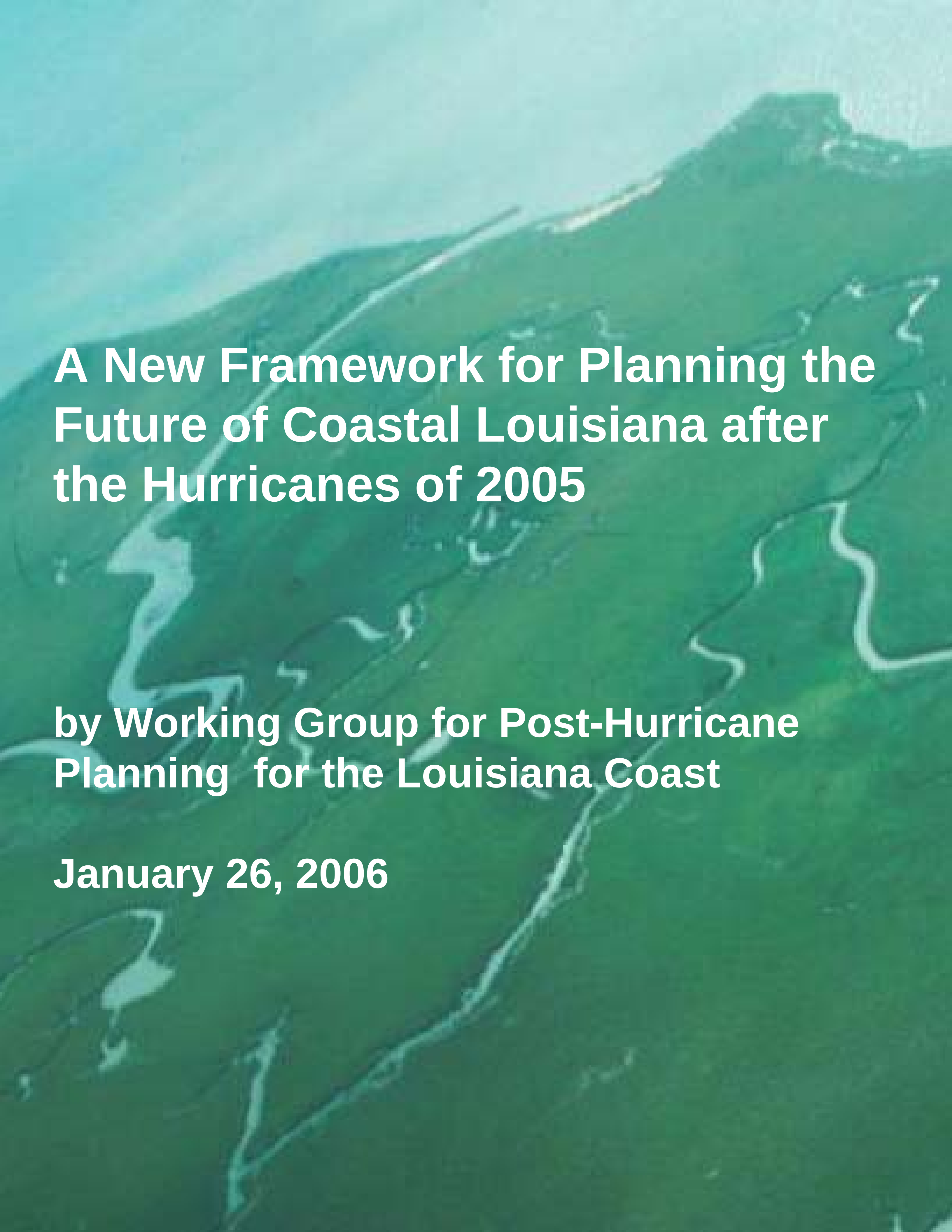

A New Framework for Planning the Future of Coastal Louisiana after the Hurricanes of 2005

by Working Group for Post-Hurricane Planning for the Louisiana Coast

January 26, 2006

University of Maryland
CENTER FOR ENVIRONMENTAL SCIENCE

INTEGRATION APPLICATION NETWORK

An independent Working Group of scientists and engineers prepared this report with logistical support provided by the Institute of Water Resources of the U.S. Army Corps of Engineers and the National Research Council. The opinions expressed are those of the authors and do not necessarily represent the views of the Corps, the Federal government or the NRC.

The Integration and Application Network of the University of Maryland Center for Environmental Science was responsible for final preparation of the report. Copies can be obtained from the Center at the following address or electronically through the website www.umces.edu/la-restore.

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SUMMARY

This report was prepared by a working group of scientists and engineers as a rapid response to the national imperative to develop and execute a strategy for reducing hurricane risks in New Orleans and along the Louisiana coast, while sustaining the wetland-dominated landscapes that surround those population centers. Those landscapes are important not only as a buffer from hurricanes, but also are of great value to the Nation for the natural resources and ecosystem services provided. The principal messages abstracted from our report are the following:

1. The large-scale deterioration of coastal landscapes, particularly during the past fifty years, threatens the sustainability (viability over this century) of both human habitation and the rich natural resource base of coastal Louisiana. Storm events such as hurricanes have both negative and positive effects on wetlands that dominate these landscapes, but deterioration of these wetlands is mostly caused by human activities that both disrupt natural processes building the coastal landscape (river inputs, sedimentation, tidal fluctuation, etc.) and accelerate destructive processes (altered hydrology, subsidence, etc.). **In the long term, hurricane protection for larger population centers, including the New Orleans region, can only be secured with a combination of levees and a sustainable coastal landscape.** This will require adapting to changing conditions by re-establishing the constructive processes associated with distributing Mississippi River water and sediments across the coastal landscape, as well as alleviating the other destructive effects of past or future human activities.

2. The sustainable coastal landscape must include extensive marshes and swamps and the bayous, coastal barriers and ridges that characterize the Mississippi deltaic plain and the Chenier plain in the southwest. If natural processes are not interrupted, coastal wetlands are able to sustain themselves over hundreds of years even where the land is subsiding or the sea level is rising. **With presently observed subsidence rates and anticipated acceleration of sea-level rise, most—although not all—of the coastal landscape could be maintained through the 21st century. And with efficient management of the river's resources, this landscape could be expanded in some places.** However, this result can only be achieved with very aggressive, strategic, and well-informed restoration efforts, varying in size and objective but integrated within a landscape management plan.

3. Hurricanes Katrina and Rita provide poignant evidence that no longer can coastal ecosystem management and restoration, flood protection, and navigation be planned, executed and maintained independently. **We must integrate planning, investment and management decisions under a new framework in order to secure these multiple purposes, while recognizing: the forces of nature; the imperative to protect life, property and communities; the value of natural**

resources and ecosystem services; the environmental and economic sustainability of the solutions; and financial constraints. Furthermore, planning to support this integrated decision making must be an adaptive process that creates and uses new knowledge about this "working coast." Integrated management requires that coastal landscape restoration alternatives be screened through a "storm damage reduction filter" (e.g., how might they reduce risks and how quickly might the result be realized?). Conversely, hurricane storm damage reduction or navigation alternatives should be screened through an "environmental consequences filter" (e.g., how might the elements affect ecosystem services and the sustainability of the landscape?). This does not mean that restoration features are justified only because they significantly reduce storm damages—many are required to sustain environmental resources or build landscapes away from population centers. It does mean that priorities must be determined by multiple benefits more than has been the case in past planning.

4. **The near-term critical restoration features selected by Louisiana Coastal Area Ecosystem Restoration Study should be reexamined and prioritized to assure that they provide environmentally and economically sustainable approaches that advance both ecosystem restoration goals and support storm damage reduction.** While a truly integrated planning process has not yet been developed, there is sufficient understanding to prioritize near-term restoration features based on their likely contribution to the effectiveness of existing and intended storm damage reduction efforts, as well as advancing ecosystem restoration. Furthermore, long-term restoration strategies for the four geographic subprovinces should be refined by incorporating integrated objectives and framed around critical foundation features.

5. **Federal and State governments should engage scientists, economists, engineers, government officials, communities and stakeholders to develop a spatially explicit vision of a future coastal Louisiana that incorporates long-term challenges, opportunities and overarching goals.** As recently stressed by the National Research Council, such a vision should guide integrated, multi-objective management within geomorphic subprovinces and along the entire coast throughout the planning and project implementation process. Stakeholders should participate in formulating and evaluating alternatives that recognize the opportunities and limitations associated with maintaining the status quo under the perilous, urgent and changing circumstances. The vision should anticipate future changes that may affect options, for example energy scarcity, climate change and demographic shifts. As adaptations occur and new projects are realized, the vision for the coast can be revised in light of changing landscape and socio-economic conditions, knowledge of the system, and social preferences.

6. The President and Congress have mandated studies of potential supplements to the existing but strengthened storm protection works. Particular attention is being given to a continuous peripheral coastal defense (a hurricane barrier) similar to that used in the Netherlands. Although the systematic approach of the Dutch is commendable, substantial differences between the Netherlands and south

Louisiana limit the applicability of their model, including contrasts in human settlement patterns, land uses, geology, hydrodynamics and coastal ecology. Maintaining functioning estuarine ecosystems and self-sustaining wetlands inside and adjacent to such peripheral defenses would be extremely difficult, if not impossible, because extended levees and floodgates would obstruct key hydrological processes that maintain the coastal landscape. The relatively dispersed populations and low intensity of land use may make investment in such a barrier difficult to justify. Rather than simply adopting the Dutch approach, the plan for Louisiana should recognize the different Louisiana setting and take advantage of its characteristic coastal landscape. **Storm damage reduction should be achieved through a combination of stronger inner defenses around larger population centers; broader, self-sustaining wetland landscapes that reduce storm surge and wave fetch; restrictions along artificial channels to limit storm surge propagation; and maintaining barrier islands along selected areas of the coast.** This may include lower elevation, semi-porous barriers placed between the levees protecting population centers and the open coast that attenuate storm surge but allow tidal exchange. However, any such barriers should be compatible with sustainable coastal landscapes. To the extent possible, extensive wetland areas should not be enclosed by levee systems.

7. Navigation channels that cut across the coastal gradient have resulted in substantial degradation of wetland habitats, thus increasing hurricane surge vulnerability. **Future integrated planning and decision making should recognize, account for and mitigate the disruption of coastal landscape dynamics when formulating and evaluating navigation channel expansion, maintenance or abandonment.** One of these channels, the Mississippi River-Gulf Outlet (MRGO), is likely to be decommissioned as a deep-draft navigation channel as a result of the risks it poses and its weak economic contribution. However, even if mostly closed it will remain a feature on the coastal landscape that has to be integrated into a coastal restoration and storm damage reduction strategy for the vulnerable east side of Greater New Orleans.

8. A new management framework requires improved organizational arrangements for coordinating and integrating planning, decision making, implementation and evaluation. **A joint Federal-State body should be given the responsibility and organizational and fiscal support for guiding the program.** The Corps, or another appropriate agency, would continue to have the responsibility to design, construct and, if authorized, operate and maintain projects. An integrated assessment group and an engineering and science program focused on reducing decision-relevant uncertainties (scientific and otherwise) would support decision making in an adaptive management process.

9. **Authorization and financing should be separated from the Water Resources Development Act process.** The integrated planning process, engineering and science program and smaller investment projects should be supported by a programmatic authorization and a more reliable appropriation stream. Funding

for larger projects should be provided through a Congressionally-chartered coastal investment corporation.

10. **Project planning should rely on innovative decision-support analyses that engage stakeholders and responsible agencies in resolution of conflicts and in identifying and synergies among projects.** The analyses would formulate and evaluate project alternatives using performance measures derived from the policies, goals and objectives of the Nation and the region. Significant areas of risk and uncertainty will be highlighted for decision making, as well as for establishing monitoring and research priorities for the adaptive management program.

INTRODUCTION

On August 29, 2005 Hurricane Katrina struck the northern Gulf Coast, causing the loss of over 1,300 lives and great devastation. Damage was particularly severe along the Mississippi Gulf Coast and in Greater New Orleans, where many protection works were overtopped or suffered catastrophic structural failure. Less than four weeks later, Hurricane Rita came ashore in southwestern Louisiana, pushing a storm surge that reflooded parts of New Orleans through previous floodwall breaches and inundated many communities across the Louisiana coast, destroying homes, businesses and public services. The impacts of these large and powerful storms focused the nation's attention on how development proceeded under these risks and on the adequacy of current protection from hurricane storm surges. It also highlighted the question of whether vulnerability to storms has increased as a result of the rapid and largely human-induced deterioration of the wetland-dominated coastal landscapes along the Louisiana coast.

On December 15, 2005 President Bush pledged to rebuild New Orleans' shattered levee system better and stronger than before Hurricane Katrina. He directed the U.S. Army Corps of Engineers to accelerate the study of options to further reduce the risk of flood and storm damage, including both engineered infrastructure and non-engineered solutions, such as improved emergency preparedness and evacuation planning, strengthened building codes, relocation, and creation of additional wetlands to help reduce future storm surge. The White House stressed that a comprehensive plan must be based on all relevant facts and the best available science, including information from local and state initiatives, universities, professional organizations and private sector entities.

The authors of this report endorse the intention of these actions and highlight key issues and make recommendations aimed at securing a sustainable[1] future for coastal Louisiana. For reasons largely related to differences in the coastal environments and associated flood protection challenges, we are not addressing future conditions in the affected portions of Mississippi, Alabama or Texas. Many participants in the working group have been advising the Corps of Engineers as members of the National Technical Review Committee (NTRC) or through other mechanisms during the development of the Louisiana Coastal Area (LCA) Study, which focused on ecosystem restoration[2] but gave little consideration to hurricane protection or navigation infrastructure. However, the devastation from the hurricanes, as well as new and pending Federal commitments, prompt a reexamination of the coastal restoration strategies, as well as storm protection and navigation improvement plans, that have developed over time. Actions undertaken for ecosystem restoration, flood protection and navigation must be reconciled and integrated in ways that have not been attempted, much less achieved. Consideration must also be given to future changes in the human population and economy, activities influencing the hydrology of the Mississippi Basin, and the global and regional climate. In short, planning the future of coastal Louisiana and acting on these plans must proceed in ways that are coherent across scales, multi-purpose, forward-looking, feasible and appropriately expeditious.

The working group worked over a six-week period to exchange information, deliberate on the requirements for effective planning and decision making and craft this report. Thirteen members of the group met on December 14-15, 2005 in Washington, D.C. We appreciate the travel and logistical support provided by the Institute for Water Resources and the National Research Council, but stress that we undertook this task independently as concerned scientists and engineers, rather than under official mandate or charge from the Corps of Engineers or the NRC. We did, however, receive the cooperation of officials from the Corps and State of Louisiana.

The working group approached its task by first relying on current knowledge and plans to reconsider how coastal ecosystem restoration planning and project selection might be affected if hurricane protection were now a major consideration, in addition to the other ecosystem services derived from the coastal landscape. We then asked how planning and project selection for storm damage reduction and navigation might be affected if the consequences for the coastal landscape were also a major consideration. This allows us to offer specific recommendations on near-term restoration project priorities and longer-term considerations for each of four geomorphic subprovinces of the Louisiana coast.

The Working Group did not address issues of rebuilding in the city of New Orleans, where multiple economic, social and cultural as well as environmental factors are in play.[3] Moreover, we do not recommend where and to what performance and design standards to build additional levees or barriers, the exact formulation of landscape restoration actions, or the configurations of the navigation networks consistent with these other purposes. Such recommendations will require more detailed assessments and difficult social and economic choices. We do provide recommendations for a new framework of organizations, funding and analysis for conducting such assessments and expediting decision making and execution.

Hurricane Katrina approaching the Louisiana coast

SETTING THE STAGE

The coastal zone of Louisiana is comprised of two wetland-dominated provinces, the Mississippi deltaic plain in the southeast and the closely linked Chenier plain in the southwest (Figure 1). The deltaic plain consists of two active distributaries, the Mississippi and Atchafalaya rivers, several mostly inactive distributaries, and extensive tidal wetlands, swamps, and lagoons lying between the distributaries or enclosed by fringing barrier islands. The 9,600 square-mile (25,000 km^2) deltaic plain was formed and sustained over the last 6,000 years following the relative stabilization of sea level, by delta lobe switching, crevasses, river floods, storms, tides and wetland plants. Overlapping delta lobes of the Mississippi River grew by deposition of sediment at the river mouth, through breaches in the natural levees of distributary channels, and overbank flooding. As each delta lobe matured and became less efficient in transporting the river to the Gulf, its river course switched to build a new lobe and gradually abandoned the old one, which eventually diminished in area. The Chenier plain developed as a result of the interplay of three coastal plain rivers and the longshore transport of sediments escaping the Mississippi-Atchafalaya delta system. Periodic switching between coastal erosion and aggradation produced a series of parallel, forested ridges and intervening marshes and lakes. Wetlands across the coast survived for centuries after substantial inputs of river sediment were removed. These wetlands trapped remobilized sediments and the plants added peat to the accreting soil.

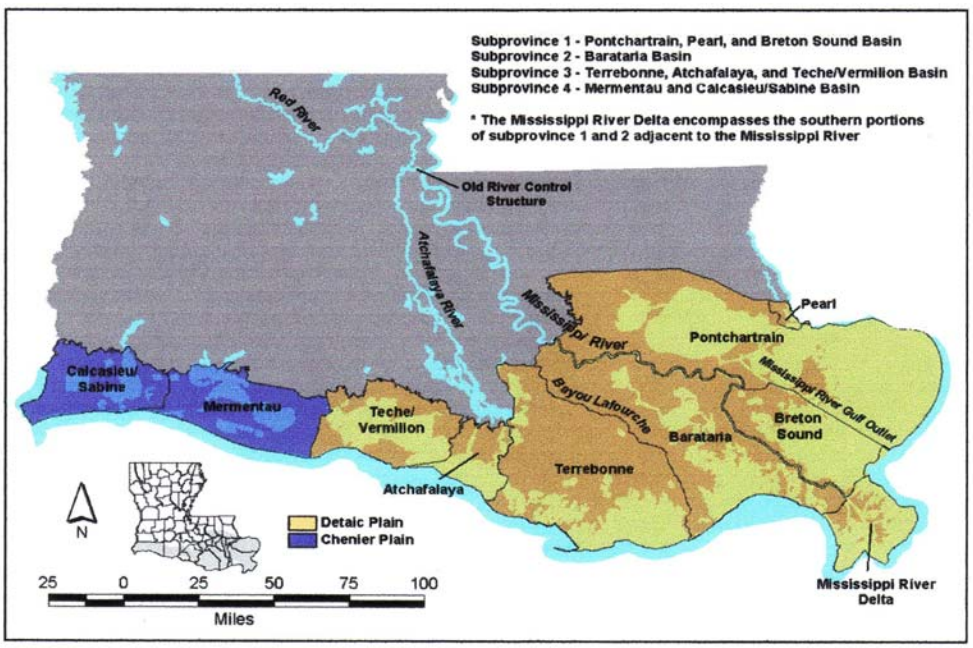
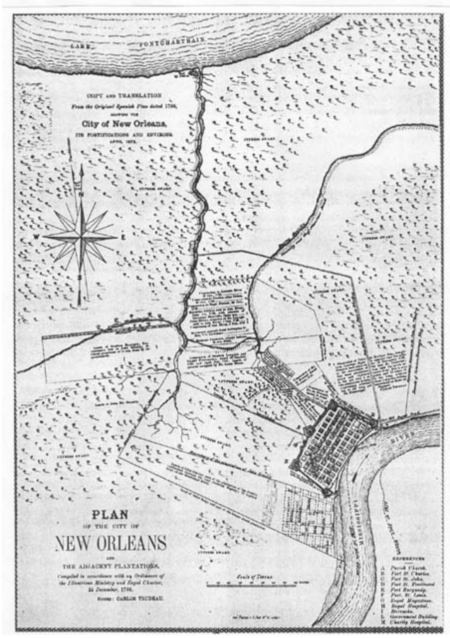


Figure 1. The two major provinces and four subprovinces of coastal Louisiana.[11]

When Bienville established New Orleans in 1718, many Mississippi distributaries still conveyed some river discharge and older natural levee ridges and barrier islands formed an extensive skeletal framework. Thus, the interior areas of the deltaic plain were protected from marine forces and the intrusion of salt water was limited. Regular overbank flooding and crevasses periodically provided a fluvial subsidy to this coastal landscape. The French colonists established their new city on the high ground of Mississippi's natural levee at a strategic location that also provided access to the Gulf of Mexico via Bayou St. John and Lake Pontchartrain.[4] They faced regular challenges from river floods, but were buffered from hurricane storm surges by the extensive and intact coastal landscape that separated the city from the Gulf. Even as the 19th century city grew out into the swamps, backwater flooding from the river was more of a threat than Gulf storms.[5]



However, from that beginning to the present day human activities in the region, as well as through the upper Mississippi Basin, have altered the tidal wetlands and other landforms of the Louisiana coast, causing rapid deterioration during the last half of the 20th century. Closing distributaries and constructing artificial levees along the river to provide for flood protection and allow expanded land development have brought many benefits to the residents and the Nation, but have also limited nourishment of wetlands with sediments and fresh water. Canals dredged for navigation and oil and gas production and transportation made the region a critical center of domestic energy production and international trade, but also greatly modified coastal hydrology, thereby accelerating wetland loss. Locally, forced drainage of reclaimed wetlands caused rapid sinking of land and, recent evidence suggests, fluid withdrawals associated with oil and gas production may have increased local subsidence rates.[6] Particularly in the Chenier Plain, impoundments designed to manage water levels for specific purposes have also contributed to the conversion of wetlands to open water.

While drainage and infilling are typically seen as the main threats to wetlands elsewhere, most wetland losses in Louisiana have resulted from soil water logging, as vertical accretion of new soil is unable to keep pace with relative sea-level rise (the combined effect of subsidence and changes in the level of the coastal ocean) and altered hydrology. Over 1,900 square miles (4,900 km^2) of coastal land, mainly tidal wetlands, have been lost since the 1930s,[7] reversing the long-term trend of net land building (Figure 2). Although the annual-equivalent rate of loss has slowed somewhat from a peak of 40 square miles (100 km^2) per year in the 1960s and 1970s, it is estimated to have averaged 24 square miles (62 km^2) per year between 1990 and 2000. Approximately 500 square miles (1,300 km^2) of additional land loss is projected by 2050—a slower average rate of loss because the inventory of highly vulnerable wetlands is being depleted.

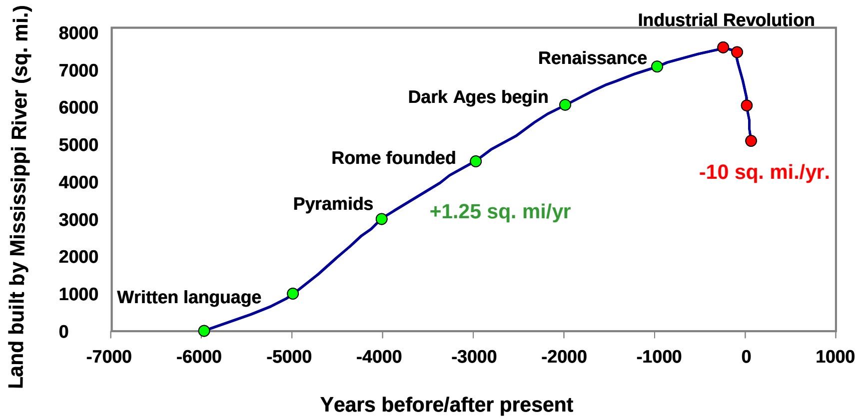


Figure 2. Historical perspective on Louisiana coastal land building and loss.

In the past and until recently, public investments in the coastal region were focused on storm protection and navigation improvements. Growing concerns about the rate and consequences of coastal wetland loss for natural resources have stimulated much advocacy and planning for substantial public investments for ecosystem restoration.[8] In addition it has been argued that deterioration of the coastal landscape of barrier islands, wetlands and higher ridges puts coastal communities at increasing risk to hurricane flooding. Policies and programs to respond to these concerns initially included more restrictive permitting of dredge and fill activities and the authorization and funding of the federal Coastal Wetlands, Planning, Protection and Restoration Act of 1990 (CWPPRA), which currently provides approximately $50 million annually. However, it was soon realized that investments in much larger-scale restoration efforts would be required. State and Federal agencies, local governments, scientists and stakeholders collaborated in the development of a strategic plan for coast-wide ecosystem restoration, entitled "Coast 2050—Toward a Sustainable Coastal Louisiana."[9] This plan included a diverse amalgamation of projects of various sizes and purposes located within the four geomorphic subprovinces along the coast.

The Coast 2050 Plan led to a May 1999 reconnaissance report by the Corps of Engineers, which in turn provided the basis for the Louisiana Coastal Area (LCA) Ecosystem Restoration Study report. More detailed and quantitative analyses of various restoration "features" (projects or actions) in different locations were employed in the LCA Study and the cost and effectiveness of suites of various features in achieving ecosystem benefits assessed. In 2003, the Corps sent a draft of the LCA Study[10] for review by the Office of Management and Budget (OMB). Seven alternative plans ranging in cost from $5 to 17 billion were presented and contrasted. OMB directed that the LCA Plan be scaled back to include a limited number of near-term projects that could be completed in a five-year period and demonstration projects and scientific assessments to reduce uncertainties concerning longer-term restoration projects.

Subsequently, the LCA Study Final Report[11] was prepared and a Chief of Engineers Report[12] submitted to Congress on January 31, 2005 recommending authorization of five "near-term critical ecosystem restoration features," a science and technology program, a demonstration program, beneficial use of dredged materials, and further investigations of other near-term restoration features, at a cost of nearly $2 billion. The Assistant

Secretary of the Army submitted to Congress a Record of Decision requesting programmatic authorization for these elements totaling $1.12 billion. Authorization for this plan, currently awaits passage of a Water Resources Development Act (WRDA) or some other legislative action.

In its November 2005 evaluation of the LCA Study Final Report, the National Research Council[13] concluded: "… although the individual projects in the study are scientifically sound, there should be more and larger scale projects that provide a comprehensive approach to addressing land loss over such a large area. More importantly, the study should be guided by a detailed map of the expected future landscape of coastal Louisiana that is developed from agreed upon goals for the region and the nation." In addition, the NRC questioned the inclusion of stabilization of the Mississippi River-Gulf Outlet (MRGO) among the five near-term critical restoration features and suggested that the ambitious concept of creating a "third delta" be reconsidered in favor of an alternate large diversion upstream of the Birdfoot delta that would reduce the number of stakeholders impacted while also providing more effective sediment nourishment of barrier islands.

As the attention to landscape restoration increased, planning and decision making remained separate, for the most part, from that for storm protection and navigation. In LCA planning restoration features were evaluated according to the ecosystem benefits and the financial costs incurred so the most cost-effective array of features could be identified. Benefits did not specifically include storm damage reduction values and costs were only financial outlays by governments, even though the features might impose costs or yield benefits to current users of the ecosystem (anglers, oyster growers, oil and gas and navigation interests). These analytical limitations effectively isolated restoration plan formulation from other potential synergies or conflicts with flood protection, storm damage reduction, and navigation needs across the coast.

In this report we address hurricane protection and navigation, but in the context of coastal landscape restoration. As described earlier, the President has committed to strengthening the existing levee system around the Greater New Orleans region. This includes rebuilding and raising levees and floodwalls to their design height, accelerating the completion of previously authorized levee projects, armoring levees to improve reliability, and eventually closing three interior drainage canals and installing pump stations on them at the lakefront. These efforts will not extend levee protection and will still leave communities in eastern New Orleans and St. Bernard Parish susceptible to flooding from a Katrina-like hurricane. Moreover, this will not assure protection from a maximum possible storm surge (so-called Category 5 protection). The Corps of Engineers is, however, evaluating longer-term structural and non-structural options to address such a maximum surge. In separate instructions, the Corps has been asked to continue to study, and in some cases begin to implement, coastal wetland restoration projects. An implicit but essential planning requirement is to jointly formulate and evaluate hurricane protection works, landscape restoration, and navigation networks in terms of the multiple purposes and objectives for this "working coast."[14] After reviewing the consequences and lessons of Katrina and Rita, the rest of this report includes findings and recommendations that reflect this need for an integrated perspective.

CONSEQUENCES OF HURRICANES KATRINA AND RITA

Communities and Infrastructure

The record-setting hurricane season of 2005 produced two hurricanes, Katrina and Rita (Figure 3), whose impacts on coastal communities and infrastructure were extensive, widespread and reported in detail in the news media. They are briefly summarized here in order to provide perspective regarding storm surge vulnerability. After crossing the tip of Florida, Hurricane Katrina strengthened into a Category 5 cyclone (maximum sustained winds 150 knots at 0900 CDT on August 28) as it traveled over the warm waters of the Gulf of Mexico.[15] Although it weakened as it approached the northern Gulf Coast, Katrina still had maximum sustained winds of 115 knots (Category 4) just two hours before making landfall at Buras, Louisiana. Although much has been made of the retrospective analysis that it was only a Category 3 cyclone at landfall, Katrina was unusually large and the extent of its tropical storm-force and hurricane-force winds remained nearly the same as its maximum winds weakened. As Katrina progressed across Breton Sound and Lake Borgne, with landfall again at the Mississippi-Louisiana border as a Category 3 storm (105 knots sustained winds), it generated a storm surge that probably exceeded 30 feet (10 m) along the Mississippi coast and 20 feet (7 m) over the wetlands east of New Orleans.

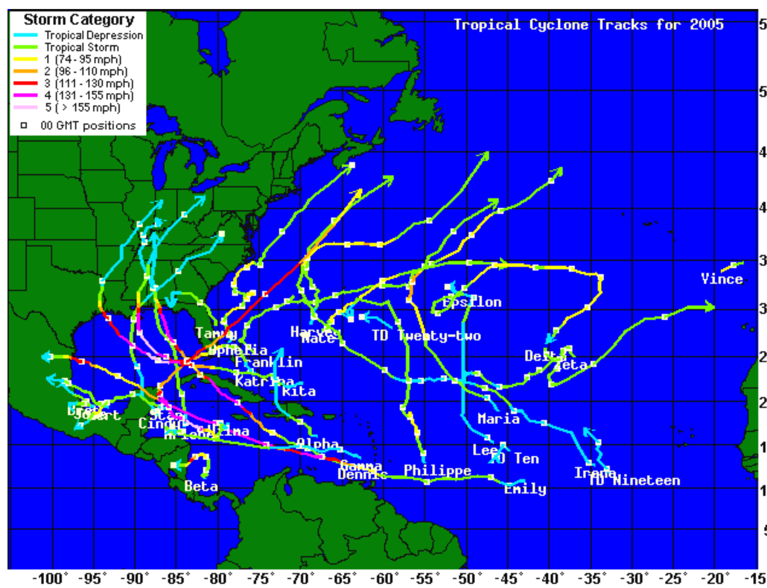


Figure 3. 2005 produced more Atlantic tropical cyclones and more Category 4 and 5 cyclones than any year on record.

In Louisiana, communities in and around Slidell and in lower St. Bernard Parish that were unprotected by levees were inundated, and the storm surge also overtopped and in places destroyed the levee defenses and floodwalls of communities in eastern New Orleans and St. Bernard and Plaquemines parishes. Floodwalls along two forced drainage canals connected to Lake Pontchartrain were breached, possibly as a result of geotechnical failure, flooding most of the rest of New Orleans west of the Inner Harbor Navigation Canal (IHNC). Because much of this area is below sea level, the floodwaters remained for several weeks until levees could be repaired and water pumped out. Over 1,300 people are confirmed dead as a direct or indirect result of Hurricane Katrina, nearly 1,100 of them in Louisiana.

Hurricane Rita made landfall near Sabine Pass at the Louisiana-Texas border on September 24, 2005 as a Category 3 hurricane with sustained wind speed of 105 knots and a storm surge of at least 20 feet (6 m). Coastal communities in Cameron Parish were essentially destroyed and parts of Lake Charles experienced 6-8 foot deep floodwaters. Overall, however, the loss of life and property was far less than Katrina. Nonetheless, because of the southeasterly approach of the hurricane, a storm surge of at least 9 feet extending along the entire Louisiana coast preceded or accompanied landfall. This surge breached the temporary repairs of the New Orleans floodwalls, reflooding the Gentilly and Lower Ninth Ward neighborhoods, and overtopped hurricane protection levees, flooded coastal communities and displaced residents from Jefferson to Vermilion parishes.

Important infrastructure also received severe damage, particularly from Katrina. This included roads and bridges, notably the Interstate 10 twin causeways over eastern Lake Pontchartrain, electrical, telecommunications, health care, educational, water supply, sewerage, and drainage systems. Not only is recovery of this infrastructure extremely costly, but it also is a significant impediment to repopulation and economic and social recovery. Infrastructures supporting the two most important sectors of the coastal economy—fisheries and oil and gas production, transportation and refining—were also severely damaged. The Mississippi River at Southwest Pass and Port Fourchon were operational one week after Katrina, but with restricted access. The Mississippi River Gulf Outlet and the Inner Harbor Navigation Canal were severely impacted. Economic losses to commercial fisheries landings and sport fishing expenditures exceeded $200 million, not counting the effects on infrastructure (docks, vessels, processing facilities, oyster grounds, etc.) The reduction in refinery output caused a surge of gasoline prices that brought the storm impacts of the hurricane on the energy industry home to citizens across the country. Disruption of production from the offshore oil and gas fields tightened the supply of feedstocks and stimulated a release from the Strategic Petroleum Reserve, some of which is located in coastal Louisiana.

The vulnerability of New Orleans to catastrophic flooding as a result of a major hurricane was well publicized prior to Katrina through various media, including feature articles in *Scientific American*[16], the *Times-Picayune*[17], and *National Geographic*[18] as well as in the scientific literature. Many of the worst fears expressed in these articles were realized in Katrina, except that loss of life was less than many expectations because over 80% of the residents had evacuated. Still, the inability or unwillingness of many residents to evacuate led to dramatic rescues, overwhelmed shelters, and personal tragedies graphically conveyed by the news media. Particularly challenging now are the enormity of the clean-up, repair, and demolition requirements and the dependence of recovery on the nexus of infrastructure, services and employment opportunities.

Key to the immediate recovery and longer-term options for impacted communities are the on-going governmental decisions concerning financial relief, insurance-linked rebuilding requirements, zoning, infrastructure capacity, disaster preparedness and evacuation measures that affect the extent to which displaced individuals return and rebuild. We recognize that these will be influenced by and, at the same time, influence decisions concerning the hurricane protection system, although in this report we only address storm damage reduction as it relates to navigation infrastructure and coastal landscape restoration.

Coastal Environments

Based on preliminary estimates by the U.S. Geological Survey derived from Landsat images taken in September and October 2005, approximately 100 square miles (259 km^2) of wetlands in the Mississippi deltaic plain were transformed into shallow open water by the hurricanes.[19] Hardest hit areas were the interior marshes of Breton Sound (39 square miles) and the active Mississippi Delta (14 square miles), while the remainder of the losses were scattered through the Pontchartrain, Pearl River, Barataria and Terrebonne basins. It is premature to conclude that these wetland losses are permanent because regrowth from roots and rhizomes and re-vegetation of mudflats may occur during the next growing season or two, as was observed after Hurricane Andrew in 1992. Prior to Katrina the rates of land loss in the Breton Sound basin and Biloxi marshes east of the river were lower than in most other parts of the Louisiana coast.

Based on rapid and preliminary assessment by several authors of this report, the more saline marshes on either side of the Mississippi River appear physically intact after the storms, although there was some erosion of marsh margins facing open bays by waves. Brackish marshes landward of the saline zone and along eastern Lake Pontchartrain also show little signs of physical disruption, although the vegetation currently appears brown as a result of inundation by higher salinity waters. The most severe marsh disturbance was in the lower salinity (often referred to as intermediate) marshes and tidal freshwater marshes. The highly organic soils of these wetlands were torn by the combined effect of storm surge and wave energy, resulting in “marsh balls” and larger rafts of marsh turf deposited by the receding floodwaters. While the hurricane storm surge eroded or uprooted large areas of wetlands, it also deposited huge quantities of muddy sediments (4-10 cm [1.5-4.0 inches] thick in most places), released by wetland erosion or resuspended from bay bottoms or the inner shelf, in the remaining wetlands and shallow ponds. This has a beneficial effect on the very important process of soil accretion in the subsiding wetlands.

The heavily impacted Breton Sound basin is the recipient of the Caernarvon freshwater diversion, which has been periodically delivering 2,000 to 4,000 cfs (55-110 m^3sec^{-1}) of river water since the early 1990s. These flows were too low to provide other than a very localized subsidy of sediments to the wetlands. Preliminary observations indicate that those soils receiving the highest amount of sediment from the diversion were less susceptible to the physical disruption found in adjacent, more organic marshes. The diversion is designed to handle 8,000 cfs but flows have been constrained because of stakeholder objections to salinity changes. However, given the urgency of restoring basin wetlands, the State has apparently decided to maintain higher flows through the diversion to assist marsh recovery by flushing out salts, depositing sediment in shallow mud flat areas (thus encouraging them to re-vegetate), and providing nutrients to stimulate plant growth.

Direct impacts from Hurricane Rita were not as severe as those from Katrina, but extended through the Barataria and Terrebonne basins and into the Acadiana bays and Chenier Plain to the west. Rips to the root mass of intermediate and fresh marshes, although less severe than those in Breton Sound, were noticeable in the Barataria and Terrebonne basins and the storm appeared to reactivate scars attributable to Hurricane Lili in 2002 in western Terrebonne and Cote Blanche Bay. Rita's impact on the wetlands of the Chenier Plain may not be fully evident for months as marsh management systems, consisting of earthen dikes and control structure to manage water levels, held salty (12-17 psu) storm water within the landscape. Salt and sulfide impacts on vegetation in these areas will take longer to develop than physical damage of the storm, however preliminary reports suggest significant areas of freshwater wetlands have been lost.

Responses of coastal landscapes demonstrate both the vulnerability and resilience of these ecosystems to hurricane impacts:

- Hurricanes provide important supplements of sediment to coastal marshes, as do river pulses and more regularly occurring tropical storms and cold front passage.
- Storm surges also bring salt into previously fresh wetlands making them susceptible to salt and sulfide toxicity. While the recovery of marsh vegetation will not be fully known until at least the next growing season, the pulse of saline waters moving into fresh areas is not necessarily fatal to fresh marsh plants if there is sufficient rainfall or runoff to flush the salts from soil matrix. Damage will probably be less where there are not artificial barriers to prevent the runoff of salt waters from the landscape.
- Wetland soils with higher bulk density (i.e., more inorganic or mineral sediment) seem more resilient to physical disruption. Lower bulk density soils are more buoyant during wave action and storm surge, resulting in fragmentation, dispersal and increased open water. Some of the mats of soil and vegetation may survive and grow in their new locations. In the Caernarvon recipient area, there are extensive areas of exposed, perched mudflats, which probably can be re-vegetated.

Even at this early stage of assessment, several implications for the long-term viability of the Louisiana coastal wetlands are apparent:

- The Louisiana coastal landscape developed over the past 6,000 years in the face of repeated hurricane assaults, but the current deteriorated condition has made some wetlands more susceptible to the destructive forces of hurricanes.
- Storm events, through the import and redistribution of sediment, make an important contribution to the sustainability of wetlands in the face of sea-level rise and subsidence.
- Future restoration efforts that seek to provide flood protection benefits by including extensive landscape restoration (marsh, swamp and low ridge) should emphasize projects and locations that will be resilient (i.e. resist damage or recover rapidly) in the face of storm impacts.
- Restoration planning that includes approaches building or nourishing wetland substrates with sediment will result in more resilient restoration outcomes.

LESSONS LEARNED

Coastal Landscapes and Storm Surge Vulnerability

The height and landward extent of storm surge from Hurricane Katrina were unprecedented in the recorded history of the region. While Katrina's inundation of Greater New Orleans and the Mississippi Gulf Coast received prominent attention, storm surge flooding of the central and southwestern Louisiana coastal zone by Rita was less well reported, but also apparently exceeded previous records. Quite understandably, this brings into question the degree to which storm surge flooding was exacerbated by the deterioration of coastal wetlands and barriers that has occurred, and the corollary question of how a restored landscape might affect storm surge and inundation.

Barrier islands, shoals, marshes, forested wetlands and other features of the coastal landscape can provide a significant and potentially sustainable buffer from wind wave action and storm surge generated by tropical storms and hurricanes. Anecdotal data accumulated after Hurricane Andrew suggest that a storm surge reduction along the central Louisiana coast of about three inches per mile of marsh.[20] In a somewhat analogous event, damages from the 2004 Indian Ocean tsunami were reduced by the presence of an extensive, intact mangrove fringe.[21]

Emergent canopies such as provided by forested wetlands can greatly diminish wind penetration, thereby reducing the wind stress available to generate surface waves and storm surge.[22] The sheltering effect of these canopied areas also affects the fetch over which wave development takes place. Shallow water depths attenuate waves via bottom friction and breaking, while vegetation provides additional frictional drag and wave attenuation[23] and also limits static wave setup[24]. Extracting energy from waves either by breaking or increased drag in front of levees would reduce the destructive storm wave action on the levees themselves. Indeed, where there were trees in front of overtopped levees they received little structural damage from Hurricane Katrina.[25]

Geologic features such as barrier islands or the land mass and vegetated canopy associated with marshes and wetlands can block or channelize flow. These areas have increased drag that will slow water velocities[26] and may reduce the speed at which storm surge propagates. Together, these effects can significantly restrict the volume of water that is able to reach back-barrier areas and, consequently, that is available to inundate the mainland. Conversely, steady-state, vertically integrated storm surge theory predicts that the water surface slope (and consequently the inland surge elevation) is proportional to the wind stress divided by the water depth.[27] If an offshore circulation develops near the bottom of the water column, drag actually increases the surface slope (and surge) over the two-dimensional case.[28] Laboratory data comparing wind-driven setup of water level in a channel with a smooth bottom to one with artificial drag elements added in the water column clearly shows the increased water level setup in the later case.[29] While hurricanes have relatively short time scales (on the order tens of hours), the establishment time for steady state in shallow water can also be rapid (order of hours). Therefore, this general theory used in engineering practice comprises the basis for much of the current levee design in the New Orleans area. The relative role of water delivery and setup in determining storm surge is highly dependent on the geometric scales and configurations of the coastal land/vegetated areas and on the duration of the storm.

As discussed later, depending on the rate of relative sea-level rise, coastal wetlands can maintain a near sea-level landscape by trapping sediments or accumulating organic material. On the other hand, if Louisiana coastal wetlands deteriorate and disappear, the substrate undergoes wave erosion, eventually deepening to an elevation of approximately -10 to -12 feet. (-3 to -4 m) in open bays, such as Lake Borgne. The effects of this 3 to 4 m elevation difference on 6-8 m storm surges and waves is likely greater than those of the resistive fabric of wetlands. Preliminary results from storm surge models (Figure 4) show that if the wetlands east of the MRGO, GIWW and Lake Borgne are replaced by open water of depth 2.5 m (8 feet), the Katrina storm surge would be 1-2 m (3 to 6 feet) higher along St. Bernard Parish and eastern New Orleans.[30] In this case, the enhanced supply of coastal ocean water was more significant than the reduced water surface slope caused by deeper water depths.

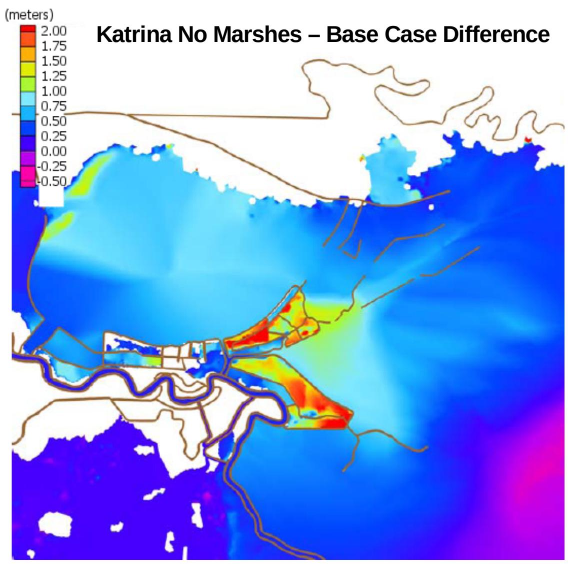


Figure 4. Differences in computed storm surge for Hurricane Katrina with the disappearance of wetland landscapes east of MRGO.[30]

Even though wetlands lost in the past would have moderated the 20-foot storm surge that advanced from the east to flood eastern New Orleans and St. Bernard Parish, hurricane protection levees may still have been overtopped. Nonetheless, looking forward, it is our opinion that continued wetland loss in this region would increase the vulnerability of levees to overtopping by storm surges and attack by wind waves and, conversely, that increasing the extent of marshes and forested wetlands would provide a self-sustaining complement to structural protection. In any case wetlands are essential to the coastal landscapes required between open waters and protection levees, working in concert with the levees to provide hurricane protection. While there is compelling evidence of this in principle, more quantitative determination of the effects on storm surge and waves is needed for the design of storm protection structures, navigation channels and restoration features.

Navigation Channels and Levees

Complex interrelationships among coastal ecosystems, flood protection systems and navigation channels were revealed by hurricanes Katrina and Rita. Among the most prominent were the consequences of navigation canals perpendicular to the coast, including the MRGO, Houma Navigation Canal and Calcasieu Ship Channel. These channels traverse the estuarine gradient and can more rapidly convey storm surges to ports and cities.

Preliminary modeling results suggest that storm surge from the Lake Borgne area was accentuated by the funneling effect of the spoil bank/levees of MRGO and GIWW, ultimately overtopping them to propagate up these channels into the Inner Harbor Navigation Canal.[25] This affected flooding in St. Bernard and eastern Orleans parishes in several ways. Models showed that, although the maximum computed storm surge declined from MRGO into the IHNC, it reached 3-5 feet higher than the maximum computed surge along the south shore of Lake Pontchartrain (Figure 5), and arrived roughly a half hour sooner. Models also estimated currents exceeding 8 ft/sec (2.5 m/sec) in the channels—sufficient to cause erosion of earthen works—as the surge propagated up the channel.[31] The experience of Katrina is that maintaining the integrity of earthen levees and floodwalls is at least as important as their elevation. Maximum surge levels last just a few hours, limiting the amount of over-weir flooding, while breaches allow floodwaters to pour in with more force over a longer time and impede removal of floodwaters.

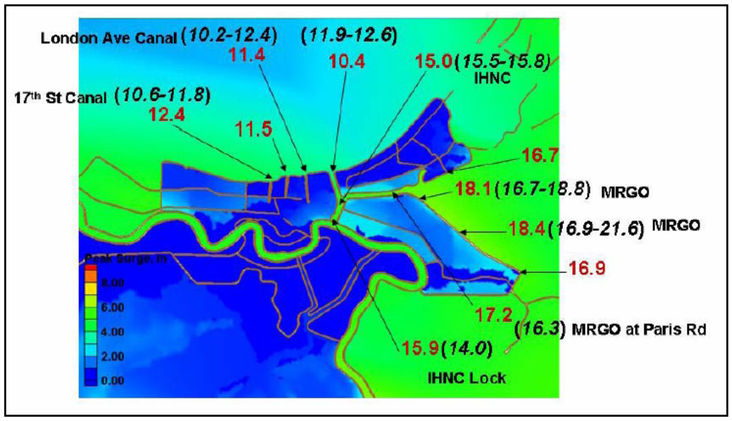


Figure 5. Maximum computed storm surge (red, water elevations in feet relative to NGVD29 datum) and high water marks (black, relative to NAVD88) in the metropolitan New Orleans region.[25]

The marine transportation system has and will continue to make a contribution to the nation's economic well being. At the same time, channels that promote commercial transportation create access for coastal ocean forces, by both routine and storm-event processes that may increase risks to wetland ecosystems, natural resources, and human communities. Navigation channels alter coastal processes, such as astronomic and meteorological tides, the erosive forces of currents, waves, and the distribution of salinity. Some deep, straight channels and associated levees conversely convey freshwater and sediment resources directly toward the Gulf, bypassing coastal wetlands and barriers along the Gulf shoreline. In this way, sediment and sand resources are lost from the system, reducing the resilience of the wetland and barrier systems.

Levees and spoil banks also affect storm surges and survival of the coastal landscape. As discussed earlier, the spoil banks along MRGO and GIWW form the infamous "V" funnel that accentuated the storm surge from Katrina. The construction of levees and drainage systems has allowed a century-long extension of development into swamps and marshes. The elevations of these drained areas then rapidly dropped as soils dewatered and oxidized, forming the sub-sea-level bowls that retained floodwaters. Smaller levees and berms built for water management can result in impoundment of saline floodwaters. The spoil banks of navigation channels and myriad smaller oil and gas canals also reduce sediment inputs and thus wetland survival.

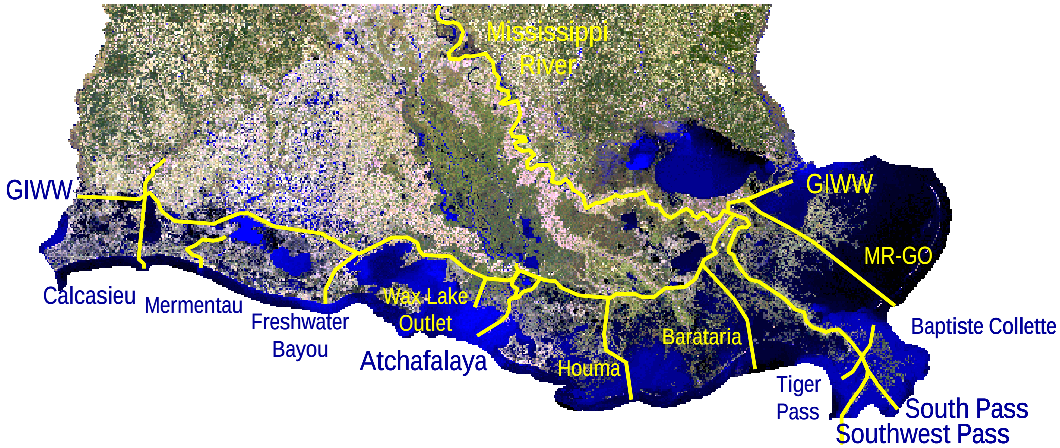


Figure 6. The Federally maintained navigation system of coastal Louisiana.

On the other hand, navigation channels, existing oil and gas canals, and their associated levees and spoil banks may offer opportunities to integrate storm protection and coastal restoration. These artificial features of the coastal landscape might be modified to distribute freshwater and sediment resources across the landscape. Thus, regional water and sediment management that includes the contribution of such navigation features and natural and artificial ridges should be included in planning coastal restoration. An example might be the operation of the proposed navigation lock on the Houma Navigation Canal to regulate salinity and water levels in the wetlands. Elevated dredged material deposits sidecast along navigation channels do provided some hindrance to storm surges but can also limit important tidal exchanges that sustain adjacent wetlands. Analysis of the relative effects of and management opportunities for navigation and levee/spoil bank features must consider site-specific conditions that can only be determined during the detailed assessment of project and system-wide plans.

Rebuilding damaged levees along MRGO

CHALLENGES MOVING FORWARD

Sustainability of the Landscape

Following Hurricane Katrina some commentators, including both public figures and scientists, questioned whether the landscapes of coastal Louisiana could survive the 21st century, whether New Orleans would survive only as an island surrounded by miles of open water[32] or should be abandoned altogether,[33] and whether coastal wetlands and barrier islands should be restored.[34] Given the high rates of subsidence and the specter of accelerated sea-level rise as a result of global warming, doubts about the sustainability of coastal restoration and hurricane protection solutions are not unreasonable. By "sustainability" we mean the ability of the coastal landscape to persist during this century. Considerations beyond that exceed the horizon for planning investments and confront large uncertainties concerning the global climate trajectory.[35]

Louisiana coastal wetlands have been subjected to high rates of relative sea-level rise (RSLR) for centuries due to subsidence associated with crustal downwarping and compaction and dewatering of deltaic sediments as well as short and long-term variations in the level of the sea itself. Some Louisiana wetlands have adjusted, and still survive in areas where measured rates of RSLR during the late 20th century are over 1 cm (0.4 inch) per year;[36] but others are experiencing stress which may in part be driven by the RSLR. By one estimate salt marshes with high sediment loading (such as those in Louisiana) should be able to build soil to keep pace with RSLR of at most 1.2 cm (0.5 inch) per year.[37] This estimate is based on tidal flooding regimes being the main determinant of sediment accretion. In Louisiana high-water events associated with frontal passages, tropical storms and hurricanes deliver most of the sediment deposited in salt marshes,[38] indicating that they may be able to survive higher rates of RSLR. This may also be true if inputs of fluvial sediments are large (Figure 7) as is evident in the Birdfoot delta. Eustatic factors are projected to result in a sea-level rise of approximately 17 cm (7 inches) by the year 2050 and 40 cm (16 inches) by the end of the century, although there is much uncertainty surrounding sea-level rise rates projected

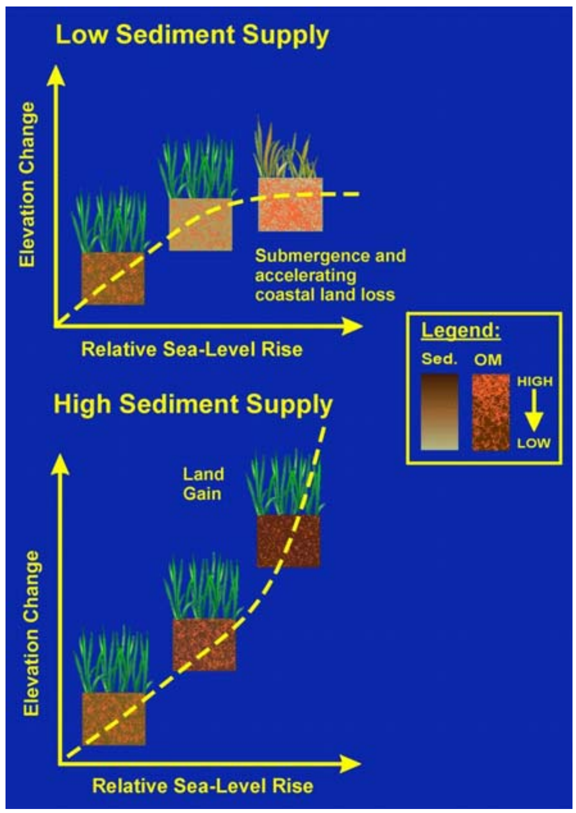


Figure 7. The ability of wetlands to be maintained with rising sea level depends on sediment supply.[35]

for later in the century.[39] If high rates of subsidence continue, this suggests that many Louisiana marshes may deteriorate markedly under future sea-level rise conditions as rates increase beyond their maximum ability to build soil, if there is not sufficient sediment input. In the past sediment would also have been periodically supplied during major river floods.

Predicting wetland sustainability in the 21st century is confounded by two important uncertainties:

1. Will current rates of subsidence continue in the future? Recent analyses[40] suggest that extensive oil and gas extraction from subsurface reservoirs during the 1960s and 1970s may have led to local rates of subsidence two to three times higher than in previous decades. The extraction may have reactivated faults resulting in subsidence as well as reservoir compaction,[41] but the timing of fault movement or compaction relative to mineral extraction has yet to be clearly identified. Thus, it is possible that locally high subsidence rates identified in recent decades may not continue in the future, thereby giving coastal wetlands a greater chance of survival.
2. Is there adequate sediment supply to sustain the coastal wetland landscape? Reworked sediment undoubtedly contributes to the sustainability of existing Louisiana wetlands, especially those with more mineral soils. Where organic processes alone dominate soil accumulation, wetlands can frequently maintain their elevation. But, as evidenced in Hurricane Katrina, these soils are vulnerable to physical damage during storm events. The reduction in sediment load of the Mississippi River due to upstream management[42] reduces the sediment available, but recent studies[10] of various restoration scenarios using existing river sediment resources show that with efficient use these sediments can rebuild and sustain an extensive wetland area.

If some Louisiana wetlands have survived the high subsidence-induced rises in water level and limited river sediment input experienced in the second half of the 20th century, current evidence suggests that future sea-level rise alone may not increase rates of land loss. More likely, a new equilibrium will be reached in which slower rates of wetland losses are balanced by small gains, albeit with a much smaller total ecosystem area.[43] The challenge to restoration is enhancing that wetland area by more efficiently managing the available sediment resource. This will depend on a combination of river diversions that use gravity flow and rely on self-design of the wetlands in the recipient basins, and creative use of dredged materials and pumped sediment slurries to build structural platforms that can be sustained by diversions over the long term. There is still time to plan and execute such a restoration approach through the 21st century. If during the latter half of the century, sea-level rise is accelerating much faster than most of the present forecasts, for example as a result of rapid loss of polar ice, then restoration efforts would be re-evaluated in consideration of the costs, technologies and scientific understanding and social goals that will exit at that future time. Of course, this would also force major choices of protection and retreat in many other coastal regions of the Nation. In any case, we doubt that New Orleans could be effectively protected without some surrounding coastal landscapes, even though some pundits suggest that New

Orleans might exist as an island surrounded by open water and protected by soaring levees.

Expanded Hurricane Protection

As made clear by the President's announcement, initial efforts to improve hurricane protection will focus on strengthening existing levees and floodwalls protecting urban areas (Figure 8). An in-depth analysis of the feasibility and environmental consequences of expanded hurricane protection (EHP) is beyond the scope of the framework developed here. The Corps of Engineers is currently assessing the feasibility of such an expanded and enhanced protection system, the details of which are not yet in the public domain. Based on general information made available to the working group we discuss four possible protection strategies and their implications for restoration and conservation of coastal ecosystems:

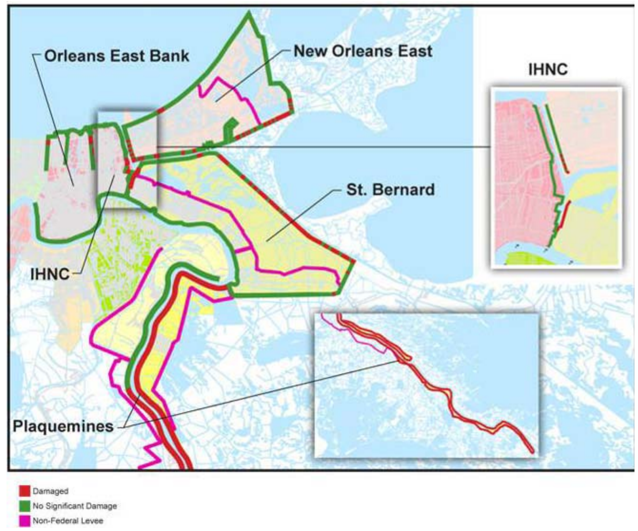


Figure 8. Affected flood protection systems in Greater New Orleans, including damaged federal (red) and non-federal levees (magenta).[25]

- Strategy 1: Protect only New Orleans and larger population centers by strengthening existing protection systems without providing additional flood protection farther out in the coastal zone. Restoration would focus on the same activities that were being planned before the hurricanes, but with more attention to the coastal landscapes adjacent to urban areas.
- Strategy 2: Construct storm surge barriers along the inner coastal zone between population centers and the outer coast. Openings in the system for water management could provide potential opportunities for restoration and conservation but altered hydrologic conditions inside the barrier could also have potential negative impacts (e.g., changes in salinity and tidal regimes and reductions in soil accretion due to sediment starvation) that should be considered. Opportunities would still exist for restoration outside the barrier system.
- Strategy 3: Establish a first line of defense along the existing coastline, e.g. by maintaining barrier islands, to dampen storm surges. This would potentially minimize the destructive impacts of hurricanes, but modeling should be conducted to quantify the likely benefits.[44] These "speed bumps" would be far from the urban areas with extensive open water and wetlands behind them and, when overtopped, may not adequately reduce the storm surge to prevent extensive damage farther inland. A benefit of outer speed bumps is that they could provide opportunities for landward restoration and continue to allow for sediment

deposition during storms. However, these barriers would be highly erosive features requiring long-term maintenance.

- Strategy 4: Combine elements of strategies 2 and 3. This would provide the greatest opportunity for both protection of populations and conservation of coastal landscapes. The outer ring of speed bumps limits hydrologic impacts to existing wetlands and also provides opportunities for additional restoration in areas behind the features. The inner series of partial barriers (scenario 2) would provide the same opportunities as described above but synergy between the two protection systems would potentially allow for additional restoration opportunities outside of the inner ring of barriers.

Table 1 shows how the environmental consequences and opportunities provided by some of the flood protection plans under consideration can be generalized as part of a screening process. This is meant to illustrate the kind of considerations that must be undertaken in detail rather than to provide a definitive assessment. We acknowledge that considerations of cost, effects on navigation and other interests must be part of such a detailed assessment.

Table 1. Screening of possible hurricane protection measures for synergies and conflicts with ecosystem restoration.

Measure	Affects Large Area of Ecosystem	Affects Tidal Processes	Other Considerations
Rigolets/Chef Menteur Pass floodgates	Yes	Yes if they affect cross-section	Improved freshwater management
Heightened levees around Greater NO communities	No	None	Footprint impact
Outer defense barrier in St. Bernard-Orleans Parish	Moderate	Yes, unless permeable	Opportunity for treated sewage effluents to promote swamp in interior
Hwy 90 barrier Barataria basin	Moderate	Somewhat	Could be designed to improve exchange
GIWW barrier Barataria basin	Yes	Yes	Multiple exchange points and overflows would be required, decreasing tidal exchange over extensive interior wetlands
Morganza-to-Gulf in Terrebonne basin	Yes	No	Operation of environmental structures needs definition
Houma Canal lock	Yes	Yes	Potential for fresh water distribution
Houma-Morgan City barrier	No	Minor	Follows existing barrier
GIWW barrier west of Wax Lake Outlet	No	Minor	Provide exchange to contained wetland areas and streams

Applicability of the Dutch Model

There has been considerable discussion concerning using the Dutch experience as a model for flood protection in Louisiana. The Dutch model relies on massive coastal defenses (dikes) at the outer perimeter, with large floodgates and locks controlling the aquatic environments within this perimeter. While there is much to be emulated in its systematic approach to managing flood risks, significant difference must be considered before adapting the Dutch model to coastal Louisiana, including the following:

- The Netherlands sits on a more stable geological foundation. Rates of subsidence are much lower than in coastal Louisiana. Dikes sink less rapidly not only because of lower regional subsidence but also because underlying sediments do not compress as much under their weight.
- Maximum storm surges experienced from tropical cyclones that threaten the Louisiana coast exceed those due to the North Sea winter storms that threaten the Netherlands.
- Implementation of the flood protection system in the Netherlands has resulted in significant environmental degradation. Over 90% of wetland habitat has been lost and there are pervasive water quality problems behind dikes.
- The Dutch system requires a commitment of resources that is large, energy intensive, and thereby probably increasing over time.
- Minimizing risks for the Netherlands as a whole has been a priority of the government and is supported by its citizens over many decades. Indeed for centuries the Dutch have been reclaiming land from the sea. Consequently, a large portion of the very densely populated Netherlands is at risk from river flooding or storm surges. Notwithstanding the extensive damages from Katrina and Rita, policy makers should evaluate whether the costs (financial and environmental) of a "Dutch solution" are justified in Louisiana, which has a coastline three times as long. Other alternatives should be considered that protect smaller areas against extreme hurricane events and rely elsewhere on non-structural approaches such as elevated buildings or managed retreat.

Risk Management Considerations

A broader risk management perspective in the wake of Hurricanes Katrina and Rita should be adopted in place of a singular focus on structural protection works. This means recognizing and managing risks to the landscape as such works are considered, recognizing and managing risks to communities, and managing risks in consideration of future external forces. Each is discussed in turn.

The construction of an extensive outer hurricane protection system has implications for areas landward of the levees. Hurricanes are extremely important in providing input of resuspended sediments to coastal wetlands and many coastal wetlands (in the absence of river input) would probably not survive without sediment input due to hurricanes and other episodic inundation.[38,45] Many interior wetlands of the Mississippi delta already have an accretion deficit.[46] Also, saltwater may be trapped when hurricane protection levees are overtopped by storm surge. With continued subsidence and a deficit in soil accretion, both wetlands and the built environment landward of levees are threatened by periodic saltwater inputs from storms. Ultimately, the whole area behind some levees may have to be placed under forced drainage to avoid total inundation. Heavy rainfall associated with hurricanes may lead to flooding when floodgates are closed to prevent storm surges. In other words, the "bowl effect" conundrum evident in New Orleans could be expanded to other areas. The assessment of such risks and their consideration in plan formulation and evaluation must be extended beyond the initial screening level analysis in Table 1.

Investment in hurricane protection should be focused on where the populations and communities will likely be located in the future. Even then, the costs of such investments will need to be justified by the risk reduction benefits that will be realized from that cost, in comparison with other approaches to risk reduction. Current and future configurations of communities and movements of people away from or into coastal areas will determine the size of the population and activities to be protected.[47] Given the time required to plan and build an EHP system, it is likely that some coastal communities will decline or disappear by phases of attrition caused by "disinvestment" of each element of coastal capital—businesses, insurance industry, communities (as they reduce services due to tax revenue declines), and individual families (as they encourage their children to move inland). Such a "fading away" had already begun before Hurricanes Katrina and Rita.[48] It is inevitable that in some areas decimated by these storms many of the residents will not return. Although more are expected to return, at the end of 2005 only 12% of the pre-Katrina inhabitants of St. Bernard Parish were residing there, for Plaquemines Parish, this was 50% (Figure 9).[49] Depending on how this process is managed will obviously influence hurricane protection decisions.

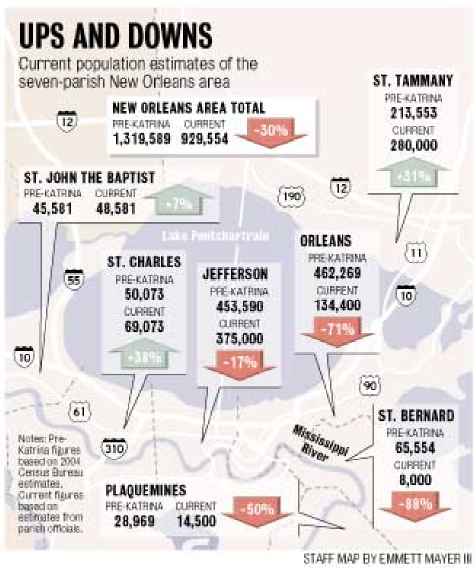


Figure 9. Population estimates for the Greater New Orleans area in late December 2005.[49]

Forced relocation of whole communities is seldom if ever accomplished,[50] so a first consideration is usually given to what could be done to enable coastal communities to remain in place. Elevating structures to previous flood levels, rebuilding with water resistant materials, building codes that require coastal storm resistance, removing structures from flood zones when justified are all actions that can allow communities to persist in an area. They should be coupled with mandatory flood insurance to indemnify losses from significant flood events. Multiple FEMA programs assist mitigation approaches, including: (1) the Community Rating System (CRS) of the National Flood Insurance Program (NFIP) that rewards communities that mitigate by reducing their flood insurance rates; (2) the Base Flood Elevation requirements of NFIP and imposed through local building ordinances; and (3) the Project Impact initiative implemented with the collaboration of the Institute for Business and Home Safety. Many insurance, financing and rebuilding decisions currently await FEMA's new Base Flood Elevation maps.[51] The American Meteorological Society Policy Forum on Hurricane Katrina strongly advocated such non-structural mitigation for Hurricanes Katrina and Rita-impacted areas.[52] A recent report demonstrates a $4 saving for every $1 spent on mitigation,[53] although extending these results from the sample of mitigation actions to a general mitigation program should be done with extreme caution.

If retreat is the way in which the risk exposure is resolved, then current means of assistance for the coastal refugees could be extended and other safety nets created to ease the transition. One method may be to relocate extended families and even friendship groups into the same communities and to communities that might have similar resource extraction potential (such as has been done by and for other immigrant refugee groups such as the Vietnamese). Drawing upon the experiences of earlier displaced groups, some government support will be required for a successful retreat from some coastal communities.

Investments in EHP would be expected to yield benefits over long periods of time, therefore possible changes in conditions that might occur should be considered as alternative future scenarios in any assessment of an EHP strategy. The locally high rates of subsidence experienced in the late 20th century may decrease because the human activities that caused them (fluid withdrawals, drainage of wetland soils, etc.) may be abated or increase because of the mass loading by larger levees. Thus, planning for an EHP must consider the sensitivity of designs to future subsidence and, thus, relative sea-level rise across the coast. Also, potential climate changes have a number of implications for an EHP system. These include accelerated sea-level rise, warmer temperatures, and changes in local freshwater runoff.[54] Some climatologists forecast increased hurricane frequency and intensity over the coming decades, either as a result of climatic cycles or global warming, which some recent analyses suggest this may already be occurring.[55] Rarity of freezing temperatures along the coast (there has not been a killing freeze at the coast since 1989) would allow the spread of mangroves, which are more effective than marshes in reducing storm surge.

Economic conditions and energy resources will not remain throughout the life of the system as they were before the hurricanes. However, given that an EHP system will likely take decades to complete, consideration must be given to how construction and maintenance of the system will be affected by significant changes in economic conditions or changing energy prices. Because construction and maintenance of earthen works and operation of pumps are energy intensive, their costs might increase greatly. Thus, careful analyses are required of the feasibility of such energy intensive approaches to both flood protection and restoration in contrast to approaches that utilize the energy of natural forces. If costs do rise what will be the commitment to maintaining such a system? For example, mainline Mississippi River levees are currently below design grade and section. Similarly, interest in funding the EHP operations and maintenance may dwindle over time. Development that occurs within expanded levees could become move vulnerable over several decades.

Integration of Restoration, Flood Protection and Navigation

The Louisiana coastal region is a montage of barrier islands, natural ridges, wetlands (marshes, mangroves and swamps), shallow bays, oyster reefs, canals, channels, levees, roads, port facilities and water control structures. Land uses include energy development support and agriculture. Human habitation is concentrated in some areas, but is more sparsely dispersed over virtually the whole landscape. The economic and environmental services to the region and the Nation that flow from this montage are the result of the interdependence among all these coastal elements. Despite these clear inter-relationships, prior to Katrina planning for navigation, hurricane protection and coastal restoration were largely separate activities. Interdependence and incongruence were acknowledged in principle, but there was no scientifically rigorous analysis of the linkages in investment plan formulation and evaluation or in permitting.

In the Coast 2050 Plan[9] restoration features were fit together as in a puzzle by intuitive spatial planning within subprovinces. The 2003 LCA Draft Plan[10] employed more quantitative modeling to address coherence among restoration features. Future planning will have to improve on these approaches, with the additional complexity of considering protection for communities and infrastructure while integrating coastal ecosystem restoration with those goals. Flood protection, navigation and ecosystem restoration features must be appropriately sequenced and built around certain "foundation" features that are essential to the success of restoration within a subprovince.

The many ports and channels that form the marine transportation network have already had adverse effects on wetlands and storm risks. Planning and operation of these facilities clearly must now be integrated with storm protection and restoration requirements. For example, if, as the NRC report recommended, consideration is given to large-scale diversions above the Head of Passes, what new investments would be required to accommodate ocean going traffic?

In addition, subprovince plans must be linked across the coast in order to optimize the allocation of limited freshwater and sediment resources and to effectively use available financial resources. Not all regions and settlements can be protected or restored to the same degree, or at affordable costs.

These realities demand early and continuing engagement of local interests who will undoubtedly demand equal and maximum protection. Indeed, the NRC report stressed that formidable constraints confront coastal restoration as a result of stakeholder interests, whether it is demanding protection of endangered communities, opposing alteration of salinity gradients in order to maintain existing distributions of oysters or sport fisheries, or allocating the burden for mitigating damage (e.g., oil and gas industry or wildlife managers). The damage inflicted by the hurricanes has altered some of these stakeholder perspectives, goals, and influences. Nonetheless, difficult and not universally popular decisions must be made and these decisions should be informed by the best available science, a full recognition and acknowledgement of uncertainties, meaningful participation of stakeholders, and an integrated planning and analysis system that provides the information base for such decision making. This will require an approach that is not only integrated, but also is adaptive, leads to sustainable outcomes, and avoids serious unintended consequences.[56]

ADAPTING RESTORATION PLANS

After Katrina and Rita, there has been an understandable attention to reducing the prospect of future storm damages. This focus has resulted in budget commitments of approximately $3 billion to replace and improve upon the structural works that were protecting New Orleans before the storms. The hurricane protection infrastructure will be restored and more reliable designs will be put in place. Also, there are commitments to advance the implementation of storm damage reduction projects in other areas of the Louisiana coast and to advance the study of restoration alternatives. These multiple protection projects are what we start from: the "without action" condition includes significant structural improvements to get to the so-called Category 3 protection for the most populated areas of the coast.

Clearly, much has changed in recent months. The LCA and predecessor reports prepared before Katrina and Rita were focused on the ecological benefits of landscape restoration. Now there is more explicit attention to how landscape restoration can be integrated with storm damage reduction. This said, the existing reports, as well as the vast scientific literature on the region, provide a wealth of background knowledge that can rapidly advance a well-informed investment and management program. Nonetheless, the existing agency reports are not sufficient guides to comprehensive and integrated action. Actions proposed under the LCA Study that had priority before the storm might not still be priorities, especially since that study did not include any explicit analysis of how coastal landscape protection and restoration could contribute to storm damage reduction and infrastructure protection. The lessons learned as reviewed above should inform the initial scoping and screening of all features and projects: (a) in determining priorities for near-term investments in restoration that also contribute to storm damage reduction and are synergistic with navigation needs; (b) for considering structural approaches to storm damage reduction beyond the current commitments (as discussed earlier); and (c) for long-term planning within the four units, or subprovinces, along the Louisiana coast.

Screening Near-Term Restoration Features

The near-term LCA Plan[11] includes five "near-term critical restoration features" that can be implemented within five years and for which planning is already underway (Table 2). Ten additional near-term restoration features that provide restoration opportunities within the next ten years are also identified for further investigation. Both classes of near-term features should be reassessed within the context of integrated coastal planning to ensure that the limited resources (e.g., fresh water, sediments and money) are used to afford timely restoration for ecosystem benefits, and now also for storm protection.

Because barrier shorelines, ridges, marshes and coastal forests are at or above sea level, they can contribute to flood protection by limiting wave attack on levees and, in some cases, attenuating surge elevation relative to open water areas. While, as described earlier, specific quantification of these effects is not possible without geographically explicit studies, available competent models can be employed to strategically place restoration features that contribute to the protection of vulnerable areas. An example of how the near-term features included in the LCA Plan might be screened for their contribution to hurricane protection is provided in Table 2.

Table 2. Example of screening of near-term ecosystem restoration features included in the LCA Plan[11] for relevance to hurricane protection.

Feature	Decreases water depth over large area	Limits fetch (e.g., ridge)	Buffers wind-wave (e.g., forest)	Location re. important infrastructure	Other considerations
Near-Term Critical Ecosystem Restoration Features Included in Plan Authorization					
Small Bayou Lafourche reintroduction	Only in isolated areas	No	No	Distant	Net wetland benefits are minor and distributed
MRGO environmental restoration	For a small area	No	No	Greater New Orleans	Stopping the breach to Lake Borgne would not significantly affect storm surge
Small diversion at Hope Canal	No	No	Potentially	Distant and up-estuary	Depends on diversion size
Barataria basin shoreline restoration	No	Yes	No	Plaquemines and West Bank	Only one section proposed
Medium diversion at Myrtle Grove	Yes	No	No	Plaquemines and West Bank	Depends on diversion size and operation
Additional Near-Term Restoration Features for Further Investigation					
Multi-purpose operation of Houma Canal lock					Primarily for flood protection
Terrebonne basin barrier-shoreline restoration	No	Yes	No	Terrebonne	
Land bridge at Caillou Lake	Moderate area	No	No	Distant from Terrebonne communities	Seaward of existing marshes
Small diversion at Convent	No	No	Possibly	Distant and up-estuary	Depends on diversion size
Amite River diversion canal	No	No	Possibly	Distant and up-estuary	Depends on diversion size
Medium diversion at White's Ditch	Yes	No	No	Greater New Orleans	
Shoreline stabilization at Point au Fer	No	No	No	Distant	
Modification of Caernarvon diversion	Yes	No	No	Greater New Orleans	Depends on diversion size and operation
Modification of Davis Pond diversion	Yes	No	No	West Bank	Depends on diversion size and operation

From the perspective of hurricane protection screening, the Barataria shoreline project and the Myrtle Grove diversion both provide landscape features (barriers and extensive wetlands) that could contribute to protection of Plaquemines and West Bank communities. Bayou Lafourche, however, provides limited wetland benefits distributed over a large area higher in the Terrebonne and Barataria basins and thus provides only marginal flood protection to less vulnerable areas. Similarly, the MRGO bank restoration provides for little increase in wetland area and the hydrologic goal of preventing connection between Lake Borgne and MRGO is likely of limited consequence to large storm surges. The Hope Canal diversion will revitalize coastal swamps, landscapes that can be important to wave attenuation and, in that way, may be a useful proof of concept. However, its location at the upper end of the Pontchartrain basin does not afford protection to important infrastructure or heavily populated areas.

Preliminary perspectives on the other near-term restoration features identified for further investigation include the following:

- Multi-purpose operation of the Houma Canal lock. This feature is already part of a planned protection system.
- Terrebonne basin barrier-shoreline restoration. These outer barriers both limit fetch and storm surge due to their height and could contribute to protection of the Terrebonne Parish communities.
- Maintain land bridge between Caillou Lake and Gulf of Mexico. This wetland area is close to the Gulf and remote from populated areas. Maintaining wetland areas contributes to flood protection but the marginal effect of this project for protection within the context of Terrebonne wetlands may be small.
- Small diversion at Convent/Blind River. This project has similar flood protection considerations as the Hope Canal project.
- Increase Amite River Diversion Canal influence by gapping banks. This project has similar flood protection considerations as the Hope Canal project.
- Medium diversion at White’s Ditch. The nourishment and building of extensive wetland areas using diversions can contribute to flood protection if the diversion conveys significant amounts of sediments and the location of this project within the Breton Sound basin could contribute to flood protection for St. Bernard Parish.
- Stabilize Gulf shoreline at Point au Fer Island. This project seeks to limit erosion on the edge of an extensive wetland area remote from population and thus in itself provides limited direct hurricane protection benefits.
- Convey Atchafalaya River water and suspended sediments to northern Terrebonne wetlands. The extensive wetlands of western Terrebonne had limited storm surge penetration towards small communities between Houma and Morgan City during Andrew and Rita. Nourishment of these

wetlands makes them more resilient to storm impacts and ensures that continued protection.

- Re-authorization of Caernarvon diversion—optimize for marsh creation. This could bolster wetlands adjacent to the urban areas and contribute to flood protection.
- Re-authorization of Davis Pond diversion—optimize for wetland creation. This could bolster wetlands adjacent to the urban areas and contribute to flood protection

We stress that hurricane protection should not be considered an exclusive, or even primary, screening criterion. There will be restoration features needed to ensure the sustainability of the Louisiana coastal landscape in a cumulative way (for example, diversions along the lower river) or to provide important natural resources or other ecosystem services. Hurricane protection should never be the sole reason to restore the Louisiana coastal landscape.

Long-term Planning in the Subprovinces

Pontchartrain Basin Breton Sound (Subprovince 1). Previous LCA planning in this subprovince emphasized features involving river reintroductions into Lake Maurepas and eastern Lake Pontchartrain areas and along the lower river in Plaquemines Parish. Except for the MRGO environmental restoration feature, which has been criticized by many including the NRC, for being oriented more toward sustaining the navigation channel than the ecosystem, very little attention was paid to the Lake Borgne area and the wetlands of St. Bernard and Orleans parishes. Yet, it is these latter areas that proved so important to the Hurricane Katrina storm surge. Clearly, more attention must be paid to sustaining coastal landscapes in this region and storm barriers associated with MRGO and GIWW should be integrated into that planning. Thus far, restoration options have been constrained because of these navigation channels, distances from the river and suburban development. However, the constraints and priorities have been shifted somewhat as a result of Katrina.

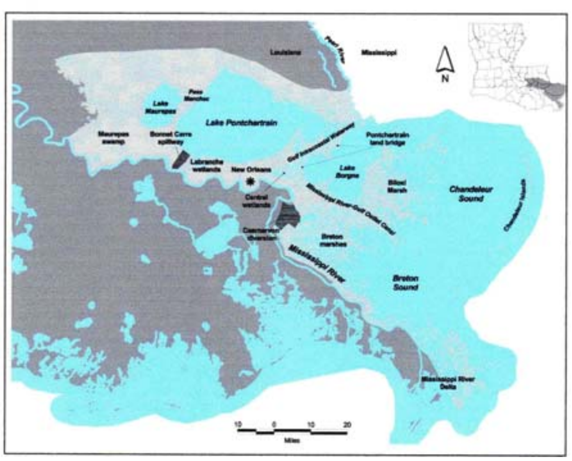


Figure 10. Because of the vulnerability of New Orleans to hurricane surge from the east, coastal landscape restoration in Subprovince 1[11] takes on new importance in integrated planning.

To address the combined needs of ecosystem restoration and storm damage reduction a potential foundation feature for Subprovince 1 is a large, land building diversion into Lake Borgne that uses a shallower, decommissioned MRGO and Bayou LaLoutre as a means of distributing freshwater and sediment to nourish the Biloxi marshes. Additional innovative approaches that should now be considered are: (1) extensive cypress swamp restoration (tied into enhanced freshwater, even treated wastewater, inputs); (2) sediment delivery via pipeline to rapidly develop marshes in the funnel formed at the junction of MRGO and GIWW and the New Orleans East land bridge; (3) acceleration of consideration of increased flows at Caernarvon and new diversions lower in the Breton Sound basin (White's Ditch and California/American Bay); and (4) consideration of the use of dredged material to create marsh in certain parts of the basin not benefiting from diversions. In addition, effects of floodgates at the Rigolets and Chef Menteur Pass on storm surge risk, tidal exchange and the ecosystem must be evaluated, keeping in mind that these barriers will not affect setup or seiching ("sloshing") within the Lake Pontchartrain. At least for New Orleans, storm surge from Lake Pontchartrain must, in any case, be defended using robust levees on the south shore.

Barataria Basin and the Birdfoot Delta (Subprovince 2). The Barataria basin is also very important with regard to hurricane surge vulnerability of the Greater New Orleans area and the basin has suffered more extensive loss of wetlands than the Pontchartrain-Breton Sound basin. The West Bank communities that largely escaped flooding from Katrina would be vulnerable to a major hurricane tracking west of the city that drives a storm surge up the Barataria Bay. Outer hurricane barriers are being considered along two routes. The U.S. Highway 90 alignment would follow an existing hydrologic barrier, but would need to maintain tidal exchange into Lac des Allemands. There is only one point of significant exchange, but floodgates could be designed to maintain or even increase exchange with the upper basin. However, a lower route building on the spoil banks of the GIWW would require numerous floodgates as the system is more open at this location, likely restricting tidal exchange and jeopardizing the functioning and sustainability of extensive existing wetlands between the GIWW and Highway 90. Restoring the integrity of the Barataria shoreline along the Gulf of Mexico would also impede hurricane storm surges entering the basin as well as reduce wave erosion of wetlands in the lower basin. As discussed earlier, the shoreline restoration included among the proposed near-term critical restoration features would begin to re-establish this integrity, but would by itself have little influence on hurricane storm surge.

The foundation feature of this basin is the large-scale reintroduction of riverine freshwater and sediments to rebuild extensive wetlands to both sustain the ecosystem and provide storm damage reduction. Two alternatives were considered at some length in the NRC report: (1) the so-called third delta that will direct sizeable flows through a channel parallel to Bayou Lafourche into both Barataria and Terrebonne basins, and (2) substantial abandonment of the active Birdfoot delta by redirecting most of the river flow onto the inner shelf, thus providing more sediment into the coastal system. There are major scientific uncertainties as well as practical challenges for both of these approaches, including: physical performance and self-organization; long time horizons for planning, execution and system response; effects on eutrophication, particularly the scale of hypoxia in the Gulf (a critical issue in terms of national interest); habitat losses attendant with the conveyance channel footprint (in the case of the third delta) and active delta abandonment; navigation, freshwater supply and flood protection considerations; and optimal use of the limited supply of fresh water and sediments available in the lower Mississippi River. Nonetheless, the time to begin evaluating these alternatives is now. Such large reintroduction of the river into the deltaic plain is essential to long-term sustainability of the coastal landscape of southeastern Louisiana.

Terrebonne Basin-Acadiana Bays (Subprovince 3). The principal storm damage reduction initiative currently underway is the Morganza-to-Gulf barrier-lock system designed to allow tidal exchange but prevent hurricane storm-surge flooding of most communities in Terrebonne Parish from a Category 3 storm. Importantly this barrier has been evaluated and designed with the sustainability of landward wetland systems in mind, including pursuing opportunities to reconnect presently impounded areas to tidal exchange. The Timbalier-Terrebonne barrier shoreline will also be important in impeding storm surge and reducing the erosive forces of tidal and wave energy.

The foundation feature for the Terrebonne Basin-Acadiana bays subprovince is the more effective use of freshwater and sediment resources of the Atchafalaya that can support sustainable coastal landscapes. The Atchafalaya River supplies sediments to the west Terrebonne wetlands, which as a consequence have been suffering little loss or are actually expanding. The use of existing channels to convey more of these inputs to the east and the west should be actively considered to enhance and sustain the ecosystem and provide extensive wetland protection for coastal communities.

Chenier Plain (Subprovince 4). Because of its separation from direct fluvial sediment inputs and its domination by water control infrastructure, the Chenier Plain presents a different set of restoration, flood protection and navigation challenges. The Chenier Plain is currently managed primarily for purposes that are different from the ecological functions that operated historically. It was much like the Everglades in that it was dominated by sawgrass and relied on delivery and timing of freshwater surface flows from interconnected rivers, bayous and lakes. Water management units that supply one of the largest rice producing regions in the U.S. have disrupted this regional hydrologic network, restricting freshwater flow to the south and retaining water in the interior. Waterfowl management impoundments and roads provide other flow restrictions. In addition, extensive navigation canals to support commerce and the chemical industry increased saltwater intrusion to the north, particularly in the Lake Calcasieu and Sabine Lake regions.

The foundation feature for the Chenier Plain must be improved water management. This involves developing a more comprehensive regional water management plan, including structures on major navigation channels. The plans should use seasonally available freshwater supplies and existing waterways to reduce saltwater intrusion and restore some of the historical hydroperiods. The only alternative is to enhance the present management approach of providing impoundments to support waterfowl and agriculture and prevent saltwater intrusion. This reality needs to be recognized and restoration activities in the region should be based on acceptance of either of these approaches, or some compromise between the two. A disadvantage of the current approach of using managed impoundments is the retention of salt water that occurred following Hurricane Rita. Moreover, options should be actively explored to use nearshore sediments in the “mud stream” downdrift of the Atchafalaya for restoration of wetlands seaward of Grand Chenier.

ORGANIZATION AND FUNDING

The existing plans for strengthening storm damage reduction, initiating the LCA ecosystem restoration, and maintaining and improving navigation infrastructure provide a foundation for planning, but cannot be the only basis for future investments. As we have repeatedly stressed, future decisions on projects and their operations must be informed by an integrated assessment of contributions of these and other projects to the multiple economic, environmental, social and cultural objectives. Such integrated assessment will identify conflicts, synergies and opportunities for securing multiple purposes. The value of, and possibilities for, integrated assessment are illustrated by the preliminary analysis and evaluation included above. Importantly, a future integrated planning process should be structured and supported as an adaptive management program that recognizes and reduces uncertainties to improve the effectiveness of future decision making. Some of those decision-critical uncertainties have been highlighted earlier in this report.[57]

A complex of state and federal agencies already exists with missions, budgets and authorities affecting planning, investment and implementation. However, improvements to the existing organizational, funding and planning structures will be needed to meet planning needs and expedite project implementation by the Corps and the State.

The organizational and funding barriers that have inhibited the adoption of an integrated planning and adaptive decision making process persist.[58] Both new organization and funding reforms are needed to support coastal planning and project implementation by the Corps and the state. We recognize that there are many ways in which the government can organize to carry out integrated planning and decision making as long as the organization, funding and analytical needs for such a new process are served. To better illustrate these concepts, and organizational possibilities, the Working Group offers one such approach.

Maritime Transportation Planning

While the President and Congress have mandated the Corps to take actions and develop investment plans for hurricane protection and ecosystem restoration, they were silent on planning maritime transportation investments. Similarly, the scope of the Coastal Protection and Restoration Authority (CPRA) recently created by the Louisiana Legislature does not seem to encompass maritime transportation. However, a marine transportation network that will continue to be maintained and upgraded over time characterizes the Louisiana coast. Marine transportation interests are primarily concerned with: (1) the availability of a system of reliable channels; (2) transit time from to and from port to deep water; and (3) a minimization of cargo handling costs. These goals will continue to be advanced through new project proposals and maintenance of existing projects. As discussed earlier, some elements of the navigation network can be detrimental to hurricane protection and coastal landscapes. Moreover, innovatively conceived navigation realignments and utilization of existing channels could enhance sediment dispersal through the coastal wetlands or reduce storm damages. Therefore, consideration of plan formulation and evaluation for marine transportation investments should be incorporated into the more comprehensive study authorities and re-organization plans, such as those proposed below.

Federal Intragovernmental Coordination

At present, the Federal program for coastal planning is led by the Corps of Engineers, but it is not clear how the responsibilities of the other federal agencies will be represented going forward. The new integrated management framework would require tradeoffs that impact agency responsibilities and the streamlining of NEPA and other reviews. It requires the Federal government to speak with one voice. The Comprehensive Everglades Restoration Program (CERP) has been working to overcome interagency coordination barriers and may offer useful experiences, if not a model. The Corps is the lead agency for CERP, but there is extensive involvement by other federal agencies. The federal agencies have joined a Memorandum of Understanding (MOU) specifying a dispute resolution process and a time line for resolution. An interagency MOU, similar to that prepared for the CERP, should be signed by the federal agencies with significant participation in coastal Louisiana planning.

The Corps itself is organized along “business lines” including (a) navigation, (b) flood and storm and flood hazard management and (c) ecosystem restoration. The business line organization can create organizational barriers to integrated planning and evaluation. These organization barriers exist both at the districts and headquarters. Also, Corps planning and funding mechanisms are currently not well structured to meet the challenge of integrated and adaptive management. The Corps headquarters should create a unit, led by a Senior Executive, charged with fostering innovations in the planning and assessment approaches required for the integrated management of the Louisiana coastal area, as well as for CERP, Missouri, Upper Mississippi, the Columbia River and other areas where the multiple missions of the Corps can be best achieved through more integrated management.

Coastal Louisiana Authority

The Corps and the state, as well as partner federal agencies, have developed working relationships through the LCA, the CWPPRA, and as cost-share partners on local navigation and storm damage reduction projects. However, differences persist in viewpoint, ranging from cost-sharing responsibilities to project priorities. For example, project selection through the CWPPRA Task Force sometimes led to individual agency advocacy and agreements that accommodated the different agencies demands, rather than true integration.

Louisiana has created a new Coastal Protection and Restoration Authority (CPRA) to centralize and integrate its coastal efforts and the Legislature will shortly be considering additional legislation for consolidation of the numerous levee districts. However, there is still a need in coastal Louisiana to clarify the federal-state responsibilities for planning, to make and implement joint decisions, and in so doing to expedite outcomes and ensure coordination with water resource and other activities of the federal and state governments. A Federal-State body, which we will for convenience refer to as the “Coastal Louisiana Authority” (it could alternately be a “board” or “commission”), should be established to fulfill this role. The CLA would be comprised of a small number of members with appointments made by the President and the Governor of Louisiana. The group would have a small administrative staff and an executive director, as necessary to execute its functions. Its authorization should be subject to periodic review and renewal by the Congress and the state. The CLA could report to the President and Governor or operate under the administrative jurisdiction and support of an appropriate federal agency to ensure coordination with the water resources and other activities of the federal government.

The CLA’s responsibilities and powers would be limited to three areas. First, it would be responsible for leading the development of joint federal-state policies that govern an integrated investment and management program (discussed later in this section) and for revising those policies over time as new knowledge emerges, and social, economic and environmental conditions change. Second, the CLA would review and approve the use of the programmatic funds (see discussion of authorization and funding, below) allocated for adaptive management and the science and technology program, as well as other uses discussed below. Third, the CLA would direct, receive and use analyses of its Coastal Assessment Group (CAG) and, based on those analyses, stakeholder input and coordination with the Mississippi River Commission and the Louisiana CPRA, would make funding recommendations for significant investments (those that exceed a defined threshold). The recommendations of the CLA would be an affirmation that the proposed project has been formulated and evaluated in full consideration of the agreed policies. Based on such recommendations the Corps, or another appropriate agency, would have the responsibility to design, construct and, if authorized, operate and maintain the recommended project.

Coastal Assessment Group

The CLA would base its advice on analyses conducted under the direction of a Coastal Assessment Group (CAG). The CAG should have a professional staff with a full range of skills and perspectives (multiple purposes and multiple disciplines including natural science, social science, economics, and engineering). However, the staff would remain small, but could be expanded to address specific tasks with personnel from the state and federal agencies on temporary assignment.

The CAG would have two roles. First, the CAG would be responsible for executing the integrated assessment to assure that each proposed project investment in storm protection, navigation and coastal restoration takes advantage of synergies and avoids and mitigates conflicts among purposes. Also the CAG would report whether and to what extent different economic, environmental and social objectives are served. The integrated planning process would be led by the CAG, however detailed project design, basic data acquisition and modeling, and other tasks contributing to project execution would be done in the existing agencies, principally the Corps and the state. Second, the

CAG would be responsible for the direction and oversight of the Coastal Engineering and Science Program (CESP) in order to assure that the work of that program is targeted to the decision making needs of the CLA.

Coastal Engineering and Science Program

A Coastal Engineering and Science Program office would build on the concepts developed for the LCA Science and Technology Program,[59] but would be broadened to address storm damage reduction and maritime transportation, encompassing the natural science, engineering, social science and economics applications deemed relevant to the integrated management framework. In particular, it would be responsible and accountable for supporting adaptive management, including participatory decision making, and ensuring rigorous, independent peer review. A key responsibility of the managers of the CESP is to respond to the oversight of the CAG and assure that the scientific uncertainties deemed relevant to decision making are addressed through the program. The CESP would rely on scientists and engineers in agencies, universities and the private sector to perform most of the required research, modeling, and monitoring. Consequently, the office staff would remain small.

Programmatic Authorization and Funding

While the total composition and costs of the integrated planning and investment program can not be determined at present, it is necessary for the Administration and the Congress to make a significant and certain up-front commitment of funds and establish new procedures for expeditiously funding this program over time.

Programmatic Funding. No less than two hundred million dollars per year, for a 10-year period, should be authorized by the Congress to support the CLA and the CAG. Appropriations should follow that authorization. The agencies receiving the appropriations would manage those funds consistent with the guidance of the CLA for: (a) the integrated systems planning program; (b) the CESP research on decision-critical technical uncertainties, including funding pilot projects to test project design concepts; and (c) comprehensive post-implementation monitoring and assessment. Also, the CLA would be authorized to allocate funds for projects costing less than some threshold, e.g. $25 million, with project execution being the responsibility of the Corps and the State. In the future, consideration should be given to administering the existing CWPPRA program through the CLA some time after the efficacy of the CLA has been established.

Programmatic funding would loosen the restrictions on adaptive management costs as a percentage of total project costs, as well as the requirements for separate authorization for each component project. With a certain funding stream there could be a continuity of programs and staff, an adequately funded and reasonably managed engineering and science support program, and accelerated planning for implementation of smaller projects.

Louisiana Coastal Investment Corporation. The CLA could recommend authorization and appropriations for Corps projects that exceed the thresholds in the programmatic authority, or for project maintenance, through the existing WRDA and appropriations processes. However, reliance on authorization through the uncertain WRDA process (the last WRDA was passed in 2000) seriously risks delay and programmatic incoherence. A more predictable and flexible alternative approach would be to legislatively create an entity, for convenience referred to as the Louisiana Coastal Investment Corporation (LCIC), as an independent funding authority for new projects and their maintenance.[60] The LCIC would receive recommendations from the CLA and would fund projects meeting investment criteria established by Congress when it authorizes the LCIC policies. The corporation would be given the authorization to issue bonds with maturities of up to 50 years to finance investment projects to meet the three purposes of storm protection, marine transportation and coastal landscape restoration. An initial bonding authority of $5-10 billion appears to be justified by the extensive storm protection, navigation and restoration needs of the region.

The long-term bonding authority aligns the financing of the new investments with the long-term benefits they provide. The federal government would guarantee the bonds. In addition the Congress could set a financial limit on the bonding authority when the corporation is chartered. The Congress could review the LCIC on a five-year basis, could dissolve the corporation at those times or choose to raise or lower the bonding authority. The bonds could be repaid with a combination of funding sources that may include, but would not be limited to: future federal appropriations; fees on port, waterway or pipeline users; wetlands permitting fees; receipts from Outer Continental Shelf (OCS) mineral revenues; and non-federal cost sharing payments. Intergovernmental cost-sharing requirements would be established by a Congressional formula and a legally binding agreement to make payments that contribute to retiring the bonds would be required before issuing any bond.

Professional Staffing

An essential element in enhancing the credibility and soundness of planning and implementation is an agency's internal staff capabilities. The Corps of Engineers is facing a significant loss of staff numbers and capability through retirement, just at the time that the demands for its skills are increasing. Indeed, the integrated planning process will demand a wider array of skills from the engineering, hydrologic, geological, biological and social sciences than is currently available in the agency or in federal or state agencies generally. Also, the effectiveness of the long-term program requires the institutional memory that develops within a permanent and professional staff. This is not to suggest that all the work needs to be done by agency staff. However, if much of the work is done by contract, agency professionalism and competence are essential for comprehending advice from outside experts and translating it into useful information to support decision making. The Corps and the bodies recommended here must have the ability to recruit and the ability to retain talented personnel.

DECISION SUPPORT

The CAG would be organizationally responsible (1) for directing the CESP's resources to identify and resolve decision-relevant technical uncertainties, and (2) for the decision support analysis program. The programmatic funding process proposed earlier will assure that these dual responsibilities are met.

Support for Adaptive Management

Integrated coastal management should be an ongoing process of planning, execution and assessment of predicted system response, leading to continuous improvements in decisions made. This learning-while-doing process is the essence of adaptive management (AM), an approach embraced at the most general level in the LCA Study, CERP and many other Corps restoration programs.[61] AM is a means to successively reduce decision-relevant uncertainty over time rather than be paralyzed by it.

Adaptive management is more than a process for learning about natural system response to restoration projects. For navigation systems, for example, initial traffic predictions made using models and assumptions may later prove to be incorrect, largely due to unanticipated shifts in shipping patterns and shipping and freight handling technology. As new knowledge about the transportation is gained through experience the goals for segments of the transportation network should be revised. Interdependencies trigger other analyses, including assessment of how changes of shipping pattern affect the design and location of landside port facilities and the justification for locks. Revision of goals through learning is what a group of authors call "evolutionary problems solving."[62] In the context of multi-objective management envisioned here AM should also include continued learning about environmental, economic and social systems. Toward this end the CESP must test, evaluate and improve models as different statistical trends emerge concerning: navigation traffic flows and port utilization; effects on salinities; storm surge; fisheries and ecosystem services; and demography.

In a structured and responsive way, AM tracks the intended effects of actions, projects, and programs to determine whether the benefits materialize as predicted, and then uses that information to reconfigure or adjust the designs and operations of projects in place. AM requires a commitment not only to making adjustments to past projects, but also to improved modeling and data evaluation to improve the decision support models and knowledge for planning future projects. To meet these expectations the CESP must be aggressively supported in both the planning and budgetary processes and the areas of research expanded beyond the scope currently envisioned for the science and technology program in the LCA. In addition, the CAG, by its organizational responsibility and access to programmatic funds, will assure that the CESP research will support the AM process.

Models, whether conceptual, empirical or intuitive, are the only analytical way to represent complexity and interdependency. Therefore, a significant concern of the CAG should be the CESP modeling support efforts, including the following considerations:

1. In complex systems multiple models are required based on resolution of scale, purpose of modeling, need for transparency and other factors. Therefore, the CAG should discourage reliance on a single "super model" and should encourage development of alternative models of similar phenomena. Differences among models reveal important uncertainties in predictions and point to critical assumptions that must be tested to reduce these uncertainties.
2. Models should be used to help establish research priorities. Sensitivity analyses and data assimilation can be used to identify uncertainties that are most critical to decision making. The priorities identified can be addressed by traditional research using experimental methods, pilot projects to test key concepts, and post-implementation monitoring of projects and operations. Technical uncertainties critical to ecosystem restoration decisions were identified in the LCA planning process as an outcome of model development and application.[63] As new knowledge is secured, the CAG should have the responsibility of assuring that it is incorporated to improve the forecasting accuracy of decision-support models.
3. As discussed at greater length below, design of and support for models to aid stakeholder participation should be a priority for the CAG. Integrated planning will highlight and then must mediate competing stakeholder interests. Models can be an important platform with which to advance stakeholder learning and negotiate disputes.

System-Scale Plan Formulation and Evaluation

The most basic plan for the Louisiana coast is an inventory of completed projects and their operations, along with potential future actions requiring further formulation and evaluation. However, a more comprehensive plan would catalog policy goals, funding sources, and the planning process to support decision making across the coast. While an example description can be provided here, development of a detailed comprehensive plan should be a high priority for the CLA and CAG.[64]

A starting point should be readily assembled from the Coast 2050[9] and LCA Study reports[10,11] and the Corps' October 2005 assessment on hurricane protection. Also, multiple reports on navigation plans are available. These can serve as a foundation for setting project investment priorities, recognizing that the project list as well as the priorities will be modified over time. This planning will support decisions on how the limited resources of funds, fresh water and sediment are allocated across the coastal region and among purposes over time. What would emerge is not so much a "map," but a spatially explicit vision of a future coastal Louisiana that incorporates long-term challenges, opportunities and overarching goals.

Over the longer term, because of the large spatial scale, complexity, long time horizon for planning and implementation, there will be successive rounds of planning as new projects are advanced by the agencies for consideration by the CAG. Ideally, projects will not be considered individually, but there would be planning rounds including multiple projects. This subset of proposed actions would be chosen based on knowledge gained in previous rounds. The proposed investment package would be formulated and then justified by how well it secures incremental gains in performance measures (discussed below).

This multi-project investment planning process requires the work of agency-led project development and design teams (PDDTs), but PDDTs cannot locate, scale and set operational rules for projects independent of what the other PDDTs are designing. For example, one PDDT might predict the amount, timing and location of sediment deliveries from different project scales and possible locations, as well as estimate the engineering cost of the different alternatives. Another PDDT might be charged with design of different storm protection structures (heights, slopes, construction materials, etc.) and estimate the engineering cost of the different alternatives. However, the CAG has the responsibility of developing and using the necessary models to forecast the system-wide performance outcomes from different combinations of technically feasible actions identified by the PDDTs. The geographic scale of the "system" will depend on the primary focus of the analysis. For an economic analysis of a navigation expansion the system might include all the other navigation facilities in the southeast region, but certainly in the Louisiana coastal region. If coastal landscape restoration is the primary focus of the analysis the system might be only one part of a subprovince. However, if that restoration action results in a significant claim on the total sediment resources in the river, then the system might be a much larger area. This kind of integrated analysis can only be done at the system level, because only at the system level can the synergies and interdependencies among existing and proposed actions be modeled and evaluated. Therefore, the only analytically tractable study organization is for the agency-led PDDTs to work through the CAG. Once decisions are made the final design, implementation, maintenance and operation of the projects become the responsibility of the Corps of Engineers or another designated organization.

Participatory Decision Making and Modeling

Conflicts among stakeholders over proposed alternatives must be expected and a planning process that bridges the gap between technical analysis and stakeholder collaboration should inform and mediate such conflicts. The general case for appropriate, stakeholder and multi-agency engagement in planning and decision making is well documented, as are the limits such involvement can place on expeditious decision making.[65] The Corps has been recognized for its research and application of public participation methods.[66] The CAG and the CLA should build on this experience to assure that participation is initiated at the earliest stages of the formulation and evaluation processes and is organized around the modeling and assessment program, rather than being limited to review and comment on plans that are already well-formulated.

Early stakeholder participation will secure the benefits of traditional and localized knowledge in the analytical process. Also, early involvement of agencies and stakeholders will reduce the likelihood that subsequent review processes will identify problems or issues that extend the planning to accommodate new analyses or modify recommendations. Early engagement may delay the start of the analytical processes until representation and organization is worked out, but will ultimately save time. Finally, early engagement can identify conflicts and objections to particular formulations of alternatives and can make modifications or identify economic mitigation actions that will increase the acceptance of plans that serve coast-wide purposes and objectives.

For effective collaboration, the assumptions and functional logic of system-synthesis models should be transparent to all relevant decision makers. The synthesis model is the tool that the CAG would develop and use in its decision-support work and not a free-standing modeling activity. Technical specialists, the CLA and the stakeholders and agencies should cooperatively develop this model to simulate and jointly evaluate alternatives, relying on the CESP research and component model development. The Corps Institute for Water Resources has called this approach "shared vision modeling" (SVM).[67] Other similar modeling systems—generally categorized as computer aided decision support systems—are available in both the public and private sectors.[68] The "system model" for serving the collaboration process has the following features:

- coarse resolution, but it could draw upon models of finer spatial and temporal scales for its construction;
- simple but not simplistic, in that it informs choices about general project designs, locations and operations rather than day-to-day operations or design refinements;
- empirical, but where there are significant uncertainties in data or in relationships among variables in the model, characterization of the uncertainty and how it affects the results would be necessary.

Decision Making Under Risk and Uncertainty

A central premise of the adaptive management is that uncertainty will accompany decision making. The identification and representation of uncertainty is critical for decision making that seeks to incrementally reduce that uncertainty in selection of investments. Two processes for characterizing risk and uncertainty can be applied.

Scenario Analysis. Many of the critical factors that affect the future of the Louisiana coast are uncertain and assumptions about them can radically alter the justification for different investments. For example, justification for future storm protection works and landscape restoration is based on assumptions concerning future settlement patterns across the coast. The future of oil and gas exploitation in the Gulf region, especially the location of land-based facilities, will affect protection decisions. Other uncertainties include such matters as future patterns of international trade, the rate of future sea-level rise and land subsidence. Major uncertainties may be best represented as alternative scenarios. The CAG should be expected to apply scenario-based planning to communicate and elevate key uncertainties to the CLA on the assumptions and uncertainties that will have the greatest influence on decisions to be made.

Multiple criteria have been offered for making decisions under uncertainty. One rule argues for choosing the most robust strategy (choose the alternative that is viable under the most varied future conditions). A rule to minimize the maximum regret[69] might be applied, where regret includes financial costs, forgone opportunities for other uses of sediment and river water and reduced level of one purpose from pursuing another. The CAG should present information in a format for decision making so that the CLA and stakeholders can apply one or more of these criteria when making a decision.[70]

Probability Analysis. Congress has requested an evaluation of protection strategies for a most likely hurricane and the most extreme hurricane. This request implies some expectation that probabilities will be used to characterize the likelihood and consequences of different hurricanes striking the area with different forward speed, surge, and path. Likewise, there might be estimates of the likelihood of structures with differing designs withstanding the forces of each hurricane. The Corps of Engineers has pioneered the use of risk-based analysis that applies probability and consequences analysis for storm and flood protection, and has tools that extend this logic to other purposes.[71] This analytical process can be usefully applied to hurricane assessment, even though the storm events are infrequent and provide only limited data for a statistical frequency analysis. In fact, the Dutch have applied risk assessment in the design and location of different protection barriers based on probabilities of different descriptive parameters of storms and to establish different acceptable risk levels.[72]

A probabilistic analysis can be applied to reporting on the contribution of land restoration to storm surge or wave energy reduction. Given the lack of data to establish statistical frequency relationships, it may be necessary to rely on expert elicitation,[73] and adopt a Bayesian analytical posture that allows for combining expert elicitation and frequency data. This facilitates revising prior probabilities based on new knowledge developed through the science and technology program.

Performance and Evaluation Measures

There is no single dimension by which to judge any project investment. Instead there must be an extended set of formulation and evaluation criteria. The criteria can be derived from the particular policies that are developed to govern decision making for the coast. Therefore, the CLA should cooperatively develop such policies with local leaders, stakeholders and scientists, as well as the responsible federal agencies. These policies might describe broad evaluation criteria (economic, environmental, and social), as well as other more specific instructions such as choice of discount rates, expected minimum level of protection for urban areas or more. The policies will be dynamic. As problems are solved, as conditions change, as new scientific understandings are gained, and as new problems and opportunities are identified, the policies are revised.

Policies are transformed into a set of performance measures that guide the work of the CAG and the federal and state agencies. Performance measures are based on data or calculated metrics. They are unambiguous in their interpretation as they relate to policy, represent the best professional practice (e.g., economic benefit estimation for marine transportation), and are understandable to analysts as well as stakeholders and decision makers. Performance measures are the focus for plan formulation and evaluation and for modeling, clarifying tradeoffs for stakeholders and focusing monitoring and assessment. Measures cannot be hard targets that must be met. In fact, at times even measures for a single purpose may be in conflict—a measure that is positive for oysters may be negative for other species. Useful measures illuminate choices and allow for the assessment of progress.

Physical and Ecological Measures*.* A policy that calls for ecosystem restoration, as opposed to simply land building as an end in itself, might result in measures such as dynamic salinity gradients or landscape features in particular locations. Conceptual models might be used to affirm the expected biological results for particular species from such measures. For example, a measure that represents the mix of fresh and brackish marsh in a certain location might yield insight into the ecological responses of any action. A more definitive measure might represent the quality index for shrimp habitat across a sub-province and this should yield insight to interested stakeholders and reflect the net interaction of restoration measures, ecosystem dynamics, and other infrastructure.

A policy that calls for populated areas having hurricane protection to withstand a Category 4 or 5 storm might result in measures that characterize storm hazard with and without any protective actions for particular locations, such a residual property and lives at risk under different protection programs or mapped areas of inundation for different storm events. A policy that calls for an internationally competitive marine transportation system might yield measures that characterize regional port capacity, channel reliability indices, transit time from to and from port to deep water, or cargo handling times.

Economic Performance Measures. Physical and ecological performance measures provide information useful to decision making in their own right, but also many can be represented as economic calculations. The LCA Study was criticized for an absence of economic analysis, given that at least a collateral justification included storm damage reduction, infrastructure protection and commercial fishery enhancements—all effects that are traditionally considered in a national economic analysis. At the same time ecosystem restoration features may produce adverse effects on navigation, port access and oyster production—costs that are amenable to appropriate economic analysis. Recently, there have been suggestions that the assessment of "Category 5 hurricane protection" should not include an economic analysis.

One should draw a distinction between economic analysis and economic justification. Rejecting a net benefits rule as the determinant of whether a restoration project or hurricane protection system should be put in place or enlarged, does not mean that economic information should not be used to help inform priorities among alternatives. Also, economic analyses do not require placing monetary values on all the ecosystem services or on human life.[13] In fact, such comprehensive net benefit calculations generally make little substantive contribution to decision making.[74] However, properly calculated and utilized economic analysis of traditional purposes such as flood damage reduction, residual damages, navigation benefits and costs, and commercial fishery effects can add information useful in making choices in the face of limited financial, sediment and water budgets.

CONCLUDING REMARKS

Reducing the rate of destruction of Louisiana’s coastal ecosystems and, where possible, restoring them should be a national priority in itself. Moreover, we have presented evidence and reasoning to demonstrate that the long-term protection of human communities from the devastating effects of hurricanes depends on the continuance of the coastal landscape in addition to strengthened levees and storm surge barriers. The longevity of this landscape fundamentally depends on our success in restoring the natural processes that created and maintain it.

Clearly, a new framework is required to integrate planning, investment and regulatory decisions to secure the multiple purposes of coastal landscape restoration, storm damage reduction and marine transportation. The priorities for near-term coastal restoration features should be revaluated within this new framework. For longer-term planning, an adaptable, but spatially explicit vision of a future coastal Louisiana, incorporating long-term challenges, opportunities and overarching goals, is required rather than a fixed map. This integrated vision can accommodate hurricane surge barriers beyond strengthened inner defenses, but only if they do not interfere with the processes which sustain the coastal landscape or diminish ecosystem services.

This new integrated coastal management framework requires different organizational and funding arrangements for coordinating and integrating planning, decision making, and implementation by the state and federal government. While many actions to improve agency coordination and capacity can be taken immediately, innovations in organization and funding, as well as planning approaches, will be needed. A joint Federal-State body should be given the responsibility to determine the priorities for the integrated management of the coast. A targeted engineering and science program that supports both immediate decision-making needs and longer-term adaptive management should support it. Authorization and funding for the new organizations, planning, engineering and science, and for routine plan implementation should be programmatic. For significant investments the Corps and other agencies should be freed from constraints of the Water Resources Development Act process. Congress should charter a new investment corporation that would ensure more expeditious funding and implementation of projects.

Finally, planning should emphasize early and substantive engagement of all agencies and stakeholders, with the process and deliberations organized around mutually developed and mutually understood system models. These can be the basis for defining performance measures for plan formulation and evaluation, recognizing uncertainties, and addressing often-difficult tradeoffs among purposes and objectives. Such participation may delay the analytical processes at the start, but will ultimately lead to more expeditious and acceptable decisions.

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[1] Sustainability is operationally defined for this report as persisting through the 21st century. Persistence in the 22nd century will be determined by the effectiveness of actions taken and the presently unresolved trajectory of global climate change.

[2] Ecosystem restoration does not mean recreation of some historic or pre-existing state, but refers to the process of recovery of sufficient biotic and abiotic resources to continue its development without further assistance or subsidy. See Society for Ecological Restoration International Science & Policy Working Group. 2004. *The SER International Primer on Ecosystem Restoration*. Society for Ecological Restoration, Tucson. Available online: http://www.ser.org/content/ecological_restoration_primer.asp

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