Integrated Ecosystem Restoration and Hurricane Protection: Louisiana's Comprehensive Master Plan for a Sustainable Coast

Appendix D: Sustainable Management and Mississippi River Resource Availability

Coastal Protection and Restoration Authority of Louisiana

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1.0 Introduction

For thousands of years Louisiana's coast has been in a constant state of change. As the Mississippi River approaches the Gulf of Mexico the hydraulic slope flattens and water from the river spreads over the shallow marshes and estuaries along the Louisiana coast. As the river overflows its banks, sediment transported by the river from the central North American continent begins to settle out. This natural process forms natural levees along the top bank of the river, and elongates the channel into the gulf. The elongation of the channel increases river stages, allowing the natural levee along the top bank to be broken and a new channel to develop. This natural process of channel abandonment has occurred numerous times throughout the geologic history of the coast of Louisiana, but was halted beginning when Europeans settled the region 300 years ago.

European settlers found coastal Louisiana to possess rich soil for agriculture, to provide tremendous fishery resources, and to be on an excellent water transportation system into the inland portions of the continent. More agricultural land, as well as protection from the overflowing river, was needed as population increased along the coast. With better materials available to build levees and more reliable navigation, people moved further into the coastal area. Finally, after the Great Flood of 1927, the United States Congress authorized the Mississippi River and Tributaries (MR&T) project and assigned the U.S. Army Corps of Engineers to provide reliable flood protection and navigation. The MR&T project built higher and more reliable levees. They covered some banks with articulated concrete mat to prevent erosion. A deep navigation channel was constructed. Collectively these measures forced more of the sediment and water to pass beyond the marshes and estuaries into the deep water of the Gulf of Mexico. In the early 1900's the discovery of oil and natural gas also hastened the changes to the natural landscape. Wells were drilled in the marsh, and channels were cut for pipelines to transport the oil and gas to the refineries being built along the river. By the 1960's people realized that the coastal landscape was deteriorating. Salt water intrusion, subsidence and other physical changes to the environment were increasing land loss throughout the coastal zone. Storms were causing significant impacts to populated areas. It become clear that the entire coastal region would continue to deteriorate and all the development would be at increased risk unless the natural processes that built and maintained coastal Louisiana were re-established. The fresh water and sediment carried by the Mississippi River are the basic resources that will provide a sustainable and productive coastal region for the State of Louisiana.

The continued loss of Louisiana's coastal wetlands will have significant ecological, societal, and economic impacts on the region and on the Nation as the tremendous resources supplied from the coastal zone are put at an increasing risk. Appendix D provides an overview of the geologic history, what is at stake, and the actions needed to ensure the long-term sustainability of the Louisiana's coastal zone if implemented in a coordinated and strategic manner. It then presents the volumes of water and sediment that have been delivered by the Mississippi River historically, and lays out a process for formulating the actions necessary to build river diversion projects to provide for the long-term sustainability of the natural landscape and the services that the coastal zone provides to the region and the Nation. Louisiana has a unique and precarious relationship with the river and the sediment it delivers. Significant changes have taken place in the upper Mississippi River Basin that has negatively impacted the availability of sediments. To achieve a truly sustainable coast, the water and sediment resources of the future must be managed very carefully.

2.0 Sustainable Coastal Management

Although the coastal Louisiana ecosystem contains 30 percent of the coastal marsh in the contiguous United States, it suffers 90 percent of the total coastal marsh loss. Since the 1930s, coastal Louisiana has lost over 1.2 million acres (1,875 mi^2), an area nearly the size of Delaware (Barras et al., 2003; and Dunbar et al., 1992). At present, the rate of loss is approximately 15,300 acres per year (23.9 mi^2/ yr), but estimates indicate that coastal Louisiana could experience a net loss of an additional 328,000 acres (513 mi^2/yr) by the year 2050 (Barras et al., 2003).

In addition to this predicted trend, a study by the U.S. Geological Survey (USGS) has reported that the storms of 2005 converted approximately 217 square miles of marsh to water. Of this total, 98 square miles of land were lost in southwestern Louisiana, and 119 square miles were lost in southeastern Louisiana. Analyses of future growing seasons will indicate how much of this damage is permanent, as marsh plants may rebound in some spots and not in others. Regardless of the final outcome, the storms have aggravated an already dire land loss emergency.

The past and continual loss of Louisiana's coastal wetlands will have significant ecological, societal, and economic impacts on the region and the Nation as tremendous resources supported by the coastal zone are put at risk.

2.1 River and Coastal Processes

The Deltaic Plain, found in the southeastern portion of coastal Louisiana, was built by the shifting of the Mississippi River through dynamic and episodic progression of events known as the delta cycle. The delta cycle is the process of alternating periods of delta-building, or the seaward advancement of land, when occupied by the Mississippi River and the subsequent landward retreat of that delta when the river shifts its course. This is also described in the Coast 2050 report (Task Force. 1998). The Mississippi River has built 6 delta lobes (Figure 2.1), including the currently prograding Atchafalaya Delta, along Louisiana’s coast over the past 7,000 years. The modern delta (the Plaquemines-Balize or bird-foot delta) has formed over the last 800-1,000 years (Draut et al., 2005; Roberts, 1997).

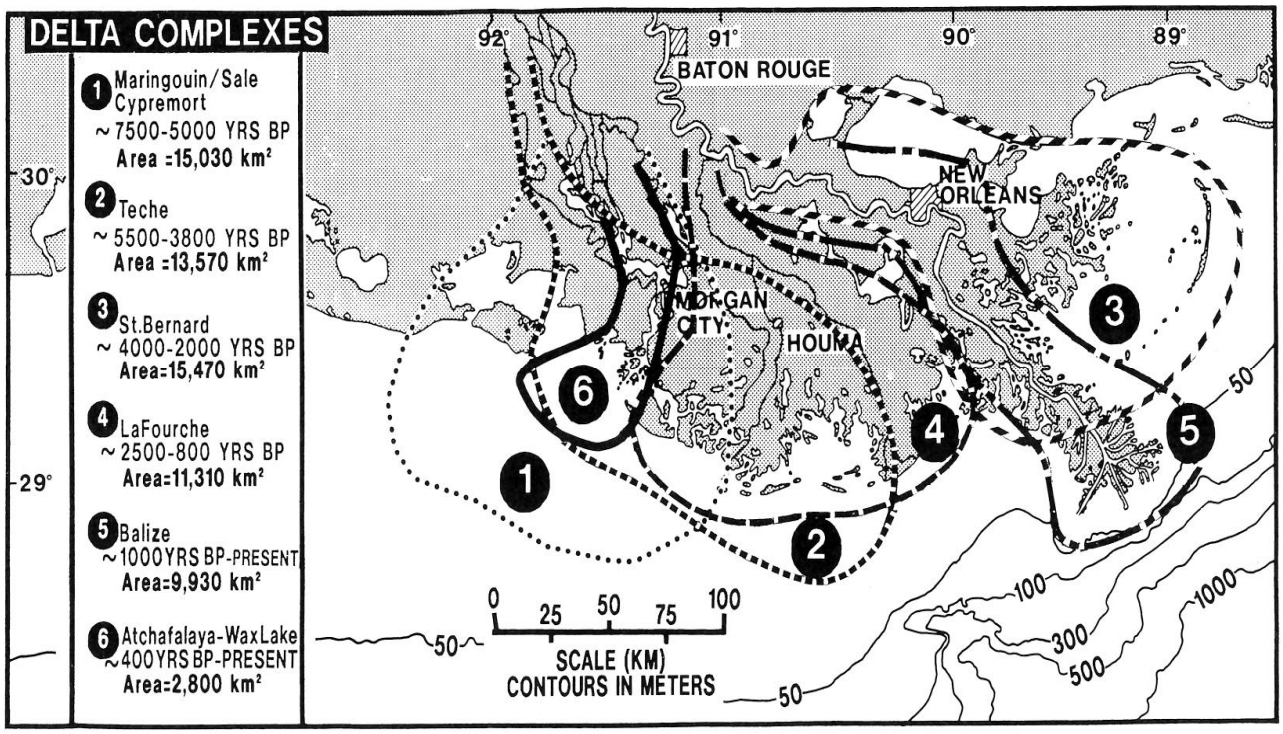

Figure 2.1: Current and historical delta lobes of the Mississippi River (from Roberts, 1997)

In a progading delta, crevassing and overbank flooding promotes sheet flow which introduces freshwater, nutrients and mineral sediments into the wetland ecosystem. The nutrients are removed by plant uptake allowing for an overall increase in vegetation production and biomass. In a sustainable wetland ecosystem, this increase in organic matter production, combined with the enhanced deposition of mineral sediments from the river, allows vertical accretion to counterbalance relative sea level rise (subsidence plus sea level rise), thereby preventing wetland loss.

During delta growth, distributaries continue to branch, and ultimately reduce the efficiency of the delta to transport sediment and water. This decreased hydraulic efficiency is caused by a reduction in the gradient of the channel as the delta lobe advances into the gulf. Eventually, the main channel is captured upriver by a more hydraulically efficient channel, and the once prograding delta is “abandoned” by the river. As nutrient and mineral sediment supplies decrease, the wetlands’ ability to keep pace with changes in relative sea level rise also decreases. This allows Gulf wave action to rework sediments in the delta into a barrier headland (Figure 2.2). As the delta lobe continues to degrade, the barrier headland is converted into barrier islands and, finally, into a submerged shoal.

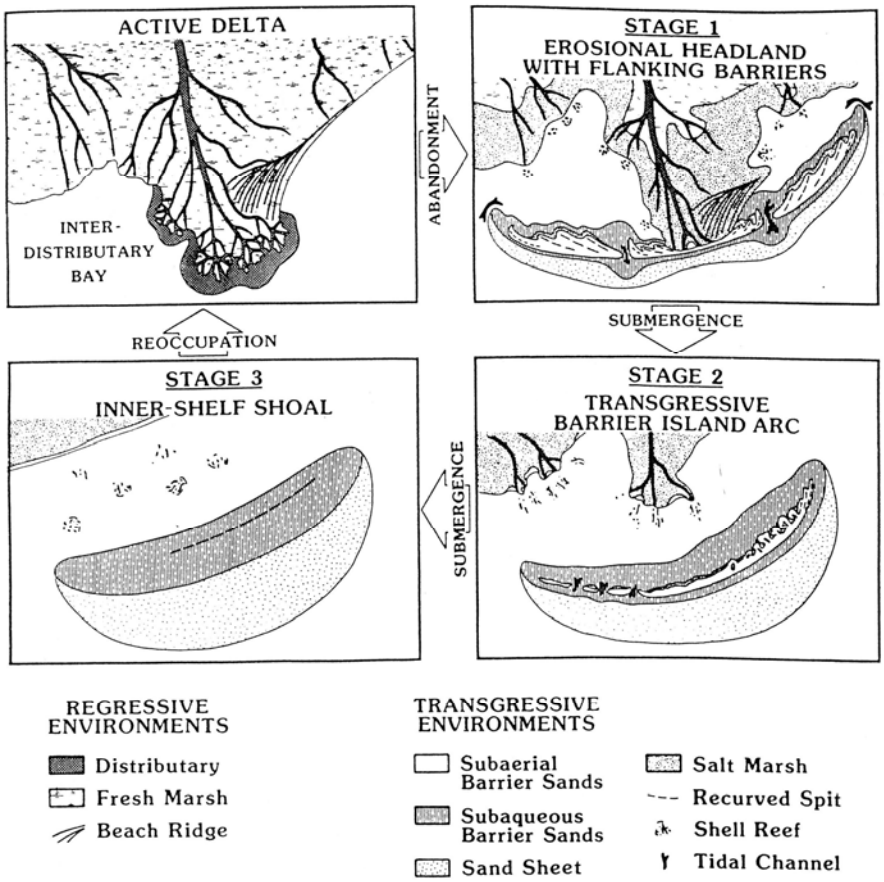

Figure 2.2: Delta Cycle (Penland et al., 1988)

The Chenier Plain, found in the southwestern portion of coastal Louisiana, developed primarily as a result of the interplay of an intermittent mudstream from historic Mississippi River distributaries, smaller coastal rivers, and the Gulf of Mexico. Historically, mudflat progradation resulted from pulses of sediment when a major distributary of the Mississippi River was located in the western portion of the deltaic plain. When this distributary shifted to the east, erosion and physical reworking of mineral sediments winnowed out fine-grained materials, leaving the deposits of sand and shell. This material was worked into elevated ridges by wave energy from the Gulf of Mexico (Figure 2.3). Through repetitions of this process the elevated ridges, called cheniers, were formed, and ultimately supported deciduous vegetation growth (Penland and Suter, 1989; Hoyt, 1969). The predominance of oak trees on these ridges gave the region its name; “chene” is the French word for oak.

In this region, tidal exchange with the saline Gulf of Mexico historically was limited to small river mouths. Salt water influence was minimal with the system being dominated by freshwater inputs from upland runoff delivered by meandering rivers and precipitation. The interior of the Chenier Plain was a low salinity estuary.

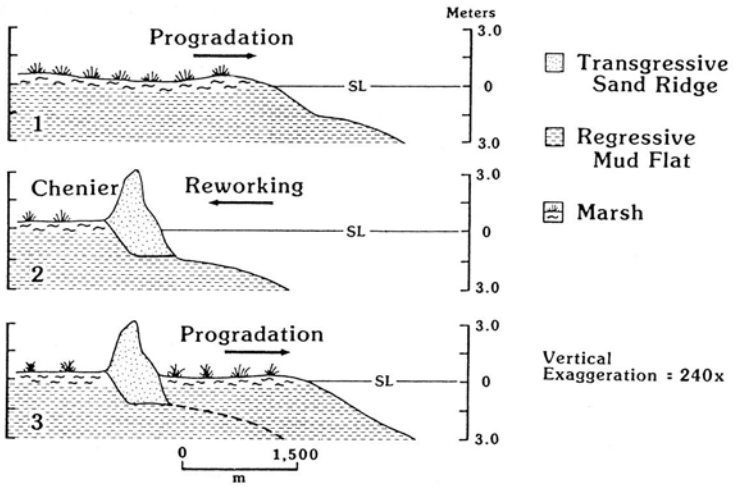

Figure 2.3: Process of Chenier development. (Penland and Sueter, 1989)

In their natural state, wetlands in coastal Louisiana were able to keep pace with relative sea level rise (subsidence and eustatic sea level rise). Subsidence, a natural process in deltas, is the sinking of land due to compaction and dewatering of deposited sediments and the decomposition of organic matter. Eustatic sea level rise is the change in global sea level as a result of such factors as the melting of continental glaciers and ice sheets and the expansion of ocean waters heated by global warming. In a self-sustaining or growing delta, periodic inputs of mineral sediment from external sources and vertical accumulation of organic matter will balance loss due to subsidence. In addition to the energy and material that rivers deliver to their deltaic systems, the associated sediment deposition, nutrient availability and lower salinities increase vegetation production. Loss of wetland sustainability occurs when soil building cannot keep pace with relative sea level rise. In a low sloping landscape such as a river delta, a sea level rise of a few centimeters can be devastating to large areas of marsh. Although global sea levels and subsidence have affected system sustainability throughout geologic time, human intervention has exacerbated this problem.

2.2 Human Intervention

With the arrival of the European settlers came major changes to the natural landscape to create more stable and safe living conditions in this naturally dynamic region. Alterations included construction of levees to render this system even more suitable for habitation, efficient for navigation and agriculturally productive. By 1844, levees were continuous along the banks of the Mississippi River from 20 miles below New Orleans to the mouth of the Arkansas River on the right descending bank and to Baton Rouge on the left (Elliot et al. 1932). However, early levees were privately built and maintained, and they were not sufficient to prevent over topping and crevassing along the banks. Although the number of crevasses formed during floods decreased after federal involvement in levee construction began in 1892, the magnitude and destruction caused by those that did occur continued to increase (Vogel 1930). Thus, the Flood Control Act of 1928, the nation's first comprehensive flood control and navigation act, was passed and the Mississippi River and Tributaries (MR&T) project was authorized (http://www.mvn.usace.army.mil/pao/bro/misstrib.htm). Following the flood of 1927, United States Army Corps of Engineers (USACE) was tasked with building a new levee system that would prevent overbank flooding during river discharges of considerably greater magnitude than experienced in 1927. Since 1928, $12.5 billion has been invested for planning, construction, operation and maintenance of the MR&T Project. An estimated $306 billion in damages have been prevented by this investment, resulting in a 24.5 to 1 return on each dollar invested.

Today, levees, floodways, channel improvements, and tributary basin improvements provide a comprehensive navigation and flood control plan to protect interests along the Mississippi River from catastrophic flooding. No MR&T levee has ever failed or overtopped, and since the completion of the present-day flood protection system, the frequency of overtopping and crevassing of the non- MR&T levees along the lower river has declined markedly (USACE 1965, Templet & Meyer-Ardent 1988).

Successfully containing the Mississippi River within a stabilized channel and implementing erosion control measures in the drainage basin has decreased the sediment load of the Mississippi River. Improved techniques for managing agricultural lands and the construction of reservoirs, since the late 1800's, has caused the suspended sediment load of the Mississippi River to decrease by almost 80 percent. Along with this decrease in concentration, there has been reduction in grain size of the remaining load. Sand carried as bedload down river of Baton Rouge has decreased by approximately 50 percent (Keown et al. 1986). These reductions could play a significant role in the deterioration of the skeletal marsh framework and in the loss of land surrounding the delta front (Kesel 1989). This reduction of available sediment and the disconnection of the Mississippi River from its coastal floodplain severely hamper the ability of marsh to counterbalance sea level rise.

Percy Viosca first documented declines in fish and wildlife species in 1927, and he attributed these changes to building of levees that prevent "flood water from entering the extensive lowland basins where it normally deposited its fertility before the river stages lowered to such an extent that it could find an outlet to the sea." Indeed mineral sediment input to Louisiana's coast has decreased in recent decades because of the levee system along the Mississippi River. This levee system is critical for the continued inhabitance of many portions of coastal Louisiana, and it is critical for the sustainability of many economic services that this region provides to the Nation. But, by preventing overbank flooding and crevassing of the Mississippi River, the surrounding wetlands are now largely deprived of the mineral sediment, freshwater, and nutrients required for offsetting subsidence and sea level rise. The impacts of decreased mineral sediment on a system facing accelerated submergence rates may be catastrophic. Decreased nutrient inputs and increased salinities also stress existing plant species, thereby reducing plant biomass production and associated organic matter that would contribute to vertical accretion. Because of the documented negative impacts of levees, a commitment must be made to ensure that new levee designs allow for hydrologic exchange across these barriers. Such exchange will sustain wetlands on both sides of the levees.

Louisiana's coastal wetlands contain an extraordinary diversity of coastal resources that support many nationally significant economic and environmental services. These services include: protection of inland areas from storm actions; navigation; oil and gas production; fisheries and hunting; agriculture; and internationally important wild bird habitats. These services have been utilized by humans throughout Louisiana's history to support their habitation of the coastal zone.

Additional physical changes to the landscape and the disruption of the land-building and sustaining processes came with the initiation of oil and gas exploration. There are nearly 15,000 miles of pipelines in coastal Louisiana. They service approximately 50,000 oil and gas production facilities (USACE 2004). Some estimates state that as much as 30 percent of coastal marsh loss is attributable to the construction of canals and their associated spoil banks (Mac et al. 1998). Canals also alter hydrology and allow for saltwater intrusion. Their associated spoil banks may cause water to pond and drown wetlands. In fact, Turner (1997) argues that most indirect wetland loss is caused by these effects. Others have asserted that another significant effect of oil and gas activity in the coastal zone is accelerated subsidence caused by fluid (oil & gas) extraction. Peaks in this activity closely correlate with peak measurements of subsidence and land loss rates in the delta plain, and suggest that

accelerations in subsidence rates between the 1950's and 1970's were largely human-induced (Morton et al. 1998; Morton et al. 2002).

There are also 10 major navigation canals in coastal Louisiana. While they serve to transport goods through and out of Louisiana, they also allow saltwater to intrude into and degrade freshwater wetlands (Day et al. 2000). In addition there are cases, such as the Mississippi River-Gulf Outlet where the continued erosion of channel banks has caused the direct loss of substantial amounts of wetland.

These human-induced factors interact with natural factors to create the land loss crisis facing Louisiana's coastal zone today. Causes of loss can be divided into direct causes, such as canal construction, erosion caused by storms or ship wakes, and herbivory; and system-wide causes such as levees, agricultural practices and channel stabilizations works that reduce the sediment load below that needed for long-term sustainability of the coastal wetlands and other landforms.

Direct loss, caused by natural and human factors, refers to immediate destruction or damage to wetlands. Natural erosive forces caused by winter storms and hurricanes result in direct wetland loss. Humans have accelerated this natural process with increased wave energies from commercial navigation activities. The extensive network of oil, gas, and navigation canals throughout the coastal zone has directly removed and buried wetlands. The direct impacts of herbivory have become catastrophic in coastal wetlands since the human introduction of the South American nutria. Historically, muskrat, beaver, deer, and feral pig have contributed to direct wetland loss, but the prolific nutria has an extremely high birth rate that enables its devastation of fresh and brackish wetlands. Between 1993 and 2001, it is estimated that over 100,000 acres of wetlands have been impacted by nutria herbivory (See the Coastwide Nutria Control Program Fact Sheet at: http://data.lacoast.gov/reports/gpfs/LA-03b.pdf).

The low-salinity estuary that existed in the Chenier Plain has been modified to a system of impoundments to support agriculture and to maintain habitats for species that live in freshwater wetlands such as alligators and ducks. The upper Mermentau River Basin is now maintained as a freshwater reservoir utilizing a system of five floodgate complexes and navigation locks. Several State and Federal wildlife refuges also maintain desired water levels and freshwater conditions over large expanses of the area. Coastal restoration projects have traditionally been operated to minimize water level and salinity fluctuations.

In direct opposition to this desire for fresher systems in the Chenier Plain, all of the major rivers in the area have been straightened and their cross-sections increased for deeper draft navigation. These changes provide for more rapid drainage of flood waters. This has the effect of minimizing retention of fresh water in the system which allows for increased marine (saltwater and tidal) influences over the majority of coastal areas that have not already been impounded. Activities to extract oil and gas and harvest the economically important mammals have also exacerbated the situation by creating an extensive series of canals which allows saltwater into sensitive wetlands. Road building has also disrupted the hydrology by disrupting natural drainage patterns on a large scale.

On a geologic scale, maintaining the flow distribution from the Red and Mississippi rivers at constant levels down the Atchafalaya River has prevented the Atchafalaya from capturing the main flow of the Mississippi River. This has limited the level of sediment input that could have been expected via long-shore transport of sediment from an active distributary of a major river, and it has limited the progradation of the eastern Chenier Plain.

These human interventions have altered to balance of natural forces and have contributed to the land loss crisis we face in coastal Louisiana today. Alone, any one of these factors would have caused some degree of land loss in

the coastal zone. Combined, they have had overwhelming effects on the stability of this rich and productive ecosystem.

2.3 Environmental Sustainability

In order to restore coastal Louisiana to a self-sustaining environment, near-term solutions to address immediate needs must be merged with long-term goals to reach system sustainability. Landscape integrity in coastal Louisiana requires the presence of barrier islands, beaches, Chenier ridges, intact saline, brackish and fresh marsh habitat, and healthy swamp forests. To enhance the health and integrity of the coastal Louisiana ecosystem, the altered processes must be restored by mimicking to extent possible the natural processes of a sustainable coast. To restore disconnected and modified hydrologic linkages, regional water management options should reconnect and maintain linkages to sediment and nutrient delivery to interior wetlands while reducing sediment loss to offshore environments. Regional water flow patterns should be restored and maintained by mimicking natural process and cycles, minimizing the impact of artificial waterways. Reduced sediment input should be corrected by the delivery of new sediments to coastal basins using a combination of river diversions and pipeline conveyance of dredged sediment. Additionally, the redistribution of sediments via long-shore currents and redistribution of water using the GIWW and other navigation channels both contribute to rebuilding and maintaining the coastal landscape.

By taking these steps to restore the process of a sustainable coast, fragmentation of the coastal landscape will be reduced and an estuarine gradient and landscape features will be maintained to support an array of habitats for associated plants and animals, including resident and migratory bird communities. Through restoration projects that are of sufficient scale to sustain and expand a variety of coastal wetland and other landscape features, a sustainable environment can be maintained that integrates the function of the ecosystem with the complex needs of the working coast.

2.4 Socio-economic Sustainability

"It is trite to say that Louisiana is culturally diverse. The truth is that few people realize the degree of complexity and variation in the cultures of the state."

Maida Owens, Louisiana's Traditional Cultures: An Overview, 1999

"Failing to rebuild a viable city would have consequences far beyond Louisiana. New Orleans' two ports are, by tonnage, the nation's biggest. They need to be - the region handles a third of the nation's seafood and more than a quarter of its oil and natural gas. Some 4,000 oil and natural-gas platforms, linked by 33,000 miles of pipeline, spread out along the Louisiana coast. Among the facilities are the four largest refineries in the Western Hemisphere. Southern Louisiana is easily as important to the nation's energy supply as the Persian Gulf."

Charles Mann, Fortune Magazine, August 2006

"First and foremost, we have to say that this is a human tragedy that....has a potential to be the largest cultural tragedy in the history of this country, because New Orleans is unlike any other city in this country or, indeed, in the world. Fifty percent of the city consists of 20 historic districts containing 37,000 historic structures. There is no greater concentration of historic structures anywhere else in the country."

Richard Moe, National Trust for Historic Preservation, October 2005

For over 12,000 years people have lived, worked and played in Louisiana, leaving their mark on the landscape. This shaping of the landscape began early in human history as evidenced by over 700 mound sites in Louisiana. Mounds vary in size, shape, and purpose. Some were built as burial sites; others were built for ceremonial purposes; and, in some cases, they served as a base for residential structures. Watson Brake in north Louisiana,

dated to approximately 3400 B.C. (well before Stonehenge), is currently considered to be the oldest mound site in North America. Other mound sites dot the state, including many located along the coast. One of these, the Banana Bayou mound site on Avery Island in south Louisiana dates from about 2500 B.C. (Neuman & Hawkins 1993). The Poverty Point site (ca. 1700 B.C.), located in north Louisiana adjacent to the Mississippi floodplain, is regarded by many as the first true city in North America.

Of interest is the vastness of this site's confirmed trade network. Copper was used from the Great Lakes region, steatite from the Appalachians (as far east as Georgia), and flint from throughout the east and Midwest. Based on identified early Native American sites to date, access to the Mississippi River system and the coast was important to the Poverty Point culture (Gibson 1996), driving community location decisions, including the locations of major settlements along the Vermilion and the Lower Pearl Rivers in south Louisiana. This same access to the Mississippi River system and coast was important also to successive cultures, including the Tchefuncte culture (200 B.C.-A.D.400) who settled along the entire Louisiana coast from Lake Pontchartrain to the cheniers of the west, the Marksville culture (A.D. 100-550) with occupations along the coast including Bayou Teche, and the Troyville culture (A.D. 500-950) with occupations along the Mississippi River and Bayou Lafourche (Goins & Caldwell 1995).

Today, the federally recognized Chitimacha are Louisiana's only indigenous tribe continuing to live on ancestral lands. The Chitimacha have lived on the coast of Louisiana for at least 2,500 years; this documented long-term residency is expressed in their traditional cultural beliefs by the statement, "We have always been here". Based in the community of Charenton, in south Louisiana next to Bayou Teche, they once also had settlements along the lower Mississippi River and at the mouth of Bayou Lafourche (once known as "Lafourche of the Chitimachas"). Bayou Teche takes its name from the Chitimacha word for "snake". The Teche marks, according to tribal lore, the channel dug out by the death throes of a great snake vanquished by the tribe many years ago. The tribe today is focusing its efforts and resources on regaining tribal land, preserving its heritage and preparing its children for competitive jobs in the global marketplace. One element of tribal culture being preserved is the tradition of basket making. Chitimacha baskets are widely regarded as the finest Native American basketry in the Southeast and possibly the nation, with prices for contemporary pieces going for many thousands of dollars. There are only a few basket weavers today and one of the reasons is the limited availability of river cane. River cane (*Arundinaria gigantean*), one of only two bamboos native to the continental United States, is the traditional material used for these baskets as well as other weavings. The Natural Resources Conservation Service has been working with the Chitimacha to reestablish stocks of river cane in order to overcome the shortage and continue an uninterrupted supply of this traditional material.

Access to the coast (for reasons of proximity to natural resources and facilitating long-distance trade) has continued to drive historic and modern decisions in Louisiana regarding community location. This included the 1718 founding of the city of New Orleans at the location of the portage between the Mississippi River and Lake Pontchartrain, along Bayou St. John. Located strategically, New Orleans quickly prospered as a trade city. Validation of the value of New Orleans as a trade center of international importance was proved less than 100 years later in 1803, when Thomas Jefferson authorized negotiations with France for the purchase of New Orleans for up to 10 million dollars. This intent of the purchase was to avert what appeared to be possible conflict between France and Great Britain over access to the port, and assured continued access to the port for the growing nation. The inclusion of the remainder of the Louisiana Purchase for an additional 5 million dollars was an unexpected windfall that not only doubled the size of the United States, but more importantly, ended any future uncertainty over control of trade in the central North American continent.

Perhaps because New Orleans was an early center of international trade, Louisiana has a rich and diverse heritage. Louisiana residents today include, in addition to a continuing strong Native American presence, descendants of European, African and Asian cultures. These include French (Canadian traders, Acadians, French soldiers, French royalists, Bonapartists), Spanish (including Islenos from the Canary Islands), English, Irish, Germans, Italians (including Sicilians), Senegalese, Dahomeans, Congolese, Czechs, Hungarians, Lebanese, Croatians, Filipinos, Chinese, Vietnamese, Laotian, and Thai (Owens 1999). All of these cultures have made a direct recognizable contribution to Louisiana culture. The Louisiana culture, particularly coastal Louisiana, is unique because it is not homogenous (Spitzer 1985). Like gumbo itself, south Louisiana's culture is made up of diverse ingredients from all parts of the world. Each retains its individual identity and flavor, but they come together to make a distinctive "dish" with its own recognizable identity. It is an identity that is strongly embraced by its residents. According to the 2000 census, Louisiana is the state with the highest percentage of native born residents, with 79.4 percent of current residents having been born in Louisiana.

This same census indicated that two million people, or over 65 percent of the population of Louisiana, live within 50 miles of the coast. Based on 2001 census estimates, the total population for the seventeen coastal parishes and the nine adjacent parishes that "connect economically to the coastal parishes" was almost three million (Richardson et al., 2004). Louisiana's economy is concentrated in the southern region of the state. This includes 73.5 percent of total state employment, almost 60 percent of oil and gas employment, 77 percent of pre-hurricanes Katrina/Rita construction employment, and 67 percent of all manufacturing employment in the state (Richardson et al., 2004). Industries directly tied to locations on the coast and major waterways include not only the production of oil and gas, but offshore oil and gas exploration, development and transport; shipbuilding and other manufacturing of transportation equipment; petroleum and chemical refining; and water-borne transportation.

According to 2004 USACE Navigation Data Center statistics, Louisiana has five of the top fifteen ports by tonnage in the United States: the Port of South Louisiana, the Port of New Orleans, the Port of Baton Rouge, the Port of Plaquemines and the Port of Lake Charles. The Port of Louisiana is the top ranked port by tonnage in the United States. The adjacent Louisiana ports of South Louisiana and New Orleans combined are the largest port (by tonnage) in the world. Together, these two ports account for $150 billion and 20 percent of U.S. import/export cargo traffic annually (Department of Commerce, 2005). The Port of Lake Charles is the largest liquid natural gas (LNG) port in the United States.

Gary LaGrange, executive director of the Port of New Orleans, states "Our economists tell us that 380,000 people realize their income as a result of the port of New Orleans, around the nation. Sixty two percent of the consumer-spending public in the United States receive their goods and depend on getting their goods through the gateway at the port of New Orleans" (Flakus, 2006). In spite of a loss in container and terminal capacity after the storms, the Port of New Orleans has increased activity over the past year due to increased steel and rubber shipments coming from various parts of the world. These steel imports reflect both the decline of steel production in the United States and increased demand for steel by various US industries (Flakus 2006). One of the assets of the Port of New Orleans is its connectivity to the rest of the country. Not only is it connected by the Mississippi River and its tributaries, it is the only deepwater port in the United States served by six class one railroads (Canadian National, CSX, Burlington Northern/Santa Fe, Kansas City Southern, Norfolk Southern, and Union Pacific). This and its connection to the interstate roadway system gives port users direct and economical rail and roadway service to or from anywhere in the country.

Supporting the ports of Louisiana is the Gulf Intracoastal Waterway (GIWW) which crosses southern Louisiana from the Texas state line east to the Mississippi state line. In 2000 over 520 million tons were moved by barge

along the GIWW in Louisiana with estimated savings of $4.7 billion in transportation costs compared to non-water based transport (Richardson et al. 2004). Figure 2 illustrates the interstates, federal navigation channels, and railways that are found in coastal Louisiana.

Commercial fishing has a long history in Louisiana. Le Page du Pratz in his 1758 *Histoire de la Louisiane*, wrote of observing shrimp being fished in the lakes south of New Orleans using nets from France. Shrimp were first canned commercially in Louisiana as early as 1867 at Grand Terre Island. Shrimping is a way of life and a family tradition in Louisiana extending well back into the 19th century and earlier, but it does not belong exclusively to one ethnic culture. Filipinos, who first settled in Louisiana in the community of St. Malo in the mid 1700's, were widely known as fishermen and shrimpers. St. Malo was one of the first Asian settlements in what is now the United States. The Filipinos of St. Malo are widely speculated to have been the "Spanish pirates" who fought along side other Louisianans in the Battle of New Orleans.

Today, Louisiana is second only to Alaska in terms of both tonnage and dockside revenues from commercial fishing. Seven of the top 50 seafood landing ports in the United States are in south Louisiana. Three of these ports, Empire-Venice, Intracoastal City and Cameron, are in the top 6 seafood landing ports by tonnage. Almost 75 percent of the fish landed in the Gulf of Mexico come through a Louisiana port (NOAA Fisheries 2005). Louisiana in 1997 had more fishing vessels than any other state except Alaska (Richardson et al. 2004). In addition, in 1999, Louisiana had 122 commercial fish processing plants, as well as 161 wholesalers (Richardson et al. 2004).

The Louisiana coast is widely regarded as one of the top ten recreational fishing spots in the world. Annual expenditures related to recreational salt water fishing in Louisiana can amount to between $279 million (USDI 2001) and $1.2 billion, including equipment, bait, boats (including charter boats), food, lodging and transportation (Gentner et al. 2001).

In the United States, sugar cane is produced, harvested and processed in Florida, Louisiana, Texas and Hawaii. Louisiana's current production is ranked second, just behind Florida. Louisiana's sugar cane production produces about 20 percent of the total sugar grown in the United States from all sources, including sugar produced from beet, as well as cane (American Sugar Cane League 2006). Sugar cane was first planted in Louisiana in 1751 by the Jesuits in what is now the city of New Orleans. Sugar cane is a tropical grass, needing at a minimum a subtropical climate with at least 24 inches of rainfall a year. Sugar cane has been a major crop in Louisiana for over 200 years, and is the number one row crop in Louisiana in terms of value. In 2005, sugar cane was grown in 24 Louisiana parishes with over 500,000 acres in cultivation. Production in 2005 included 1.2 million tons of raw sugar and 6.4 million gallons of molasses. (It should be noted that these figures reflect lowered per acre sugar and molasses production resulting from damages from Hurricane Lili and Tropical Storm Isidore in 2002. Sugar cane is salt sensitive as well as susceptible to wind damage. Because sugar cane is a perennial, damage occurring in one year may continue to be reflected in subsequent harvests.) There are currently 15 sugar mills in Louisiana and approximately 27,000 workers are involved in the production and processing of sugar in Louisiana.

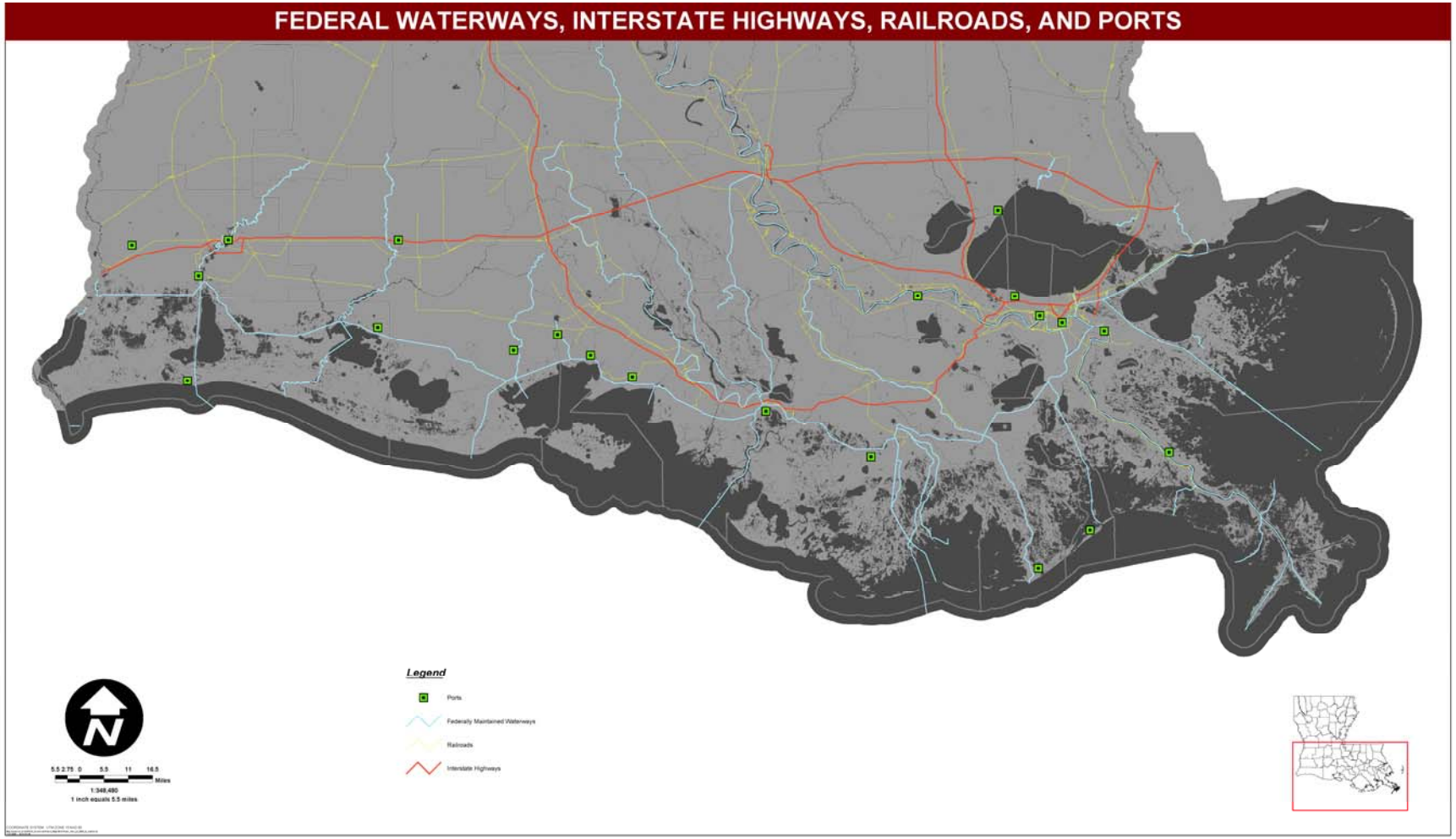

Figure 2.4: Interstates, federal navigation channels, and railways in coastal Louisiana.

There are two sugar refineries in Louisiana with a third refinery being built to begin operation in 2008.

The cattle industry in Louisiana has its roots in the colonial period with the raising of longhorns originally brought in by the Spanish. According to the University of Texas at Austin's, *Handbook of Texas Online*, "Modern scholarship places the birth of the Texas ranching industry in the southeast Texas-southwestern Louisiana area, from where cattle raisers drove herds to market in New Orleans." "By 1802, the Louisiana cattle industry was firmly established and the prairies were the main suppliers of beef to New Orleans and points northeast" (Vidrine 1991). Today, south Louisiana continues this tradition. The western coastal parishes of Vermilion and Calcasieu rank second and third, respectively, in cattle production among the 64 Louisiana parishes (USDA National Agricultural Statistics Service 2006).

Rice has long been a traditional food on the Louisiana table and is an essential component of at least three internationally famous Louisiana dishes: red beans and rice; gumbo; and jambalaya. While grown domestically prior to the 1850's, commercial rice production began in Louisiana in the middle of the nineteenth century. Evidence of rice's rapid rise to a major crop in this time period is that the first newspaper to be published in Plaquemines Parish was named *The Rice Planter*. Louisiana is currently the third highest rice producing state, behind Arkansas and California, even with reduced plantings following Hurricanes Katrina and Rita. According to USDA estimates, in 2006 only 360,000 acres of rice were planted in Louisiana, down 32 percent from 2005 (USDA, June 30, 2006). The three southwestern parishes of Acadia, Jefferson Davis and Vermilion are the top three rice producing parishes in Louisiana. Rice is also an important crop for the southwestern coastal parishes of Cameron and Calcasieu. As crawfish becomes a more important crop, some rice varieties are now being chosen and planted primarily for forage for crawfish (see below). It should be noted that rice is an extremely salt-sensitive crop, and it requires a reliable fresh water source.

Crawfish and Louisiana are often regarded as synonymous. Crawfish has long been both food and symbol in Louisiana—the red crawfish historically was a war emblem of the Houma tribe (and as such was not eaten by the Houma). Others, however, have much enjoyed eating crawfish and Louisiana began experimenting with farming them in ponds in the 1950's. Today, there are about 1,200 crawfish producers cultivating over 115,000 acres of crawfish ponds. Annual harvest from these commercial ponds ranges from 75 to 105 million pounds annually with a value of more than $40 million. There is an additional wild harvest of well over a million pounds annually, primarily from the Atchafalaya Basin, with an economic value of nearly $5 million. Approximately 90 percent of the nation's crawfish is produced in Louisiana, with 70 percent of that being consumed locally (LSU Agricultural Center, 2006). Most farmers in Louisiana raise crawfish as a double crop with rice. This shortens the crawfish production season by one or two months (draining fields early to begin rice planting) and reduces overall yield of crawfish per pond acre from dedicated crawfish only ponds, however, it allows the second commercial crop of rice to be grown. The infrastructure in place for rice— ponds located in clayey soils, water supply and management ability, and the rice plant itself as forage for the crawfish— makes these two crops ideal companions for double cropping. Crawfish processors in south Louisiana add value to the harvest, easing shipment and increasing product availability. There are currently 12 crawfish processors in the state (Mclain et al. 2004).

Alligators have been hunted for centuries in Louisiana. However, by the mid 20th century, intervention was required to protect the species. With protection provided under the Endangered Species Act, alligators have made a successful comeback throughout its range and part of this continued success is the strong management program which includes both harvest from the wild and farming. Louisiana is the nation's top alligator producer. In 2003, the production of Louisiana alligator farmers was valued at over $28 million for the raw products alone (LA DWF 2005). The wild harvest during the 2004 season was valued at $9 million (LA DWF 2005). Alligator farming

allows the taking of eggs from the wild by permit and requires that a portion of farm alligators raised be released to the wild near locations where the eggs were collected. This not only helps to assure numbers in the wild population, it also encourages healthy marsh management. The continued success and increase in production each year has led to the establishment of tanneries in Louisiana, as well as food processing facilities that specialize in alligator meat. These continue to add value to the product after harvest.

Food is important in Louisiana. Good food is enjoyed at home, as well as "eating out." According to the Louisiana Restaurant Association (2006), "The restaurant industry in Louisiana is the state's largest private employer with more than 120,000 employed directly and another 50,000 indirectly employed. Restaurants in Louisiana generate $4.8 billion in annual sales." In testimony before Congress on behalf of the National Restaurant Association, Ralph Brennan pointed out that before Hurricanes Katrina and Rita, the restaurant industry was the number one private employer in New Orleans. It employed 54,000 people directly. Indirectly, another 20,000 people were employed to supply the industry with goods and services. In recognition of this economic importance, and the knowledge and skills that are necessary to be successful in this field, Nicholls State University, which is located in Thibodaux, now offers both associate and Bachelor of Science degrees in culinary arts.

As good food is valued, so is good music. New Orleans is known as the birthplace of jazz, what is not as widely known is that music and music performances have been part of its earliest history. The first documented opera performance in New Orleans was in 1796; one of the earliest opera performances in what is now the United States. While music from all cultures and countries have found a home in Louisiana, south Louisiana is known internationally for its homegrown jazz, blues, Cajun, zydeco, swamp pop, and New Orleans brass band styles. The Louisiana music industry is a 2.2 billion dollar industry that depends on the people, culture and talent of Louisiana to maintain its vitality and to continue (Louisiana Music Commission, July1998). The sharing and playing of music with family, friends and the larger community is imbedded in Louisiana culture. It is this interaction that has allowed Louisiana's music to be preserved, to develop distinctive styles and to flourish. As such, Louisiana's music may be one of the more vulnerable of its industries and cultural legacies to a storm diaspora.

What is more difficult to quantify is the richness of Louisiana's culture, a richness in part driven by the history that is present throughout the state. In coastal Louisiana alone, there are well over 634 properties listed on the National Register of Historic Places, and many of these properties are historic districts containing multiple historic structures. New Orleans held one of the largest collections of historic districts and structures in the United States. Louisiana has also recognized the need to not only preserve structures and the material expressions of culture, but the need to preserve less tangible language and customs as well. With the legislative establishment of the Council for the Development of French in Louisiana over 35 years ago, there has been widespread support for French being taught in Louisiana schools and recognition of the value of cultural preservation. French programming, enthusiastically embraced in the Lafayette area, has spread throughout southern Louisiana with several parishes today offering French language immersion programs. It is this indefinable richness that has made tourism such an important contributor to Louisiana's economy, whether this richness comes from historic architecture, food, music, language or culture. According to the Louisiana Department of Culture, Recreation & Tourism (2004) over $4.4 billion of visitor spending in Louisiana was from New Orleans and Lake Charles. Where coastal Louisianans live, work, and play, is part of their identity. Sustaining Louisiana's coastal culture is dependant on sustaining Louisiana's coast.

2.5 Program Sustainability

Development of sustainable management programs in Louisiana and around the world all face similar challenges, chief among them obtaining and maintaining appropriate funding streams and maintaining political will to enforce laws and regulations put in place to support the goals of the program. A dedicated funding source and a well defined program codified into Federal and State law are keys to successfully restoring sustainability to the natural and human environment in coastal Louisiana.

Reliable funding streams must be obtained for both the federal and non-federal shares of program costs. To date, the State's Coastal Protection and Restoration Fund receives scheduled inputs of $25 million annually to address coastal protection and restoration issues. Without a significant change in cost sharing requirements for federal projects, this level of funding is not adequate to address the problem. Similarly, the federal government dedicates approximately $50 million per year to the restoration program through the Coastal Wetlands Planning, Protection, and Restoration Act (CWPPRA) program. Funding for hurricane protection projects and other coastal restoration activities comes through annual Federal and State appropriations process, and as such, it is subject to fluctuations due to changing priorities. This may slow the pace of critical projects. The State has been fortunate to receive two installments of funding from outer continental shelf oil and gas funds through the first two phases of the Coastal Impact Assistance Program. These two installments total approximately $565 million, but the unpredictable nature of the timing (separated by five years) and magnitude range ($25 million vs. $540 million), make it difficult to plan for long-term implementation.

Because it is likely that overall funding will be limited and unpredictable in the near-term due to reliance on annual Federal and State appropriations processes, there are several mechanisms that must be used to manage implementation costs and ensure maximum efficiency of the program. This can be accomplished in a number of ways.

- Life cycle costs must be minimized. Minimizing operations and maintenance requirements will allow a greater focus on design and construction, and may result in more reliable systems. At least in the near term, these projects, as much as practicable, should be designed for easy adaptation or modification as we continue to reduce uncertainties in program implementation. Specifically, projects should be authorized and constructed with maximum flexibility for environmental operations, and wherever possible, should provide for ready modification to increase protection levels if a risk review determines it is warranted.
- Fluctuation of implementation costs can be managed by minimizing reliance on resources that are either scarce or likely to become scarce in the future. In addition, reliance on technology that uses fossil fuels for operations ensures rising and volatile costs into the foreseeable future. Utilizing less energy intensive techniques, or increasingly relying on renewable energy sources, may stabilize costs into the future.
- It will be necessary to strictly enforce existing, and possibly new, regulations and obtain appropriate easements in the coastal zone, especially in wetlands landward of hurricane protection systems, to maintain these important natural buffer zones. Allowing development of low-lying areas within protected systems not only increases exposure to damages in the event of a system failure, but also diminishes effectiveness of the protection works themselves by removing water storage areas from the system.
- A strong science and technology program that is focused on reducing uncertainties in program implementation can help to ensure effectiveness of projects. Technological advances may also allow for more efficient solutions in the future. This science and technology program will provide a basis for assessing and reporting on program efficiency and effectiveness in order to ensure accountability.

Successful national civil works programs, such as the construction of the Interstate Highway system and the MR&T project, are useful examples of programs that were initiated with great uncertainties as to details of final constructed projects. Both programs, however, were made national priorities and significant and regular funding was made available to implement more certain aspects of the programs even as uncertainties were being reduced in the overall program. Coordinated Federal and State legislation will be necessary to define and implement a program that will be capable of responding to the protection and restoration problems of coastal Louisiana in a timely manner and at appropriate scales. Provision of a reliable source of funds, with strict accountability standards, is necessary to ensure sustainability of program implementation.

2.6 Moving Forward

While humans have been successful in altering the natural system to meet our needs, the unintended consequences of these actions have been realized and steps are now being taken to reverse them. Consequently, the Water Resources Development Act, the CWPPRA Program, and other programs have taken steps to re-introduce freshwater, sediment and nutrients into the coastal ecosystem. This is an excellent example of "adaptive management," and the initial management paradigm of the lower Mississippi River and associated delta plain will continue to evolve as new information becomes available. Implementation of the State Master Plan will take this improved management to the next logical level. It will contribute to an even greater extent to the sustainability of the delta plain coastal wetlands of the nation's largest river system and will provide increased levels of protection to the communities that live and work within them.

3.0 Mississippi River Resources

3.1 Man's Alteration of the River

In the more than 300 years since the Lower Mississippi River Valley was settled by Europeans, the Mississippi River has undergone many changes resulting in decreased sediment loads. The changes in the watersheds of the Mississippi River and its tributaries have included the removal of snags and other navigation obstacles from the river; the stabilization of river banks; the construction of cut-offs; the initiation of river inspections to identify riverbank settlement; and the construction of left and right bank levee systems for effective flood control. The activities have stabilized the river from Cairo, IL to near Head of Passes, LA.

Levee building for flood protection began in the 1700's. The construction of bank stabilization features began in the 1800's, primarily as efforts to protect the integrity of levees. Channel stabilization for navigation purposes did not get serious attention until the early 1950's. Flood control reservoirs were built in the 1950's and 1960's. Today, reservoirs and dams, bank stabilization mattress, locks, dike fields, and levee systems control the Lower Mississippi River and much of its tributary system. Over the past 50 years manmade structures and conservation practices have effected changes in total sediment load and to a lesser degree annual flow hydrographs and bed and bank materials. Before human settlement, the primary areas of land surface erosion in the Mississippi Basin were the uplands that bordered the river. During the early periods of human settlement, upland erosion increased exponentially because of land use practices (Turnbull et al., 1966). However, in recent years, the erosion has been reduced substantially by bank stabilization and better soil conservation practices.

As a result of the cumulative changes, water and sediment budgets have been altered significantly. More than half of historic sediment loads are now circumvented by better land conservation, bank stabilization, and reservoirs throughout the watershed. The Old River Control Structure maintains a 70 percent distribution of flow down the Mississippi River and 30 percent down the Atchafalaya River. The flow from the Red River is a part of the 30 percent in the Atchafalaya River. Engineering practices and new structures have allowed water and sediment to flow down the Atchafalaya River. Two outlets from the floodway are provided. The historic Lower Atchafalaya River flows toward the east, and the Wax Lake Outlet connects to the west side of the floodway. The Lower Atchafalaya River and the Wax Lake Outlet flow into a shallow estuary resulting in active delta building. By contrast, to provide a deep-draft navigation channel, the Mississippi River flows through a jetty and dike field system into deep water off the continental shelf.

3.2 Water Budget

A major constraint on the annual budgeting of river water downstream of New Orleans is the requirement to maintain a minimum magnitude of 250,000 cfs (cubic feet per second) discharge at the Head of Passes, to maintain the leading edge of the riverine saltwater wedge from the Gulf of Mexico no further upstream than the Head of Passes (river mile 0.0).

By comparison, the average annual minimum discharge for the Mississippi River from 1930-2005 was 165,000 cfs at Tarbert Landing, just downstream from the Old River Control Structure complex. Therefore, the saltwater wedge currently moves upstream of the Head of Passes in most years but generally not for long durations and seldom to the point that fresh water supply for large communities is impacted. However, during the 1988 drought the river discharge dropped to approximately 100,000 cfs at New Orleans, and the saltwater wedge was held back only by the construction of a sand sill across the Mississippi River Channel just upstream of Myrtle Grove, LA.

Table 1 provides long-term average values of flow for annual minimum, mean, and maximum flow in the Mississippi River for the period of record 1930–2005 at the Tarbert Landing Gage maintained by the U.S. Army Corps of Engineers. The same table provides flow parameters for each month of the year for the same period of record. The months of March, April, and May provide highest average flows, and the months of August, September, and October provide lowest average flows. However, the average flows could be significantly different in any given year. Table 2 provides the same data for the Simmesport gage on the Atchafalaya River. This gage is also maintained by the U.S. Army Corps of Engineers.

Table 1: Mississippi River Tarbert Landing Discharge, Period of Record 1930 - 2005

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
MIN	120	170	270	290	280	180	125	120	115	100	100	105
AVE	520	620	730	770	710	580	420	290	240	250	290	410
MAX	1240	1390	1380	1480	1440	1290	960	795	550	735	710	1000

Compiled from U.S. Army, Corps of Engineer District, New Orleans, Stage and Discharge Data
Discharge values in 1000 cubic feet per sec (cfs)
Values are averages for the months for period of record
Average Annual Minimum –165,000 cfs
Average Annual Average –486,000 cfs
Average Annual Maximum –1,081,000 cfs

Table 2: Atchafalaya River Simmesport Discharge, Period of Record 1930 - 2005

	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
MIN	25	35	80	95	80	45	30	20	20	20	20	25
AVE	205	250	295	325	300	245	180	120	90	100	115	170
MAX	535	565	605	675	740	570	375	350	250	310	335	440

Compiled from U.S. Army, Corps of Engineer District, New Orleans, Stage and Discharge Data
Discharge values in 1000 cubic feet per sec (cfs)
Values are averages for the months for period of record
Average Annual Minimum –41,000 cfs
Average Annual Average –200,000 cfs
Average Annual Maximum –483,000 cfs

Budgeting high river discharges presents a set of possibilities. The river generally transports the largest sediment loads at high water discharges. Thus, it is important to allow that sediment to flow into wetlands at these times, rather than allowing this material to continue to flow into the deep waters of the Gulf of Mexico. However, when there are high river discharges there are generally drainage problems in the receiving area due to local rainfall. The potential for damage from high water will have to be balanced against the benefits of diversions. One constraint to be considered even at high flows, however, is the need to maintain the minimum of 250,000 cfs at Head of Passes.

The upper limit of discharges that can be diverted from the river is approximately 500,000 cfs. If 250,000 cfs is to be maintained at Head of Passes, the total river discharge that is required to divert 500,000 cfs is 750,000 cfs.

The highest, long-term average monthly discharge on record at Tarbert Landing occurs in the month of April. It is 770,000 cfs. Therefore, there have been many years, and a number of days in most other years, when 500,000 cfs discharge was available on a limited basis. For example, the long-term maximum monthly averages for the months of January, February, March, April, May, and June exceed 1,000,000 cubic feet per second. However, the long-term averages of the monthly discharges for those months fall below 750,000 cfs. In summary, a budget of 500,000 cfs may be available periodically, but it will not be a dependable resource month-to-month and year-to-year.

A constraint on the discharge rate at a diversion is the hydraulic head. The head will vary from one location to another along the river. Table 3 provides the average monthly water surface elevation at select locations along the river. If marsh elevation is assumed to be 1 foot, the hydraulic head may be calculated. For example, at mile 100 above Head of Passes, the available head between the Mississippi River and the adjacent marsh is about 9.7 feet in April (10.7 – 1.0 = 9.7). At the same location, for the month of September' 2.4 feet (3.4 –1.0 = 2.4) of hydraulic head would be available.

For a given location, a range of hydraulic heads exists during a given year depending on the river discharge, the gulf elevations and other diversions that might be flowing. As new diversions are added to the river, the hydraulic grade line will change, depending on the magnitude, location and operating scheme of the diversions. The effect on the system should be checked each time a new diversion begins operation. It is possible that with all the planned diversions operating at one time at a combined discharge of 500,000 cfs, those diversions located in the lower reaches would perform well below expectations because of a lack of adequate hydraulic head.

As more and more water is diverted from the river, a point of diminishing return is reached. Specifically, the more water diverted from the river the less water there is in the river and the less head available to divert water from the river. Further as more water is diverted, the ability of the river to transport sediment will decrease.

Ultimately, all of the water and sediment in the river cannot be withdrawn for beneficial uses upstream. A portion of the flow will always reach the gulf at the mouth of the river. At this point the possibility of total diversion of the river for delta building needs to be considered. At some location below New Orleans the river could be diverted to the east and/or west so that all the fresh water and sediment is placed in the coastal zone for delta building. This would be similar to the existing outlets at Wax Lake and the Lower Atchafalaya River. In order to accomplish this, there will have to be accommodations for navigation, such as a sail-thru lock. One advantage of such a system is that the navigation depth, currently limited to 45 ft, could be deepened to as much as 65 ft. Such a major diversion, and currently one is planned in the Mississippi River Delta Management Study, requires extensive study

Table 3 shows the stages for the average monthly discharges at twenty mile intervals from New Orleans to the Head of Passes. These values are from 1972 data. The table was prepared from Figures 84 to 95 in the report, "The Transport of Sediment by Gravity for Coastal Restoration and Wetland Rehabilitation in Louisiana." This report was prepared jointly by the Department of Civil and Environmental Engineering University of New Orleans and Sogreah Ingenierie and Coastal Restoration Consultants, September 15, 1997.

Table 3: Elevation Equivalent to Average Monthly Flow

Miles above Head of Passes	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
20	2.6	2.8	3.5	4	3.6	3.4	2.7	2.3	2.2	2	1.8	2.5
40	3.8	4.1	5.1	5.7	5.2	4.7	3.4	2.7	2.5	2.4	2.5	3.6
60	5	5.3	6.8	7.3	6.8	6	4.2	3.1	2.7	2.8	3.1	4.7
80	6.2	6.6	8.4	9	8.3	7.3	4.7	3.5	3.1	3.3	3.6	5.8
100	7.4	7.9	10	10.7	9.9	8.6	5.2	3.9	3.4	3.7	4.2	6.9
Average Monthly Flow using Period 1972 to 1992.												
	579	599	758	814	745	632	435	326	275	297	355	555

3.3 Sediment Budget

Recognizing the significance of sediment to the sustainability of coastal Louisiana and developing a sediment budget to promote effective utilization of sediment resources available from the Mississippi River is a critical element for the LCCPMP. Notwithstanding the reduction in sediment flowing in the Mississippi River, effective and prudent use of the available sediment is critical for sustaining coastal Louisiana. Measured suspended sediment loads in the Mississippi River have decreased substantially in magnitude over the past 60 years. The Tarbert Landing gage also provides the summary of measured suspended sediment flowing in the Mississippi River. The Simmesport gage provides measured suspended sediments entering the Atchafalaya Floodway. The suspended sediment load of the Red River is included in the reported measurements. Tables 4 and 5 report annual averages of Total Measured Suspended Load, Sand Silt Ratio, Water Year Discharge, and Average Sediment Concentration in parts per million (PPM) for Tarbert Landing for the water year 1949-1950 through water year 2003-2004 and Simmesport for water year 1951-1952 through water year 2003-2004.

Tables 1 and 2 show the presence of a low water period in late summer and early fall. The two main months of low discharge are September and October. The measured suspended sediment loads follow a similar pattern. Over time, large events in either of these two months can be much more than the long-term average. Use of the tables of long-term monthly average discharges and the average measured suspended sediment load can provide a close approximation of the amount of material available for different periods of the year. Monthly distribution of measured suspended sediments generally follows the monthly discharge trends, Table 6.

Table 6 shows monthly sediment concentrations in the Mississippi River at four locations. They are presented from north to south: Arkansas City, Arkansas, Vicksburg, Mississippi, Natchez, Mississippi, and Belle Chase, Louisiana. Data for the first three locations were collected over the period 1968-1974. The Belle Chase data were collected over the period 1977-1995. The two lowest values at both of these gages occurred during the months of September and October. It should be noted that the concentrations were greater in the three upper reaches of the Mississippi River than they were at Belle Chase. This pattern of lower concentrations at Belle Chase is also noted in Table 7 where the annual measured suspended loads at Tarbert Landing are compared with values at Belle Chase.

Table 4: U.S. Army Engineer District, New Orleans Reports Control Symbol (DAEN-CWE-12)
Summary of Measured Suspended Sediment Loads at Main River Stations
Lower Mississippi River at Tarbert Landing, Mississippi

Water Year	Total Measured Suspended Load	Sand		Silt and Clay		Water Discharge	Concentration
OCT-SEP	(1000 Tons)	(1000 Tons)	%	(1000 Tons)	%	(1000 DSF)	(PPM)
1949-50	548,330	107,000	20	440,560	80	245,200	828
1950-51	575,280	67,600	12	507,680	88	224,810	947
1951-52	408,390	73,820	18	334,570	82	200,660	754
1952-53	212,580	28,920	14	183,660	86	142,200	552
1953-54	107,730	14,090	13	93,650	87	88,660	449
1954-55	211,490	39,930	19	171,550	81	137,460	570
1955-56	161,220	25,920	16	135,300	84	127,530	468
1956-57	291,388	53,043	18	238,345	82	172,875	624
1957-58	325,774	95,302	29	230,571	71	195,654	616
1958-59	230,504	78,693	34	151,811	66	129,253	660
1959-60	318,234	77,291	24	241,015	76	163,850	718
1960-61	231,754	71,471	31	160,283	69	168,133	510
1961-62	264,031	94,037	36	169,994	64	191,007	512
1962-63	100,397	23,770	24	76,627	76	105,125	353
1963-64	121,697	18,242	15	103,455	85	124,967	361
1964-65	203,678	41,316	20	162,362	80	150,152	502
1965-66	174,645	46,144	26	128,501	74	138,020	469
1966-67	111,200	15,356	14	95,835	86	131,843	312
1967-68	155,577	36,454	23	119,123	77	163,071	353
1968-69	155,576	39,373	25	116,203	75	167,999	343
1969-70	148,907	48,969	33	99,938	67	151,448	364
1970-71	181,913	75,410	41	106,503	59	147,586	456
1971-72	152,166	47,945	32	104,221	68	151,057	373
1972-73	227,574	75,188	33	152,386	67	266,099	316
1973-74	197,205	47,688	24	149,517	76	230,846	316
1974-75	164,805	40,375	24	124,430	76	203,806	300
1975-76	115,434	20,258	18	95,176	82	145,275	294
1976-77	80,998	9,532	12	71,466	88	113,247	265
1977-78	172,585	33,563	19	139,022	81	184,543	347
1978-79	194,343	53,961	28	140,382	72	244,086	295
1979-80	143,852	26,607	18	117,245	82	180,731	298
1980-81	114,541	14,633	13	99,908	87	129,316	329
1981-82	188,011	27,786	15	160,225	85	179,510	351
1982-83	199,402	37,728	19	161,674	81	254,372	291
1983-84	174,860	27,097	15	145,763	85	217,945	298
1984-85	172,724	32,815	19	139,909	81	205,850	311
1985-86	164,168	14,412	9	149,756	91	183,313	332
1986-87	139,375	4,111	3	135,264	97	186,776	277
1987-88	79,900	2,869	4	77,031	96	138,486	214
1988-89	96,343	3,820	4	92,523	96	204,595	175
1989-90	131,072	19,573	15	111,499	85	218,809	222

Table 4 (Continued): Summary of Measured Suspended Sediment Loads at Main River Stations
Lower Mississippi River at Tarbert Landing, Mississippi

Water Year OCT-SEP	Total Measured Suspended Load (1000 Tons)	Sand (1000 Tons)	%	Silt (1000 Tons)	%	Discharge (1000 DSF)	Average Concentration (PPM)
1990-91	157,029	52,209	33	104,820	67	229,635	253
1991-92	119,115	36,549	31	81,070	69	170,358	259
1992-93	205,054	78,193	38	126,861	62	266,722	285
1993-94	135,537	57,854	43	77,683	57	227,308	221
1994-95	107,026	18,349	17	88,101	83	194,186	204
1995-96	117,233	25,008	21	91,364	79	180,105	241
1996-97	156,751	32,918	21	123,833	79	245,435	237
1997-98	171,267	39,391	23	131,876	77	211,292	300
1998-99	167,622	35,201	21	132,421	79	196,967	315
1999-00	72,649	13,803	19	58,846	81	117,497	229
2000-01	133,389	22,676	17	110,713	83	166,163	297
2001-02	114,426	24,029	21	90,397	79	200,030	212
2002-03	119,575	33,481	28	86,094	72	180,573	245
2003-04	136,773	32,826	24	103,947	76	103,432	265

Note: The sand fraction is the material retained on the No. 230 Sieve (0.062 mm). The silt fraction includes all of the fine material passing the No. 230 Sieve.

Day-Second-Feet (DSF).

Table 5: U.S. Army Engineer District, New Orleans Reports Control Symbol (DAEN-CWE-12)
Summary of Measured Suspended Sediment Loads at Main River Stations
Atchafalaya River at Simmesport, Louisiana

Water Year OCT-SEP	Total Measured Suspended Load (1000 Tons)	Sand (1000 Tons)	%	Silt (1000 Tons)	%	Discharge (1000 DSF)	Average Concentration (PPM)
1951-52	196,460	48,890	25	147,570	75	80,800	900
1952-53	135,230	28,440	21	106,790	79	56,960	880
1953-54	54,130	13,110	24	41,020	76	31,980	627
1954-55	93,360	24,080	26	69,280	74	50,425	686
1955-56	67,175	15,540	23	51,730	77	49,080	507
1956-57	225,474	55,700	25	169,774	75	74,059	1,126
1957-58	214,390	48,082	22	166,308	78	89,413	887
1958-59	83,230	20,944	25	62,286	75	55,729	553
1959-60	131,878	24,153	18	107,725	82	69,333	704
1960-61	133,372	40,524	30	92,848	70	76,814	643
1961-62	151,913	57,675	38	94,238	62	88,881	633
1962-63	44,876	8,610	19	36,266	81	47,060	353
1963-64	52,591	10,414	20	42,177	80	33,177	588
1964-65	108,871	27,472	25	81,399	75	66,444	607
1965-66	88,522	17,468	20	71,055	80	51,024	642
1966-67	55,710	6,794	12	48,916	88	57,314	360
1967-68	121,351	16,727	14	104,624	86	80,105	561
1968-69	115,245	27,170	24	88,075	76	83,329	512
1969-70	75,098	19,790	26	55,308	74	74,278	374
1970-71	72,441	19,625	27	52,816	73	71,721	374
1971-72	89,587	18,732	21	70,855	79	75,407	440
1972-73	124,468	45,363	36	79,105	64	139,951	329
1973-74	142,994	32,235	23	110,759	77	116,972	453
1974-75	157,938	35,106	22	122,832	78	117,129	499
1975-76	56,113	8,464	15	47,649	85	65,925	315
1976-77	57,137	6,050	11	51,087	89	47,800	443
1977-78	71,194	12,497	18	58,697	82	79,737	331
1978-79	112,343	25,548	23	86,795	77	104,824	397
1979-80	67,801	10,652	16	57,149	84	77,609	312
1980-81	51,079	5,343	10	45,736	90	54,995	277
1981-82	104,102	11,403	11	92,699	89	77,494	481
1982-83	100,894	25,055	25	75,839	75	108,584	345
1983-84	73,213	12,349	17	60,864	83	93,081	292
1984-85	116,757	16,995	15	99,762	85	88,848	487
1985-86	81,794	9,289	11	72,505	89	78,649	386
1986-87	71,855	4,173	6	67,682	94	80,288	332
1987-88	57,780	6,556	11	51,224	89	59,347	361
1988-89	52,228	2,545	5	49,683	95	87,867	220
1989-90	91,039	18,288	20	72,751	80	93,720	360
1990-91	92,481	37,094	40	55,387	60	98,300	348
1991-92	69,596	27,098	39	47,589	61	73,248	352
1992-93	97,770	34,037	35	63,733	65	114,087	317
1993-94	61,344	21,057	34	40,287	66	97,453	233

Table 5 (Continued): Summary of Measured Suspended Sediment Loads at Main River Stations
Atchafalaya River at Simmesport, Louisiana

Water Year OCT-SEP	Total Measured Suspended Load (1000 Tons)	Sand (1000 Tons)	%	Silt (1000 Tons)	%	Discharge (1000 DSF)	Average Concentration (PPM)
1994-95	67,748	20,291	30	47,481	70	83,256	301
1995-96	48,909	11,554	24	37,405	76	77,213	235
1996-97	77,213	21,620	28	55,593	72	105,118	272
1997-98	90,067	35,126	39	54,941	61	90,584	368
1998-99	72,803	17,473	24	55,330	76	84,388	320
1999-00	29,582	3,550	12	26,032	88	50,466	217
2000-01	58,884	16,488	28	42,396	72	71,138	307
2001-02	52,625	15,261	29	37,364	71	85,740	227
2002-03	42,633	11,085	26	31,548	74	77,367	204
2003-04	50,150	10,030	20	40,120	80	81,876	227

Note: The sand fraction is the material retained on the No. 230 Sieve (0.062 mm). The silt fraction includes all of the fine material passing the No. 230 Sieve.

Day-Second-Feet (DSF)

Table 6: Measured Suspended Sediment Monthly Average PPM

	Jan	**Feb**	**Mar**	**Apr**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
Arkansas City[1]	380	400	310	280	300	300	220	190	110	220	360	310
Vicksburg[1]	370	430	410	360	290	260	250	195	140	270	380	410
Natchez[1]	300	310	310	290	270	230	280	230	150	290	420	340
Belle Chase[2]	233	272	295	267	255	240	215	130	102	124	89	269

Source: [1]U.S. Army Corps of Engineers, Little Rock and Vicksburg Districts. [2] "The Transport of Sediment by Gravity for Coastal Restoration and Wetland Rehabilitation in Louisiana." Department of Civil and Environmental Engineering, University of New Orleans and Sogreah Ingenierie and Coastal Restoration Consultants, September 15, 1997

Table 7: Mississippi River Measured Suspended Sediment

OCT-SEP	Tarbert Landing[1] (PPM)	Belle Chase[2] (PPM)
1977-78	347	263
1978-79	295	274
1979-80	298	224
1980-81	329	259
1981-82	351	314
1982-83	291	217
1983-84	298	242
1984-85	311	203
1985-86	332	205
1986-87	277	172
1987-88	214	162
1988-89	175	133
1989-90	222	212
1990-91	253	152
1991-92	259	199
1992-93	285	226
1993-94	221	130
1994-95	204	187

Source: [1]U.S. Army Engineer District, New Orleans, Reports Control Symbol (DAEN-CWE-12). [2] "The Transport of Sediment by Gravity for Coastal Restoration and Wetland Rehabilitation in Louisiana." Department of Civil and Environmental Engineering University of New Orleans and Sogreah Ingenierie and Coastal Restoration Consultants, September 15, 1997

Another aspect of sediment load transported by rivers and streams is referred to as unmeasured bedload discharge. The term bedload is used as an identifier because this material travels at or near the bed of the river. The bedload material is coarser than that carried in suspension except during major flood discharges. Some estimates indicate that the unmeasured load is approximately 15 to 25 percent of the total measured suspended load. Using data from Tarbert Landing and the partial record of 1971-1972 through 2003-2004, the average measured load is 142,900,000 tons. However, the magnitude and design of the individual diversions may preclude any consideration of the unmeasured load as a part of their discharge, as the sill elevation would need to be deep in individual diversion structures to tap into the unmeasured bedload.

Bedload may be utilized for marsh creation if it is delivered directly to areas of need. Direct delivery, commonly referred to as "pipeline transport", involves dredging and transporting sediments via pipeline. This is a major aspect of the overall plan to effectively utilize the sediments supplied by the Mississippi River. Numerous sandbars characterize the Mississippi River upstream of Baton Rouge. These sandbars are very large and represent a large storage area of coarse material. The Mississippi River downstream of Baton Rouge and particularly downstream of New Orleans has a narrow channel width, deeper depths, and smaller, less visible or submerged sandbars. These reaches of the river do, however, have bend ways. The convex side of the channel in a bend way is a place of deposition. These areas or reaches at and downstream of New Orleans offer opportunities for providing direct delivery of sediment to the wetlands.

Analysis of river charts show potential reaches that may be considered for dredging. In many cases, however, barge and boat anchorages occur in the reach, which either eliminates the reach from consideration or shortens the length of the possible dredging areas, although it may be possible to do some limited dredging in some of

anchorage areas at times. A number of potential reaches were identified. Information in Table 8 notes the potential reaches identified by right or left descending bank and river mile. They are listed from upstream to downstream in direction, and an estimate in miles is shown for the length of each source. In total, four reaches on the right descending bank and six reaches on the left descending bank were identified. The total cumulative length of potential borrow reaches is 26.5 miles. Dredging could be conducted in each area annually, and the excavated area would refill during the next high water period. That scenario depends on the magnitude and duration of high water periods. Annual river maintenance operations would provide information that aid in establishing annual available magnitudes.

Table 8: Potential Areas for Direct Delivery Dredging and/Or Small Diversions, Mississippi River-New Orleans to Head of Passes

1. Left descending bank, River Mile 61.5 to 60.3 ------- 1.2 Miles
2. Left descending bank, River Mile 55.0 to 52.3 ------- 2.7 Miles
3. Right descending bank, River Mile 51.3 to 49.5 ----- 1.8 Miles
4. Left descending bank, River Mile 44.0 to 43.0 ------- 1.0 Miles
5. Left descending bank, River Mile 40.0 to 35.0 ------- 5.0 Miles
6. Right descending bank, River Mile 34.0 to 32.3 ----- 1.7 Miles
7. Left descending bank, River Mile 31.0 to 25.0 ------ 6.0 Miles
8. Right descending bank, River Mile 24.2 to23.0 ------ 1.2 Miles
9. Left descending bank, River Mile 22.0 to 20.0 ------- 2.0 Miles
10. Right descending bank, River Mile 19.0 to 16.0 ----- 3.0 Miles

TOTAL ---------- 25.6 Miles

4 areas – right bank
6 areas – left bank

Conditions that generated historic sediment loads and the natural sediment budget in the river have changed dramatically over time. Measured suspended sediment load of the Mississippi River has decreased significantly over the past half century. Whether the decrease will continue into the future and further impact land building capability is not known.

3.4 Mississippi River Resources Summary

The annual quantities of sediments available from the Mississippi River are significantly reduced from the quantities delivered by the river 50 to 60 years ago. Future rebounding in magnitude of annual supply of sediments is not a reasonable expectation. Plans to better utilize available Mississippi River resources should recognize:

- The maximum water available for simultaneous diversions is generally limited to 500,000 cfs in the winter, spring and early summer. Late summer and early fall will generally offer limited to no availability.
- The magnitude of water available for diversions along the river must consider that the total flow of the river at Head of Passes must be maintained at or above 250,000 cfs to control the salt-water wedge at Head-of-Passes.
- Multiple diversions from the river must be coordinated so that maximum benefit from the available sediment and fresh water is obtained.
- There should be much more diversion capacity built than can be diverted at any given time to allow pulsing and timing of the diversions for land building and habitat benefits.

- On average, there are about 94.3 million cubic yards of measured suspended sediments and an estimated 18 million cubic yards of unmeasured sediment load available for LCCPMP purposes. Suspended sediment can be captured and used by diversions. However, diversions must have deep intakes and be located in sediment rich areas of the river to divert the unmeasured bedload.
- The most effective way to utilize the bedload is by direct delivery/dredging or very large diversions near the mouth of the river.
- Plans that fail to utilize the resources of the Mississippi River will not accomplish a sustainable Louisiana coast

4.0 Formulation of Diversion Projects

4.1 Purpose and Scope

A significant quantity of sediment is being transported past the coastal zone of Louisiana by the present configuration and management of the Mississippi River. In order to address the land loss crisis, the Master Plan calls for the advancement of several diversion concepts that could have major impacts on the future of the management of the river system. The total management of the Mississippi River must achieve not only the Master Plan objectives, but also ensure that navigation on the River is uninterrupted, that the channel remains stable, and that municipal water supplies remain reliable.

The scope of this chapter is to identify processes that must be quantified when locating and sizing diversion projects, to identify the issues that must be addressed when establishing project features, and to propose approaches that will provide decision makers with information needed to make educated decisions about the safety, efficiency, reliability and cost effectiveness of the proposed diversion concept. This chapter addresses the technical issues of hydrology, hydraulics, sedimentation and geomorphology. Environmental and social aspects are other technical issues that must be considered during project formulation. The recommended design and operation of diversions must also adhere to the principles and objectives in the Master Plan.

4.2 Utilizing Riverine Resources for Ecosystem Restoration

In their report to the State of Louisiana, a study team from the University of New Orleans, Sogreah Ingenierie and Coastal Restoration Consultants states:

"The State of Louisiana Department of Wildlife & Fisheries has had good experience with small-scale uncontrolled sediment diversion projects of limited application in the Mississippi Delta off of Cubits Gap and Pass-a-Loutre." (Soileau, et al. 1997)

Perhaps the largest diversion of the Mississippi River is the Old River Control Structure (ORCS), located at the divergence of the Mississippi and Atchafalaya Rivers. This structure is operated to regulate the distribution of water between the two rivers south of the structure at 70% and 30%, respectively. This split has been determined to be most suitable for several reasons, including maintaining the Mississippi channel as the major distributary of river water, maintaining navigation in the Mississippi River and providing adequate municipal water supplies to New Orleans. With increased understanding of how vital the river's resources are to ecosystem sustainability, there is a great deal of interest in reviewing the possibility of altering this distribution to also accommodate ecosystem needs.

The Master Plan also proposes that many diversions of varying scale be located roughly between Donaldsonville and Venice to discharge fresh water, sediment, and nutrients into wetlands and shallow open water to the east and west of the lower Mississippi River. In concept they vary in size from a few thousand cubic feet per second to major diversions of the entire river. These diversions have been broadly categorized in the Master Plan as 'land sustaining' and 'land building'.

Although very large diversions are required for building new land, smaller diversions are also valuable for their ability to sustain existing wetlands. Some diversions may be uncontrolled. Others may be designed with features to allow for alteration of the discharge rate as desired to best meet objectives.

Two land sustaining diversion structures have been built in recent years to utilize Mississippi River water and sediment to manage salinities and combat annual wetland losses. One is on the east bank at Canaveron, and the other is at Davis Pond on the west bank. These projects are expected to help in the battle, but they are small relative to the land loss in the Mississippi delta. However, the existing diversions are relatively small compared to the historical loss of marsh.

As discussed in the previous chapter, the Mississippi River of today does not transport as much sediment as it did in times past, and the majority of sediments currently transported are being deposited beyond the Barataria and Breton Sound estuaries. East and west diversions of the flow into areas in great need of freshwater and sediments could reverse the annual wetland losses that are currently occurring and, over time, would restore areas that have been lost. The Master Plan calls for this major modification to the river by including diversions of the Mississippi River upstream from the present Bird's Foot Delta that are large enough to build new land. These measures will not replace the land sustaining diversions, but be in addition to them.

The precise sizes, locations, and operation of new diversions have not yet been resolved. These questions will be addressed during the feasibility studies, but the concept is to develop these new diversions based on needs in adjacent wetlands, on lessons learned from the existing diversions, and from guidance that is reported in the literature. Through analysis of alternative plans, it will be determined how best to portion out the river's resources between the Breton Sound basin to the east and the Barataria Basin to the west of the river.

With such extensive diversion of the Mississippi River into the marshes, mechanical measures would be needed to continue deep water navigation in the current river channel. Many alternatives will be explored and discussed with all affected parties to arrive at the best solution. One option would be to maintain navigation within the present route through Southwest Pass to deep water off the Continental shelf by utilizing a non – stop lock system. Potential also exists to increase the navigation depth of the Mississippi River to as much as 60 feet.

4.3 Current River Management

Currently the Mississippi River passes through New Orleans and extends southward approximately one hundred miles (100 miles) to the Head of Passes (HOP). At the HOP the flow of the river is divided into three channels: Pass a Loutre to the southeast; South Pass to the south and Southwest Pass to the west. Over the years deep water navigation has used Southwest Pass. To accommodate deeper draft vessels, Southwest Pass was confined with rock jetties and dredged to deeper depths. The current navigation depth is maintained at approximately 45 feet. Greater depths are authorized, but there are no efforts to provide those depths at this time. The navigation channel extends to deep water at the edge of the continental shelf.

The mainline levees of the Mississippi River have protected New Orleans and surrounding communities from river flooding for many years. They extend to Venice, Louisiana, on the west bank and to Pointe a la Hache on the east bank. In addition to the levees, the Bonnet Carre Spillway Structure and Floodway complex is used to divert excess floodwater into Lake Pontchartrain when the river flow exceeds 1,250,000 cubic feet per second.

4.4 Characteristics of Diversions

A diversion has two main components: The river side intake structure and the land side conveyance system. The basic characteristics of the diversions are their location and dimensions. The study team determined that the head needed for gravity transfer is available all along the Mississippi River,

"…however, the total effective length of a diversion canal is directly proportional to the seasonally available head for a given site." (Soileau, et al. 1997)

The primary design consideration is efficiency in diverting and transporting the water-sediment mixture.

The characteristics of diversions also include operational requirements. There will be years and seasons when the water discharge in the Mississippi River less than diversion requirements or when the water quality is not suitable for diversion objectives. During those times it may be desirable to control the diversion using gated structures.

There also may be cases where it is desirable to influence the sediment concentration in the diverted water. Such influence is possible, to some extent, by locating the diversion at geomorphological features that are known to influence the secondary current pattern in the water column. In the report on sediment transport by gravity flow, the study team made the following observation:

"In order to be efficient, the [diverted] flow must carry higher sand concentrations than that of the river flow. To achieve this, it is firstly important to locate the intake structure in a sediment-rich area. Secondly, the design of the intake structure must incorporate features that will help increase the sand intake of the diverted flow.

Artificially increasing the concentration of sediment can also be accomplished by locating the diversion channel close to areas where significant regular dredging activity exists. This would facilitate a controlled manner of injection of dredged sand into the diverted flow.

Sediment concentration can also be increased during the rising leg of flood flows by causing more intense sediment diversion at this time." (Soileau, et al. 1997)

4.5 Phases in Project Formulation

The process of transforming the general concepts of the Master Plan into operational projects is organized into four general phases. The first phase emphasizes the need, the possible alternatives to meet that need, and the most attractive of those alternatives to carry forward to the next phase. The second phase emphasizes the feasibility of developing the most attractive alternative into a project that meets the need. The third phase emphasizes the engineering studies that are needed to identify project features and determine their dimensions. The fourth phase is the preparation of plans and specifications for construction. This chapter mainly focuses on considerations for the first two phases of development of these projects.

Identification of the exact needs is critical to building the project that best addresses all concerns without unintended consequences. In order to ensure successful implementation of larger and more complex projects, more effort is needed in the first phase of alternatives analysis and, once constructed, more intensive monitoring

of project performance is required. Program implementation also must allow for adjustments to operations or even components as needed to ensure that projects perform as intended into the future. The approach to implementing the Master Plan allows for this adaptability.

River diversion projects are good examples of the need for staged formulation, and adaptability in implementation, because these projects are competing for the same, limited water and sediment resources. The allocation of these resources to one diversion project impacts the ability of the system to meet the demands of the other diversion projects as well as other demands on the river's resources, such as navigation and municipal water supplies. Consideration must also be given to both the positive and potential negative impacts to the areas receiving the riverine resources. While the purpose of such projects is to ensure sustainability of the ecosystem and landscape, potential consequences exist that must be acknowledged. Examples of potential consequences include shifts in ecosystem habitats and, thus, locations of commercially important fisheries; and potential degradation of water quality if increased nutrient concentrations in estuaries result in excessive algal blooms. Such potential consequences may be avoided or alleviated if they are recognized during planning and design phases of project development.

4.5.1 Identification of Alternatives

This phase begins by setting the specific goals of the projects that are consistent with the four objectives and principles of the Master Plan. In addition to the project alternatives, the no-action alternative will be analyzed. Computational sedimentation models will be needed to route the water-sediment mixture through the system of diversion projects. Also computational models that simulate the interaction between ships, tows and currents will be needed to study navigation issues. Land change and ecosystem models will also be employed to understand the potential impacts (both desirable and unintended) to the receiving area.

4.5.1.1 Boundaries of Study Area

The geographic area that encompasses all of the proposed diversions, as well as the existing natural diversions in the Bird's Foot delta and the existing manmade diversions along the river, are within the study area. They will function as a system and must be analyzed as such.

The limits of the study area must be outside all components in the system. It is purposed that the upstream limit of the study area will be at the Tarbert Landing Gage. This gage is located at River Mile 306.3 above Head of Passes. The downstream end will include the entire Bird's Foot delta and extend sufficiently far into the Gulf of Mexico to reach geometric and hydrodynamic conditions that will not be altered by processes in the Mississippi River Delta over the next 100 years.

Since multiple diversion sites will add flow to the marsh on each side of the river, one discharge will affect the base level energy at other diversion sites. A change in base level energy at a site that is due to the interaction between that flow and the flow from other diversion sites will affect the diversions at both sites. This creates a feedback loop that must be included in the diversion computations. Therefore, the lateral limits of the system will include the marsh side of each diversion as well as the river side. It will terminate where the diverted water flows into the Gulf of Mexico.

4.5.1.2 The No-Action Alternative

Under current conditions, a portion of the water-sediment mixture flowing in the present Mississippi River channel is already diverted out of the lower portion of the river in the vicinity of the Bird's Foot Delta. These

diversions are into distributaries - natural openings - that have formed in the banks of the present river channel. Water and sediment is diverted to the east through Baptiste Collette Bayou, Cubits Gap, and Pass a Loutre. Flow and sediment are diverted to the west through Grand Pass and Southwest Pass. South Pass conveys a significant portion of the water and sediment. The final diversion point, RM 0, is located at Head of Passes. These natural diversion points are listed in the following table. The location in River Miles above Head of Passes (AHP) is shown in the following table.

Table 9. Natural Diversion Channels in the Mississippi Delta

Diversion to East	AHP
Baptiste Collette Bayou	RM 12.4
Cubits Gap	RM 11.4
Pass a Loutre	RM 0
Diversions to West	**AHP**
Grand Pass	RM 10.5
Southwest Pass	RM 0
Diversions to South	**AHP**
South Pass	RM 0

Technology is available to measure the water discharge leaving the main channel. It is more difficult to measure the sediment discharge. An early task will need to be to allocate the percentage of water and sediment yield through each of the distributaries in the existing Bird's Foot Delta. The fraction of sand, silt and clay in the sediment mixture will have to be determined for each distributary. The fate of this sediment - i.e. how much must be dredged; how much will deposit on either side of the conveyance channel; how much will be added to the littoral drift; and how much is actually transported off the continental shelf, will be determined. Sedimentation processes refer to the erosion, entrainment, transportation, deposition and compaction of sediments. (ASCE, 1977) Sedimentation processes are sensitive to the size of sediment particles in motion. In some river morphology studies, it is possible to reach conclusions by analyzing only the bed material. However, in this study it will be important to analyze the full range of particle sizes in transport. These range from clay to sand. In addition to these inorganic sediments, these studies must also include the contribution that organic sediments and nutrients make to the ecosystem. Computer simulations will be needed to quantify the sedimentation processes over long periods of time. Existing work will be reviewed to determine what has been done to date and to recommend what actions are needed to complete this evaluation.

Next, that distribution will be projected for 100 years into the future. After the historical system and future without further action scenario is understood, the analysis can move into the more abstract realm of the Master Plan diversions.

4.5.1.3 Alternative Plans

Once existing conditions have been characterized, the work can begin to identify the best locations in the river to site diversions with consideration for sediment availability at various locations on the river, targeted receiving area, channel stability, navigation, and other issues associated with maintaining the critical services.

Decisions on siting, sizing, and operation of the diversions will be an iterative process. This will include analyses of effects of the diversions, working as a system, on the four Master Plan objectives. Analyses will include impacts to fisheries, water quality, and other ecosystem and societal concerns; testing operational alternatives to best balance ecosystem and societal needs; potential for flooding consequences to communities; navigation impacts; and other concerns identified earlier in the planning phase.

Hydrology, hydraulics and sedimentation processes in the diversions will also be investigated. These analyses will start with preparing a preliminary design of the outflow structure and the conveyance channel for each diversion. Then the capability of the design to supply the water and sediment to the receiving area will be tested in a computational sedimentation model.

The discharge rates into all diversion structures would need to be computed. Computations will include hydraulic parameters of velocity, depth, width, slope and roughness in the outflow channels, and computation of the sedimentation processes that are produced by those hydraulic parameters. This computational analysis requires short time-intervals. An acceptable resolution is expected to be mean daily water discharges. Historical records are available at Tarbert Landing for developing hydrographs of mean daily flows.

In their report on the transport of sediment by gravity, the study team presented several issues to consider in the design of the conveyance canal located downstream of the intake structure *(Soileau et al. 1997).*

"…assure that the average energy gradient (energy line) maintains the given particle sizes of sand in suspension over the design length of the channel."

"…design the channel dimensions and geometry according to the local soil conditions to assure reasonable stability against erosion from the expected flow velocities"

"…for small canals, protect channel side slopes wherever possible with locally available natural material, such as stiff clay; for larger canals, protection should consist of a layer of granular or crushed bedding material large enough to prevent side slope degradation."

"…for short and small channels, build sheet-pile sides; such designs may be used in areas with low soil strength for channels branching out of the main channel."

"…due to the eventual cost of side slope protection for large canals, the use of T-groins (constructed with an appropriate combination of: sheet pile, rockfill, clay and landfill) spaced approximately twice the width of the channel (at the water surface) should be considered."

The annual water yield and sediment yield for the Mississippi River are necessary to create the preliminary design, but they are not sufficient for sizing and locating the diversion structures. A mean daily water discharge

hydrograph will need to be formed from the historical records. The sediment concentrations in, and water temperature of, those mean daily water discharges will be developed from historical records, also. The elevation of the Gulf of Mexico at the downstream boundary of the model will be developed from concurrent records at gages in the Gulf of Mexico. These four hydrographs are the boundary conditions that are needed to route the water-sediment mixture from Tarbert Landing to the Gulf of Mexico. Each hydrograph will be 100-years long. Not only will the routing provide water and sediment in the water column, but also it will compute changes to the cross sections along the river and to cross sections in the marsh due to sedimentation processes.

The water and sediment discharges that the river can deliver may then be computed for potential diversion structures by routing the water and sediment discharges from Tarbert Landing to the Gulf of Mexico. This computation will require a short interval time step. It will provide the heads and discharges at each diversion structure. The model will include the land side of the system as well as the river side.

Multiple iterations will be required to arrive at satisfactory sizes and locations of the diversion structures. However, the result of this analysis will be the range of flows, heads and water surface elevations at each structure. Additional iterations will be required to analyze the potential of operating structures in a pulse mode or time intervals to accommodate other ecosystem or cultural objectives.

The next step is to modify the boundary condition hydrographs for future conditions and repeat the routing computations. The Gulf Elevation Hydrograph would be modified to include sea level rise. The water discharge hydrograph of flows at Tarbert Landing would be modified to reflect the water runoff predicted for the next 100 years. The inflowing sediment concentration and water temperature hydrographs would be changed to future predictions. The simulation will be run again with these predicted future hydrographs, and the computed diversion hydrographs will be compared to the target hydrographs.

In total, the analyses conducted for this study must reveal the potential for the diverted flow to adversely impact existing land forms, existing land uses, existing infrastructure and other diversions. Each of these potential conflicts must be resolved in order to implement the diversions.

The Master Plan also includes the existing, authorized levels of flood protection and navigation. One of the engineering challenges is to blend navigation into the land-building diversions. This is such a significant issue that an entire section of this appendix is devoted to it. Several significant issues are presented. These will be addressed in the first phase of project formulation.

4.5.2 The Determination of Feasibility

This study will address multiple issues. 1) Is it feasible to get sediment out of the river and into the diverted water; 2) is it feasible to restore/create marsh with this diversion; 3) what will be the ecosystem effects of operating diversions; 4) what will be the impacts to local and regional culture, including businesses dependent upon fisheries and navigation. None of these issues can be left to chance.

The diversions must meet the expectation for marsh creation and restoration subject to the existing requirements for flood protection and land use. An engineered solution will be required to ensure that these diversions do not cause flooding or other unintended consequences to existing land use or infrastructure.

Each diversion project can be analyzed separately during this phase because the interaction issue will be known from the system study in the first phase. The range of design heads, stages and durations will be provided by the

system study. The level of study that is required will be simpler for the small projects than it is for the land building diversions. Because of its complexity, a section is devoted to the land building diversions below.

4.5.3 General Design Studies

The design phase will refine the siting, the hydraulic and structural design, and the operation and maintenance procedures for the diversion projects. Siting refers to the details for locating the structures relative to geological, geotechnical and geo-morphological features. The study team reported:

"Future sediment diversion projects will require careful site selection studies involving field verifications and detailed physical and numerical modeling."

Refining hydraulic design features will require physical model studies. Those studies will refine the project features to accommodate local hydrodynamics and sedimentation processes in the river, and they will refine the size and shape of the diversion structures so the river sediment is diverted to the marsh.

4.5.3.1 Land Building Diversions

The land building diversions will be included in first phase of project formulation along with the other diversions. However, it is such a large undertaking that special consideration is given here for the other studies that will be required.

4.5.3.2 Water Budget

Because all of the diversions act collectively as a system, the land building diversions will have significant impact on all the other diversions. Reference is made to Table 4, chapter 3 of this appendix, Mississippi River Tarbert Landing Discharge-period of record 1930-2005. The Tarbert Landing gage and discharge range is located downstream from the inflow channel for the Old River Auxiliary Structure. It represents the most downstream station for long term flow and sediment data for reach of river from Old River to the Gulf which includes New Orleans.

Table 1of this Appendix shows a breakdown of the monthly discharges at Tarberts Landing for the same period of record (1930-2005). For the month of January the minimum discharge in the period of record for that month was 120,000 cfs, the average discharge for that month in the period of record was 520,000cfs and the maximum discharge for that month in the period of record was 1,240,000 cfs. The same data is shown for each month. The largest discharges can be expected in the months of January, February, March, April and May. The lowest months are August and September.

Under average conditions the supply of freshwater is sufficient for the metropolitan area of New Orleans and surrounding communities. However, in 1988 droughts in the upper Mississippi River basin reduced river discharges to a point that the freshwater supply for New Orleans was endangered. As a result of this experience it was determined that a minimum discharge of 250,000 cfs at the Head of Passes allows saltwater to begin to proceed up river moving along the river bottom under the freshwater flow. The number of diversions, the design discharges and the time of expected use should be planned in such a manner as to avoid reducing total discharge of the river to this critical value at any time. Development of the sizing, design, and operation of the major diversions must include an analysis of the salt water interface to insure that unintended consequences will not occur.

4.5.3.3 Sediment Budget

Sediment load denotes the material that is being transported, and it can be divided into bed load and suspended load. The annual total measured suspended loads reported at Tarbert Landing, just downstream of the Old River Auxiliary inflow channel and tabulated in Table 4, chapter 3 of this appendix demonstrates that the measured suspended load does include sand, but it is primarily classified as silt. The unmeasured load would be primarily sand and cannot be reliably measured. The bed load material is estimated and generally expressed as a percentage of the measured suspended load. The percentage is generally reported ranges from 15 to 25 percent of the total measured suspended load. (Soileauil et al., 1997) Using the last 14 years of reported annual total measured suspended load in Table 4 (water years 1990-91 thru 2003-04, a period of 14 years) the average annual measured suspended load was 136,675,000 tons/year. Using the above range, the average unmeasured bed load is computed to be between 20,000,000 (15%) and 35,000,000 (25%) tons per year of unmeasured bed load sediment. Include the unmeasured bed load, and the total sediment delivered to the marsh could be between 156,675,000 and 171,675,000 tons/year.

Assuming an average of 164,175,000 tons of sediment per year, land building potential could be as much as 118 square miles per year assuming a specific weight of 100 lbs/ft^3 for the sediment and a 1-foot, uniform deposition. This does not take into account consolidation or the fact that as much as 1/3 of the sediment load could be clay particles which do not settle readily. Therefore, the reality is the annual rate of land building under the conditions described could be reduced to 2/3 of the square miles stated.

4.5.3.4 Non-Stop Navigation System

In concept, the non-stop navigation system will consist of an upstream lock complex and a downstream lock complex. Two independent channels will connect the upstream and downstream lock complexes. These channels will be immediately adjacent to each other. One lock and channel system will be used by down bound ships and the other will be by up-bound ships. The strategy of two systems is to permit two way traffic without stoppages. Towboats, crewboats, etc. can more easily push into the bank and wait if it is necessary, but it is difficult for downbound ships to pull over and wait. It is believed that the dual system will be safer and more reliable than a single channel system. Also, it may be possible to provide a deeper navigation channel than can be maintained in the existing navigation project.

The non-stop navigation system should be located adjacent to the existing river channel and operational prior to opening or operating the two diversions upstream. As currently envisioned, the diversions would be controlled, and should be operational at the same time as the navigation locks.

4.5.3.5 Operations & Maintenance

The plan should include elements that initiate periodic inspections, describe operational and maintenance procedures, and provide for the disposal of dredged material in the marshes to extend their development beyond the immediate proximity of the diversion channel. The developing deltas should be monitored annually and channels extended as necessary to keep the marsh and delta building process going out into the coastal area.

4.6 System-wide Considerations

There are significant unknowns and risks in a planning and design effort of this complexity and magnitude. Some of the significant issues to be addressed are:

a. The study must have adequate data collected over a sufficient period of time.

b. The sedimentation processes must be understood and adaptively managed to maximize the potential for land building.

c. Salinity will be altered dramatically. The environmental and physical impacts of the dynamic salinity levels must be clearly understood and managed.

d. The existing Bird's Foot Delta may deteriorate rapidly once the land building diversions are implemented. These changes and losses must be anticipated.

e. The barrier islands are key to trapping efficiency of the diversions. The barrier islands and the openings between them will have to be maintained to preserve the sedimentation trapping in the marsh.

f. Currently, the nutrient rich waters of the Mississippi River cause a hypoxic zone in the Gulf of Mexico. Nutrient uptake in the marshes will be essential to reducing the hypoxic zone offshore and ensuring that water quality is not compromised inshore.

g. Diverting the total flow of the Mississippi River will have tremendous impacts on existing infrastructure, historically habitated areas, and the environment. All must be clearly understood and addressed during feasibility analyses.

h. Creating a slack water channel will change the nature of sedimentation problems in the navigation channel.

5.0 Conclusions

For over 12,000 years people have lived, worked and played in Louisiana, leaving their mark on the landscape. Access to the coast, for reasons of proximity to natural resources and facilitating long-distance trade, has continued to drive historic and modern decisions in Louisiana regarding community location. This included the 1718 founding of the city of New Orleans at the location of the portage between the Mississippi River and Lake Pontchartrain, along Bayou St. John.

Nationally important industries are located on the coast and major waterways. These include the production of oil and gas, offshore oil and gas exploration, development and transport; shipbuilding and other manufacturing of transportation equipment; petroleum and chemical refining; and water-borne transportation, as well as seafood production and harvest. Today, nearly 9,300 miles of oil and gas pipelines cross the wetlands of coastal Louisiana (USACE 2004). The network of associated energy facilities produces or transports nearly one-third of the nation's oil and gas supply, and is tied to 50% of the nation's refining capacity (DNR 2006). Additionally, 80% of the nation's offshore domestic oil and gas supply is transported through coastal Louisiana. Coastal Louisiana also supports intermodal transportation that is critical to the viability of the nation. Five of the busiest cargo ports in the United States, ranked by total tons, are located here, handling approximately 19% of the annual U.S. waterborne commerce (USACE 2003).

Louisiana is known as "Sportsman's Paradise" for the diverse habitats found along its coast, which in turn support a vast diversity of fish and wildlife species. Louisiana is by far the nation's largest shrimp, oyster, and blue crab producer and provides 26% (by weight) of the commercial fish landings in the lower 48 states. In fact, Louisiana is second only to Alaska in annual volume of seafood landings. According to National Oceanography and Atmospheric Administration reports (US Department of Commerce 2004; US Department of Commerce 2005), three of the nation's top seafood ports by volume are in Louisiana. Coastal Louisiana's wetlands also provide stopover habitat for millions of threatened and endangered neotropical migratory birds, and more than five million migratory waterfowl. These natural resources provide the state with vital jobs to support the commercial and recreational industries, and the nation with valued seafood.

What is more difficult to quantify is the richness of Louisiana's culture, a richness in part driven by the history that is present throughout the state. Perhaps because New Orleans was an early center of international trade, Louisiana has a rich and diverse heritage. Louisiana residents today include, in addition to a continuing strong Native American presence, descendants of European, African and Asian cultures. All of these cultures have made a direct recognizable contribution to Louisiana culture. What is unique about Louisiana and particularly coastal Louisiana is not that it has a distinct culture, but that what is regarded as "Louisiana culture" is one that is not homogenous (Spitzer 1985). Like gumbo itself, south Louisiana's culture is made up of diverse ingredients from all parts of the world, each retaining its individual identity and flavor, but coming together to make a distinctive dish with its own immediately recognizable identity. It is this indefinable richness that has made tourism such an important contributor to Louisiana's economy, whether this richness comes from historic architecture, food, music, language or culture. According to the Louisiana Department of Culture, Recreation & Tourism over $4.4 billion of visitor spending in Louisiana in 2004 was from New Orleans and Lake Charles. Where coastal Louisianans live, work, and play, is part of their identity. Sustaining Louisiana's coastal culture is dependant on sustaining Louisiana's coast.

However, this unique region is under extreme threat. With the arrival of the European settlers came major changes to the natural landscape to create more stable and safe living conditions in this naturally dynamic region. Alterations included construction of levees to render this system even more suitable for habitation, efficient for

navigation, and agriculturally productive. Additional physical changes to the landscape and the disruption of the land-building and sustaining processes came with the initiation of oil and gas exploration. There are also 10 major navigation canals in coastal Louisiana. While they serve to transport goods through and out of Louisiana, they also allow for saltwater to intrude into and degrade freshwater wetlands

Consequently, although the coastal Louisiana ecosystem contains 30 percent of the coastal marsh in the contiguous United States, it suffers 90 percent of the total coastal marsh loss. The human alterations to the ecosystem interact with natural factors to create the land loss crisis facing Louisiana's coastal zone today. Causes of loss can be divided into direct causes, such as canal construction, erosion caused by storms or ship wakes, and herbivory; and system-wide disruptions to long-term sustainability, that include subsidence, sea level rise, levee construction, and agricultural practices in the basin and channel stabilization practices along the river. These have reduced the sediment load the Mississippi River delivers within coastal Louisiana.

The storms of 2005 called out another extreme vulnerability to the long-term viability of coastal Louisiana – that of the inadequacy of hurricane protection measures in this fragile region. Hurricanes Katrina and Rita caused severe damage to over 200,000 homes, and one year after the storm approximately 440,000 Louisiana citizens were still displaced from their homes. The Congressional Budget Office estimated that losses of physical capital totaled between $70 and $130 billion. Approximately 45% of these losses involved business structures or equipment, including resources owned by national concerns.

This leaves Louisiana’s citizens with an interesting dilemma: how do we protect our communities and nationally significant infrastructure while also providing for the long-term sustainability of the ecosystem? Levees are a crucial aspect of providing for a sustainable coast, given that many south Louisiana communities are situated in the delta plain of one of the world’s major rivers, and are subject to relatively high wave energy and storm surge levels due to their proximity to deep waters of the Gulf of Mexico. Many of these communities are historic and integral to the delivery of essential services to the nation, but they would not exist without levees. In recognition of the need for structural protection, levees are recommended in high risk areas that must be protected to avoid severe consequences for the state and nation.

Yet, as traditionally constructed, levees are in conflict with the need for a healthy ecosystem. Mineral sediment input to Louisiana's coast has decreased in recent decades because of the Mississippi River & Tributaries project that has been very effective in meeting its goals of providing flood control to communities and channel stabilization for safer navigation. This levee system is critical for the continued inhabitance of many portions of the Mississippi River flood plain, including coastal Louisiana, and for the sustainability of many economic services that this region provides to the Nation. But by preventing overbank flooding and crevassing of the Mississippi River, the surrounding wetlands are now largely deprived of the mineral sediment, freshwater, and nutrients required for offsetting subsidence and sea level rise. Although the negative impacts of levees on ecosystem health and sustainability have been documented, levees are an essential to the survival of communities that exist in this naturally subsiding delta plain.

This presents the science and engineering community with the challenge of advancing technology to ensure that new levee designs allow for hydrologic exchange across these barriers, allowing for the sustainability of wetlands on both sides of the levees. The coastal landscape – comprised of barrier islands, Chenier ridges, saline, brackish and fresh marsh habitat, and healthy forested wetlands – and the levee protection of infrastructure and communities that supply the workforce for these industries must co-exist to ensure that the risk from storm damage and supply disruption of these nationally important resources is minimized. For these reasons and more, this region must be sustained for the well being of the state and the nation.

In order to restore the ecosystem of coastal Louisiana to a self-sustaining environment, near-term solutions to address immediate needs must be merged with long-term goals to reach system sustainability. To enhance the health and integrity of the coastal Louisiana ecosystem, the altered processes must be restored by mimicking to the extent possible the natural processes of a sustainable coast. To restore disconnected and modified hydrologic linkages, regional water management options should reconnect and maintain linkages to sediment and nutrient delivery to interior wetlands while reducing sediment loss to offshore environments. Regional water flow patterns should be restored and maintained by mimicking natural process and cycles, minimizing the impact of artificial waterways. Reduced sediment input should be corrected by the delivery of new sediments to coastal basins using a combination of river diversions and pipeline conveyance of dredged sediment. Additionally, the redistribution of sediments via long-shore currents and redistribution of water using the GIWW and other navigation channels both contribute to rebuilding and maintaining the coastal landscape.

To allow the past and current degradation of Louisiana's coastal landscape to continue unchecked into the future would have significant ecological, societal, and economic impacts on the region and the Nation as tremendous resources supported by the coastal zone are put at risk. But by taking these steps to restore the process of a sustainable coast, an estuarine gradient and landscape features will be maintained to support an array of habitats for associated plants and animals, including resident and migratory bird communities. Through restoration projects that are of sufficient scale to sustain and expand a variety of coastal landscape features and integrity, a sustainable environment can be maintained that integrates the function of the ecosystem as well as the complex needs of the working coast.