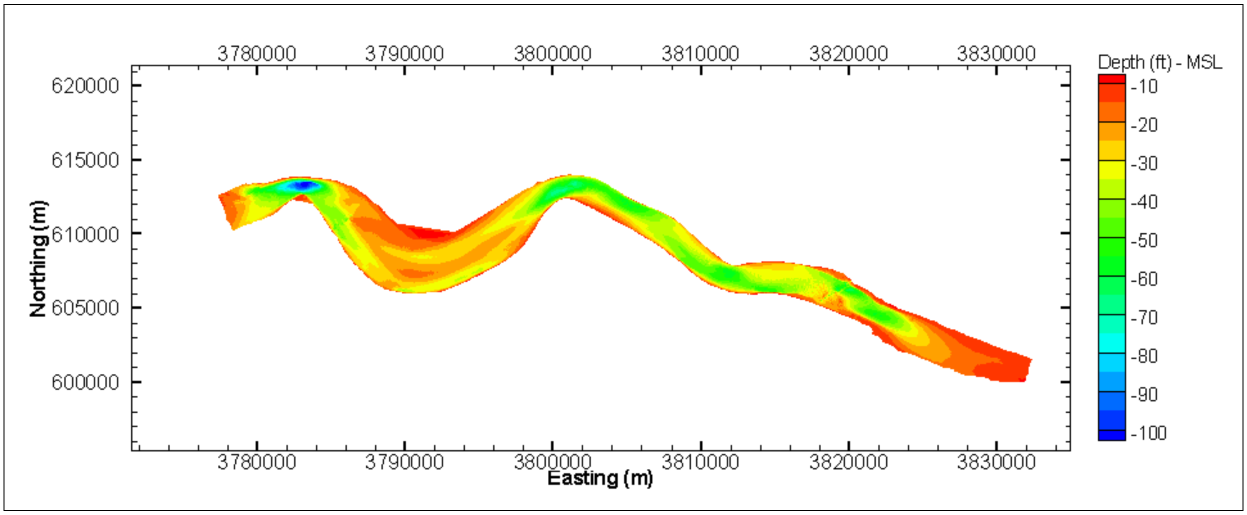


Figure A-7: Tecplot Image of Pass Rigolets. The Northing and Easting axes are in the Louisiana State Plane (1702) coordinate system with units of meters. The vertical coordinate or depth is in units of feet. It should be noted that the image extends beyond the length of the actual pass into both Lakes Pontchartrain and Borgne.

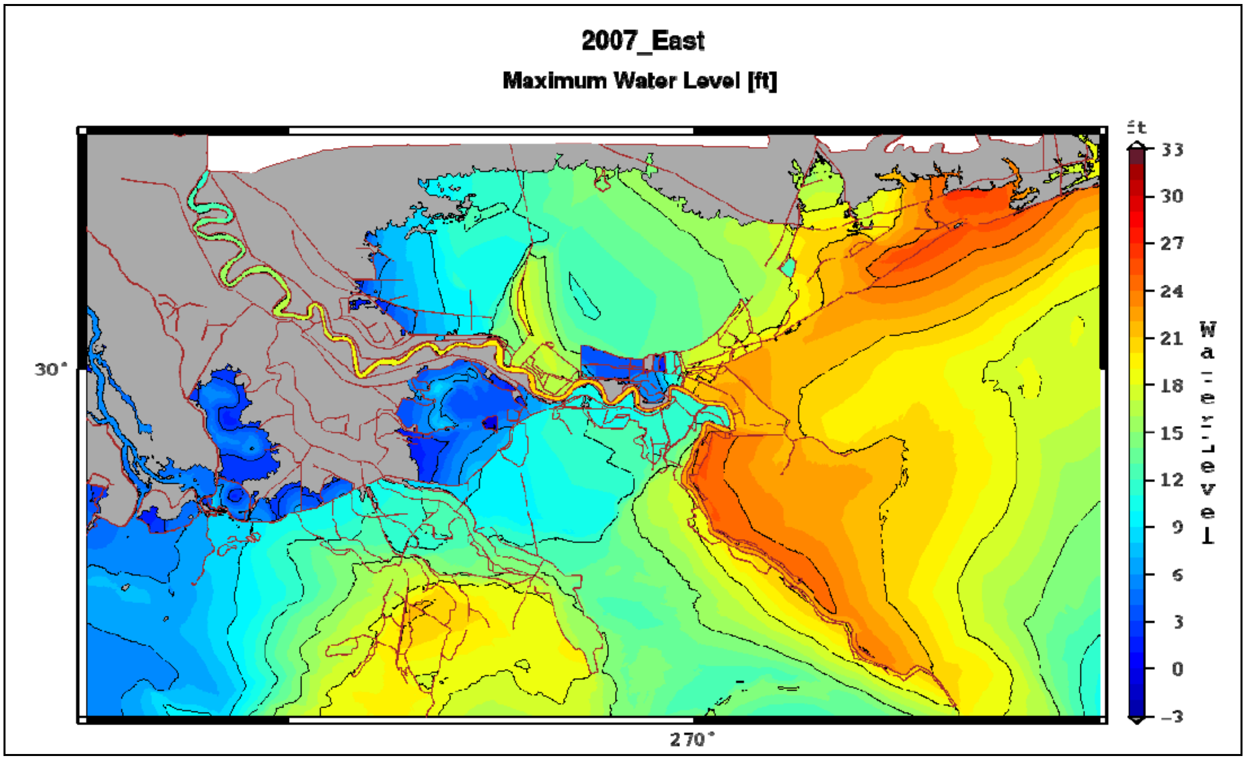


Figure A-8: LACPR Base Case Contour Map indicating existing conditions, Page 217 (LACPR, 2009).

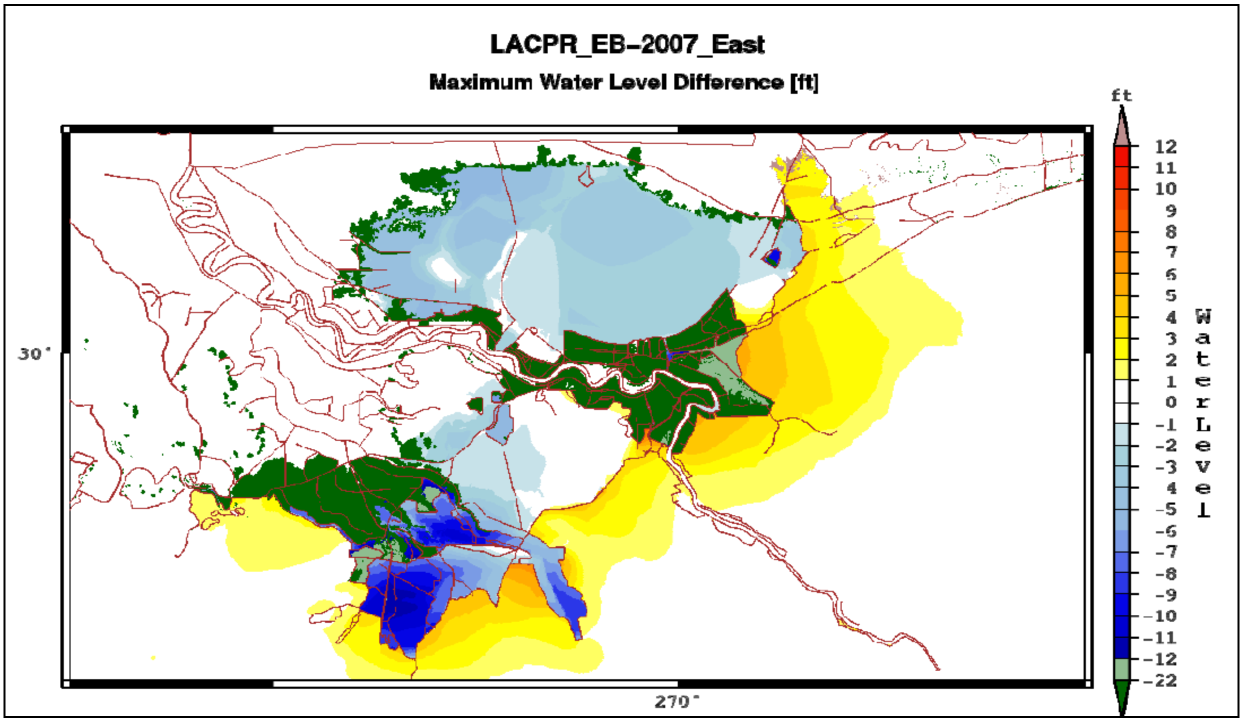


Figure A-9: LACPR Maximum Water Level Difference Contour Map with the "Barrier Plan" Structures in the Rigolets and Chef Menteur Passes and across the Orleans Land Bridge at the 100-Yr Level Elevations (12 ft), Page 223 (LACPR, 2009).