Envisioning the Future of the Louisiana Gulf Coast

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SUMMARY

This vision of the future of the Louisiana Gulf Coast over the next fifty years was developed from the perspective of an environmental scientist with nearly a half-century of experience in the diagnosis and treatment of coastal environmental deterioration in various parts of the world. It was developed with the empathy of a native, the knowledge drawn from extensive experience on the Louisiana coast, an objectivity afforded by having lived outside of the state for nearly three decades, and a perspective based on engagement in addressing environmental change at the regional scale. Within the bounds of scientific reality, it is a purposely optimistic vision, one that assumes that humankind did all the right things including environmental restoration in Louisiana, better management of the Mississippi-Atchafalaya River Basin, and limiting climate change. It seeks to describe a plausible best case for the future, one in which Louisiana's coastal environments can be more productive and valuable than they are today.

The vision builds on decades of analysis and planning for the rehabilitation of rapidly deteriorating landforms and ecosystems, the protection of residents in the Mississippi Deltaic Plains, and the adjacent Chenier Plains that together comprise the Louisiana coast. The vision starts with the Louisiana's 2017 Coastal Master Plan, elements from which are already being implemented. While written for a broad audience, including those who have influence on decisions, an important objective for the vision is to inform and inspire the development of the 2023 Coastal Master Plan that is already underway.

Commendably, Louisiana's Coastal Master Plan has taken into account environmental changes that could occur in the future. The three scenarios used in the 2017 plan are examined with regard to how they might affect achievable futures. Numerical and spatial modeling of land changes under these scenarios with and without component restoration projects is used to provide a basis to envision outcomes. Because it is built on thick layers of unconsolidated sediments deposited over just the last 7,000 years, the Louisiana coast is subsiding faster than any place along the U.S. coast. Controversies remain over the effective rates of subsidence in wetlands and the extent to which subsidence may have slowed with reduced oil and gas withdrawals. Substantial effort is being expended to provide more reliable subsidence rates for use in project planning and in the next Coastal Master Plan. The other environmental changes assumed in the scenarios are affected by human-influenced climate change, including precipitation and runoff, storm frequencies and intensities, and the rise in the levels of the Gulf of Mexico. The degree to which the Gulf sea-level rise accelerates will be the predominant factor governing the extent of coastal changes later in the century.

The amount of sea-level rise experienced in the Gulf of Mexico will be determined by how much Earth's temperature warms and on the amount of greenhouse gases humans emit. The scientific consensus, as reflected in the most recent projections of global sea-level rise by the Intergovernmental Panel on Climate Change, offers some good news and some bad news for coastal Louisiana. It is unlikely that sea level will rise over the next fifty years as much as predicted under the lowest assumption used in the 2017 Coastal Master Plan, thus affording an opportunity for restoration measures to work more effectively.

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If global emissions are reduced sufficiently to keep global warming well under 2°C, consistent with the goal of the Paris Climate Agreement, sea-level rise should be relatively manageable well into the next century. On the other hand, if emissions of greenhouse gases continue to grow at recent rates, Gulf levels could likely rise by over 6 feet over the next hundred years, ultimately inundating the coast Louisiana is working to restore and the communities it is trying to protect.

A fifty-year vision is outlined for each of six basins comprising the Louisiana coast: Pontchartrain (including the Breton Basin), the Birdsfoot Delta, Barataria, Terrebonne, Atchafalaya (including the Teche/Vermilion Basin) and the Chenier Plain (comprised of the Mermentau and Calcasieu/Sabine basins). For each basin, the particular setting and trends of coastal land loss are reviewed, the restoration accomplished and planned are assessed using the modeling framework of the 2017 Coastal Master Plan, and a vision is developed that offers further considerations for protection and restoration. These considerations are not necessarily novel, in fact, many are already being evaluated by the Coastal Protection and Restoration Authority. Treatment by basin allows the integration of various restoration measures, such as sediment diversions, maintenance of barrier islands, and marsh creations within a place-specific context.

From a higher altitude, Louisiana's coastal planning and implementation must fundamentally involve the effective distribution of freshwater and sediment flows together with adjustments to maintain a reasonably stable boundary with the Gulf of Mexico, important landscape features, and to enhance the longevity of intertidal wetlands. Net land loss will continue over most regions of coastal Louisiana over the next fifty years. With the rise in sea level likely over this time, it is possible to maintain the basic integrity of Louisiana's coastal landscapes, take steps that will help sustain it over a longer term, and enhance its biological productivity and value. Prudent and effective choices will require sound technical guidance, appropriate resources, and strong societal and political will.

During this same fifty-year period, there will be a massive global transition in the sources and uses of energy that will involve Louisiana. Indeed, the future of its coast over the subsequent fifty-year interval will depend on how quickly and completely this transition is effected. The transition requires that Louisiana adapt its economy and society as fossil-fuel production and manufacture declines or changes at the same time during which the state is working to restore its coast. The nature of the work in this Working Coast will change with less oil and gas production and constraints on the use of diesel engines for transportation and restoration, but increase opportunities for renewable energy production and carbon sequestration, global leadership in coastal sustainability, and for more productive and profitable cultivation of the state's bountiful living resources. The critical role played as the global commercial gateway to the American Heartland continues even as shipping adapts, placing urgency on planning for a sustainable river entrance and the lower Mississippi infrastructure needed for the future. This provides more impetus for working on a national scale for the comprehensive management of the Mississippi-Atchafalaya River Basin to address flooding, upstream pollution, sediment transport, and navigation.

Assuming work along the coast will remain the same while we restore and sustain its landscape, it is just not realistic. Rather, Louisiana should embrace this new future with all its threats along with its abundant opportunities.

INTRODUCTION

Why Another Vision?

Why, the reader might ask, yet another vision of the future of the Louisiana Gulf Coast? Surely, there have been many other books, reports, and plans that describe the challenges faced in stemming the alarming loss of coastal lands, the degradation of productive and diverse ecosystems, and the increasing vulnerability of its human residents and their distinctive cultures. After all, Louisiana already has a Comprehensive Master Plan for a Sustainable Coast,[1] a third edition revised in 2017. The Coastal Master Plan laid out a forecast of future conditions along with an ambitious path to respond to forces driving the loss of land. It included an array of specific projects that built or maintained land and reduced storm-surge flood risks to communities over a fifty-year period. The plan used the "best available science and engineering" and extensively engaged coastal stakeholders and communities. What can just one scientist who has lived and worked outside of Louisiana for the last 30 years expect to contribute that has not already been addressed in the Coastal Master Plan's massive undertaking?

As comprehensive as it is, the Coastal Master Plan acknowledged that it is not set in stone — as if there were naturally any stone amid the sand, mud, peat, and shells of coastal Louisiana — but must constantly improve. Additional research, analysis, and planning is proceeding, leading not only to refinements, but also in addressing issues not fully resolved in the 2017 plan. A revision of the Coastal Master Plan mandated for 2023 has technical analyses currently underway. It is my objective and sincere hope that the vision I develop here informs and inspires the development of the next Coastal Master Plan.

Although the State of Louisiana deserves great credit for its use of science and technology in the consideration, evaluation, and the design of coastal restoration and storm-surge protection projects, the development of the Coastal Master Plan is political. I do not mean "political" in any disparaging sense, but in realization that its development is a public affair that incorporates the interests of society, including those focused quite locally where people live and on the near-term. I hope that my detached scientific appraisal of likely future conditions, challenges, and opportunities can assist those entrusted with difficult policy decisions and the adaptive management to which the states planning is committed.

Why My Vision?

My perspective is that of an environmental scientist with nearly a half-century worth of experience in the diagnosis and treatment of coastal environmental deterioration in various parts of the world. I was born and raised in Louisiana, where all of my ancestors over three to four generations before me lived. I have engrained empathy for the state's unique coastal environments and residents. As an undergraduate at Tulane University, I cut my scientific teeth conducting research on Louisiana's marine life before undertaking my graduate education and early professional career on the East Coast. I returned in 1980 as the first Executive Director of the Louisiana Universities Marine Consortium (LUMCON), assuming the responsibility for building the state's first modern marine laboratory and Gulf research vessels for Louisiana's universities. That decade was the time when the dimensions and seriousness of coastal land loss along with the Dead Zone of severe oxygen depletion on Louisiana's continental shelf became fully apparent.

Although I moved to lead the University of Maryland Center for Environmental Science in 1990, I have remained engaged and "on call" to help deal with Louisiana's coastal crises by:

- chairing a historically significant scientific assessment of coastal wetland loss, restoration and management — the so-called Green Book or W. Alton Jones report;[2]
- chairing the Science Board for the federal-state Louisiana Coastal Area Ecosystem Restoration Program for three years; and
- co-authoring a highly cited paper in *Science* magazine that brought international attention to the need to integrate coastal restoration and hurricane protection in the wake of Hurricane Katrina.[3]

In 2010, the President appointed me as one of seven members of the National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling charged with determining the root causes of that tragic blowout. The commission recommended that 80 percent of the Clean Water Act penalties be devoted to long-term environmental restoration in the Gulf. Subsequently, I was the U.S. Government's key witness on environmental effects in the trial that led to the settlement of those penalties, as well as the payments for natural resources damages. The resulting money has proved critical in beginning the implementation of the Coastal Master Plan. One can appreciate, then, my abiding interest in the effectiveness of these investments.

In addition to these Gulf-specific experiences, I have been engaged in assessments of the consequences of climate change at both national and regional levels over the last 20 years. I contributed to three of the four U.S. National Climate Assessments and led comprehensive assessments for Maryland, particularly focused on preparing for sea-level rise. I served on the Maryland Commission on Climate Change that has addressed greenhouse gas reduction strategies as well as adaptation to the changing climate. I have also brought the knowledge and experience gained in these endeavors to bear in this report.

Retiring after 47 years as a professor and without present obligations to an employer, I agreed to develop this positive but realistic vision of the future of the Louisiana coast as a Fellow of the Walton Family Foundation. The Foundation has heavily invested in advocating for the restoration of the wetlands and natural systems of the Gulf Coast. I am grateful that the Foundation recognized the value of an independent voice that is informed by knowledge and understanding of the science and circumstances that will affect the future of this coast.

How Did I Develop This Vision?

The Coastal Master Plan includes an attention-grabbing map of projected land changes along the Louisiana coast over the next fifty years if there is no additional action taken. Vast swaths of red depict areas predicted to be lost and considerably smaller areas of green project new land created in the Mississippi and Atchafalaya river deltas. Both the 2012 and 2017 Coastal Master Plans recognized that not all the existing land could be retained, acknowledging that there would be a significant net loss of land even with the full implementation of elements from the Plan.

What then could the map of coastal Louisiana look like in fifty years if all the most prudent and effective choices were made in restoration, protection, and sustainable societal actions? Could these choices lead to ecosystems that are more productive of living resources and effective in providing society their services as today? The questions that I developed in this report are the guiding visions of the future.

Yes, my vision is purposefully based on optimism, but it is also bounded by the reality that science demands. It is a vision that eschews the fatalistic acceptance that devastating trends will continue, but recognizes that societies can and will make choices that redirect these trends. What if humankind changed those devastating trends not only within Louisiana, but also more broadly? For example, what if we took decisive action to limit climate change or reduce upstream pollution? Developing such a plausible best case can help coastal planners and the public sort out approaches that, although desirable, might not be realistic. My hope is that the vision will also open consideration of choices that might substantially contribute to a more sustainable coast.

Although I have reviewed a voluminous literature and had numerous discussions with experts and planners, this vision of the future coast is the product of one person, without either the benefit or baggage of consensus or the capacity for complex computer models. I have relied on the more detailed analyses of others, some performed for the 2017 Master Plan, and others that are ongoing for research or planning purposes. Consequently, my vision of the future cannot be geographically precise or detailed, but hopefully can contribute to shaping the collective goals for an achievable, vibrant coast, as well as stimulate productive pathways for future research and modeling needed to provide useful details for future decisions.

Readers should understand that very few of the suggestions offered here are truly novel. Many scientists, engineers, planners, and advocates whose writings I have assimilated or with whom I have spoken over the course of developing this vision have deeply informed the readers. Many of the "new" approaches I suggest are already under active evaluation for consideration in the next Coastal Master Plan. I am forever grateful to the capable, experienced, and dedicated experts who have worked for years — in some cases for their whole careers — on meeting the challenges of coastal Louisiana.

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I have long had a compelling interest in the future of the Louisiana Gulf Coast. So, I am very grateful to the Walton Family Foundation for supporting my efforts to research deeper, consult with numerous experts and thought leaders, and form and compose this vision. Barry Gold invited me to undertake this endeavor and his support was continued by Moira McDonald. Kristin Tracz provided unflaggingly positive outlook, sage guidance, and great patience throughout. I greatly benefited from collaborative learning with Kate Orff, Mike Biros, Justine Holzman, and their talented colleagues at SCAPE Landscape Architecture as they graphically expressed this vision. The leaders of the Restore the Mississippi Delta Coalition, David Muth, Steve Cochran, Brian Moore, John Lopez, Kimberly Davis Reyher, Alisha Renfro, and Simone Maloz provided excellent insights and assistance. The leadership of Louisiana's Coastal Protection and Restoration Authority (CPRA), Bren Haase, Greg Grandy, Brian Lezina, and Charles Sutcliffe, extended its full cooperation and facilitated access to the agency's scientific experts. My consultations with these dedicated experts and many others in universities, other agencies, non-governmental organizations, and even elected office proved invaluable. Finally, I am greatly indebted to Denise Reed, John Day, Andy Nyman, Ehab Meselhe, John Lopez, Mead Allison, Robert Twilley, Sam Bentley, Natalie Snider, and technical experts within CPRA for reading drafts and offering their constructive advice. The report is more accurate and thoughtful because of their candor and the efforts they made. Any errors, omissions, or wayward ideas are strictly my own.

ADDRESSING LOUISIANA'S COASTAL CRISIS

A Challenge of Immense Scale and Gravity

The people of South Louisiana live on the geologically youngest land in the United States, except for a few small communities built on barrier islands or on landfills.[4] It is also the most rapidly disappearing land in America.

The coastal landscapes of Louisiana continuously expanded after rapid sea level stopped about 7,000 years ago. The Mississippi River was then able to build a series of deltas that encroached into the Gulf of Mexico, creating the vast Mississippi Deltaic Plain of southeast Louisiana (Figure 1). As the river deserted a delta to seek a shorter path to the sea and create a new delta, the abandoned delta inexorably subsided and eroded while new lands created in active deltas countered these losses. Sediment discharged into the Gulf or released from eroding shorelines drifted to the west along the coast under the influence of currents and waves, building the expansive Chenier Plain of southwestern Louisiana. This strand plain consists of remnant beach ridges and mostly fresh to brackish wetlands. It lost ground when eastern delta lobes were the most active, but gained ground when the river switched its course back to the west.

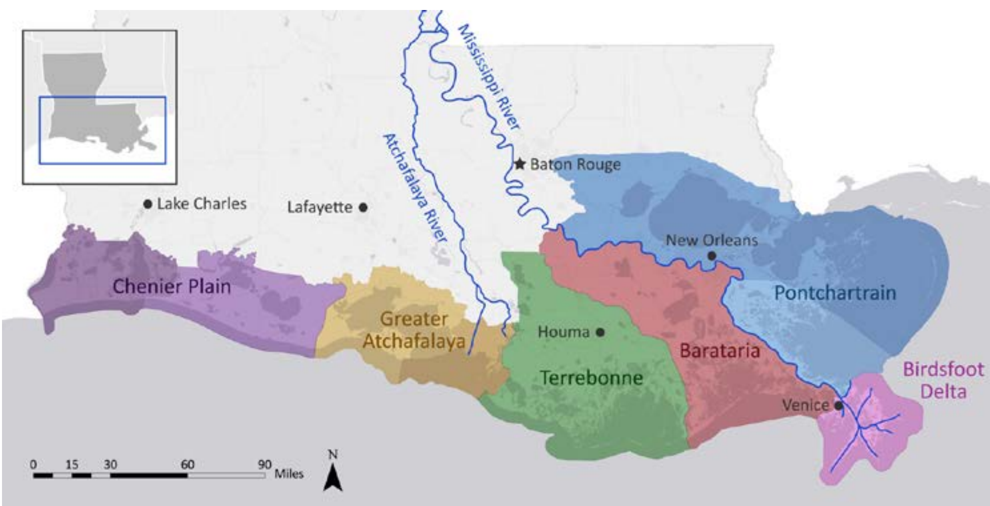

Figure 1. *Coastal basins of Louisiana as used in this report. Except for the Chenier Plain, these basins comprise the Mississippi Deltaic Plain.*

The multi-millennial trend in nearly continuous net growth of land along the Louisiana coast was dramatically reversed during the 20th Century. Best estimates of land losses during the late 1970s soared to 32 square miles per year (83 km^2/y), but have slowed to 11 square miles per year (28 km^2/y).[5] Altogether, over 2,000 square miles of land were lost between 1932 and 2016.

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The presently active Mississippi River, or Birdsfoot, Delta is perched on the edge of the continental shelf and has been depositing much of its terminal load of alluvial sediments into deep waters of the Gulf of Mexico rather than retaining sediments within the coastal zone. Human-caused changes within the great river basins are also responsible for some of the net losses of land. Soil erosion associated with land clearing within the basin increased the river's sediment load during the 19th Century, but then dams constructed throughout the catchment by the middle of the 20th Century trapped much of the sediments upstream. Coupled with improved soil conservation practices, sediment retention by dams has resulted in a reduction by half of the suspended sediment of the lower Mississippi since the 1950s[6] to loads probably less than those occurring when major delta lobes were being built.[7] More of the combined river flow of the Mississippi and Red rivers began to travel down the Atchafalaya Basin after logs clogging flow were cleared in the 1830s. This extensive basin trapped a large share of the sediments transported, such that a new delta did not began to emerge from Atchafalaya Bay until 1973.[8]

Additionally, overflows and crevassing events along the lower Mississippi River were increasingly constrained by effective flood protection levees. The closure of distributary channels has further prevented riverine sediments from accommodating the subsiding wetlands and shallow waters. This was foreseen back as far as 1897, when an article in the *National Geographic*[9] stated: "no doubt the great benefit to the present and two or three following generations accruing from a complete system of absolutely protective levees excluding the flood waters entirely from the great areas of the lower delta country, far outweighs the disadvantages to future generations from the subsidence of the Gulf delta lands below the level of the sea and their gradual abandonment due to this cause." Unfortunately, we have already reached the fourth generation and are now fully experiencing those disadvantages.

In addition to changes in the supply and distribution of sediments required to sustain the deltaic and coastal plain landscapes, other human activities have resulted in land losses, particularly consisting of wetlands. These include the kind of wetland "reclamation" and dredge-and-fill activities that have caused wetland losses elsewhere, but particularly notable in Louisiana has been the extensive dredging of canals through the coastal wetlands. These canals include large channels constructed for industrial navigation, but also myriad smaller canals mainly dredged for access to drilling sites and laying pipelines associated with oil and gas production. Access canals were seldom backfilled and generally do not fill in naturally by themselves. The spoil banks left interfere with the tidal water-level fluctuations needed for healthy, accreting wetland soils. The direct and indirect effects of oil and gas canals have been responsible for at least 30 percent and possibly 50 percent of the wetland losses during the second half of the 20th Century.[10]

Several factors have been posited for the high rates of land loss experienced during the 1970s and 1980s and the declining rates thereafter. The substantial reduction in new oil and gas canal dredging may have contributed to the lower rates of coastal wetland loss in recent decades.[5] High water anomalies attributed to atmospheric phenomena (pressures and winds) were prevalent during most of the years from 1973 to 1994, causing greater inundations of wetlands.[11] High rates of subsidence may have been linked to subsurface fluid withdrawal associated with oil and gas production that peaked in the 1970s.[12] Withdrawals of oil, gas, and associated briny water in some depleted and depressurized fields are associated with locally increased subsidence and wetland loss.[13],[14] Slippage along the many growth faults within the deltaic deposits during a 20th Century episode of "neo-tectonic" activity has been suggested for being responsible for observed patterns of wetland loss,[15] but causes of the more active fault movement or its cessation in the 1990s are not apparent.

In aggregate, multiple consequences of human activities have resulted in deterioration of the coastal landscape within a century that in the past would have taken under a millennium for the natural processes to take place including subsidence, gradual sediment depravation, and erosion due to winds and hurricanes. This deterioration has resulted in the increased encroachment of the Gulf of Mexico and its violent storms on places where people live and the loss of habitats that support the legendary, rich living resources of the Louisiana coast.

Evolution of Comprehensive Planning

Although there were earlier efforts to forecast and address the degradation of Louisiana's coastal environments,[16] public and political attention to the problem began to galvanize with the 1980 assessment that Louisiana was losing as much as 50 square miles per year of its coastal lands.[17] In 1990, Louisiana members of Congress succeeded in enacting the Coastal Wetland Planning, Protection, and Restoration Act (CWPPRA) that produced a stream of dedicated funding for wetland restoration averaging about $100 million per year over the past 30 years. As required by the act, a federal-state task force produced the *Louisiana Coastal Wetlands Restoration Plan* in 1993.[18] Looking further into the future, in 1998, the state issued a strategic plan entitled *Coast 2050: Toward a Sustainable Coastal Louisiana*.[19]

Presaged by a feasibility study[20] undertaken by the U.S. Army Corps of Engineers and the State, the Water Resources and Development Act of 2007 authorized the Louisiana Coastal Area (LCA) Program. Much like the Everglades Restoration Program, the Congressional authorization calls for a long-term systematic approach to coastal ecosystem restoration as well as some critical short-term projects. However, the devastating effects of Hurricane Katrina in 2005 made it clear that coastal restoration and storm surge protection had yet to be evaluated, planned, and executed in concert.[3] Non-governmental organizations advocated for a Multiple Lines of Defense strategy integrating coastal restoration and structural and non-structural protection.[21] In response, the Corps of Engineers produced the Louisiana Coastal Protection and Restoration Study[22] and the State created the Coastal Protection and Restoration Authority (CPRA). CPRA issued its first Coastal Master Plan in 2007 and refined the plan in 2012, and again in 2017. While benefiting from the substantial federal investments in improved storm surge protection after Katrina but lacking federal appropriations for the LCA Program, the state's Coastal Master Plan has practically taken over the task of planning the comprehensive future of the Louisiana coast.

The last *Louisiana's Comprehensive Master Plan for a Sustainable Coast*[1] was approved by the state legislature in June of 2017. It was the product of an extraordinary array of technical and economic analyses that considered varying assumptions about future conditions, resource constraints, and a multitude of project proposals. There were also extensive public consultations throughout its development and prior to its ratification.

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The Coastal Master Plan intends to serve as a blueprint for the State's efforts co-equally in flood risk reduction, resilience, and ecosystem restoration over a fifty-year period. It emphasized the protection and resilience of coastal communities, rather than industrial infrastructure, both through structural risk reduction, such as provided by levees and storm-surge barriers, and non-structural risk reduction, such as through elevation of buildings, preparedness for flooding, and moving out of areas of high risk. It also considered the consequences of continued land loss and the potential effects of restoration projects on local communities along with regional and national economies. Restoration of coastal landscapes intends to produce ecosystem benefits including habitat for living resources and contribute to storm-surge attenuation. The first Coastal Master Plan offered the ambitious goal of reversing net land loss, but the current plan focuses on recognizing the reality of a smaller footprint of coastal lands in the future. Consequently, "restoration" in this context is more the rehabilitation of functions that sustain the ecosystem and maintain as much land as possible instead of returning to a previous condition.

The Coastal Master Plan estimated that the 124 projects could build or maintain more than 800 square miles of land and reduce expected damages from storm surges and other flooding by more than $150 billion over the next fifty years. The component projects include restoration of barrier islands and headlands, sediment diversions from the Mississippi and Atchafalaya rivers, hydrological restoration, marsh creation using dredged sediment, ridge restoration, cultivating oyster barrier reefs, shoreline protection, structural protection from floods, and non-structural risk reduction. The plan recognized that not all needs are addressed by its current array of projects. More information will be learned through further investigation through the planning, implementation, operations, maintenance, monitoring, and adaptive management of projects.

The Coastal Master Plan estimated that implementation of component projects would require $50 billion, split equally between risk reduction and environmental restoration, with $19 billion going to structural risk reduction and nearly $18 billion for marsh creation. The financial requirements of implementing the Coastal Master Plan far outstrip the recurring revenue streams such as through CWPPRA and shared revenues from offshore oil and gas development under the Gulf of Mexico Energy and Security Act (GOMESA). Currently, substantial funding is provided from various fines, natural resource damage payments, and plea agreements related to the BP Deepwater Horizon oil spill through a complicated array of mechanisms commonly referred to as RESTORE, NRDA, and GEBF.[23] All together, these should provide approximately $10 billion through 2030, most of that for environmental restoration.[1]

The CPRA is required by law to produce an Annual Plan[24] that inventories projects, presents implementation schedules for these projects, and identifies funding schedules and budgets. It also must submit an updated Coastal Master Plan for approval by the Legislature in 2023. The development of the 2023 Coastal Master Plan has already begun and provides strong impetus for the articulation of this vision for the Louisiana coast.

AN OVERARCHING VISION

My overarching vision for the future of the Louisiana coast is much less fatalistic than expressed by respected policy leaders such as former Interior Secretary Bruce Babbitt "The alternative to sea walls and wholesale elimination of coastal wetlands is to plan for strategic retreat and adaptation, a process that concedes some land to the sea, while allowing adjacent wetlands space to migrate inland,"[25] coastal geologists such as Orrin Pilkey "most of the Mississippi Delta will drown by 2100; most of the roughly two million people who live on the Delta will become sea-level-rise refugees,"[26] and ecologists such as Jeremy Jackson "Indeed the latest version of the Louisiana Coastal Master Plan paints a very grim picture of the chance of saving much if anything along the coast." [27]

In my vision, most of Louisiana's coastal landscapes will be sustained over the next half-century by reinstating and managing the processes that built them in the first place. The productivity and value of these ecosystems will be maintained if not enhanced. Beyond that period, the fate of the coast will depend on global society's success in meeting accepted goals to limit global warming, and thus sea-level rise. It is not too late to achieve these goals if we rapidly reduce the greenhouse gas emissions that are responsible.

The technical bases for this overarching vision and the details of sustaining actions for each of the coastal basins are provided in the following sections of this report. Presenting the overarching vision upfront hopefully provides a context for those considerations.

Louisiana's Coastal Master Plan provides a good roadmap for actions to sustain coastal landscapes, which will continuously evolve with knowledge and experience. In no way does this suggest that we can be complacent or coast along. We will mainly be struggling to hold what we have, rather than regain what we have lost. The ambitious projects included in the Coastal Master Plan and others that will be conceived will require significant resources — both monetary and sedimentary — that are in limited supply and a societal ability to make difficult decisions. There is little time for procrastination or delay.

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Rapid land subsidence and the inundation and erosion that result from it are causing the deterioration of coastal landscapes. These processes have gone on for millennia, during which coastal wetlands survived for many centuries. Ongoing land losses can be counteracted by the more complete use of the sedimentary resources of the Mississippi-Atchafalaya river system by repairing the human disruptions that accelerated these losses. In doing that, some coastal landscapes and waterbodies will change their characteristics but remain intact and productive.

The level of the ocean, including the Gulf of Mexico, has been rising over the past century at an accelerating rate, commensurate with a warming Earth. This will certainly continue, but the amount of sea-level rise experienced over the next fifty years will likely be less than assumed in the scenarios used in the last Coastal Master Plan. In my vision, land loss is less than projected and restoration measures such as sediment diversions and barrier island restoration more effective and durable. However, unless global greenhouse gas emissions are reduced substantially over these same fifty years, warming of the atmosphere and ocean would result in sea-level rise likely to exceed coastal subsidence rates by early next century. Hurricanes would become ever more intense and dangerous. These changes would result in the retreat, refugees, and grim picture of saving much of the coast that Babbitt, Pilkey, and Jackson wrote about.

This is a future that I am not prepared to accept. In my vision, global society will make this dramatic energy transition, perhaps not to net-zero emissions in fifty years, but most of the way there. This will have profound consequences for Louisiana and for sustaining its coast. The “working coast” would be more engaged in producing energy from the wind and the sun than from fossil fuels and would be pursuing the injection of carbon dioxide rather than the extraction of hydrocarbons out of deep reservoirs under the Gulf. We will be using electric motors rather than diesel engines to propel vessels and pump dredged material. It is hard to think of human enterprises in the coastal zone that would not be affected, by this transition.

While adapting to the changes in the work done along the coast, my vision is that we will also adapt how we exploit and sustain its bountiful living resources. Reconnecting the rivers’ constructive forces to sustain coastal ecosystems will alter the distribution of these resources, but also provide opportunities to enhance the overall productivity of fish, shellfish, and wildlife. We will also modernize how we cultivate and utilize these resources to enhance their value.

My vision eschews the status quo; as society must be prepared to not only accommodate major changes that must be made, but also find ways to benefit from them. There are certainly very consequential challenges immediately before us, including accomplishing the energy transition, determining places we can and cannot protect from storm surges, comprehensively managing the vast Mississippi-Atchafalaya river system to protect from flooding and reduce pollution, and providing reliable navigation gateways in the national interest. We have the scientific and technical capacity to meet these challenges, but do we have the will?

KEY CONSIDERATIONS

Building on the Coastal Master Plan

In developing my vision for the future of the Louisiana Gulf Coast, I took the 2017 Coastal Master Plan as the starting point. I reviewed the status of its implementation as presented in the Fiscal Year 2020 Annual Plan and its projections of land loss, environmental risk, and flood risk conditions in the future, without action and with the implementation of its component projects. Then, I considered the most critical of these projects and whether there may be additional approaches that should be deliberated in the development of the 2023 Coastal Master Plan. I made no attempt to evaluate project costs, but did take note of relative cost effectiveness as identified in the Plan.

To its credit, the CPRA recognized the reality of changing conditions during the 21st Century and uncertainties regarding these changes from the very first Coastal Master Plan in 2007. Successive plans have employed multiple environmental scenarios in assessing future land loss and storm surge risks. The 2017 Coastal Master plan used Low, Medium, and High environmental scenarios, each with different assumptions about changes in drivers including precipitation, evapotranspiration, sea-level rise, subsidence, storm frequency, and average storm intensity (Table 1). Except for subsidence, all of these are impacted by the warming Earth and climate change.

SCENARIO	LOW	MEDIUM	HIGH
Precipitation	>Historical	>Historical	Historical
Evapotranspiration	<Historical	Historical	Historical
Sea-level Rise	43 cm	63 cm	83 cm
Subsidence	20% of range	20%of range	50% of range
Storm Frequency	-28%	-14%	0%
Avg. Storm Intensity	+10.0%	+12.5%	+25.0%

Table 1. *Environmental scenarios used in Coastal Master Plan.*[1]

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The Coastal Master Plan considered the consequences of these scenarios on future landscape and ecosystem conditions using a computer simulation, the Integrated Compartment Model (ICM), developed specifically for the plan.[1] The ICM integrates four different models that simulate hydrodynamic and sediment dynamic processes, barrier island morphology, vegetation changes, and wetland elevation changes. From these, the ICM estimates spatially explicit landscapes and environmental conditions, such as salinity, for each year over the fifty-year planning horizon. The ICM was run for the Low, Medium, and High environmental scenarios under a future without action and with the inclusion of component projects. More detailed presentations of the ICM forecasts are provided in a report on maximizing the use of Mississippi River resources,[28] aspects of which have also been recently published in the peer-reviewed literature.[29]

The effects of environmental changes and projects on storm surge and wave heights, flooding depth and frequency, and economic damages were evaluated by a separate Coastal Louisiana Risk Assessment model (CLARA).[1] The ICM and CLARA models were used to assess the performance of the various restoration and structural protection and nonstructural risk-reduction projects.

The focus of my vision is on coastal landscape changes rather than on flood risks and damages. Consequently, I will first evaluate the assumptions of the environmental scenarios that affect the future landscape and ecosystem condition based on the predictions of the ICM. In doing so, I will take a much deeper dive on the assumptions regarding sea-level rise as it is a critical determinant of future coastal land loss, as well as flood risks, and the effectiveness of landscape restoration measures.

Subsidence

Along the Louisiana coast, the level of the tidal waters of the Gulf of Mexico with respect to the land, including wetlands, has been increasing at a rapid rate compared to other coasts of the United States. For example, the fixed tide gauge at Grand Isle has registered an average rate of relative sea-level rise of about 9 mm per year since 1950, raising the water level more than 2 feet during those 70 years.[30] This is at least double the rate witnessed elsewhere along the U.S. Atlantic and Gulf coasts. This difference is because Louisiana's coastal lands are subsiding at a more rapid rate than elsewhere as the thick sediments deposited in the Mississippi River delta over the past several thousand years compress and their mass bears down on underlying geological strata. Because these are long-term geological processes, subsidence rates over the recent past are expected to continue through this century, although questions remain concerning how fluid withdrawals and tectonic activity might affect these rates.

Subsidence rates are not uniform along the Louisiana coast. Different regional rates were used in the land-change models used in the development of 2017 Coastal Master Plan. The same regions and plausible ranges in subsidence rates developed for the 2012 Coastal Master Plan were used because of the lack of definitive data or studies that would justify a change.[31] In that earlier plan, the subsidence rates assumed for the Moderate scenario ranged from 3 mm/year around Lake Pontchartrain to 19 mm/year for the Birdsfoot Delta. Higher rates were assumed for certain sub regions where exceptional subsidence had been noted. For the scenarios considered in the 2017 Coastal Master Plan, both the Low and the Medium scenarios assumed subsidence rates at 20% of the range of reported rates for a specific region (Table 1). These are generally comparable to the rates assumed for the Moderate scenario in 2012. The 2017 Coastal Master Plan's High scenario assumed rates at 50% of the range of reported rates, comparable to the rates assumed for the Less Optimistic scenario in 2012.

The processes causing subsidence in coastal Louisiana are multiple and complex and the causes and rates of subsidence are actively debated within the scientific community. Processes contributing to subsidence include:

- readjustment of basement rocks following the melting of glaciers from the Ice Age 17,000 years ago;
- faulting through those rigid strata as well as through the sediments deposited on top of them, often related to plastic adjustment of salt deposits;
- down warping of the basement rocks because of loading due to thick deposits of sediments laid down over the last 7,000 years;
- the compaction of those sediments;
- human withdrawals of oil, gas, and water from underlying formations; and
- surface water drainage and management.[32]

Some geologists have emphasized the importance of down warping and faulting in surface subsidence.[33] A recent assessment based on a massive array of stratigraphic and subsidence data concludes that approximately 80% of historically measured surface subsidence results from compaction and dewatering of the thick fluvial and deltaic sediment layers deposited during the current Holocene epoch since the end of the last Ice Age less than 12,000 years ago.[34] Generally speaking, the denser and younger these deposits are across the Louisiana coast, the greater the rate of current subsidence.

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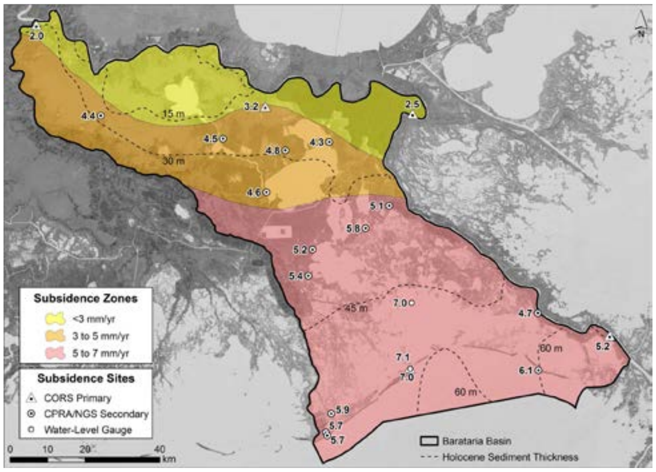

Figure 2. *Subsidence rates estimated for benchmark and tide-gauge locations in the Barataria Basin.*[35]

Subsidence rates are generally computed from benchmark leveling data (now using the Geographic Positioning System), tide gauge measurements, or dating of buried peat horizons. Surface subsidence rates in the Barataria Basin inferred from releveling of benchmarks over periods of 6 to 16 years are shown in Figure 2.[35] A generally similar subsidence rate of 7.1 mm/year at the Grand Isle was inferred over the 70-year tide gauge record there — which showed an average relative sea-level rise of 9.1 mm/year — by adjusting for the 2.1 mm/year relative sea-level rise measured at Cedar Key, Florida, which experiences negligible subsidence. The greatest thickness of Holocene sediments within Barataria Basin (60 m) is found in the center of the lower basin, consequently, where the highest subsidence rates are found. Subsidence rates estimated from the GPS relevelling (representing time series of 6 to 16 years) decline as one moves up the basin and the sediment loads thin.

These ranges of subsidence rates of 5 – 7 mm/year for the lower basin and 2 – 5 mm/year for the upper basin are narrower than the ranges used in the 2017 Coastal Master Plan of 6 – 20 mm/year and 2 – 10 mm/year, respectively. The 20% of range used in the Plan's Low and Medium scenarios is somewhat higher than these newer subsidence rates for the lower Barataria Basin and slightly lower for the upper basin. Of course, there are "hot-spots" of faster subsidence: where deltaic sediments are very thick, such as in the Birdsfoot Delta; localized areas where geological faulting has occurred; or where human activities such as fluid withdrawals or dewatering of wetlands has hastened surface subsidence. Other coastal basins with thinner deposits of Holocene sediments than the Barataria, such as the Pontchartrain Basin and Chenier Plain, are expected to experience slower subsidence. In particular, the Biloxi Marsh complex at the distal (eastern) end of the Pontchartrain Basin, likely experiences slower subsidence than assumed in the 2017 Coastal Master Plan because it is underlain by an older, stable continental shelf edge on top of which sit relatively on thinner and older Holocene sediments.[36] Such regional differences were taken into account in the previous Coastal Master Plans and without a doubt will be updated for the 2023 Plan.

Continued →

Subsidence rates based on benchmarks and tide gauges to some extent underestimate the subsidence confronting wetlands. Benchmarks are generally anchored more than 14 m below the surface and do not capture compaction and other processes above that level, particularly in the wetland soils occurring in the top 5 m.[37] The contributions of near-surface processes can be estimated using rod surface-elevation table-marker horizon (RSET-MH) techniques for direct measurements of changes in surface elevations in the wetlands. Fortunately, there is an extensive network of RSET-MH sites included in the Coastal Reference Monitoring System (CRMS), an exceptionally progressive and useful monitoring program established by the state and the U.S. Geological Survey. By combining with the benchmark estimates reflecting deeper subsidence, considerably greater rates of subsidence have been reported.[38] For the lower Barataria Basin, the mean subsidence rates were 10.3 mm/year versus 5.8 mm/year based on benchmark leveling and tide gauges. While it has been suggested that benchmark rods not surrounded by a sleeve would be drawn down along with the near-surface compaction and consequently accurately reflect surface subsidence, [35] the skin friction resistance seems insufficient to effect this draw down.[39] These differences in interpretation are consequential and should be resolved for future planning and design.

Another controversy concerns whether withdrawals of oil, gas, and associated briny water from geological formations have induced faster subsidence, including through accelerating fault slippage. Inferences based on an analyses of the Grand Isle tide gauge record suggest a subsidence rate of only 3.16 mm/year prior to 1958, a higher rate of 9.8 mm/year during the period of peak oil production in south Louisiana between 1958 and 1991, and a much lower rate of 1.04 mm/year between 1992 and 2006, following a precipitous decline in production.[40] Similarly timed, increase-then-decline trends in subsidence rates measured at survey benchmarks both in space and time have also been tied to production of oil, gas, and formation water.[41] Geotechnical analyses, however, have indicated that such induced subsidence should be localized and not extend over broad areas of the coast.[42] Of course, water levels measured at a tide gauge are also influenced by variations in the Gulf of Mexico levels in addition to subsidence. Detrended water levels were anomalously high at Grand Isle during most years from 1970 through 1995, presumably because of decade-scale weather cycles that affect the winds that blow waters toward or away from the coast.[11] All of these issues are relevant to future projections of the coastal landscape, making it important to resolve whether subsidence rates in the future might be lower with likely continued declines in coastal oil and gas production.

CPRA is working to resolve these differences and controversies and refine the assumptions of future subsidence used both in the next Coastal Master Plan and project planning. Meanwhile, I have accepted the subsidence rate assumptions of the 2017 Coastal Master Plan in forming my vision for the future of the Louisiana Gulf Coast, while recognizing that if either lower or higher subsidence rates are justified, they could have substantial consequences for sustainable restoration.

Sea-Level Rise, Critical Determinant of the Future Coast

Sea level is rising faster

Exacerbating the high subsidence rates along the Louisiana coast, the rate of rise of the ocean level has been accelerating based on careful analyses of tide gauges and satellite measurements of sea-surface height around the world. The rate of global mean sea-level rise has increased from an average of 1.4 mm/year during the 20th Century to over 3 mm/year since 1993.[43] This increase is attributable to the expanding volume of the ocean, as it has heated along with the loss of ice that resided in mountain glaciers and the polar ice sheets in Greenland and Antarctica. Furthermore, there is a statistically significant acceleration in the rate of global mean sea-level rise. One can infer, based solely on empirical observations, that the rate of global sea-level rise will continue to increase as the century progresses.

The Coastal Master Plan has taken sea-level rise into account

To the CPRA's credit, the rising level of the Gulf of Mexico and the prospect that sea-level rise may accelerate as Earth's climate continues to change has been considered in the development of successive Coastal Master Plans for Louisiana. The first plan in 2007 acknowledged the acceleration of global sea-level rise to about 3 mm and that it was related to climate change.[44] The plan took note of the then-recently published Fourth Assessment of the Intergovernmental Panel on Climate Change (IPCC) that indicated that the rate could become much higher through the 21st Century.[45] In 2012, the second plan took the step of considering two environmental scenarios: a Moderate scenario under which the level of the Gulf of Mexico would increase by 27 cm (0.89 feet) over the fifty-year planning horizon and a Less Optimistic scenario under which Gulf levels would rise 45 cm (1.48 feet).[46] To be sure, there were also different assumptions about the rates of subsidence and other environmental factors between the scenarios, but the different rates of sea-level rise produced substantially different outcomes in terms of coastal land loss. Nonetheless, planning based on the Moderate environmental scenario offered the prospect of achieving no net loss of coastal lands over the fifty years if the restoration projects were implemented.

The 2017 Coastal Master Plan continued with the multiple scenario approach (Table 1), considering different amounts of sea-level rise for the three environmental scenarios: Low (1.41 feet or 43 cm of sea-level rise over fifty years), Medium (2.07 feet or 63 cm), and High (2.72 feet or 83 cm).[1] Although shifted by five years, the assumed sea-level rise over fifty years for the Low scenario approximates that was used for the Less Optimistic scenario in the 2012 Plan. The sea-level rise in fifty years assumed in the 2017 Plan for the Medium and High scenarios was, respectively, approximately fifty percent more and double the amount assumed in the Moderate scenario on which the 2012 Plan was based. The consequences of assuming greater sea-level rise, along with updated modeling of soil accretion and marsh collapse thresholds, on land-loss projections in the 2017 Plan were substantial, with the ICM simulations indicating an 1,800 square mile net loss of land over fifty years with no action, even under the Low scenario. An in-depth investigation using the same ICM modeling framework showed that, except for sediment-poor areas, coastal marshes could accumulate sufficient soil to avoid loss due to inundation under the Low scenario, but would require substantial augmentation of sediments to survive under the other scenarios.[47]

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Future sea-level rise will depend on greenhouse gas emissions

The three sea-level rise scenarios used in the 2017 Plan were not explicitly tied to the rate of global warming or to the pathways of atmospheric greenhouse gas concentrations that might determine those rates of warming, although various sea-level rise projections were taken into account in order to assess the impact on land loss or building. This might have been to avoid dismissal of the plan by those who resist the notion that human activities are causing global warming and sea-level rise. To be fair, the multiple sea-level rise scenarios used in U.S. Government guidelines are not specifically tied to pathways of emissions or projections of warming.[48] It is scientifically established that the rates of sea-level rise have been and will be determined primarily by the thermal expansion of the oceans and the loss of the mass of ice resting on the land. Furthermore, the warming of the atmosphere and oceans that drives those two processes has been and will be driven by the atmospheric concentrations of carbon dioxide and other heat-trapping gases, which are in turn, determined by the net rate of emissions of those gases.

Being consistent with my objective of developing a realistic vision of the best possible future, what does our current scientific understanding tell us about the amount of sea-level rise we would experience if the global society reduced its emissions to limit global warming as the nations of the world committed to do under the Paris Climate Agreement? How does this compare with the amount of sea-level rise if greenhouse gas concentrations continued to grow through this century? How much of a difference would these different pathways make for coastal Louisiana?

Advances in scientific projections of sea level can guide us

There is a very large and rapidly growing scientific literature presenting sea-level rise projections based on the IPCC's scenarios of greenhouse gas concentrations and emissions pathways used in its Fifth Assessment.[49] The IPCC issues both periodic assessments and special reports that include consensus projections of sea-level rise for separate emissions pathways based on the contemporary scientific literature. The sea-level rise assumed under the High scenario in the 2017 Coastal Master Plan (83 cm over fifty years) is, in fact, derived from a publication that employed a semi-empirical approach[50] to project the global sea-level rise to the year 2100, assuming continued growth in emissions (the IPCC's Representative Concentration Pathway 8.5, Figure 3).[51]

As a precaution against possibly underestimating global sea-level rise, the CPRA, with concurrence of its scientific advisors, chose rather than the publication's mean of 1.10 m (between the period 1980-2000 and 2100), the 95% probability level of 1.65 m. In other words, there is only a 5% chance that sea-level rise would be greater than 1.65 m. It then assumed that sea-level rise in the Gulf of Mexico could be 20% higher than that, i.e. 1.98 m, based on a world map in the IPCC Fifth Assessment report showing regional deviations from the global mean.[52] The High scenario assumption of 83 cm over the fifty-year planning period is the sea-level rise from 2015 to 2065 along a curve leading to 1.98 m in 2100. Sea-level rise over the same period for the Medium to Low scenarios was assumed to be 63 cm and 43 cm to demonstrate the effects of different rates of sea-level rise on ICM landscape projections rather than based on projections under lower emissions pathways.

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The approach used in the 2017 Coastal Master Plan intentionally incorporates a great deal of precaution against underestimating the sea-level rise threat, using a High scenario projection based on the continued growth in greenhouse gas emissions, near the high end of its probability range, and adjusted by 20% to accommodate a potential regional disparity from global mean sea level. This is understandable if one were planning for structural or nonstructural protection of human communities from recurrent flooding or storm surge with some margin of safety. However, by planning for a level of rise that has only a 5% chance of occurring, the approach could exaggerate the challenges to the survival of existing barrier island and coastal wetland landscapes and the restoration projects being considered, at least over the fifty-year period. Consideration of the middle of the likely range of the probability distribution, rather than the 95th percentile, might be a more realistic basis for planning restoration projects.

Furthermore, how does the High scenario estimation based on a paper published in 2012 comport with numerous, more recent projections, which to varying degrees take into account the prospect of greater sea-level rise from rapid sheet loss, now being observed in Greenland and Antarctica? Finally, how much difference will it make in the sea-level rise experienced along coastal Louisiana if global warming were limited by substantially reducing global greenhouse gas emissions over the next several decades as called for under the Paris Climate Agreement?

Fortunately, there are many recent publications of sea-level rise projections that help answer these questions. The most recent is the IPCC *Special Report on the Ocean and Cryosphere in a Changing Climate* (SROCC).[53] The SROCC report estimates contributions from ice-mass loss in providing projections for global mean sea level (GMSL) for three standard IPCC Representative Concentration Pathways (RCPs, Figure 3):

- RCP 8.5 in which global emissions continue to grow at rates similar to the recent past before leveling off by the end of the 21st Century;
- RCP 4.5 in which emissions continue to grow more slowly than during the recent past before declining during the second half of the century; and
- RCP 2.6 which is purposefully constructed to produce the reasonable prospect that global mean temperature will not exceed 2°C above pre-industrial levels as called for under the Paris Agreement.

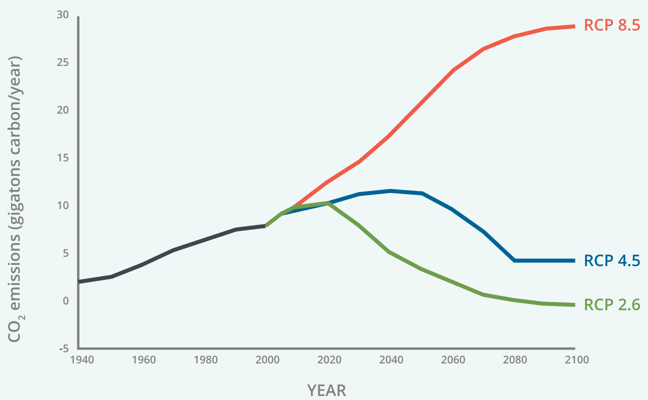

Figure 3. *The RCP CO_2 emissions pathways used in many projections of sea-level rise.*

These emissions pathways lead to median increases of global mean temperature above preindustrial levels by the end of this century of 1.6°C (likely range 0.9–2.4°C), 2.5°C (1.7–3.3°C), and 4.3°C (3.2–5.4°C) for RCP 2.6, RCP 4.5 and RCP 8.5, respectively. The RCP 8.5 pathway was not intended to represent "business as usual" growth in emissions and, as some commitments to reductions have already been made, the world seems to be on a course for around 3°C warming by the end of the century, or 4°C if some of these commitments are not met.[54]

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The SROCC projections for global mean sea-level rise — depicted in Figure 4 to the year 2200 — represent the current international consensus of scientific experts until the IPCC's Sixth Assessment is released in April 2021. To make them easier to comprehend I have labeled the RCP 8.5 projections as Growing Emissions and the RCP 2.6 projections as Paris Agreement, as I did in a report on sea-level rise projections for Maryland.[55] IPCC projections are conservative in that they must be based on accepted, quantitative estimation of the processes responsible. The projections depicted are based on those made in IPCC's Fifth Assessment in 2013, but amended in the SROCC to include more thorough and up-to-date consideration of the contributions of ice loss in Antarctica. Consequently, the sea-level rise projected under the Growing Emissions pathway from late in this century and into the next are higher than earlier IPCC projections, but not as high as some more-speculative projections that have been published but not based on accepted, quantitative estimation of the responsible processes.

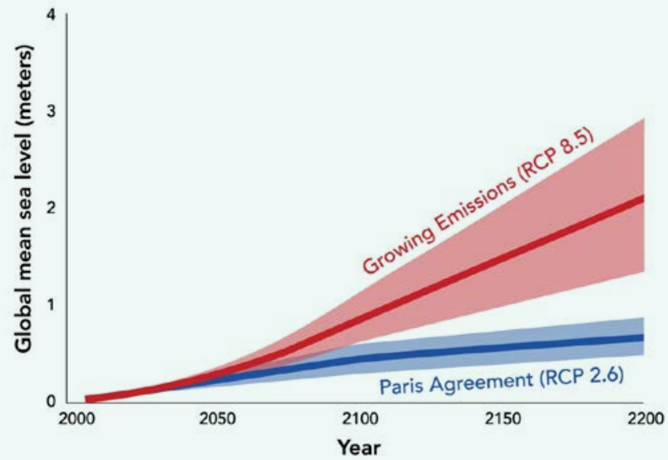

Figure 4. *SROCC projections of global mean sea-level rise through 2200 (from a 1986–2005 baseline) if emissions continued to grow over this century or were reduced consistent with the objective of Paris Climate Agreement. Shaded areas depict the likely ranges (17–83% probability), lines the medians.*

In order to compare the SROCC projections with the sea-level rise assumptions used in the Coastal Master Plan scenarios, it is first necessary to consider the degree to which sea-level rise experienced in the Gulf of Mexico might differ with global mean sea-level rise. The High scenario assumed it would be 20% greater. Simply explained, the amount of sea-level rise a region would experience is inversely related to the distance from the source of the land-based ice that was lost to the ocean. Thus, the loss of ice from Antarctica would cause sea level to rise in the Gulf more than the global mean and the loss of the same amount of ice from Greenland would contribute less. The contributions of these sources in the SROCC projections suggest that Antarctic ice will contribute very little over the next fifty years and that sea-level rise in the Gulf should closely track the global mean through this century. This is consistent with other regional projections for the Gulf[56] and National Oceanic and Atmospheric Administration guidance for application of the sea-level rise scenarios used in the Fourth National Climate Assessment.[57]

The assumption that sea-level rise in the Gulf should be similar to the global mean in this timeframe does not take into account the so-called dynamic contributions to regional sea-level rise that might result from changes in major ocean currents or regional differences in ocean warming. These effects are not yet fully understood much less reliably modeled.[58] It is important to note that sea level along the northern Gulf Coast can vary by as much as 10 cm over multi-decadal periods because of ocean-basin-scale climatic oscillations and it has significant implications for coastal wetland sustainability and restoration.[11] If high-water anomalies prevailing during the 1970s and 1980s return for extended periods, wetland loss rates could increase.

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Over the next fifty years, sea-level rise is likely to be less than assumed, but emissions still matter

Projections of medians and likely ranges of Gulf sea-level rise — assuming that it tracks the global mean — for the same fifty-year period considered in the 2017 Coastal Master Plan are provided in Figure 5. The intermediate RCP 4.5 pathway, representing Stabilized Emissions, is considered in addition to the Growing Emissions and Paris Agreement pathways. As discussed earlier, the Growing Emissions (RCP 8.5) emissions pathway now seems implausible through this century, but the worst-case should not be much different within this period. The amounts of sea-level rise under the Plan's High, Medium, and Low environmental scenarios are provided for comparison. Two very important points emerged. First, both stabilizing and reducing greenhouse gas emissions consistent with the Paris Climate Agreement would affect the amount of sea-level rise even over the next fifty years. The median estimate for sea-level rise if emissions were reduced to limit warming to less than 2°C (22 cm) is substantially less than that for the Growing Emissions pathway (33 cm). Second, sea-level rise during this same fifty-year period is likely (less than 17% chance of exceeding) to remain below the 43 cm assumption of the Low environmental scenario, even if greenhouse gas emissions continued to grow at recent rates.

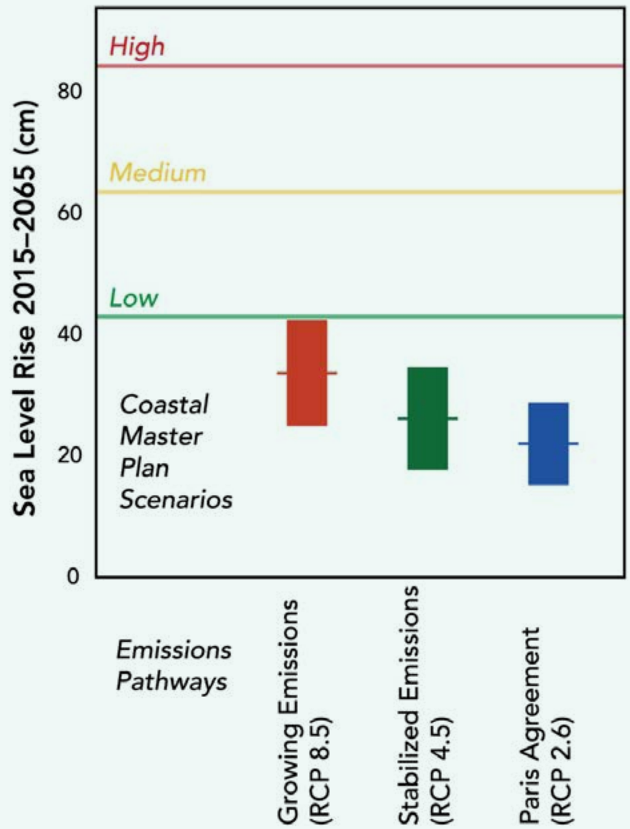

Figure 5. *The median and likely range (17-83% probability) for SROCC projections of global mean sea-level rise over the period 2015-2065 under different greenhouse gas emissions pathways, compared to the Gulf-level rise assumed in the 2017 Coastal Master Plan scenarios.*

These sea-level rise estimates extracted from the SROCC projections provide confidence in using the land-change estimates that were generated for the Low environmental scenario in the 2017 Coastal Master Plan as a sufficiently conservative basis (low likelihood of being exceeded) for future conditions in the rest of this report. The ICM modeling of future land loss and gain without action showed about 70% greater land loss coast wide after fifty years under the Medium environmental scenario than under the Low scenario with the same assumptions of subsidence rates.[1] Projected land loss under the High scenario, which assumed greater subsidence rates, was two and a half times that under the Low scenario.

While the likely range is more appropriate for assessing coastal land changes and effectiveness of restoration measures, a lower probability, high-end benchmark, such as 95% probability could still be used for evaluating measures to protect against coastal flooding. The SROCC only presents medians and likely ranges, however, there are other published sources that present full probability distributions. For example, one widely used method that produced an approximately similar median and likely range as that extracted from the SROCC projections under Growing Emissions (likely range 25–42 cm), estimated a 95% probability of 51 cm.[56] This is still well below the 63 cm assumed under the Medium environmental scenario.

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Greenhouse gas emissions will determine the ultimate future of the Louisiana coast

Gulf of Mexico sea-level rise will likely be less than Louisiana's forward-looking, coastal planning had anticipated, indicating that coastal land loss will not exceed that projected under the Low scenario and may be less. Of course, this assumes that new modeling expectations and environmental drivers do not produce a substantial counteracting effect. Less sea-level rise should allow better performance and longevity of restoration measures intended to strengthen, build and sustain coastal landscapes than had been evaluated. This is good news only relatively speaking. It presents opportunities, but should not alleviate the sense of urgency. First, we must remember that the high rates of subsidence along the Louisiana coast will continue to constitute most of relative sea-level rise over the next fifty years. It is this relative sea-level rise that will erode and submerge lands. Second, the rise of ocean levels could later exceed the rate of subsidence and will certainly continue centuries into the future and, if global warming is not limited, at ever faster rates as losses of the polar ice sheets accelerate.

The IPCC's SROCC presented sea-level rise estimates for the next two centuries as influenced by 21st Century emissions pathways. While estimations are much less certain beyond this century, the implication of failing to reduce and ultimately eliminate human greenhouse gas emissions in the coming decades is startling. If greenhouse gas emissions are not substantially reduced during this century, there is serious risk of heating that would cross-tipping points for polar ice sheet disintegration that will not be possible to stop. By the end of this century, sea-level rise could cross the 83 cm level that produced such devastating outcomes under the Coastal Master Plan's High scenario. It would continue to accelerate into the next century during which the oceans could rise 3 meters, or 10 feet (Figure 4). This would inundate, obliterate, or render ineffective most of the protection and restoration investments made over the next half-century, calling into question both the wisdom and ability to protect even urban areas against storm surges riding atop a 12-foot increase in relative sea level. If such sea-level rise would occur, the Gulf of Mexico would reclaim most of the Deltaic and Chenier plains of Louisiana.

Such a dire future is avoidable. The SROCC projections suggest it is likely that the rise of the oceans can still be kept under 1 meter well into the next century if global warming were limited to well under 2°C by eliminating greenhouse gas emissions during the next 40 to 50 years — during which Gulf sea-level would likely rise less than 30 cm. This would allow a sustainable future for much of coastal Louisiana into the next century. Redistribution of the sediment resources supplied by the Mississippi and Atchafalaya rivers might then allow some, but not all, coastal landscapes to keep up with relative sea-level rise. Although relocation of some communities and infrastructure would still have to be accomplished, storm-surge risk reduction could be incrementally enhanced for others.

Storm Frequency and Intensity

The environmental scenarios used in developing the 2017 Coastal Master Plan (Table 1) assumed changes in tropical storm frequency and intensity (measured as central pressure deficit) resulting of natural climatic fluctuations and global warming.[59] The Low scenario assumed a 28% reduction in storm frequency and 10% increase in average intensity. The Medium scenario assumed a 14% reduction in storm frequency and 12.5% increase in average intensity. The High scenario assumed no change in storm frequency and a 15% increase in average intensity. These assumptions were based on published models and expert input concerning Atlantic tropical cyclones in general, as it is not possible to predict changes in landfalls in Louisiana or any other segment of the coast.

The assumption that there may be fewer tropical cyclones but more intense hurricanes is consistent with the scientific developments since the scenarios were crafted in 2015. The Fourth National Climate Assessment concluded that both theory and numerical modeling simulations indicated that an increase in tropical cyclone intensity is likely in a warmer world and it is more likely the frequency of tropical storms will either decrease or remain the same.[60] While the three Coastal Master Plan scenarios were not explicitly tied to the IPCC Representative Concentration Pathways discussed above, the higher the greenhouse gas concentrations are in the future, the more intense tropical storms are likely to be, even if they are less frequent.

Sensitivity analysis conducted to select the three scenarios used in the 2017 Coastal Master Plan found that the differences in storm frequency and intensity affected land loss in different ways in Louisiana's coastal basins, but there were little net effects across the coast.[61] Accordingly, the scenario assumptions for storm frequency and intensity were not used in the Integrated Component Model (ICM) projections of the future landscape conditions considered in the plan. They were applied only to storm surge modeling used in the Coastal Louisiana Risk Assessment modeling. It is problematic, to factor in changes in storm frequency and intensity into a specific vision of future coastal landscapes. Rapidly intensifying, major hurricanes seen in recent years, may become more common in the northwestern Atlantic basin. Storms such as Harvey that move slowly on reaching the coast may result in prolonged storm surge and heavy rainfall. These will affect not only coastal landscapes, conditions, and challenge defenses, but also have an influence on the willingness and capacity to provide insurance against wind and flood damages or to finance recovery.

Precipitation and Runoff

Changes in precipitation and freshwater runoff can affect the distribution of salinity in Louisiana's coastal basins and change wetland plant communities. In particular, reductions in precipitation or increases in evapotranspiration — the sum of evaporation and plant transpiration — would reduce freshwater inputs and exacerbate saltwater intrusion into this subsiding coastal zone. In the selection of the environmental scenarios used in the 2017 Coastal Master Plan, sensitivity analysis produced the surprising result that both increases and decreases in the difference between precipitation and evapotranspiration resulted in somewhat less land loss across the Louisiana coastal zone than the assumption that historical conditions would continue.[61] The effects differed substantially within the coastal basins and over time, with the lower Terrebonne Basin showing a relative land gain and the upper Barataria showing a substantial relative land loss at the end of the fifty-year period under wetter conditions. Nonetheless, the effects of wetter conditions on land loss are much less than for different assumptions of sea-level rise. In the scenarios selected for use in the 2017 Plan, the Low scenario assumed an increase in precipitation and a decrease in evapotranspiration, the Medium scenario an increase in precipitation and no change in evapotranspiration, and the High scenario no changes in either. The Low and Medium scenarios assumed the same precipitation, but lower rates of evapotranspiration in the Low scenario. The different assumptions would result in only minor differences in land loss forecast by these two scenarios.

The Fourth U.S. National Climate Assessment showed that coastal Louisiana experienced very little change in annual precipitation from the first half of the 20th Century, however, there was slightly greater precipitation during the Spring and substantially more (>15%) in the Fall.[62] In this assessment, projected changes in seasonal precipitation for the last 30 years of the 21st Century assuming that emissions continue to grow (RCP 8.5), are for modestly less precipitation (<10%) in the Spring and Summer and more in the Fall. Annual or even seasonal precipitation averages can be misleading, as more of the rain has fallen in heavy rainfall events and this trend is expected to continue in a warming world. The implication of little overall change but more intense rainfall and a warming world is the prospect of more prolonged, drought-like conditions with drops in soil moisture.[63] This could increase the likelihood of conditions responsible for sudden marsh die-back such as in the "brown marsh" incident that occurred across the Louisiana coast during the year 2000. Although the causes of such dieback are complex, they are thought to be linked to such climatic anomalies.[64, 65] While beyond the scope of my analysis, the prospects for extended dry spells and their ramifications for Louisiana's coastal wetlands could be substantial and should be considered in future planning.

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The 2017 Coastal Master Plan did not consider potential changes in runoff from land down the Mississippi or Atchafalaya rivers that might result from climate change. While these flows only influence the wetlands of the presently active Birdsfoot and Atchafalaya deltas, future flows will affect the frequency and duration of use of the Bonnet Carré Spillway and Morganza Floodway, as well as the effectiveness and operations of planned sediment diversions. River floods have been more frequent in recent years, requiring the opening of the Bonnet Carré Spillway six times during the last eleven years. The prolonged flooding along the upper Mississippi and Missouri during 2019, uncharacteristically extending into the early summer, prompted discussion about whether large, late-season floods have become a "new normal" brought about by global climate change.

This is not yet conclusive. Dynamic modes of climate variability have certainly affected flooding trends, but river engineering for the purposes of flood mitigation, power generation, and commercial navigation has been responsible for three-quarters of the 20% increase in magnitude of the 100-year flood over past five centuries.[66] While precipitation is projected to increase in the river basin during the winter and spring by late in the century if emissions continue to grow,[62] there may not be a concomitant increase in Mississippi River flow as a result of complex factors such as less snowmelt and greater evapotranspiration. While one modeling study projected increasing river discharge because of land-use, climate, and atmospheric CO_2 changes,[67] a more recent modeling exercise projected lower discharge in the lower river during the second half of the 21st Century than what occurred during the second half of the 19th century.[68] The likely changes in the amount, timing, and variability in river flow should be taken into account in planning management options for the lower Mississippi and Atchafalaya rivers, including flood mitigation with levees and spillways, sediment diversions, and navigation.

Action to Reduce Shelf Hypoxia

In opening this report, I indicated my intention to form a vision conditioned on prudent and effective choices made in restoration, protection, and sustainable societal actions. One of these choices is the full implementation of the Gulf Hypoxia Action Plan intended to reduce, mitigate, and control hypoxia in the northern Gulf of Mexico and improve water quality in the Mississippi River Basin. Hypoxia, the occurrence of harmfully low dissolved oxygen, occurs seasonally in bottom waters of the inner continental shelf mostly off Louisiana. This so-called Dead Zone is exacerbated by pollution with excessive amounts of nitrogen and phosphorus, most of which are derived from agricultural runoff in the Mississippi-Atchafalaya River Basin.

The Gulf Hypoxia Action Plan was first approved in 2001 by a task force representing Louisiana and 11 upriver states and the federal government, led by the U.S. Environmental Protection Agency. Reissued in 2008 and amended in 2013, the plan commits to reducing the hypoxic zone by about two-thirds to less than 5,000 km^2 by 2035.[69] The task force set an interim target of a 20% reduction in loads of both nitrogen and phosphorus carried by the rivers to the Gulf by 2025, while recognizing that a reduction of 45% or more will be required to meet the hypoxia reduction goal.

While states have developed nitrogen and phosphorus load reduction strategies, implementation has not yet resulted in any diminution of loads of nitrate — the nutrient form most responsible for hypoxia — to the Gulf.[70] This is probably due to the fact that gains in nutrient-use efficiency in agriculture have been counteracted by intensification of agricultural production, particularly driven by a rapid increase in growing corn to produce ethanol fuel. Long lag-times in the transport of nutrients through the watershed may also delay pollution abatement.[71]

While hypoxia along the inner Louisiana diminishes the capacity of the ecosystem for fishery production, it is typically treated as a separate issue from the coastal land-loss crisis. Because of the international attention it has received, hypoxia is considered by some in Louisiana as a competing issue, based on my experiences. This division of perspectives has polarized regional science, and unnecessarily so.[70] Despite the reality that Louisiana is the most aggrieved party, the state has not been aggressive in insisting on the pollution reductions from the upper basin called for by the Gulf Hypoxia Action Plan. I do not intend to trivialize the difficulty, economic, and political complexity of the challenge, but this seems a necessary impetus for action.

Continued →

The Coastal Master Plan addresses the hypoxia crisis only tangentially, by considering the potential for sediment diversions to remove nutrients before reaching the Gulf. It has been proposed that revenues for this service could be derived from sectors responsible for the pollution and used to support coastal restoration. However, without imposed pollution limits, there is no cap-and-trade mechanism to accomplish this. Even if there were, nutrient retention by sediment diversions during their peak operation would likely contribute relatively little to the overall pollutant load reductions called for. Furthermore, depending on where they are placed and operated, diversions could potentially increase nutrient loads to hypoxic inner-shelf waters.

I argue that the separation of the coastal land-loss and hypoxia crises is unfortunate because they are both manifestations of broader dysfunction within the Mississippi-Atchafalaya River Basin that affects downriver flooding, sediment supplied to the Mississippi Deltaic Plain, and nutrient pollution. While it is true that Louisiana has more direct control over the rehabilitation of its coast than these other factors, they all limit its options and affect its success. More systemic thinking about managing these challenges in tandem is clearly needed. Furthermore, elevated nutrient concentrations in the Mississippi River waters risk potentially deleterious impacts when the waters are diverted to re-establish deltaic land building. In addition to possible exacerbation of shelf hypoxia mentioned above, impacts could include deterioration of wetlands growing on largely organic soils[72] and generation of harmful algal blooms.[73] High nitrate concentrations can cause degradation of organic marsh soils and reduced production of roots and rhizomes. Whether high nutrient concentrations in relatively modest freshwater diversions have contributed to marsh loss have been hotly debated.[74] However, evidence strongly suggests that sediment-rich diversions would build and not degrade wetlands.[75] Extensive blooms of cyanobacteria extending into the Mississippi Sound resulted from the prolonged releases of nutrient-rich river waters through the Bonnet Carré Spillway in 2019. Sediment diversions conceived for the lower Mississippi River would carry far less fresh water and nutrients and can be timed for pulsed releases, but still might stimulate harmful algal blooms within Louisiana’s bays.

The luxuriant wetlands of coastal Louisiana developed and were sustained over thousands of years during which nutrient concentrations in the Mississippi River were substantially lower than experienced during the last 60 years of pollution from industrialized agriculture. There is little risk that reducing nutrient pollution sufficient to meet the hypoxia reduction goals would starve coastal wetlands. Furthermore, achieving the nutrient-load reduction requirements to meet the 2035 goal of the Gulf Hypoxia Plan will alleviate potential constraints on the maximum use of the river’s freshwater and sediment resources over the critical next 20 years of the Coastal Master Plan. Therefore, Coastal Plan meet Hypoxia Plan. Louisiana should have a more integrated and coherent approach to addressing these two simultaneous and interrelated crises.

Biological Productivity and Value

There is substantial concern that the deterioration of Louisiana's coastal environments will continue to diminish the legendary high productivity of their fish and wildlife resources, their exceptional biological communities, and the valuable services these ecosystems provide. Furthermore, there is considerable anxiety about the negative effects of restoration measures, such as sediment diversions, among both commercial and recreational fishers, and some resource managers. Nevertheless, in my vision it is entirely possible to enhance biological productivity of the coast and its value to society over the coming decades as we deal with the future threats and rehabilitate landforms and ecosystems. Yes, it will involve uncomfortable choices, but choices that will be justifiable in the context of the changing world around us.

Despite recent setbacks in its commercial fisheries, Louisiana still annually lands an average of 75 million pounds of shrimp, 45 million pounds of blue crabs, and 12 million pounds of oysters. To many fishers, the changing coastal conditions have made things worse.[76] Fishers face many challenges in addition to the deterioration of the coastal environment, including market constraints on prices, unlimited entry and conflicts among fisheries, inadequate infrastructure, the disruptive impacts of river floods, and the lingering impacts of fishery closures after the Deepwater Horizon oil spill. There are also fundamental conflicts between the requirement to reestablish the wetland-building capacity of sediment inputs from the rivers for the long-term existence of the coast and the more immediate and localized dislocations of fisheries away from existing habitats, leases, communities, and ports where waters are freshened.

During the feasibility planning for the Louisiana Coastal Area program, I recall that much effort was spent in evaluating restoration measures in terms of various habitat suitability indices for multiple living resources. This approach was used in evaluating and designing specific projects supported by CWPPRA and other programs, but it often lead to irresolvable conflicts analogous to the guns or butter dilemma of macroeconomics, such as, ducks or speckled trout. Given the enormity and complexity of the coastal protection and restoration challenge, the operational metric for coast wide planning has devolved largely to acres of land — witness the focus on this in the Coastal Master Plans. Metrics of resource value are still generated and subsequent planning should find ways to integrate productivity and ecosystem functions back into the equation, seeking to optimize gains and not just minimize losses. This has to be done not with static assessments characteristic of habitat suitability indices, habitat equivalency analyses, or annual average habitat units, but in dynamic, forward-looking scenarios, recognizing both coastal changes in space and time must take place and how society exploits and consumes the resources.

For example, do river diversions provide opportunities to produce crawfish in habitats that once produced shrimp? Can we rebuild oyster reefs that provide both wave protection and spawning stock while transitioning to higher value cultivation of oysters for the consumer, as has been done most other places in the world? As the world aggressively strives toward carbon neutrality, can we harvest more highly valued Gulf shrimp that, because of high quality, carbon efficiency, and brand, compete with imports for the domestic market? As Louisiana sustains the natural diversity and bounty of its coast, why should it not be able to expand the economies of ecotourism and sports fishing? I do not pretend to have answers to these questions, but will point out opportunities as I consider the opportunities basin by basin. My point is that one's mind must be open to such changes in order to avoid resignation to a future of diminishing returns.

Projections of the Future Coast

In this report, I have developed a vision for each of the Louisiana coastal basins (Figure 1) because they differ in terms of the factors and rates of land loss, the resources and populations at risk, and the opportunities for restoration. In the subsequent visions for the coastal basins, I have combined the Pontchartrain and Breton basins, the Atchafalaya and Vermilion/Teche basins, and the Chenier and Mermentau basins to simplify the task.

I used the 2017 Coastal Master Plan as the starting point, considering its projections of land loss in the future, without action and with the implementation of its component projects, as derived from the Integrated Compartment Model. Specific projections of land loss by coastal basin under the High, Medium, and Low environmental change scenarios are provided for the future without action in Table 2. I will focus on the projections of the Low scenario because its sea-level rise assumption is not likely to be exceeded. The difference between 43 cm and 63 cm in sea-level rise over 50 years is responsible for almost all of the difference in land-loss projections compared with the Medium scenario. These two scenarios have identical assumptions concerning subsidence and the different assumptions for evapotranspiration are trivial. For the Low scenario, a breakdown of the causes of land-loss over the fifty-year period is provided for each coastal basin.

Table 2. *Land loss (in acres) cumulatively projected by the Integrated Compartment Model after a fifty-year period without action for each Louisiana coastal basin and the three environmental scenarios used in the 2017 Coastal Master Plan.[28] Proportional causes of land loss are shown for the Low scenario.*

Land loss in acres/ Percent attribution	Pontchartrain	Breton	Birdsfoot Delta	Barataria	Terrebonne	Atchafalaya	Teche/ Vermilion	Mermentau	Calcasieu/ Sabine
Causes – Low Scenario									
Salinity collapse	0.0%	0.8%	14.3%	1.2%	0.0%	0.9%	0.4%	35.3%	1.2%
Inundation collapse									
Intermediate marsh	0.1%	0.0%	1.6%	0.1%	0.8%	66.7%	0.1%	0.1%	0.0%
Brackish marsh	17.8%	33.4%	24.8%	25.5%	15.3%	0.3%	16.4%	10.2%	27.0%
Saline marsh	35.2%	11.6%	18.2%	42.0%	52.7%	0.4%	57.2%	41.2%	56.7%
Marsh edge erosion	43.3%	52.6%	41.0%	25.6%	27.3%	25.0%	25.6%	12.5%	14.1%
Dead flotant marsh	0.7%	0.9%	0.0%	1.5%	2.1%	5.1%	0.1%	0.1%	0.0%
Bareground collapse	2.8%	0.6%	0.1%	4.0%	1.8%	1.6%	0.3%	0.6%	1.1%
Low Scenario total	64,201	41,723	46,855	188,110	192,403	11,077	35,018	121,027	43,465
Medium Scenario total	157,197	77,381	55,455	303,154	333,512	17,575	87,417	237,952	121,217
Times > Low Scenario	1.8	1.9	1.2	1.6	1.7	1.6	2.5	2.0	2.2
High Scenario total	391,433	121,092	62,875	465,336	503,915	31,539	194,949	466,182	305,448
Times > Low Scenario	4.5	2.9	1.3	2.5	2.6	2.8	5.6	3.9	7.0

Using the sea-level rise assumption of the Medium environmental scenario results in 60 to 160% greater land loss in coastal basins, except for the Birdsfoot Delta, where subsidence will continue to be the overwhelming cause of high relative sea-level rise. Land-loss with the higher sea-level rise and subsidence assumptions of the High scenario is many times greater. Differences in the causes of land loss projected for the basins are taken into account in the corresponding visions.

The dominant cause of projected losses across the basins is inundation collapse of marshes, which occurs when a marsh is unable to aggrade sufficient mineral and organic soil to keep up with relative sea-level rise. Such collapse is very dependent on the rate of relative sea-level rise. Losses could be lower if sea level rises less than the 43 cm assumed under the Low scenario, as the IPCC projections suggest should be the case (Figure 5). In addition, marsh elevation trajectories have been positive at 75% of 332 CRMS sites over a recent ten-year period. Land loss at CRMS sites has generally not been associated with elevation loss, with erosion having been a greater factor than collapse.[77] As marsh edges and platforms are eroded by waves, sediments are remobilized and contribute mineral material available for the aggradation of remaining marsh surfaces.[78] These field observations and dynamics should be taken into account in the next-generation modeling to support the 2023 Coastal Master Plan.

Broad and Profound Consequences of Limiting Climate Change

While sea-level rise unleashed by unlimited global warming presents an existential threat for coastal Louisiana, other effects of climate change on the region would also be alleviated by reducing greenhouse gas emissions. These effects include higher temperatures and severe heat waves, droughts, and intense rainfall events including bigger river floods and tropical storms that are more powerful.[79] These risks increase as emission reductions are delayed. Actions taken to reduce greenhouse gas emissions will have profound consequences on the people, enterprises, and energy uses in coastal Louisiana. National and global actions will reduce the use of fossil fuels and increase reliance on renewable energy. Louisiana and its oil and gas industry will not be isolated or immune from this transition. Exploring the full consequences of and proposing effective pathways through this transition are beyond the scope of my report. While global emissions continue to grow, the transition has already begun as evidenced in the rapid growth of renewable energy and decline in coal consumption in North America and Europe. It is just a matter of how quickly this energy transition will occur.

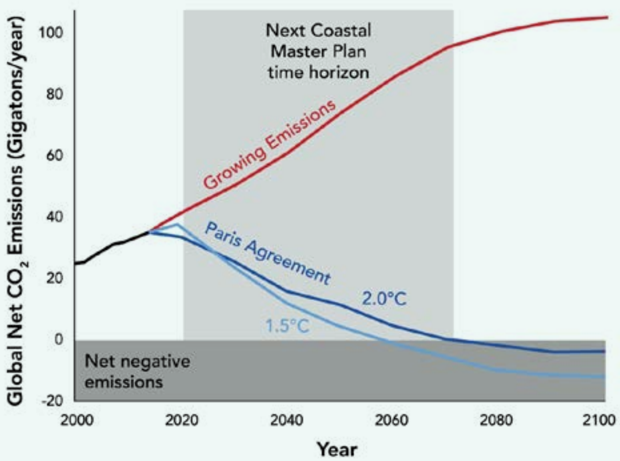

Figure 6. *Mid-range pathways for achieving the 2°C and 1.5°C goals of the Paris Climate Agreement compared with the Growing Emissions pathway.*

It is essential that the planning for the restoration and protection measures for the future Louisiana coast begin to take into account the dramatic energy transition that will be required. This should involve not only more explicitly tying future scenarios used in planning to greenhouse gas emissions, as I have done for sea-level rise, but also considering how the energy transition will affect enterprises, infrastructures, and energy uses. The fifty-year time horizon of the 2023 Coastal Master Plan will include the period during which rapid reductions in greenhouse gas emissions will have to be accomplished in order to achieve the goals of the Paris Climate Agreement, whether it is to limit global warming to 2°C, or achieve the more ambitious limit of 1.5°C warming (Figure 6).[80] By then, the potential pathways also require net-negative emissions (i.e. substantial sequestration of carbon) through the end of this century.

While there is current political disagreement within the United States over how to achieve this goal, a growing number of nations around the world, states within this nation, and international corporations — including major oil and gas corporations — have made commitments to reduce most or all of their emissions by 2050. This will affect Louisiana regardless of local opinions on the matter, where attitudes are already shifting. A recent poll indicated that over 70% of Louisiana voters believe in climate change and that it will affect their lives in the future.[81] Awareness is growing not only of the effects of climate change, but also of the steps that must be taken in order to limit the severity of these effects. Louisiana Congressman Garret Graves, who is the Ranking Member of the House Select Committee on the Climate Crisis, told a writer for *The New Yorker* that, beyond spending on adaptation and resilience, "Step two is emissions reductions. We have to reduce our emissions in the United States. Therefore, we need to be moving toward renewables, updating our grid system, investing in energy-storage technologies. I think we can actually hit Paris targets without doing damage to the American economy."[82]

Continued →

Some assessments suggest that reliance on fossil fuel energy in Louisiana's economy and high-energy costs will make coastal restoration increasingly problematic in the face of climate change.[83, 84] I am less fatalistic in thinking that a transition toward a net-carbon free energy system will occur over the next fifty years. There are substantial implications of the energy transition that should be considered in planning coastal protection and restoration, including:

1. Less onshore and offshore oil and gas development and production, rendering obsolete infrastructure for oil and gas production and transportation.

2. Declining revenues related to this production, including those dedicated to coastal protection and restoration.

3. Substantial changes in businesses and employment, particularly in the energy and transportation sectors.

4. Greater production of wind and solar power. According to one roadmap,[85] meeting Louisiana's energy demands from renewable sources would have to rely heavily on offshore wind energy (60%) and utility photovoltaic solar energy (32%). There is a significant potential for offshore wind energy on the inner continental shelf, particularly off southwestern Louisiana.[86] There is also vast space in shallow water bodies in the coastal zone where photovoltaic solar energy panels could be deployed, potentially in conjunction with wave-stilling barriers that lessen marsh erosion.

5. Potential opportunities for carbon capture and sequestration in wetland soils[87] and in deep saline reservoirs lying under the coast and continental shelf.[88]

6. Electrification of vehicular and maritime transportation and of machinery, such as pumps used to transport sediments.

VISIONS FOR THE COASTAL BASINS

Pontchartrain Basin: The Eastern Flank of Louisiana's Most Populous Region

Prologue

The most populous and expansive coastal basin in Louisiana, Lake Pontchartrain Basin, experienced the most devastating effects of Hurricane Katrina in 2005. The basin is distinguished by three large coastal lagoons; Lakes Pontchartrain, Maurepas, and Borgne, named by the French colonizers for Louis XIV's Minister of Marine, the son who succeeded him, and an anonymous one-eyed man, respectively. The coastal landscapes formed when the Mississippi River was built and then abandoned at the St. Bernard delta lobe, which was active 4,000 to 500 years ago.[89] Bayous Bienvenue, La Loutre, Terre Aux Boeufs, and Aux Chenes are remnants of the major distributaries of the former delta. The sub basin between the Bayou Terre Aux Boeufs and the Mississippi River is often referred to as the Breton Basin to distinguish it from the rest of the Pontchartrain Basin. Two broad, essentially continuous sounds, Chandeleur and Breton, separate the deltaic wetlands from the remaining portions of a chain of barrier islands with those same names to the east. These barrier islands mark the eastern extent of the formerly active delta lobe that has been reworked by erosive processes and are in the process of becoming submerged shoals.

The Pontchartrain Basin contains the Nation's most expansive storm-surge infrastructure, as well as multiple lines of environmental defense, that together protect more than 40% of Louisiana's residents. Sediment diversions from the Mississippi River, strategic creation of marshes and topographic ridges, and shoreline protection will all contribute to attenuate storm surges and support high productivity of natural resources within the estuary.

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The Pontchartrain Basin is vast, extending from the Chandeleur Islands that lie in an arc extending farther east than Biloxi, to Baton Rouge in the west (Figure 7). The basin has a large watershed that includes the Pleistocene terrace north of Lake Pontchartrain and extends into the higher uplands of southern Mississippi. The area of the coastal basin and watershed is over 10,000 square miles —17,000 square miles if one includes the Pearl River that originates above Jackson and discharges into Lake Borgne at the border with Mississippi. Consequently, even though normally isolated from Mississippi River flows, the Lake Pontchartrain coastal basin receives large freshwater inflows that maintain very low salinity conditions over most of its vast, tidally influenced waters. Even larger freshwater inflows are occasionally experienced when the Bonnet Carré Spillway is opened into southwestern Lake Pontchartrain to lower the Mississippi River stage in order to alleviate flood risks along the lower river. The spillway was first used in 1937 and has been opened 14 times, 6 times during the last 12 years, and twice during 2019 for a total of 122 days. Because large volumes of nutrient-enriched river water flowed through the spillway for an unprecedented length of time during 2019, salinity was lowered well into the Mississippi Sound and blooms of potentially toxic cyanobacteria (also called blue green algae) occurred in the lakes and the sound. This has fueled legal challenges to the Corps of Engineers by Mississippians regarding the operation of the spillway. Similar concerns have been expressed about the effects of sediment diversions of river water into the basin, even though these releases would be small compared to those from the spillway and remote from Mississippi waters.

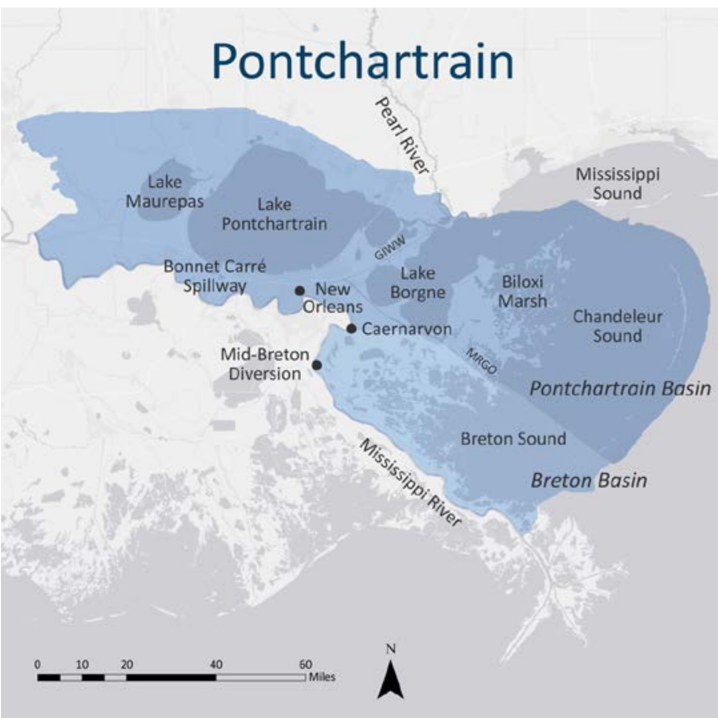

Figure 7. *The Pontchartrain Basin, here incorporating the Breton Basin.*

The Mississippi River-Gulf Outlet (MRGO) was completed in 1965 to provide shipping a shorter route from New Orleans to the Gulf of Mexico. MRGO had profound and far-reaching effects on the Pontchartrain Basin as its marsh-lined banks rapidly eroded and the deep channel allowed the intrusion of salt water into previously fresh and slightly brackish environments. Freshwater swamps and marshes were particularly affected. MRGO failed to attract the anticipated ship traffic and by the 1990s, the cost-effectiveness of maintenance dredging in the face of declining usage was increasingly questioned. After MRGO was implicated in worsening the storm surge from Hurricane Katrina in 2005 and the channel was left impassible because of extensive shoaling, the Corps of Engineers announced in 2007 that it would close the MRGO and build an earthen barrier across the channel to align with the natural ridge along Bayou La Loutre. The barrier was completed in 2009, but the restoration of marshes and swamps included in the Corps' Ecosystem Restoration Plan[90] was not undertaken because of conflicts with the State over funding responsibility and lack of Congressional appropriations. By limiting the penetration of salt water from the Gulf, the closure has had surprisingly far-field effects in lowering the salinity of waters and wetland soils as far east as Lake Maurepas and even in the Biloxi Marsh to the north of the MRGO.[91]

Continued →

Saltwater intrusion resulted in the conversion of wetland plant composition or their outright loss. In addition, the natural processes of subsidence and erosion of wetlands not nourished by mineral sediments, as well as the effects of numerous smaller channels mainly dug for oil and gas extraction and transportation, have contributed to substantial land loss in the Pontchartrain Basin. Between 1932 and 2016, 1,018 square kilometers (252,000 acres) of land were lost, most of that being tidal wetlands.[5] The rate of loss has been relatively steady over that period except for the Breton Basin, where the rate of land loss accelerated beginning in the 1960s and has remained high. Substantial areas of fresh and intermediate wetlands with highly organic and erodible soils were lost to the attack of storm surges and waves in the Breton Basin.

Fully 40% of 4.66 million people who live in Louisiana reside in the Pontchartrain Basin and its watershed. The hurricanes posing the greatest flooding risks to communities along the densely populated east bank of the lower Mississippi River, including greater New Orleans, and along the northern shore of Lake Pontchartrain, are those that approach in a way that drives storm surges into the southeast-facing Pontchartrain Basin. Hurricanes Betsy in 1965, Katrina in 2005, and Isaac in 2012 are cases in point. Exacerbated by deteriorating barrier islands and wetlands in the lower part of the basin and by the conduit provided by both MRGO and the Gulf Intracoastal Waterway, storm surges in those cases overtopped or caused failures of flood protection levees and walls.

Even before Hurricane Katrina, John Lopez of the Lake Pontchartrain Basin Foundation advocated for a Multiple Lines of Defense strategy wherein natural coastal features, such as barrier islands, land bridges, and ridges, are maintained to diminish storm surges in order to supplement structural protection, such as floodgates and levees.[92] Maintaining these natural features can diminish the height of the storm surges and of waves that might otherwise defeat the structural protections; however, there are certainly limits to the effectiveness of such natural defenses.[93] This multiple-lines-of-defense strategy has been incorporated to an extent by the Coastal Protection and Restoration Authority in its Coastal Master Plan that integrates reduction of flood risks and restoration of coastal ecosystems.

Following the devastation caused by Hurricane Katrina in 2005, substantial improvements were made in the structural protection of communities in the Lake Pontchartrain Basin, including strengthened levees, floodwalls, and surge barriers on canals draining the New Orleans region. In addition, a massive storm surge barrier was completed in 2011, located near the conjunction of the Gulf Intracoastal Waterway and the MRGO in order to limit the surges that could funnel into and propagate up these channels into the Inner Harbor Navigation Canal (IHNC). The IHNC was also isolated from Lake Pontchartrain by a new navigation gate. When closed, the IHNC Lake Borgne Surge Barrier would not fully eliminate, but greatly limit the storm surges that could confront the levees and floodwalls protecting the eastern side of New Orleans. Broader planning for the Pontchartrain Basin must consider how the rehabilitation of coastal landscapes can contribute multiple lines of defense to supplement the structural defenses.

Continued →

Restoration Projects and Plans

As is the case in all of Louisiana's coastal basins, protection and restoration measures were undertaken in the Pontchartrain Basin even before the first Coastal Master Plan in 2007. These include levees and floodwalls that defend populated areas from tropical storm flooding either from Lake Pontchartrain or from the interior wetlands of the basin. Back levees parallel the Mississippi River levees as far downriver as Bohemia. As already mentioned, many of these defenses were substantially augmented following hurricanes Betsy, Katrina, and Isaac.

A number of small marsh creation and shoreline armoring projects were undertaken and the closure of MRGO helped project existing wetlands. Relatively small diversions of river water at Violet, Caernarvon, White Ditch, Bohemia, and Bayou Lamoque, in downriver order, were completed for salinity management of flood protection, not for restoring wetlands. The Caernarvon Freshwater Diversion was purposefully designed to deliver up to 8,000 cubic feet per second to limit saltwater intrusion in the upper Breton Basin. Although not intended to introduce substantial amounts of sediments, vegetated wetlands were built near the discharge, partially filling a large pond remaining because of a previous attempt at agricultural reclamation.[94] The effects of the Caernarvon diversion have been well studied. There have been controversies about whether it has been beneficial or detrimental to wetlands beyond the proximal region where new wetlands have been built,[95] but there is a consensus that diversions carrying larger amounts of sediment would sustain and build wetlands.[96] The Bohemia Spillway is an 11-mile stretch along which river levees were degraded to allow overflow at high river stages in order to alleviate upstream flood risks.[97] These overflows have sustained adjacent wetlands. A channel, referred to as Mardi Gras Pass, began to cut through the natural levee within the spillway during the 2011 flood. It has diverted more fresh water and sediment that is distributed through a network of existing canals and natural waterways, locally building wetlands and nourishing them over a large area.[98] A similar crevasse that was developed near Fort St. Phillip during the 1973 flood has captured even more of the river's flow.

Beyond diversions themselves, there have been relatively limited efforts to restore wetlands in the Pontchartrain Basin. The Coastal Wetlands Planning, Protection, and Restoration Act (CWPPRA), the Coastal Impact Assistance Program (CIAP), and private sources have funded management of outfall areas of some of the freshwater diversions. It includes marsh creation, notably in the LaBranche wetlands near the New Orleans airport, hydrologic restoration, and shoreline protection, particularly for the New Orleans East landbridge along Lake Borgne.

Continued →

Table 3. *Restoration projects in the Pontchartrain Basin included in the 2017 Coastal Master Plan.[1]*

PROJECT TYPE	NUMBER	DESCRIPTION	PERIOD	COST ($M)
Sediment diversion	001.DI.02	Lower Breton Diversion	1-10	383
	001.DI.18	Central Wetlands Diversion	1-10	231
	001.DI.21	East Maurepas Diversion	1-10	185
	001.DI.100	Manchac Landbridge Diversion	1-10	148
	001.DI.102	Union Freshwater Diversion	1-10	877
	001.DI.104	Mid-Breton Sound Diversion	1-10	479
Marsh creation	001.MC.05	New Orleans East Landbridge	1-10	397
	001.MC.13	Golden Triangle	1-10	274
	011.MC.108	Guste Island	1-10	64
	001.MC.05	New Orleans East Landbridge	11-30	1,107
	001.MC.06a	Breton–Component A	11-30	982
	001.MC.07a	Lake Borgne-Component A	11-30	272
	001.MC.08a	Central Wetlands	11-30	122
	001.MC.102	Point a la Hache	11-30	648
	001.MC.104	East Bank Land Bridge	11-30	154
	001.MC.105	Spanish Lake	11-30	60
	001.MC.106	St. Tammany	11-30	199
	001.MC.107	Tiger Ridge	11-30	215
	001.MC.101	Uhlan Bay	31-50	29
	001.M.102	Pointe a la Hache	31-50	353
Hydrologic restoration	001.HR.100	Labranche Hydrologic Restoration	1-10	81
Ridge restoration	001.RC.100	Bayou Terre aux Boeufs	1-10	15
	001.RC.103	Carlisle	1-10	9
	001.RC.01	Bayou LaLoutre	11-30	20
Shoreline protection	001.SP.01	Manchac Landbridge	1-10	12
	001.SP.101	Unknown Pass to Rigolets	1-10	5
	001.SP.104	Labranche Wetlands	1-10	23

In contrast to the Barataria and Terrebonne basins, there has been less effort to restore or stabilize the outer barrier islands enclosing the Pontchartrain basin. Long the subject of the natural retreat and deterioration of sand deposited at the edge of St. Bernard Delta, the Chandeleur Islands were breached and reduced by hurricanes, in particular, George in 1998, and Dennis and Katrina in 2005.[99] To a certain extent, the island chain reforms during years following erosive deterioration, but its restoration faces substantial challenges of feasibility and cost. Both the Chandeleur and Breton islands are included in the Breton National Wildlife Refuge, the second oldest in the nation, a status that may pose additional constraints. During the Deepwater Horizon oil spill in 2010, sand was dredged and deposited in a berm along the northern section of the Chandeleur Islands in an attempt to reduce the amount of oil reaching the islands and the landward wetlands. The opportunity to provide a foundation for longer-term restoration was an additional motivation.
The berm did not retard the oil and, while it advanced the islands' shoreline position temporarily, it experienced rapid degradation, hastened by Tropical Storm Lee in 2011 and Hurricane Isaac in 2012.[100] A modest amount of wetland restoration behind the Chandeleur Islands was accomplished with CWPPRA funding. A more substantial effort is underway for restoration of important bird habitat on North Breton Island to repair or compensate for natural resource damages from the Deepwater Horizon oil spill.

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The Integrated Compartment Model (ICM) used in the 2017 Coastal Master Plan projected a cumulative land loss in the Pontchartrain Basin (including the Breton Basin) of 127,924 acres between 2015 and 2065, without action and under the Low environmental scenario (Table 2).[28] Modeled land loss was 80% greater under the Medium scenario and 4.5 times greater under the High scenario. Under the Low scenario assumption of sea-level rise, the predominant mechanisms for land loss, given the modeling assumptions, would be marsh-edge erosion over the first 30 years, then increasingly, inundation collapse of saline and brackish marsh. In addition to these estimates of land loss, the ICM also projects conversion of some surviving marshes to characteristics that are more saline and of some wooded swamps around Lake Maurepas to fresh marsh.

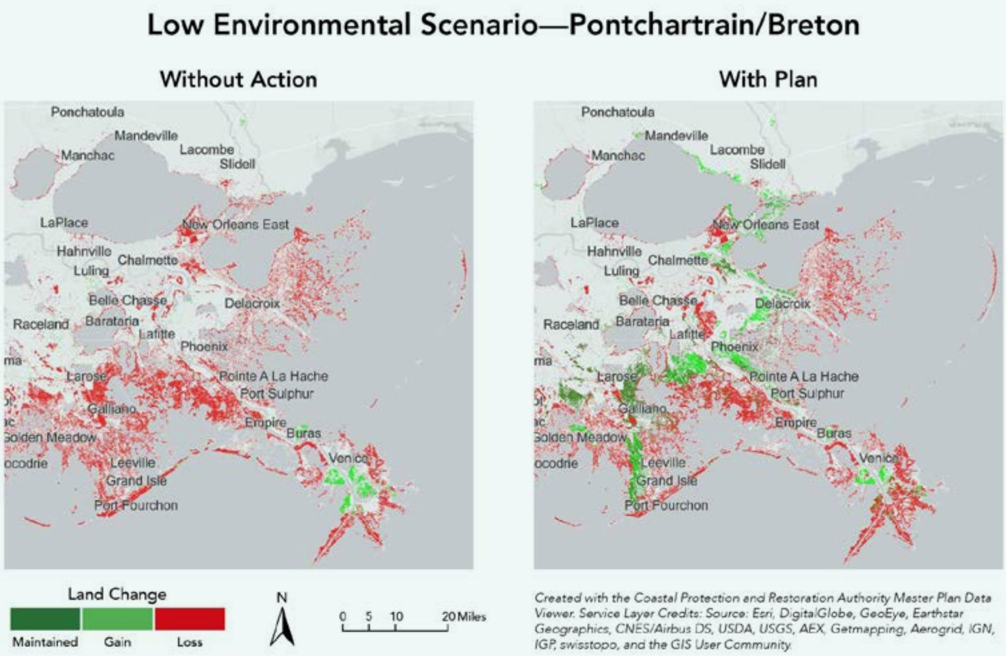

Figure 8. *Land lost, gained and maintained after fifty years in the Barataria Basin, with and without the restoration projects included in the 2017 Coastal Master Plan.*

The restoration projects included in the 2017 Coastal Master Plan are listed in Table 3 by project type, cost, and time period for execution within the fifty-year planning period. ICM simulations indicate that under the Low environmental scenario, these projects would result in a net of 17,518 fewer acres lost or a reduction in net loss of 14% (Figure 8).

Coastal Master Plan projects include five sediment diversions and one freshwater diversion to be implemented during the first ten years. The Union, East Maurepas, and Manchac Landbridge diversions would counteract saltwater intrusion, encourage vegetation growth, and provide sediment nourishment to the critical forested wetlands and low salinity marshes in Lake Maurepas and the along the landbridge that separates it from Lake Pontchartrain. The engineering design of the East Maurepas diversion is underway. The Mid-Breton diversion, located at Wills Point upriver from Phoenix, is also currently under design to carry up to 75,000 cubic feet per second (cfs) of sediment-rich river water into the deteriorating swamps and marshes of the middle region of the Breton Basin. The Lower Breton diversion awaits detailed planning, but it would be located somewhere below the end of the river levee at Bohemia. A smaller Central Wetland diversion, near Violet, would discharge into the area now enclosed within the outer storm protection levees in order to sustain and expand degraded wetlands.

Continued →

Restoration of several strategic ridges is intended to limit saltwater intrusion and to guide the flows from river diversions in the lower basin. During the first ten years of the plan, substantial marsh creation would be undertaken in two areas where healthy marshes play an important role in attenuating at least some storm surges: Golden Triangle between the conjunction of the GIWW and MRGO and the New Orleans East landbridge between lakes Borgne and Pontchartrain. In both cases, sediment would be dredged from Lake Borgne to create brackish marsh. A substantial amount of additional marsh creation is envisioned in the plan for subsequent decades, mostly around Lake Borgne and Pontchartrain, or along the lower river. The marsh creation projects planned beyond the first decade are currently estimated to cost over $4 billion. On the other hand, there are no marsh creation or other restoration projects in the Coastal Master Plan that are slated for the Biloxi Marsh that extends east of Lake Borgne, where much of the wetland loss is projected to occur toward the end of the fifty-year planning horizon (Figure 8).

Vision

While the continuing loss of coastal lands in the subsiding Pontchartrain Basin is inevitable, sustaining and expanding essential elements of the landscape would sustain coastal lands lying between the Gulf and major population centers. The Mississippi Bight, lying between the Mississippi River mouth and the state of Mississippi, can serve as a geographic funnel for tropical cyclones that drive surges up into the Pontchartrain Basin. Storm surges in this basin pose risks to more people, property, and crucial infrastructure than anywhere else along the Louisiana coast. Even though substantial improvements were made in structural protection following disasters caused by Katrina and other hurricanes, the coastal landscapes lying in front of these defenses could contribute to attenuating storm surges and waves. Without such a buffer, protective structures are more vulnerable to overtopping or failure. Incorporating the surge-attenuating benefits of coastal landscapes has been and should continue to be a key consideration of Louisiana's Coastal Master Plan.

Subsidence rates over substantial portions of the Pontchartrain Basin are lower than in other basins of the Mississippi Deltaic Plain because the deposits of deltaic sediments are thinner. Consequently, the projected losses of saline and brackish wetlands under the Low environmental scenario are less dramatic than those in the Barataria and Terrebonne basins. This is particularly because the vast Biloxi Marsh extends eastward towards Mississippi (Figures 7 and 8). Still, accelerating sea-level rise will have substantial consequences, particularly if global warming is not limited by actions taken over the next fifty years. If that becomes the case, sea level could rise by the 83 cm assumed under the high scenario by the end of the 21st Century. Land losses projected by ICM simulations suggest that the integrity of the landbridges separating the lakes Borgne, Pontchartrain, and Maurepas would be seriously threatened. Their absence would leave the New Orleans metropolitan area separated from the mainland to the north by a continuous, expansive arm of the Gulf of Mexico.

In addition to limiting global warming and sea-level rise, sustaining substantial wetland landscapes will also require maintaining much of the Pontchartrain Basin as a freshwater to low-salinity system sufficient for fresh marshes and wooded swamps to survive. Properly managed, river diversions into Lake Maurepas and its landbridge, along the lower river, should accomplish this as well as deliver sediments to build up wetland soils. Routing of sediment-laded waters from the Bonnet Carré Spillway — when it is operating — into nearby degrading wetlands was suggested in the 2017 Coastal Master Plan and should be further explored. Additional intervention in the form of planting of bald cypress and other swamp trees that contribute to the attenuation of storm surges and biodiversity will be required where water levels remain too high for natural seeding. On small scales, such planting has shown promising results as long as nearly freshwater conditions is maintained, but it would have to be scaled up substantially.[101]

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The Pontchartain Basin has the advantage that the effective use of resources of the Mississippi River along the length of the basin can nourish wetlands and block saltwater intrusion. If sea-level rise can be moderated, protective coastal landscapes that are also highly productive of living resources can be maintained well into the 22nd Century. Biological productivity can actually be enhanced by the expansion of wetlands and introduction of nutrients, although zones of productivity will shift because of the re-freshening of coastal ecosystems that had been progressively becoming marine. However, in order to use the river's resources for maximum benefit, the pollution of the river with excessive nutrients from upstream sources should be reduced consistent with commitments under the Gulf Hypoxia Action Plan. While the Pontchartrain Basin is removed from the Dead Zone offshore of the southern coast of Louisiana, lowering the nutrient concentrations in diverted river water would avoid over-fertilization that might have adverse effects on marshes with highly organic soils, stimulate harmful algal blooms, and worsen the bottom hypoxia that occasionally occurs at Lake Borgne, Chandeleur, and Breton sounds.[102]

The 2017 Coastal Master Plan included no specific restoration projects in the Biloxi Marsh complex, a prominent feature that encloses Lake Borgne at the eastern end of the Pontchartrain basin. Previous plans included marsh creation (in 2007) and restoration of barrier oyster reefs (in both 2007 and 2012). As discussed earlier, because of its more stable geological foundation and thinner deltaic deposits, this region is subsiding more slowly than the rest of the Louisiana coast and its marshes are aggrading sufficiently to keep up with relative sea-level rise.[36] However, the loss of berms of *Rangia* clamshells due to salt-water intrusion from the MRGO has increased erosion of Lake Borgne shorelines and greater hydrologic connectivity has caused erosion of interior wetlands.

Because of its geomorphic and ecological importance and potential longevity, restoration options in this region merit reconsideration in future planning. Harvesting of oysters had been restored north of the MRGO after its closure reduced salinity. At the same time, increasing river flows into Breton Sound have inhibited oysters south of MRGO.[103] Reestablished oyster reefs within eastern bays could reduce wave erosion and marsh degradation and serve as breeding stock for oysters supporting harvests in both Louisiana and Mississippi. Pilot scale establishment of "living shorelines" that recruit oysters has been undertaken and will be expanded to compensate for Deepwater Horizon natural resource damages. Substantial mortality of oysters in this area was experienced in 2019 as a result of the prolonged operation of the Bonnet Carré Spillway, so challenges would be confronted. Still, the Biloxi Marsh area represents the best bet for reestablishing oyster reefs in Louisiana as a significant geomorphic feature as well as a fishery resource. Integrated with oysters and other shoreline stabilization efforts, managing the relatively slowly subsiding, adjacent marshes to prolong the longevity could entail less costly enhancement of marshes with sediments.

Although restoration of barrier island shorelines of the Chandeleur Islands was mentioned in partnership with the U.S. Department of the Interior in the 2007 Coastal Master Plan, specific projects are not included in the subsequent plans. Restoration is planned for the smaller North Breton Island as a part of resource damage recovery from the 2010 oil spill. The ill fate of the sand berms hastily dredged during the oil spill cautions against quixotic efforts to save the islands. Nonetheless, an assessment of innovative restoration options is merited by their great importance of the Chandeleur Islands to wildlife and biodiversity as well as the initial "speed bump" they present to modest storm surges and the islands' role in maintaining the estuarine salinity gradient in the Sound and Lake Borgne.

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With these considerations in mind, I offer the following recommendations to build on the component projects of the 2017 Coastal Master Plan for protection and restoration planning for the Pontchartrain Basin:

- **Assess the potential for strategic rehabilitation of the Chandeleur Island chain**. Considerable scientific information is available on the structure and dynamics of the Chandeleurs due to research by the U.S. Geological Survey and others. This knowledge should be used to determine the feasibility, effectiveness, and cost of strategic amendments and stabilization to prolong the presence of the island chain, consistent with the objectives of the Breton Island National Wildlife Refuge.

- **Manage the environments receiving planned sediment diversions and existing river outlets such as at Fort St. Phillip and Mardi Gras Pass to ensure efficient sediment retention and integrated controls**. Much of the attention regarding siting and operational design for mid-Breton sediment diversion and its counterpart on the Barataria side of the Mississippi River has been on enhancing river sediment delivery (e.g., by location, design, and operational timing of the intake). These considerations are just the first step in optimizing land building with a diversion. Increasing sediment retention in the area receiving the diversion and minimizing erosion in the wetlands and estuaries is also required.[96] Integration of existing scientific knowledge into operating plans and adaptive management of these and other diversions is critical to maximizing the benefits of sediment diversions through what is often referred to as "outfall management." However, the scope of attention needs to be broadened to enhance the constructive potential of fine sediments escaping beyond the region of immediate deposition. Flows through regulated diversions and river outlets should be controlled in consort with management of lower river navigation.

- **Integrate the future entryway for Mississippi River navigation into the evaluation, location, and design of proposed Lower-Breton diversion**. In the next section on the Birdsfoot Delta, I conclude the alignment of the navigation channel entering the river should be carefully re-evaluated within the next few decades. Realignment would have substantial implications for the primary flow paths of the river, water, and sediment allocation in the lowermost river along with channel dredging. In particular, realignment would have major implications for the location and design of the Lower-Breton diversion that is included in the current Coastal Master Plan.

- **Developing an integrated plan to sustain the Biloxi Marsh.** This distinctive feature has pervasive consequences for the hydrodynamics, wave and storm-surge attenuation, ecosystem services, and living resources of the Pontchartrain Basin. It experiences relatively low rates of subsidence and should be sustainable as long as sea-level rise does not greatly accelerate. An integrated approach to sustaining the Biloxi Marsh should be developed involving oyster reef restoration, strategic marsh creation, shoreline protection, and hydrologic management.

- **Explore opportunities for storm-surge management across levees along the lowermost river**. Levees along both sides of the Mississippi in lower Plaquemines Parish provide a barrier to storm surges propagating either through Breton Sound or up the Barataria Basin. While they are built to afford protection, they also have the unfortunate effect of increasing storm surge levels higher in those basins as the surges have nowhere else to go. Particularly after Hurricane Katrina, populations are declining in these lower river communities while agricultural land use is in decline. The benefits and risks of lower river levees along certain sections would provide some relief for storm surges and should be explored in the holistic assessment of the Lowermost Mississippi River described under the vision for the Birdsfoot delta.

Birdsfoot Delta: Maintaining Global Access to the Heartland

Prologue

Projecting into the Gulf of Mexico between the Pontchartrain and Barataria Basin is the iconic Birdsfoot Delta of the Mississippi River, a fanning array of distributaries that carry most of the water flowing from the great river to the sea. It is the seaward extension of what is known as the Plaquemines-Balize delta, extending to the southeast past what is now New Orleans. The Birdsfoot Delta has been an active distributary for the last 750 years. When Hernando De Soto reached the mouth of the river in 1543, the landforms around him were scarcely more than 100 years old.

In 1699, the French established the "seamark," or La Balize, near where the Birdsfoot distributaries conjoined at the Head of Passes in order to control passage on the river. It became a small settlement inhabited principally by river pilots and their families. Control of commerce passing to and from the Mississippi Valley to the ocean was the principal reason for the French colonization of New Orleans, which later became Thomas Jefferson's paramount objective in securing the Louisiana Purchase. To this day, this river mouth is the only gateway for ocean going vessels into and out of the Mississippi Basin.

Seagoing vessels enter the Mississippi River through a navigation channel through the iconic Birdsfoot Delta which is it important to the national economy. As the delta rapidly subsides and receives less of the river sediment needed to keep pace, planning for a new navigation channel that might be required commences and incorporates the use of available sediment to build marshes and sustain barrier islands.

Passage through the passes of the river was perilous, even for the small sailing vessels of French colonists, because of bars created at the mouth of the passes where the flow of the river slowed as it reached the Gulf, depositing large quantities of sand and mud. Knowledgeable and skilled river pilots were required and, even then, ships had to wait for days before the right conditions of tides and weather allowed a bar crossing. When the British invaded in 1814, the large ships of their powerful navy were unable to enter the river, requiring that the army approach the city through swamps, giving the American defenders strategic advantage in the Battle of New Orleans. Admiral David Farragut had to master shoal waters as well as Confederate ironclads as his fleet entered the river on his way to capture New Orleans in 1862. Ensuring navigational access for ever-deeper draft vessels remains an ongoing challenge to this day.

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During the era of discovery and colonization, the Birdsfoot had three relatively skinny toes including the South West Pass, the South Pass, and Pass a Loutre, the last of which had two branches, South East Pass and North East Pass. Pass a Loutre was written as Pass a L'Outre on early charts so it simply meant "the other pass." Prior to the 1860s, the Pass a Loutre distributaries provided the primary entry points to the river. However, they were silting in, so attention shifted to the shorter route through South Pass as the more reliable entrance, but its shallow entrance presented severe restrictions for steamships that came to dominate maritime commerce during the second half of the 19th Century. In 1875, Captain James B. Eads proposed a solution using jetties that would train the river flow into the Gulf, thereby scouring the channel sufficient enough to maintain a 30-foot navigation depth. This was successful and by 1880, only a year after completion of the jetties, the tonnage of goods shipped from St. Louis, through New Orleans and onto Europe had increased by a factor of 66! Demand for an even deeper channel resulted in constructing similar jetties toward the end of Southwest Pass, which since their completion in 1923, has served as the principal navigational entrance to the river. Even with its jetties and domination of the river flow through the delta, extensive and continuous dredging along the extended Southwest Pass is required to maintain a 45-foot deep navigation channel. Ship traffic in the South Pass was finally discontinued in the 1970s and, with flow reduced by training more flow down the Southwest Pass, has since been infilling.

As generally used for Louisiana coastal planning purposes, the Mississippi River Delta proper, or the Birdsfoot Delta, is considered to include the region from Grand Pass at Venice on the west bank of the river to the marshes around Baptiste Collette on the east bank. The regions farther west belong to the Barataria Basin and to the north to the Pontchartrain Basin.

Until the second half of the 19th Century, the Mississippi River Delta's form was essentially that of the three-toed bird's foot that early explorers found when they arrived (Figure 9).[104] However, European settlers of the Mississippi Valley took several actions that increased the amount of sediment transported down the river. They began to plow and cultivate the prairies, which increased soil erosion. They built levees to protect themselves from spring floods that reduced the amount of sediments deposited in the floodplain and shortened the river's course by cutting shortcuts across oxbows, eroding new channels and their banks with the force of the river's flow. As a result, more land and wetlands were rapidly built in the active delta above the Head of Passes as crevasses broke through levees, or outlets were purposefully or unwittingly cut through the natural levees of the lower river. The alluvial sediments released constructed delta ssublobes into the West Bay, resulting from a crevasse breakthrough in 1838; through Cubits Gap in 1862; and at Baptiste Collette Bayou in 1874. In addition, there was extensive infilling of Garden Island Bay, between Pass-a-Loutre and South Pass. The spindly bird's foot became more like a webbed duck's foot and bulked up into the more robust landmass that existed in the early 20th Century (Figure 10).

Figure 9. *Birdsfoot Delta as shown in a post-1875 map, showing the Eads jetties at entrance of South Pass.*

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As the 20th Century proceeded, the relatively massive Birdsfoot Delta saw a reversal of fortunes because of diminishing sediment supplies from upstream. By 1848, channel straightening and logjam clearance allowed flow from the Red River into the Atchafalaya Basin. More and more flow from the Red and Mississippi rivers was entrained in that shorter route to the sea until less than a century later when about one-third of the combined flow was captured by the Atchafalaya.[8] The Old River Control Structure was completed in 1963 to stabilize that proportion at 30%, as set by an act of Congress.

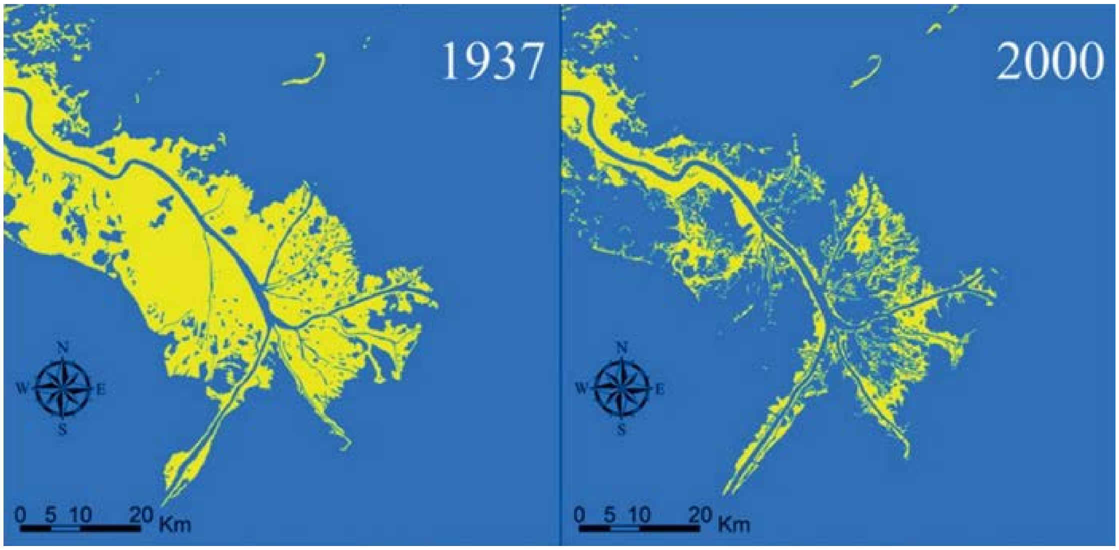

Figure 10. *Land area within the Mississippi River Delta in 1937 and 2000.[104] Compare with Figure 9.*

The expansive construction of dams—there are now some 40,000 of them within the Mississippi Basin—trapped significant amounts of sediments. Dams in the Missouri and Tennessee rivers intercept sediments eroded from ageing mountains and the large dams constructed on the Missouri during the early 1950s dramatically reduced the downstream transport of the erodible, wind-deposited soils of the Great Plains. In addition, river training structures reduced bank erosion. From 1970-2013, suspended sediment loads to the lower river (below the Old River Control Structure) were 72% less that that observed during 1950-1953. With the relative level of the Gulf rising as a result of subsidence and global sea-level rise, the hydraulic gradient has been reduced, slowing river flow rates and allowing large quantities of sand to be deposited on the previously eroding bed of the lower Mississippi rather than transported to the river mouth.

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Keep in mind that, because of the continuous and rapid compaction of the massive amount of sediments deposited onto the Gulf seafloor during the past few centuries, prodigious and sustained sedimentation is needed to keep portions of the Birdsfoot Delta above low tide. The tide gauge at the Southwest Pass shows a relative sea-level rise of 27 mm per year since 1953, approximately 90% of that due to subsidence.[105] The compacting Birdsfoot Delta, projecting nearly 40 miles across the continental shelf into the deep waters of the Gulf of Mexico, is a virtual Wonderland where, as the Red Queen noted, "Now, here, you see, it takes all the running you can do to keep in the same place."

However, the dramatic reduction in sediment supplied to the delta by the river from the early 20th Century has caused the Birdsfoot to wither away, as is shown by comparison of the extent of landscape remaining in 2000 compared to that present in 1937 (Figure 10). Most of the wetlands in the lobes built by the 19th Century crevasses above Head of Passes have subsided or eroded away, leaving only the remnant distributary channels. This reduces their ability to capture and retain sediments. The delta is again becoming reminiscent of the spindly bird's foot that existed prior to the early 19th Century, but with a diminished supply of essential building materials.

To make matters worse, the percentage of river flow exiting through lower river outlets above the Head of Passes, such as at Fort St. Phillip, Grand Pass, and Baptiste Collette, has increased since 1970. In order to sustain channel-scouring flows down the Southwest Pass, about two-thirds of the flow reaching the Head of Passes now exits through the Southwest Pass at the expense of flow through the Pass a Loutre and the South Pass. More sand is retained on the channel bed of the lower river reaches and more of the river water and remaining sediments escape before reaching the Head of Passes. It appears to delta geologists that the Mississippi is abandoning the lower outlets in favor of upstream outlets, which is a process they refer to as "back stepping."[104] As a further indicator of this sediment deprivation, recent research indicates that since 1979, the underwater sediment deposits off the Pass a Loutre and the South Pass have been eroding and are building at a much slower rate off the Southwest Pass.[106] The massive submarine delta on which the bits of land that we see on the surface rest has entered a phase of what geologists call "retrogradation." In this never-ending battle between sea and land, the sea is clearly winning.

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Projects and Plans

The 2017 Coastal Master Plan includes no specific restoration projects in the Mississippi River Delta and there are, of course, no population centers that would merit additional storm surge protection in the plan. The Birdsfoot Delta is shown as an Area of Opportunity in a map depicting projects completed or funded for construction at that time. The exclusion of the Birdsfoot Delta in the Master Plan reflects an evolution of thinking about the ultimate sustainability of restoration projects and the use of the river's resources in that region because of the high rates of subsidence experienced.

The first Coastal Master Plan in 2007 depicted two large river diversions above the Head of Passes at the approximate level of Venice under the rubric Mississippi River Delta Management. This was a planning measure intended to "identify and evaluate features that would greatly increase the deposition of Mississippi River sediment in shallow coastal areas and restore deltaic growth in the Mississippi River Delta Plain." The 2007 plan indicated that large diversions (greater than 50,000 cfs) from the Mississippi River and alternate channel alignments would be investigated. Diversion sites, capacities, and outfall management measure would be assessed to optimize diversion plans while accommodating navigation, water supply, and flood control needs.

For reasons related to uncertain federal and state responsibilities and lack of funding, the Mississippi River Delta Management measure had not commenced prior to the 2012 Coastal Master Plan. In 2014, CPRA proposed that a Lowermost Mississippi River Management Program (LMRMP) be funded under the RESTORE Act. Funding was finally approved in April 2018, more than a decade after the need was established in the first Coastal Master Plan. The program will adapt and apply models to analyze large-scale ecosystem restoration projects associated with the current alignment of the Mississippi River to inform and make decisions for future river management analyses, potentially including alternative channel alignments or management strategies. The LMRMP analysis is scheduled for completion in 2021.

Meanwhile, prominent geologists published analyses indicating that, because of reduced sediment supply and accelerating global sea-level rise, the drowning of the Mississippi delta was inevitable and that any use of the river's sediment to sustain coastal land should be directed farther up the river.[107] River diversions above the Head of Passes and some marsh creation projects in the Birdsfoot Delta were analyzed in the development of the 2012 Coastal Master Plan, but were not included in the selected projects. Moreover, several river diversions into the Pontchartrain and Barataria basins above Venice that were included in either the 2007 or 2012 plans (at Bayou Lamoque, Black Bay and Empire) were no longer included in the 2017 plan. The state of Louisiana has decided to use its resources and those of the river primarily to sustain landscapes farther up in the adjacent basins.

Nevertheless, the Federal government, and to some degree the state, has significant assets and responsibilities in the Birdsfoot Delta about which they will have to make important decisions. The vast majority of the wetlands (intermediate and fresh marshes) and waterways in the delta lie in the Delta National Wildlife Refuge (landscapes remaining from those built by the Cubit's Gap crevasse) or the state's Pass-a-Loutre Wildlife Management Area (encompassing the Pass a Loutre and the South passes). Rapid subsidence, sedimentation deficits, and hurricane damage have resulted in extensive demise of marshes and formation of ponds. Recent infestation of Roseau cane (*Phragmites australis*) by an invasive scale insect[108] and extensive oiling resulting from the Deepwater Horizon blowout have compounded the problem. Together, these two refuges include critical habitat for large numbers of wading birds as well as more than one million waterfowl annually, and provide resting spots for migrating songbirds crossing the wide expanse of the Gulf of Mexico.

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Managers have attempted to counteract wetland losses by diverting sediment-laden waters from the passes into open bays to create wetland habitat, including from the South Pass, the Pass a Loutre, and the West Bay. While this has built significant acreage, the gains have not kept up with the losses within the delta. Marshes, islands, and ridges have also been built by beneficial use of sediments dredged by the Corps of Engineers to maintain the 45-foot navigation channel down through the Southwest Pass (Figure 11). Large volumes of dredged material are still being deposited at designated offshore disposal sites, but, under some pressure from the state, the Corps has been directing more of the dredged sediment to beneficial use options, some of which have proven to be more cost-effective. These mostly involve hydraulic placement outside the dykes along the Southwest Pass. While this maintains a thread of landscape along the 20-mile long navigation channel, it does not regularly flood after placement, and is exposed to waves and rapidly subsides.

Of course, the key asset that the Corps struggles to maintain is the deep-draft navigation channel itself. Despite the fact that the delta is being starved of sediments due to reduced upstream sources and storage within and losses from the lower river, the navigation channel continues to trap large amounts of sediment where the river velocity slows on approaching the Gulf. Except during high flow periods, the tides also act to slow or even reverse flow in the river below Venice and its distributaries. Using hopper and cutter head dredges, more than 25 million cubic yards of sediment were dredged in 2019 from the navigation channel from the Gulf of Mexico 22 miles below to 11 miles above the Head of Passes in order to maintain the 45-foot deep and 750-feet wide federally authorized channel. Most of that was by hopper dredges that after loaded, have to travel to disposal sites where they dump their loads in the ocean (ODMDS) or at the Head of Passes (HDDA), incurring down time and limiting the beneficial use of the dredged material. Because Congress has not been fully funding the dredging program, there is chronically insufficient funding, as well as dredging capacity, to keep up with the task. This resulted in occasional restrictions in navigation and required lighter loading of vessels.

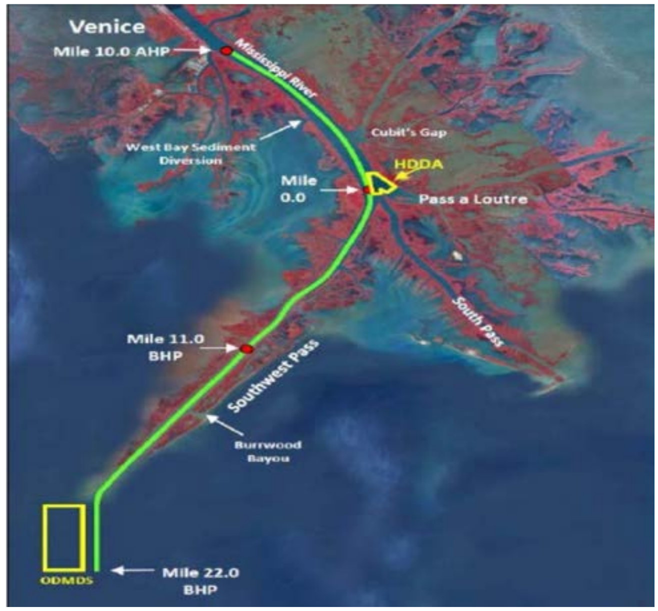

Figure 11. *Lower Mississippi River navigation channel requiring dredging and dredged material disposal sites.*

Despite the difficulties in maintaining the existing navigation channel in the lower river, in August 2018, the Corps of Engineers approved deepening of the channel in the lower Mississippi to a 50-foot control depth in order to accommodate the larger vessels dominating trade after the widening of the Panama Canal. The estimated cost of the channel improvements is mainly in the reach from 13 miles above the Head of Passes, through the Southwest Pass, and into the Gulf, is $238 million, with the state share equaling $120 million, primarily for the relocation of pipelines and other infrastructures.[109] Estimated economic benefits of $128 million substantially exceed the average annual maintenance costs of $18 million. However, Congress has not yet appropriated funds for these navigation improvements.

Plans for channel deepening include substantial beneficial use of dredged material to build wetlands and other coastal land features, both along the Southwest Pass and in the creation of as much as 2.2 square miles of wetlands in the Delta National Wildlife Refuge and the Pass-a-Loutre Wildlife Management Area. While materials dredged by cutter head dredges can be pumped across the dykes lining the river below Venice and along the Southwest Pass, the use of material dredged by hopper dredges requires hydraulic pumping from the Head of Passes dredged material disposal area (HDDA), which limits its use to the proximal parts of the refuges and will not stem the continued loss of the distal parts of the distributary sub deltas.

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Vision

The future of the Birdsfoot Delta will depend to a significant degree on efforts undertaken to maintain deep-draft navigation through the Southwest Pass. The geological processes of delta backstopping and retrogradation will continue, if not accelerate, as subsidence continues, sea-level rise accelerates, and sediments supplied to and retained by the delta diminish. Model projections of land change over fifty years used for the 2017 plan show some land gain near the river above the Head of Passes as a result of wetland creation with dredged materials, but the practical disappearance of the more distal portions of the distributary lobes is assumed even under the low sea-level rise scenario. These land losses are mainly driven by rapid subsidence, which would still be dominate relative to sea-level rise during this period.

What would be left is a human-maintained navigation channel projecting 20 to 30 miles into the Gulf of Mexico, flanked on either side by a narrow strip of land maintained by dredged material placement. In addition, the increased proportion of the river's flow exiting through upriver passes, even via sediment-rich diversions, is likely to further reduce velocities in the navigation channel, resulting in increased shoaling and dredging costs. Is this situation viable? Does it pose significant risks for very costly loss or disruption of access to the Mississippi River by ocean-going vessels if the flow path of the river breaks through this constraint because of a river flood, hurricane, or the coincidence of both? Is it time to plan for a new shipping entrance to the Mississippi River?

The last question is not new. As early as 1852, the Corps of Engineers entertained a proposal for a ship canal reaching the river below Fort St. Phillip, complete with locks and a railroad along its banks to tow vessels. The late-century map shown in Figure 9 indicates a "Proposed Ship Canal" entering from the east well above the Head of Passes. The 2007 Coastal Master Plan called for the investigation of alternative channel alignments. The long-delayed LMRMP is intended to focus on the current alignment of the Mississippi River to inform decision for future river management analysis, including alternative channel alignments. As far as I can determine, the Corps of Engineers is not presently undertaking any analyses of alternate channel alignments. This is troubling, considering the several decades that it would take to conduct assessments, design infrastructure, and secure funding for such a large undertaking as an alternate shipping channel.

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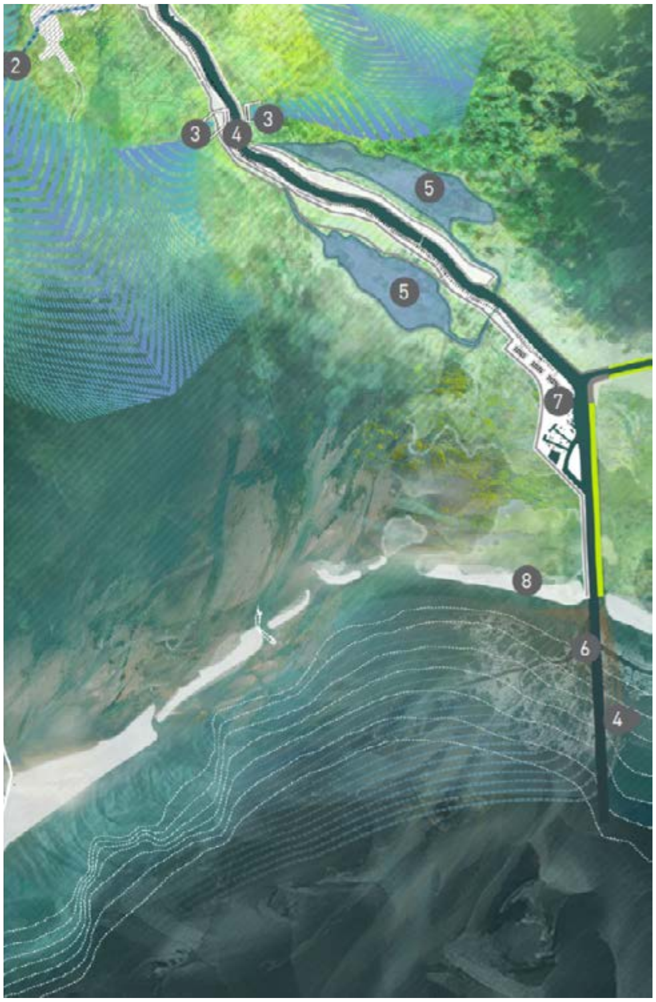

Figure 12. *One conceptual design for a new navigation channel into the lower Mississippi River by The Giving Delta team.*[111]

To stimulate creative thinking, the Environmental Defense Fund, together with other partners, sponsored the Changing Course design competition.[110] The objective was not only to protect and maximize port and maritime activities, possibly including moving the navigation channel; but also to reconnect the river to the wetlands, create more resilient communities, and increase economic opportunities in a smaller delta. The competition concluded in 2015 with the selection of three winning teams, each with somewhat different approaches. All three teams addressed the need for an alternate navigation channel and two proposed graphical depictions of what it might look like. The Giving Delta team, conceived of a deep-water navigation channel, headed due south from below Port Sulphur at about River Mile 38 (Figure 12),[111] and The New Misi-Ziibi Living Delta team, suggested a channel headed south around River Mile 50 (just above West Pointe a la Hache). Both conceptual designs also show a shallow-draft navigation canal running to the east into Breton Sound and a disappearing Birdsfoot Delta.

Conceptually, a new channel could be designed for slack water passage without locks that might delay or cause congestion for maritime traffic or with widely separated locks that allow synchronized and unimpeded passage. The latter approach could allow much of the flow and sediment loads of the river to be diverted upriver or to maintain some portion of the existing Birdsfoot Delta. Port facilities could be developed on the west bank of the river near where the new channel meets the river. The narrow strip along the river below Port Sulphur has experienced a 60% decline in its population between 2000 and 2010, when it had only 2,000 residents.[112] Presumably, the remaining sparse population and infrastructure downriver from the channel would be relocated or served by ferry, as there would be no road access across it.

I am not suggesting that a new channel headed south from this stretch of the lower river is the optimal solution or that a new channel would have be built within the next fifty years. Alternate strategies, including maintenance of a channel through one of the passes of the Birdsfoot Delta, would have to be evaluated through rigorous engineering and cost-benefit analysis.

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Small diversions of flow along any new channel to the Gulf, as well as maintenance dredging, could allow wetland creation in the presently severely deteriorating coastal landscape of the southeastern portion of the Barataria Basin. Sand dredged from the entrance channel or otherwise deposited in the shallow Gulf could be managed as a "sand engine" that would nourish shorelines to the west. Some river flow would continue down the tributaries of the deteriorating Birdsfoot Delta, both before and after any channel realignment, and distributed via small, low-cost diversions that retain sediments in the coastal system and create beneficial habitats for decades. Even after it sinks below the waves, the massive quantities of relatively sandy sediments remaining from building the Birdsfoot Delta could be mined for coastal protection and restoration.

Clearly, there is much to be done before any new navigation channel could become a reality. Trends and projections suggest that maintenance of the existing navigation channel through the Southwest Pass will likely be an increasing problem in the latter half of our fifty-year time horizon. Rapidly accelerating sea-level rise later this century would greatly increase the risks of catastrophic disruption of nationally significant maritime commerce, presently responsible for $21 billion in agricultural exports alone, including 60% of the U.S. grain exports. Because of the multiple decades required for planning, design, and execution, the following actions seem warranted now:

- **Undertake a holistic assessment of the Lowermost Mississippi River under a changing climate.** The Changing Course concepts suggest directions and the ongoing Lowermost Mississippi River Management Program should provide analyses of the use of the sediment resources, maintenance of navigation, and flood protection given the existing channel alignment. An even more holistic and forward-looking assessment is also needed that takes into account a new channel alignment and the emerging understanding of the consequences of climate change. The extraordinarily prolonged river flood of 2019 that extended into hurricane season raised concerns about increased risks of levee overtopping when river floods and Gulf storm surges coincide. The significantly higher sea levels that might be experienced later in the century present substantial consequences for reduced hydraulic gradients, sediment deposition in higher reaches, and freshwater supplies that should be taken into account. As global society makes transitions needed to limit global warming, agricultural production, oceanic shipping, dredging, and virtually everything else, will be changing. Abandonment of the Birdsfoot Delta and a new navigation channel could produce substantial effects on the coastal ocean, including circulation and the formation of continental shelf hypoxia. All these considerations should be taken on board.

- **Seek authorization of a Corps of Engineers feasibility study of an alternate shipping channel.** Because of the several decades that would be required for analyses, planning, funding, and execution, it is not too early to seek authorization of feasibility studies. I have no idea of the cost of building and maintaining a new navigation channel, but it will be substantial. However, the decisions are critical to the economic security of the nation, not just Louisiana. The case will have to be made to the citizens and business interests—particularly agriculture — within the Mississippi River Basin, for it is the nation, not Louisiana that should bear the costs. A total of about $28 billion was recently provided to agricultural interests for relief from the impacts of the U.S.-China tariff war. Surely, the potential loss of critical maritime export infrastructure is no less than a threat.

- **Incorporate the future entryway for Mississippi River navigation in the out-years of the Coastal Master Plan.** The 2017 Coastal Master Plan was silent on lower river channel and Birdsfoot Delta management. If indeed a new navigation channel were completed within the fifty-year planning horizon, it would have substantial consequences for the adjacent basin through which it passed. If its alignment were similar to the Changing Course designs, this would be the Barataria Basin. A new channel would affect freshwater inflows and circulation and could provide significant opportunities for retention of river sediments for marsh creation and nourishment in that basin and in the remaining Birdsfoot Delta, as well as for sustaining the system of barrier islands to the west. The next Coastal Master Plan should begin to incorporate these prospects.

Barataria Basin: Lafitte's Backdoor

Prologue

The Barataria Basin (Figure 13) is lodged between the Mississippi River and Bayou Lafourche, which was itself the main course of the Mississippi just 750 years ago. It has played an important role in the production of natural resources and shaping the rich history of southeastern Louisiana. Derived from the Spanish word for cheap or inexpensive, in 1615 Cervantes fictionalized the Isle of Barataria, awarded to Sancho Panza as a prank in *Don Quixote*.[113]

Maintenance of the barrier islands enclosing the estuary and reconnecting it with sediment supplied by the Mississippi River will allow the sustainable rehabilitation of this historically productive ecosystem. While managing commensurate shifts in the distribution of the estuary's living resources and the transitions in energy production, new opportunities for livelihoods and regional prosperity will be developed.

Barataria Bay was made famous by the exploits of Jean Lafitte and his band of Baratarians, who operated a smuggling operation that bypassed the tariffs leveed on goods brought from the sea up the Mississippi. Instead, they landed the contraband at Grand Terre Island at the mouth of the Bay and transported it up the basin, through the settlement of Barataria and then to New Orleans through a canal connecting with the great river.[114] True to its name, Lafitte's "back door" did make the goods less expensive and Lafitte prosperous and influential. Of course, Lafitte and his men went on to play a heroic role in defeating the British in the Battle of New Orleans in 1815, resulting in the naming of Jean Lafitte National Historic Park in his honor.

The Barataria Basin played an important role in the development of New Orleans and lower river communities even before Lafitte. Old-growth cypress timber and shells from ancient Indian mounds for use as mortar were extracted and transported to the Mississippi through the aforementioned canals to build the Vieux Carré. The Barataria estuary remains a bountiful source of oysters, shrimp, and fish for the tables of locals and visitors alike. Surrounded by warm Gulf waters, the natural levees along the lower Mississippi provided the urban populations with vegetables and citrus. The National Park's Barataria Preserve now serves as a primary locus for visitors to experience Louisiana's coastal swamps and wetlands.

Figure 13. *The Barataria Basin.*

Continued →

Grand Isle, across the tidal inlet from Lafitte's base on Grand Terre, is the only place along the Louisiana coast where one can actually drive to the Gulf of Mexico shoreline until reaching Cameron, more than 200 miles to the west. Grand Isle has become a Louisiana-style beach and sportfishing resort and an important landing port for Gulf fisheries. Oil and gas resources have also been heavily exploited throughout much of the basin, producing employment and wealth, but also other unintended consequences. The offshore support base at Port Fourchon, where Bayou Lafourche meets the Gulf; the Louisiana Offshore Oil Port (LOOP) twenty miles offshore; and the large oil and gas pipelines that extend inland through the basin are each significant with regard to the nation's energy supply.

In Lafitte's time through the 19th Century, Barataria Bay proper was a much smaller embayment lying behind Grand Terre, not more than five miles across. Mostly gone are the extensive tidal marshes separating the Barataria Bay from Caminada Bay and the vast wetlands surrounding the previously discrete bays and lakes (with the evocative names of Roquille, Baptiste, Grand Ecaille, and Bastian) to the east. Those bays have also dramatically expanded as the surrounding wetlands deteriorated. Now, Barataria Bay is up to twenty miles wide and NOAA has officially retired scores of geographic feature names from use on its charts. The channels connecting with Little Lake and Lake Salvador farther up the basin have also widened, allowing tidal exchange and brackish conditions to be experienced higher in the basin. The net result of the land loss and expansion of estuarine waters the tidal prism—the volume of water exchanged over a tidal cycle—has increased substantially. The increase in tidal energy, in addition to the expanded fetch across bay waters, has strengthened the erosive forces working on the wetlands and coastal barriers.

To some degree, the expansion of the Barataria estuarine embayment is a natural process of aging in an interdistributary basin in the Deltaic Plain,[115] but it has been aided, abetted, and accelerated by humans in numerous ways. Extension and heightening of flood protection levees along the west bank of the Mississippi River reduced and finally prevented the overtopping and crevassing of the river's natural levees during floods that formerly supplied mineral sediments that nourished the subsiding wetlands. Even after it was abandoned as the main course of the Mississippi, Bayou Lafourche continued to serve as active distributary until it was dammed at Donaldsonville in 1905. Attempts to polder and drain wetlands for agricultural production, most of which failed, resulted in more wetland loss.

Digging straight channels through the wetlands for small craft passage altered their hydrology. Dredging vastly more and larger canals to explore, extract, and transport oil and gas from the coastal zone and offshore directly and indirectly destroyed wetlands and allowed more tidal flows,[116] essentially adding an accelerant to the gradual process of senescence in a portion of the Deltaic Plain no longer nourished by river sediments. Increased subsidence resulting from extractions of oil, gas, and water from shallow geologic formations further increased coastal wetland loss in some portions of the lower basin.[13]

As a result of these human interventions, the loss of land (mostly wetlands) in the Barataria Basin has been dramatic. Between 1932 and 2016, 1,177 square kilometers (290,000 acres) of land were lost.[5] Most of that loss was between 1960 and 2000, with loss rates peaking at 25 km^2/year during the 1980s. The land loss rate was less than 5 km^2/year over the last decade, suggesting that the most vulnerable wetlands had already been lost and that destructive human activities had been moderated.

Continued →

Restoration Projects and Plans

Coastal protection and restoration measures in the Barataria Basin were undertaken before the most recent Coastal Master Plan. These included: substantial rehabilitation of Gulf shoreline barriers along the Caminada Headland and the chain of barrier islands from Grand Terre to the east; structural stabilization of eroding shorelines along the main waterways through the basin; restoration of the geomorphic landbridge across the basin (including the Bayou DuPont Ridge and Marsh Creation Project using sediment dredged from the Mississippi River); and small-scale marsh creation in the central part of the basin. These projects were funded by various means, including the CWPPRA, the CIAP, and state and local government entities. In addition, there are more recent efforts undertaken to repair or compensate for natural resources damages resulting from the Deepwater Horizon Oil Spill, such as rebuilding Queen Bess Island that supports an important brown pelican-nesting colony. Collectively, these efforts provide a base that stabilizes processes causing wetland losses and serves as the foundation for the larger restoration efforts included in the Coastal Master Plan.

As presented in the 2017 Coastal Master Plan, CPRA's Integrated Compartment Model (ICM) projected land losses over the period 2015 to 2065, both without action and with projects included in the plan. Cumulative land loss in the Barataria Basin was projected to be 188,110 acres under a future without action, assuming the plan's Low scenario in which the Gulf sea level would rise 43 cm during that period.[28] The ICM simulations indicate that land loss would increase by 61% assuming the Medium scenario (sea-level rise of 63 cm) and 141% assuming the High scenario (83 cm). Under the Low scenario, the model simulation indicates that the primary mechanisms for land loss would be inundation collapse of saline marsh (42%), marsh edge erosion (26%), and inundation collapse of brackish marsh (26%, Table 2). Marsh edge erosion dominates for the first two decades of the simulation, with inundation collapse becoming more important around year 25. However, whether it is because of collapse or edge erosion, at least for the next several decades, the substantial majority of land loss in the Barataria Basin is expected to result from the loss of saline to brackish marsh in the lower part of the basin.

Considering simulated projections just of net land loss misses other important changes in the Barataria Basin that might be expected over the next fifty years, even under Low scenario conditions. Prominent among these is the conversion of brackish to saline and fresh to brackish marshes because of salinity increases. If gradual, such conversion of marsh types generally occurs without substantial marsh loss, with the possible exception of loss of floating fresh marshes, or flotants. More problematic is the future of wooded swamps and bottomland hardwoods with increasing inundation. ICM simulations project conversion to fresh marsh, but this does not always occur and there are extensive areas throughout the Mississippi Deltaic Plain where tree remnants are left standing in expanding, permanently flooded ponds.

Continued →

Table 4. Restoration projects in the Barataria Basin included in the 2017 Coastal Master Plan.[1]

Project type	Number	Description	Period	Cost ($m)
Sediment diversion	002.DI.102	Mid-Barataria Diversion	1-10	998
	03a.DI.01	Bayou Lafourche Diversion	1-10	196
	001.DI.101	Ama Diversion	11-30	882
Marsh creation	002.MC.05e	Large-Scale Barataria	11-30	674
	03a.MC.07	Belle Pass-Golden Meadow	11-30	1,625
	002.MC.04a	Lower Barataria A	31-50	709
Ridge restoration	002.RC.101	Adams Bay	1-10	7
	002.RC.102	Bayou Eau Noire	1-10	10
	002.RC.103	Grand Bayou	1-10	10
	002.RC.02	Spanish Pass	11-30	12
	002.RC.100	Red Pass	11-30	4
Shoreline protection	002.SP.100	Lake Hermitage	1-10	15
	002.SP.102	East Snail Bay	1-10	15
	002.SP.106	Bayou Perot	1-10	13
	002.RC.103	West Snail Bay	11-30	30

The restoration projects included in the 2017 Coastal Master Plan are listed in Table 4 by project type, costs, and time period for execution within the fifty-year planning period. Substantial rehabilitation of the barrier islands fronting the Barataria Basin has already been implemented, but would be better maintained under the Plan. ICM simulations indicate that under the Low environmental scenario, these projects would result in a net of 52,739 fewer acres lost, or a reduction in net loss of 28% (Figure 14).[28] The projects include sediment diversions that would expand wetlands over a broader area and reduce marsh collapses due to inundation or salinity increase. Extensive—and expensive— marsh creation projects are also included in areas where sediment resources may be extracted either directly from the Mississippi River along the east side of the basin or from offshore in the southwest corner. The simulation suggests that, even with the implementation of the restoration projects, there would still be net land loss in the basin, primarily due to the loss of saline and brackish wetlands in the lower basin.

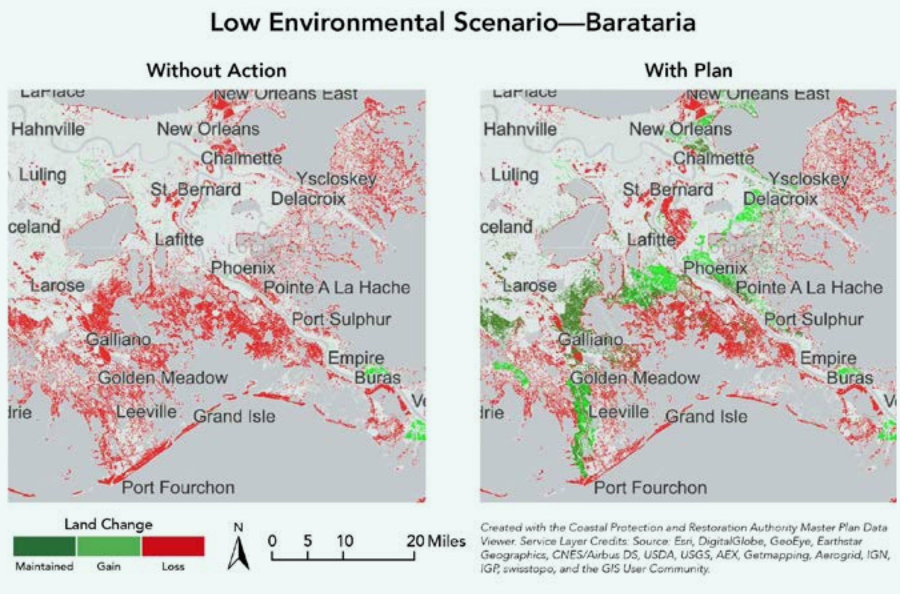

Figure 14. Land lost, gained and maintained after fifty years in the Barataria Basin, with and without the restoration projects included in the 2017 Coastal Master Plan.

Continued →

The same ICM model used for the 2017 Coastal Master Plan was employed to assess additional, innovative projects that could provide benefits in the face of sea-level rise and subsidence without continued maintenance and that would contribute to maintaining estuarine gradients in future decades.[28] The conceptual projects simulated for the Barataria Basin include: (1) tidal prism control via inlet restriction around Barataria Bay rim; (2) tidal prism control by volume reduction of lower Barataria Bay; (3) enhanced sand supply through a lower Barataria sediment diversion from the Mississippi River; and (4) delivery of fresh water to the upper western Barataria Basin. These interventions were all evaluated using the Medium scenario with Gulf sea-level rise assumed to be 63 cm over the fifty years. The outcomes would be somewhat different under the more likely lower sea-level rise.

Tidal prism control by constructing large islands in Barataria Bay produced less obvious benefits compared to controlling tidal flows around the rim of the bay. Some adaptations of this latter notion would incorporate elements that reduce shoreline erosions and direct freshwater pulses from the mid-Barataria diversion have merit for more detailed evaluation. The notion of adding sand through a diversion lower along the Mississippi should be revaluated in the context of a potential new navigation entrance for the river as discussed for the Birdsfoot Delta. Providing fresh water to forestall salinity increases at hotspots in the northwestern basin is problematic because of limited water supply, but may not be critical under lower sea-level rise projections.

Vision

The reasonable likelihood that sea-level rise over the next fifty years will not exceed the Coastal Master Plan Low scenario assumption of 43 cm offers a substantial window of opportunity to sustain and enhance a bountiful Barataria Basin over that time period. Investments have already re-established the coastal barriers enclosing the bay and improved hydrological controls within the basin. The freshwater diversion at Davis Pond has furnished the freshwater resources needed in the upper to middle part of the basin and is reinvigorating the wetland ecosystem nearby. The mid-Barataria diversion, currently in advanced design, will reestablish sedimentary processes that have built and maintained the wetlands of the basin. Together with sound, science, and engineering, the experiences gained in operation of these diversions adaptively should allow managers to enhance their constructive forces and optimize their benefits over time while the rise of Gulf waters remain relatively slow. Storm-surge protection infrastructure is largely in place around communities located along the West Bank of the Mississippi River and Bayou Lafourche and will have to be strengthened over time. In contrast with other regions of the coast, there are few population centers outside of the protection system. While some homes will likely be abandoned, others can be protected from recurrent floods with lower levees and contend with larger threats by evacuation and non-structural adaptation.

If global society were unable to sufficiently reduce its greenhouse gas emissions to stabilize the global temperature well before the end of this century as per the objective on the Paris Climate Agreement, sea-level rise would more dramatically accelerate. Sea level would then likely rise to a level in excess of that assumed in the Coastal Master Plan's High scenario early during the next century and it will be extremely challenging to maintain the restored coastal landscape features and protection infrastructure. As stressed earlier, avoiding that existential calamity and contending with the global realities of the energy transition required will also require much of Louisiana's citizens, governments, institutions, and economic enterprises. This is particularly true for the Barataria and Terrebonne basins that contain substantial infrastructure to support the production and transportation of oil and gas resources from offshore, as well as in the coastal zone. Port Fourchon is a case in point. It will be necessary to engage the corporate world not only in sustaining existing infrastructure, but also in accommodating renewable energy production, and potentially, carbon storage.

Continued →

Successfully meeting the goals of the Gulf Hypoxia Action Plan by 2035 would have several benefits for maintaining a bountiful ecosystem in the Barataria Basin. Lowering river concentration of reactive nitrogen and phosphorus by half would alleviate water quality concerns regarding the diversions of river water into the basin. The nutrient-enriched river plume from the Southwest Pass is commonly entrained in a gyre that allows nutrient-enriched, low-salinity water to be brought into Barataria Bay through tidal exchange. The most severe and persistent region of oxygen depletion on the continental shelf lies immediately offshore of the Barataria Bay, subjecting stress to larvae of fish, shrimp, and crabs that spawn offshore and are recruited to the wetland nursery of the estuary.

With these considerations in mind, I recommend the following further directions for protection and restoration planning for the Barataria Basin:

- **Manage barrier islands as a system**. The rehabilitation of coastal barrier islands and headlands fronting the Barataria Basin has progressed island by island, using sand both from the river and from offshore deposits. As a result, much has been learned about sand properties and the processes that distribute them. Sand is transported along the islands to the east toward Grand Terre until it reaches the deep and energetic Barataria pass. Similar connections exist between the Caminada headland and Grand Isle. The emerging understanding of these littoral dynamics opens up new opportunities for efficiently maintaining the Barataria barriers as interconnected systems.

- **Manage mid-Barataria sediment diversion inputs to ensure efficient sediment retention**. As mentioned for diversions in the Pontchartrain Basin, "outfall management" is a component of the mid-Barataria sediment diversion design. Increasing sediment retention in the area receiving the diversion and minimizing erosion in bays and estuaries is critically important.[96] This should be an ongoing, adaptive process that has the broad scope needed to enhance the constructive potential of fine sediments escaping the region of immediate deposition.

- **Ensure flow exchange across the Highway 90 corridor**. Flooding risks along the U.S. Highway 90 corridor crossing the Barataria Basin between Paradis and Raceland, together with demands for flood protection for communities higher in the basin along the West Bank of the Mississippi River, are driving consideration of heightened levees along the corridor. Structural restrictions risk diminishing the connectivity of the estuarine basin with Lac des Allemands and hastening the loss of forested wetlands in the uppermost basin. Not only must drainage from the upper basin be accommodated, but also it is important to maintain tidal exchanges into Lac des Allemands through appropriately placed and operated sluice gates. The efficacy of low levees around the periphery of the uppermost basin in lieu of a more restrictive along the US-90 corridor should be evaluated.

Continued →

- **Evaluate freshwater and sediment diversions in the upper basin.** The possible conversion of the forested wetlands of the uppermost basin to open water merits consideration of another diversion above the planned Ama diversion, at or below Donaldsonville, that would supply fresh water but also some sediment into the basin to help build up the ground level. This could be supplemented by cypress reforestation in areas where standing water precludes the natural recruitment of cypress saplings.

- **Reduce erosion of wetland shorelines.** Shoreline erosion of saline and brackish wetlands will likely constitute the greatest cause of wetland loss in the basin over the next few decades. Efforts to moderate erosion, particularly through use of living shoreline solutions such as establishing fringing oyster reefs, should be considered where feasible. Reducing shoreline erosion should also be integrated together with any efforts to re-compartmentalize the lower estuary or reduce the tidal prism along the Barataria Bay rim.

- **Evaluate re-compartmentalization of the lower estuary to enhance estuarine production with the operation of with large-scale sediment diversion.** A significant concern of both the users and stewards of estuarine living resources within the Barataria Basin is the displacement of these resources by diversions that introduce large amounts of river water and reduce salinity. While considerations are being made in the diversion planning to reduce the extent and duration of this impact, periodic freshening of large portions of the Barataria estuary is inevitable. Opportunities should be explored for strategic marsh creation that provides some hydrological isolation of the originally relatively discrete Caminada Bay and Bay des Illetes Baptist from Barataria Bay proper. This might allow the maintenance of estuarine gradients and resource production in the southwestern portion of the basin. Enhanced oyster production through off-bottom aquaculture might compensate any reductions in the dredged oyster fishery along the eastern side of the basin.
  Integrate the future entryway for Mississippi River navigation into basin planning. A potential new channel for maintaining deep-draft navigation into the Mississippi River considered in the vision for the Birdsfoot Delta could traverse the southeastern Barataria Basin. Planning for sustainable coastal barrier islands along the Barataria coast would have to be integrated with this channel design, operation, and maintenance. Depending on how river flows are managed, the channel could be a substantial conduit of sand to the coast. In any case, channel dredging and maintenance will provide large quantities of sediment for marsh habitat creation in the southeastern Barataria Basin. A deep-draft channel could have also substantial consequences for the salinity of offshore waters that are brought by tidal exchanges into Barataria Bay and thus affect estuarine biological production and influence the operation of sediment diversions within the basin.

Continued →

- **Explore opportunities for storm-surge management across levees along the lowermost river**. Levees along the Mississippi in lower Plaquemines Parish provide a barrier to storm surges propagating either up the Barataria Basin or through Breton Sound. While they are built to afford protection, they also have the unfortunate effect of increasing storm surge levels higher in those basins as the surges have nowhere else to go. Particularly after Katrina, populations are declining in these lower river communities and agricultural land use is in decline. The benefits and risks of lower river levees along certain sections that would provide some relief for storm surges should be explored in the holistic assessment of the Lowermost Mississippi River described under the vision for the Birdsfoot Delta.

- **Transition and repurpose of oil and gas infrastructure**. One way or another, the next fifty years will bring a pervasive transition of global energy use. As we strive to achieve zero net greenhouse gas emissions within that time period, to what degree will we need the substantial infrastructure for oil and gas exploration, production, and transport that exists around the Barataria Basin, including Port Fourchon, LOOP, and major pipelines? Are there new purposes for this infrastructure and the workforces associated with them, such as transporting captured carbon dioxide for storage in the vast deep saline formations that exist under the Louisiana coastal zone and continental shelf or for offshore wind farms? It is time that the reality of the new energy future be engrained in planning for Louisiana's future, including its coastal protection and restoration planning.

Terrebonne Basin: The Dilemma between Two Rivers

Prologue

The Terrebonne Basin encompasses a vast portion of the Mississippi Deltaic Plain lying between Bayou Lafourche and the Atchafalaya River Basin (Figure 15). While the swamps in the uppermost basin around Lake Verret and the marshes in the southwestern basin receive some fresh water from the Atchafalaya flow, over one-half of the basin is remote from both the Mississippi and Atchafalaya. In that portion, local rainfall provides the only freshwater inputs to the estuarine ecosystem, as there is minimal watershed that drains to it. Consequently, opportunities for sediment diversions from the two great rivers are limited. Broadly exposed to the Gulf of Mexico, the basin's expanding bays and deteriorating wetlands have placed a population of about 150,000 people and important industrial infrastructures at increasing risk to storm surges. This has resulted in a demand for greater structural protection, as well as the continuing northward relocation of people toward population centers. The Terrebonne Basin confronts a dilemma between two rivers.

Isolated from supplies of sediment from the Mississippi River, the basin's extensive coastal wetlands will be sustained by sediment diversions from the Atchafalaya River; strategic marsh creation and ridge and hydrologic restoration; and barrier island maintenance. Storm-surge protection of population centers will accommodate tidal exchange, while communities outside of protection will adapt and relocate in a manner respectful of their culture.

The deltaic landscapes were named Terre Bonne by early settlers for its good earth with highly fertile soils, but it remained largely a sparsely populated wilderness until the early 19th Century. The landscapes were built on a foundation laid down when the Mississippi flowed down what is now Bayou Teche and formed a delta fanning out toward the southeast some 3,500 to 2,800 year ago. The river's flow then shifted farther east and built the St. Bernard delta, only to return 1,000 years ago to lay down the broad Lafourche delta, built on top of and extending beyond the subsided Teche delta. In addition to the Bayou Lafourche that carried most of the flow just a few hundred years ago, the Lafourche delta included distributaries that formed the iconic bayous Du Large, Grand Caillou, Petite Caillou, Terrebonne, Pointe Aux Chene and Blue, that today emanate from the Houma region. The thick deposits laid down when this delta was active are still compacting, causing high subsidence rates over much of the basin.

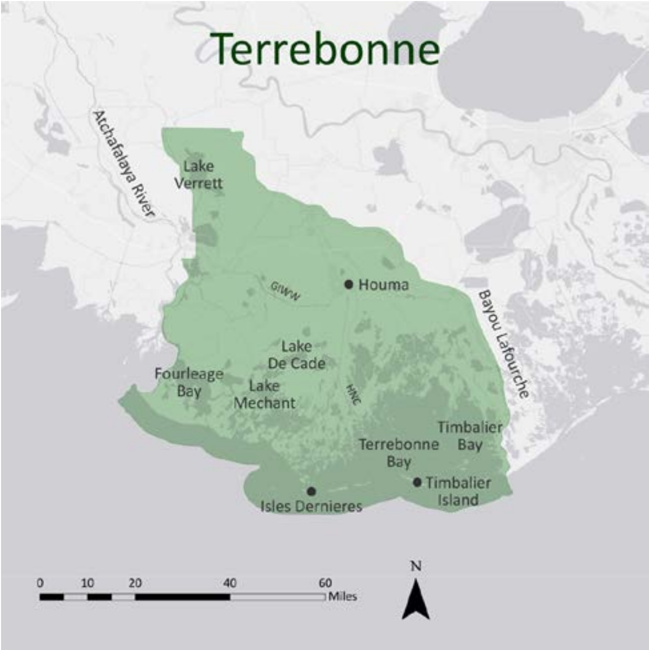

Figure 15. *The Terrebonne Basin. HNC = Houma Navigation Canal, GIWW = Gulf Intracoastal Water Way.*

Continued →

Farming and fishing communities extended along the natural levees of these abandoned distributaries, nourished by both very fertile soils and the surrounding bountiful estuarine resources. In the 19th Century, the fingers created by these bayous were being eaten away by the processes that naturally devour abandoned deltas, sinking land and the intrusive influence of the sea. Early 19th Century maps depict the bayous reaching the coast with small water bodies in between them. Even the more accurate 1870 U.S. Coast Survey chart shows land along the Bayou Pointe Aux Chene extending almost to the barrier islands, effectively separating the bays named for a drum player (Timbalier) to the east and the good earth (Terrebonne) to the west. Now, these two bays have merged, creating the 25-mile wide Terrebonne Bay. Maps still designate separate bays and lakes that once existed but are now in unbounded open water: St. Jean Baptiste, Barre, Jacko, Felicity, Old Lady, and Raccourci.

During the 20th Century, the barrier islands that fronted the Timbalier and the Terrebonne bays also retreated and shrank in size, exhausted of their sand resources and losing marshes on its bay sides. The Isle Derniere (singular) — in the mid-19th Century large enough to host an ill-fated pleasure resort — became Isles Dernieres (plural), a chain of remnant islets. Attempts to protect oil and gas infrastructure on the East Timbalier Island by placement of rock breakwaters only hastened its demise. Inlets between the islands widened, allowing for greater surges of Gulf waters from tides and storms.

Human activities during the 20th Century accelerated the loss of wetlands in the Terrebonne Basin. The Gulf Intracoastal Waterway, constructed after World War II, cuts across the basin, altering natural water flows. The GIWW allows fresh water from the Atchafalaya to enter the basin, but also saline water to intrude during dry periods. The Houma Navigation Canal, completed in 1961 to support the expanding offshore oil and gas industry from the construction and supply bases around Houma, has exacerbated saltwater intrusion and decimated salt-intolerant cypress swamps. Oil and gas extraction activities resulted in extensive channelization and increased fluid extraction (oil, gas, and the saline waters in the formations) during the 1960s has been implicated in the dramatic loss of marshes in parts of the basin through locally increasing subsidence.[117] Overall, wetland losses attributable directly or indirectly to oil and gas production—an important part of this region's economy—have been more significant in the Terrebonne Basin than in any other coastal basin in Louisiana.

Between 1932 and 2016, 1,352 square kilometers (334,000 acres) of land were lost, most of it being tidal wetlands.[5] Loss rates increased up to three-fold between 1950 and 1980, reaching more than 25 km^2 per year. After 2000, losses declined to rates less than those experienced during the 1930s. As in the Barataria Basin, the reduction in loss rate was attributable to the facts that the most vulnerable wetlands had already been lost and the initiation of destructive human activities, particularly construction of oil and gas canals and withdrawal-induced subsidence, had moderated.

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Restoration Actions and Plans

As with the Barataria Basin, there have been numerous restoration projects that have been completed under the CWPPRA, the state and local government, and landowner actions. These have focused, in particular, on restoration of the barrier islands and their bayside marshes and of the Belle Pass headland at the mouth of Bayou Lafourche. There have also been coordinated projects to create marshes, stabilize shorelines, strengthen ridges, control hydrology, and introduce fresh water from the Atchafalaya River around expanding lakes (Lost Lake, Lake Mechant, and Lake De Cade) in the southwestern part of the basin. In 2019, a $160 million effort was initiated to restore and nourish Trinity-East, the Timbalier islands, and the West Belle Pass headland that guard the southeastern margin of the Terrebonne Basin. The funding comes from the Gulf Environmental Benefit Fund managed by the National Fish and Wildlife Foundation and derived from the BP criminal plea agreement. Barrier island and back-barrier marsh restoration has also been undertaken on Whiskey Island, part of the Isles Dernieres, as part of the restoration of natural resources following the 2010 oil spill.

The ICM modeling conducted for the 2017 Coastal Master Plan projected land losses without action in the Terrebonne Basin over 2015-2065 would be 192,403 acres under the Low environmental scenario (Table 2).[28] It would be 73% and 162% greater under the Medium and High environmental scenarios, respectively. Under the more realistic sea-level rise assumed under the Low scenario, the projected losses would result mostly from inundation collapse of saline (53%), brackish (15%), and marshes and marsh edge erosion (27%). Marsh edge erosion would dominate for the first 20 years, when collapse of saline marsh would become equally or more important. Collapse of brackish marshes would only become important after 40 years. As discussed for Barataria Bay, ongoing modeling suggests that marshes are being lost far more to edge erosion than inundation collapse.

Table 5. *Restoration projects in the Terrebonne Basin included in the 2017 Coastal Master Plan.*[1]

Project type	Number	Description	Period	Cost ($m)
Sediment diversion	03a.DI.01	Bayou Lafourche	1-10	196
	03a.DI.05	Atchafalaya River	1-10	283
	03a.DI.04	Increase Flow to Terrebonne	1-10	398
Hydrologic restoration	03a.HR.02	Central Terrebonne	1-10	15
	03a.HR.100	Grand Bayou	11-30	9
Marsh creation	03a.MC.03p	Terrebonne Bay Rim	1-10	90
	03a.MC.07	Belle Pass-Golden Meadow	11-30	1,625
	03a.MC.09b	North Terrebonne Bay	11-30	299
	03a.MC.100	South Terrebonne	11-30	1,813
	03a.MC.101	North Lake Mechant	11-30	1,023
	03b.MC.09	Point Au Fer Island	31-50	728
Ridge restoration	03a.RC.04	Mauvais Bois	1-10	10
	03a.RC.06	Bayou Pointe Aux Chene	1-10	11
	03a.RC.02	Bayou Dularge	11-30	10
	03a.RC.05	Bayou Terrebonne	11-30	9
Shoreline protection	03a.SP.100	North Lake Boudreaux	11-30	29

Continued →

Planned restoration projects (Table 5) exclude the extensive barrier island restoration discussed above. Model simulations indicate that under the Low environmental scenario, these projects would result in a net of 46,824 fewer acres lost, a reduction of 24%. The sediment diversions, marsh creation projects, and ridge restoration listed would mainly counteract saline intrusion and inundation collapse of brackish wetlands, but not greatly affect the pattern of wetland losses attributable to marsh edge erosion and inundation collapse of salt marshes.

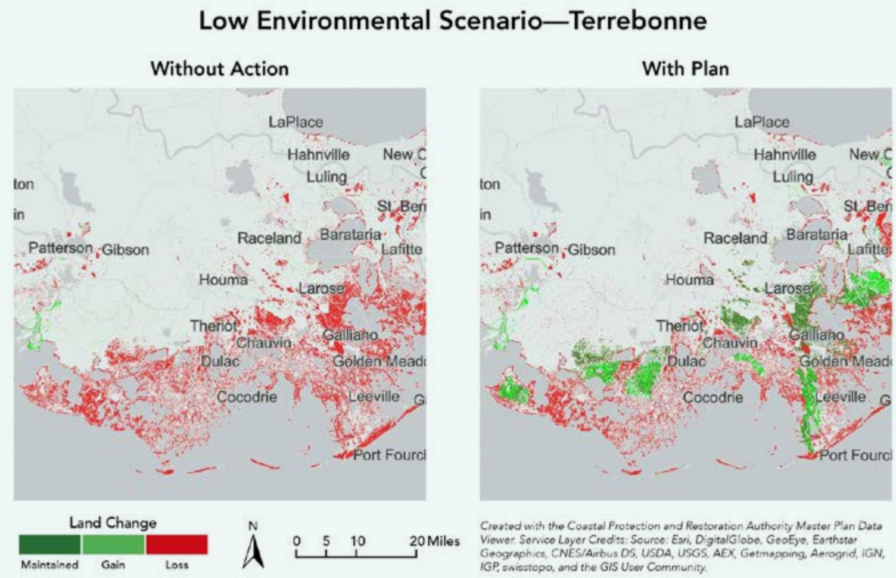

Figure 16. *Land lost, gained and maintained after fifty years in the Terrebonne Basin, with and without the restoration projects included in the 2017 Coastal Master Plan.*

The small diversion down Bayou Lafourche was discussed in the section on the Barataria Basin. It would affect salinity in both basins where the bayou reaches the GIWW, but would convey very little sediment. Planning and design are underway on the Increase Atchafalaya Flow to Terrebonne project. By dredging the GIWW east of the Atchafalaya and installing a bypass structure at Bayou Boeuf, it would divert 20 cfs of flow to increase freshwater and sediment inputs to fresh wetlands in the central basin. The Atchafalaya River sediment diversion would extract a substantial portion of the river's flow below Morgan City to build, sustain, and maintain wetlands and forestall saline intrusion within the western Terrebonne Basin. It would be designed to work in conjunction with the Mauvais Bois ridge restoration.

The Coastal Master Plan includes several large marsh creation projects to be completed by the end of the third decade of the planning period. One aims to restore and maintain marshes along Bayou Lafourche from Golden Meadow to the Belle Pass headland. It would mirror similar marsh creation in the Barataria Basin to retain a wetland margin along the waterway and highway access to Port Fourchon and Grand Isle. The other large marsh creation projects would rebuild severely degraded marshes between the bayous Grand Caillou and Du Large and between the lakes De Cade and Mechant with a continuous expanse of wetlands. The latter two are far-removed from sources sediment from the Atchafalaya River or on the continental shelf and would have to be constructed using sediments dredged from shallow water bodies.

Continued →

Two additional innovative measures have been assessed after the release of the 2017 Coastal Master Plan.[28] One involved the transport of sediment dredged from the Atchafalaya River channel via pipelines to elevate and build marshes immediately north of Lost Lake in the western basin. If continued over years, such sediment nourishment could sustain and expand marshes. However, the assessment did not consider the consequences of the sediment relocation on the Atchafalaya Delta, nor cost and other feasibility factors. The second measure involved the creation of a second line of barrier islands across the Terrebonne Bay from dredging sand from the existing barrier island and along its Gulf face. This would essentially constitute a fallback relocation intended to reduce intrusion of saltwater from the Gulf and reduce the erosion of the marsh rim along the top of the bay by waves and tidal currents. Modeling indicated that landward relocation of the islands would reduce the tidal prism and that lower salinity conditions would be maintained in basin wetlands. However, the modeling did not assess potentially important effects of the removal existing islands nor sediment dynamics on the recreated islands.

Vision

The Terrebonne Basin covers an extensive and ecologically, economically, and culturally important part of the Louisiana coast, but it truly faces a dilemma because of its relative isolation from nourishing sediments of the Mississippi and Atchafalaya rivers. I lived and worked in the Terrebonne Basin for a decade, so I must disclose a bias based on my affection. Here is the epitome of the bayou culture, located along those slim and drowning natural levees bordering those spokes of former distributaries, places where there are just two cardinal directions on land: down the bayou and up the bayou. Along the Terrebonne bayous are intact communities of indigenous people, the Biloxi-Chitimachas. For decades, communities have been losing residents, particularly in the wake of storms that force people to move up the bayou because of damages or lack of insurance. This is a “restore or retreat” country, with the incoherence of retreat and community fabric all too evident in the ongoing challenge of relocating the community of Isle de Jean Charles.

There are also population and industrial centers in the Terrebonne Basin that require protection if they are to function. The Houma and Amelia regions play a particularly important role in construction of the infrastructure of offshore oil and gas production. The Morganza to the Gulf Hurricane Protection Project includes nearly 100 miles of levees with surge barriers and locks, parts of which are being built by the state and local governments. With a cost of about $6 billion and the needed federal funding not yet forthcoming, it may never be fully completed. What is constructed will present challenges in sustaining wetlands within the levees as tidal waters continue to rise. If global warming is not limited and the rise in Gulf levels accelerates dramatically toward the end of the century, the land protected could become a huge polder with permanently closed tidal gates and totally pumped drainage.

With these broad societal perspectives in mind, I offer the following further considerations for protection and restoration planning for the Terrebonne Basin:

- **Maintain and sustain the current alignment of barrier islands**. Substantial investments have been made to rebuild and sustain the long array of barrier islands fronting the Gulf of Mexico, even as they become more distant from the northern rim of the bays behind them. They are holding up well, so far, and they play a role in moderating the wave, tidal, and storm surge energy from the Gulf. The notion of purposefully retreating this line of defense inland by dredging them up is conceptually problematic and risky. As, with the barrier islands and headlands fronting the Barataria Basin, the Terrebonne barriers should be managed as a littoral system.

Continued →

- **Optimize sediments inputs from Atchafalaya River**. Pursuing mechanisms to introduce sediments, even fine sediments, into the marshes of the southwestern Terrebonne Basin, is essential to their sustenance in the face of relative sea-level rise. Design of the Increase Atchafalaya Flow to Terrebonne project is underway, but the Atchafalaya Diversion project should be evaluated in an integrated manner with the use of sediment resources in the greater Atchafalaya Basin. Designs should optimize the retention and use of sediments diverted or transported as dredged sediment slurries.

- **Ensure tidal exchange through storm surge protection system**. As with the Highway 90 corridor in the Barataria Basin, the siting, design, and operation of gates in the Morganza to Gulf levee alignment should ensure sufficient tidal exchanges to maintain enclosed wetlands and their ecosystem functions. Because raising the elevation of this storm-surge protection structure will have such a major influence on the ecohydrology of the basin, it should be fully integrated into coastal planning.

- **Reduce erosion of wetland shorelines**. As discussed for the Barataria Basin, shoreline erosion of saline and brackish wetlands will likely constitute the greatest cause of wetland loss in the basin over the next few decades. The use of living shoreline solutions and fringing oyster reefs could also be considered. In consideration of the transition to renewable energy that is required over this same time period, it might be feasible to site solar arrays within the vast open space that now exists in the upper Terrebonne Bay in a way this infrastructure attenuates the wave energy reaching eroding wetland shorelines.

- **Strategically reassess planned marsh creation projects**. Ambitious marsh restoration projects are included in the second, third, and fourth decades of the current Master Plan. The estimated cost of these projects in present dollars is about $5.5 billion, rivaling the cost of the Morganza to the Gulf Hurricane Protection Project. Under realistic sea-level rise projections and refined subsidence rate estimates, when will they be needed, are there sufficient sediment resources, and will they be cost effective? Alternatives, such as enhancement of series of existing marshes and ridges, to moderate tidal exchanges, might be more cost effective.

- **Enhance oyster production and ecoengineering**. If relative remoteness from the big rivers may disadvantage the Terrebonne Basin in terms of sediment supply, it may be an advantage with regard to oyster production in the future. The Louisiana oyster industry is struggling in the face of flood-related mortalities and in making the transition to the more managed cultivation that has occurred elsewhere in the world. Why not make Terrebonne a focal point for profitable oyster aquaculture along with the creation of oyster reefs that serve as natural breakwaters, as well as protected spawning stocks for the fishery?

Greater Atchafalaya Basin: Keeping It Building

Prologue

As considered here, the greater Atchafalaya Basin includes the Atchafalaya Delta Basin and the Teche/Vermilion Basin, as defined in coastal Louisiana planning. These basins constitute the western-most portion of the Mississippi Deltaic Plain. The coastal landscape is the remnant of deltas built as long as 4,800 years ago and abandoned as recent as 2,800 years ago. In the early period, the Mississippi River discharged far to the west of its present course and built a delta extending well into the Gulf of Mexico, most of which was submerged and eroded away. Later, the river ran down what became arguably Louisiana's most famous bayou, Bayou Teche,[117] with its snake-like meanders from which it derived its Chitimacha name. As described for the Terrebonne Basin, the river switched course to the east toward present-day New Orleans.

As some river sediments are diverted to the Terrebonne Basin, the Atchafalaya and Wax Lake deltas will continue to create new wetlands and nourish the surrounding coastal ecosystems. Management of the growing deltas and the use of dredged materials will allow for additional marsh creation. Protection of eroding shorelines will reduce further wetland degradation.

About 600 years ago, a new bend developed on the Mississippi River well above Baton Rouge, allowing that river to capture the Red River that had flowed down the Bayou Teche.[8] A minor portion of the rivers' flow also travelled through the Atchafalaya River — Choctaw for "long river" — slowly southward through its basin swamps. The combination of dredging a cutoff across the river bend and removal of tremendous logjams that had accumulated during the mid-1800s increased the amount of Mississippi flow down the Atchafalaya, a 186-mile shorter route to the Gulf, to over 15% by the 1880s. By 1960, that proportion had reached 40%, threatening the viability of population centers and commerce from Baton Rouge to New Orleans. The Old River Control Structure was built to regulate flow and it has been operated since 1963 to allow only 30% of the flow to travel down the Atchafalaya. All but the finest sediments were still captured within the vast swamps and lakes of the Atchafalaya River Basin until the 1950s, when sediments began to accumulate on the bottom of Atchafalaya Bay. With the discharge of fine sand resulting from the record flood of 1973, a new Atchafalaya Delta began to emerge above the waters of the bay, covering 16 square miles by 1977. Although this land area is now over 38 square miles, the growth and development of this delta has been altered by maintenance of a 20-foot navigation channel down its center, with spoil banks interfering with overbank flooding, and the deep channel allowing the intrusion of saline waters from the Gulf.

Continued →

In 1942, the Corps of Engineers dredged the Wax Lake Outlet, a diversion channel from the Atchafalaya River Basin crossing the Bayou Teche and the Gulf Intracoastal Water into the Atchafalaya Bay, in order to reduce flood stages at Morgan City. Originally designed to convey 20–30% of the total flow, a weir was built in 1988 to limit flow, but removed in 1994, allowing flow through the Wax Lake Outlet to increase to as much as 45% of the total Atchafalaya flow.[8] The Wax Lake Delta began to form west of the Atchafalaya Delta — initially more slowly but more quickly since the late 1980s — and now extends over 30 square miles. Unlike the Atchafalaya Delta, the Wax Lake Delta has had very little channel dredging during its growth, so it developed naturally with bifurcating distributaries and channel bars that allowed high sediment retention. For this reason, it has been extensively studied to understand the complex interaction of factors such as sediment deposition and erosion; water level fluctuations associated with floods, tides, and winds; and plant establishment and growth.[118] The understanding of these processes is being applied in the design and operation of sediment diversions along the lower Mississippi River.

Figure 17. *The Greater Atchafalaya Basin.*

In addition to building the emerging deltas, escaping sediments also nourish subsiding wetlands to the east in the western Terrebonne Basin and to the west in the Teche/Vermilion Basin (Figure 17). The latter encompasses the East and West Cote Blanche Bays and the Vermilion Bay, separated from the Gulf by the expansive and appropriately named Marsh Island. This basin receives substantial freshwater inputs from the Atchafalaya River, both through the Atchafalaya Bay and via the Gulf Intracoastal Waterway, which intercepts flow down the Wax Lake Outlet. The Vermilion River also drains the prairie to the north. As a result, the Teche/Vermilion wetlands range from fresh to brackish, but are subject to salt stress when tidal water levels rise as a result of frontal passage or tropical storms. Many landowners have taken steps to limit saltwater intrusion by placing dykes and weirs. However, such management structures also interfere with the tidal supply of mineral sediments needed for subsiding marshes to aggrade and limit the access of young fish and shrimp to these nursery habitats. Navigation along with oil and gas canals have also altered the hydrology of the fringing wetland ecosystems. Erosion of shorelines is the main cause of marsh loss, but there are hot spots where wetlands have been lost due to saline intrusion and inundation.

Continued →

Historically, horizontally and vertically massive oyster reefs were found along the outer Atchafalaya Bay and the offshore Marsh Island. That region received enough freshwater inflow to extend brackish water offshore, allowing oysters to thrive there. It is not exactly clear why, but these oyster populations were largely extinguished by the mid-1800s. Presently, there are only a few, low-relief reefs in the bays. Between 1912 and 1996, the shell remaining from the reefs was mined for use as a lightweight base for construction on Louisiana's soft soils and other industrial purposes.[8] The extensive reefs had reduced the exposure of shorelines to erosive waves, moderated tidal exchange and storm surges, and retained fresh water and sediments within the coastal zone. This underscores the potential that restoration of oyster reefs could comprise an effective component of the restoration of wetland ecosystems along the Louisiana coast.[119]

The Atchafalaya Basin proper experienced the only net land gain among the Louisiana coastal basins. Between 1932 and 2016, 50 square kilometers (12,000 acres) of land were gained.[5] Positive gains have been evident since the 1973 flood and have exceeded 1.5% per year since 1998. On the other hand, the Teche/Vermilion lost 174 square kilometers (43,000 acres) during these 84 years. Steady losses were measured after the 1960s, but stabilized in the late-1990s, with net gains of up to 1.2% per year since then.

Restoration Actions and Plans

The Atchafalaya Basin has been restoring itself through delta building and the broader nourishment of wetlands by escaping sediments. CWPPRA projects have focused on managing sediment delivery and habitats in the Atchafalaya Delta. In the Teche/Vermilion Basin restoration, activities have been more extensive. CWPPRA projects included hydrological restoration of areas altered by canals on Marsh Island, along Cote Blanche Bay, and near the Intercoastal Waterway; marsh creation on Marsh Island; shoreline protection around Vermilion Bay; and sediment trapping by terracing off Little Vermilion Bay. Terracing is a technique in which sediment is taken from the bottom of shallow, open-waterbodies and placed in linear or various shaped rows. The object is to still wave energy, trap suspended sediments, and provide habitat. Terracing has been extensively used in southwestern Louisiana, but its efficacy has not yet been well demonstrated in the scientific literature, other than for the habitat it provides for aquatic organisms and birds.

The ICM modeling conducted for the 2017 Coastal Master Plan projected land losses without action in the Atchafalaya Basin proper over 2015-2065 are 11,077 acres under the Low environmental scenario (Table 2).[28] It would be 128% and 391% greater under the Medium and High environmental scenarios, respectively, indicating that the higher rates of sea-level rise assumed would overwhelm the capacity of the Atchafalaya to sustain wetlands. Under the more realistic sea-level rise assumed under the Low scenario, the projected losses over 50 years would result primarily from inundation collapse of intermediate marshes (67%) and marsh edge erosion (25%). For the Teche/Vermilion Basin, projected losses are 35,018 acres under the Low scenario and 150% and 457% greater under the Medium and High scenario. Most losses would come during the last 20 years of the fifty-year period and result from saline (57%), brackish (16%), marsh collapse, and marsh edge erosion (26%), according to the simulation.

Continued →

The restoration projects included in the 2017 Master Plan are very limited (Table 6). Only shoreline protection along Vermilion and West Cote Blanche bays is included. Costly marsh creation projects are included for the second and third decades of the plan.

Table 6. *Restoration projects in the Atchafalaya Basin included in the 2017 Coastal Master Plan.*[1]

Project type	Number	Description	Period	Cost ($m)
Marsh creation	03b.MC.03	Marsh Island	11-30	503
	03b.MC.101	Southeast Marsh Island	11-30	36
Shoreline protection	03b.SP.-6a	Vermilion Bay & W. Cote Blanche Bay	1-10	155

Because of the paucity of projects in the greater Atchafalaya Basin, the projected future with the Plan is not much different from the future without action assuming the Low environmental scenario (Figure 18). For the Atchafalaya Basin proper, the ICM model simulation estimated a reduction in net land loss with the Plan of only 733 acres, 7% less.[28] For the Teche/Vermilion Basin the projected net reduction in loss is more substantial at 5,972 acres, or 17%, most of which is due to avoidance of inundation collapse of marshes. In both basins, the Plan is ineffective in reducing marsh edge erosion.

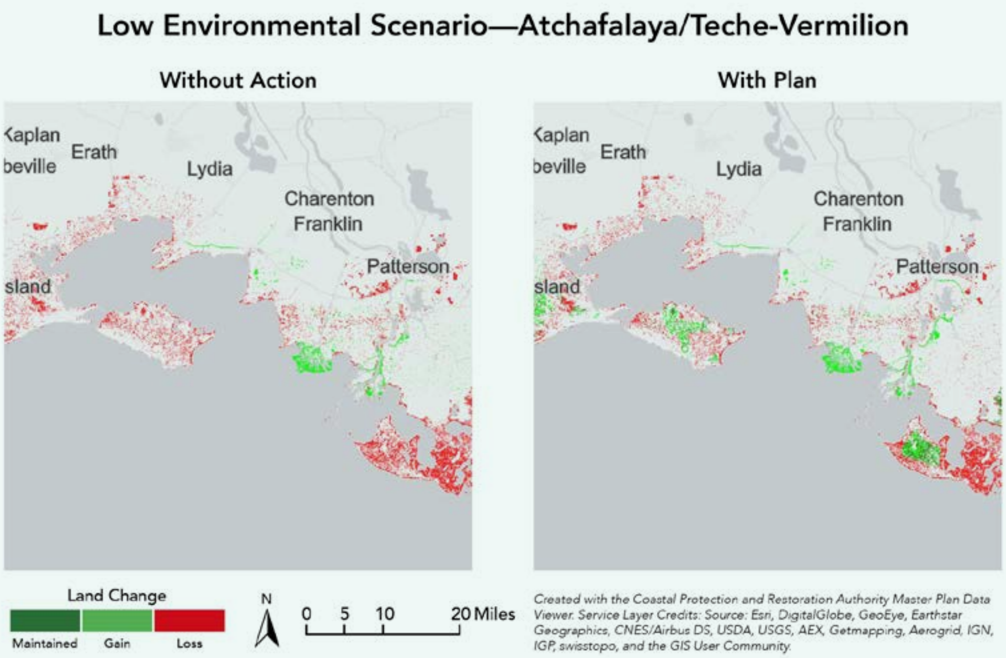

Figure 18. *Land lost, gained and maintained after fifty years in the greater Atchafalaya Basin, with and without the restoration projects included in the 2017 Coastal Master Plan.*

The ICM model was employed to assess two innovative projects in the greater Atchafalaya Basin:[28] (1) diversion of water from the Atchafalaya Basin through the Jaws outlet into the northeastern West Cote Blanche Bay; and (2) tidal prism control on selected marsh inlets. These interventions were evaluated using the Medium environmental scenario. The Jaws diversion had an expansive, yet small impact in lowering salinity and built land in open waters adjacent to the outfall. These effects would be greater under more realistic sea-level rise assumptions. The tidal prism controls affected water levels but had very limited impact on salinity.

Continued →

Vision

Over the last ninety years, the Atchafalaya Basin has actually gained land as a result of the emergence of the Atchafalaya and the Wax Lake Deltas along with the far-field effects of the increased supply of sediments escaping the Atchafalaya River Basin. The adjacent and closely connected Teche-Vermilion Basin has lost land, but at a proportional rate half or less that in any other one of Louisiana's coastal basins. Yet, both basins are projected to lose land based on the 2017 Coastal Master Plan modeling, even under the sea-level rise assumptions of the Low scenario. With the building materials supplied by the river along with human imagination and innovation, I envision that it is possible to achieve no net loss for the greater Atchafalaya Basin and a significant net gain for the Atchafalaya Basin proper over the next fifty years. This will produce considerable natural capital to confront the longer-term future, provided that our global society is able to limit the warming of Earth's climate and commensurate acceleration of sea-level rise.

With this goal in mind, I offer the suggestions further considerations for the greater Atchafalaya Basin:

- **Maximize the retention of sediments and maintain salinity distribution within the basin**. The evaluation and design of an additional, smaller diversion into the West Cote Blanche Bay should be advanced in order to maintain the low salinity conditions required by existing wetlands and provide a greater sediment subsidy to the Teche/Vermilion Basin. While experience with the rapid evolution of the Wax Lake Delta illustrates the effectiveness of natural design, there may be opportunities, particularly in the Atchafalaya Delta, to manage flows and more effectively use sediment dredged from navigation channels to enhance deposition, retention, and land building. Because of high sedimentation rates, maintaining navigation channels in and around Morgan City is financially challenging. Creative and beneficial uses of the dredged materials could contribute to viable funding.

- **Manage hydrologic connections on Marsh Island and around the Vermilion Bay to enhance wetland sustainability.** Typically, hydrologic management through use of dikes and weirs has been used for water-level regulation and salinity control. A more holistic approach to hydrologic management should be taken with the paramount objective of long-term sustainability of marshes, which includes consideration of mineral sediment nourishment as well as water levels and fluctuations, salinity, and the value as habitat for waterfowl, fisheries, and maintenance of biodiversity.

Chenier Plain: Plainly Stranded

Prologue

While distant from sustaining sediments from the two great rivers, the expansive Chenier Plain is subsiding at a slower rate than the rest of the coast. Innovative solutions facilitating the release of fresh water from the plain and its watershed, while continuing to abate saltwater intrusion, will sustain nationally significant wintering waterfowl. Maintaining cheniers will preserve communities and economies and maintain critical stopover habitat for migratory birds and insects.

The Chenier Plain was not directly formed by delta lobes of the Mississippi River, but owes its existence to the great river nonetheless. Westward-flowing currents carried sediments that escaped the active delta lobes or was released by erosion of abandoned delta lobes.[120] Some of these sediments were deposited as mudflats along the Gulf shoreline. When this longshore supply of sediments was reduced, such as when the river was discharging most of the sediment load well to the east, waves eroded these flats, leaving behind the coarser sand and shell deposits in ridges. When the supply of delta sediments increased, such as when the river deposited sediments close to the present-day Atchafalaya River, mudflats once again built out into the Gulf and the process repeated itself. This leaves what is known as a strand plain with nearly parallel ridges separated by lower-lying landscapes in between.

Louisiana's Chenier Plain, named for the oak (chêne in French) trees growing on the ridges, extends for 200 miles from the Vermillion Bay nearly to Galveston, Texas. Throughout much of southwestern Louisiana, the Chenier Plain extends inland about 30 miles from the coast and included extensive fresh marshes that have formed on top of subsiding land located inland from the cheniers themselves. The estuaries of three rivers transect the Chenier Plain. They are, from west to east and largest to smallest, the Sabine (from the Spanish word for cypress), Calcasieu (French transliteration for the Atakapa term for crying eagle), and Mermentau (a clerical misspelling of a village chief, Nementou). Louisiana coastal planning typically divides the Chenier Plain into the Mermentau Basin and the Calcasieu/Sabine Basin, separated by north-south running Highway 27 that creates a hydrological barrier.

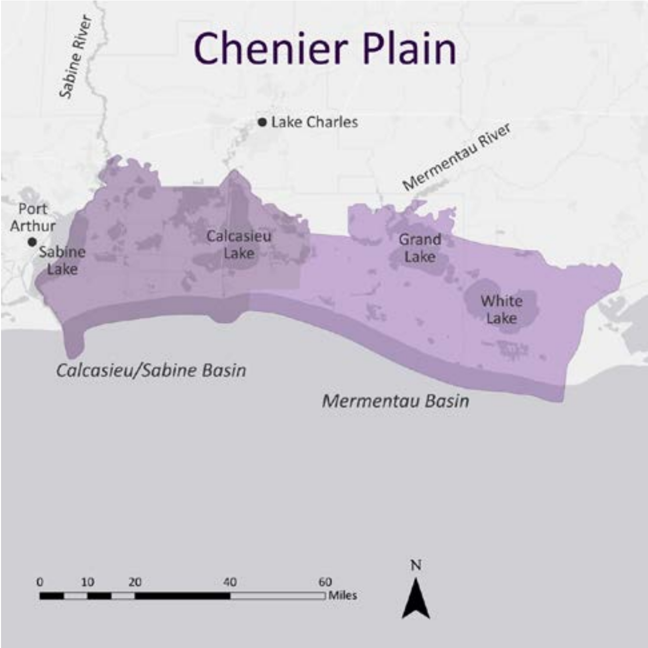

Figure 19. *The Chenier Plain.*

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The inland portion of the Mermentau Basin includes two large freshwater lakes, the Grand and White lakes, surrounded by fresh wetlands. The southern or Gulf-ward part of the basin includes the cheniers. The Calcasieu/Sabine Basin is much more influenced by the Gulf through the large estuaries, Calcasieu Lake and Sabine Lake, which both have deep 40-foot shipping channels to support heavy industrial activities around Lake Charles and Port Arthur-Beaumont, Texas, respectively. The shipping channels allow more energetic tidal exchanges and have increased saline intrusion.

CPRA has produced very insightful Basin Summary Reports for the Mermentau[121] and Calcasieu-Sabine[122] Basins that summarize human-caused and natural changes within the basins and analyze CRMS monitoring data and restoration project effects. There is very little salt marsh in the Chenier Plain, but substantial fresh marsh, particularly in the inland portion of the Mermentau Basin. The substantial majority of marsh is intermediate-to-brackish marsh. Channelization for navigation, oil and gas extraction, drainage, and irrigation has greatly altered the hydrodynamics of the systems, resulting in saline intrusion, impoundment, and the loss of large areas of marsh. This has been dealt with the emplacement of various locks, dikes, and weirs, which while stemming saline intrusion has restricted freshwater runoff, causing prolonged flooding of wetlands. However, such barriers are overwhelmed by hurricane storm surges, such as from Hurricane Rita[123] — and Hurricanes Audrey and Ike — resulting in prolonged impoundment of saline water that killed salt-intolerant wetlands. Furthermore, curtailing the limited supply of sediments brought in from the coast limits the vertical aggradation of wetland soils needed to counteract subsidence.[124] Managing water fluxes from both ends of the land-sea spectrum presents a fundamental conundrum for the future of the Chenier Plain ecosystem. Expansion of channels and shallow ponds has caused erosion by wakes and waves, further compounding the problem.

Largely because of the many human interventions in the Chenier Plain, the loss of land (mostly wetlands) has been substantial. Between 1932 and 2016, 1,078 square kilometers (266,000 acres) of land were lost, with somewhat higher percentage losses in the Calcasieu/Sabine Basin than in the Mermentau.[5] The rate of loss remained relatively steady around 6 km^2/year in the Mermentau, while in the Calcasieu/Sabine loss rates shifted from 8 – 9 km^2/year prior to the 1980s to 2 – 3 km^2/year after 1990. Recently, land area of the Mermentau Basin increased as the fresh marshes of the interior were surprisingly resilient, changing species compensation to adapt to high water levels, even though the brackish marshes of the coastal regions suffered from Gulf shoreline erosion, saltwater intrusion, and lack of sediment input.[122] On the other hand, land area in the Calcasieu-Sabine Basin continued to decline between 2005 and 2016.[123]

The Chenier Plain is particularly valuable for its abundance and diversity of living natural resources. The Central and Mississippi Flyways convene here, making it extremely important for migratory waterfowl and as important stopover for songbirds and shorebirds. Substantial portions of the Chenier Plain are in national and state wildlife refuges and conservation areas, making hunting and birding important to the local economy.

Continued →

Restoration Actions and Plans

Considerable efforts have been undertaken in the Chenier Plain to restore its coastal wetlands or otherwise mitigate the processes that affect them and their living resources. These have been undertaken by the state, local governments, and federal and private landowners. Many large recent projects have been completed with support through the CWPPRA. They include shoreline protection, marsh creation, and hydrologic restoration in both the Mermentau and Calcasieu/Sabine basins. More CWPPRA projects are currently being designed or implemented.

Shoreline protection has focused on the Grand and White lakes, in particular. Hydrologic restoration projects have aimed to limit saltwater intrusion or increase freshwater inflows. Most of the CWPPRA marsh creation efforts were located in the area west of Lake Calcasieu and were often accompanied by terracing in areas where marsh loss has resulted in large, shallow ponds, as mentioned in the discussion of restoration in the Teche/Vermilion Basin. During a recent high-altitude fly-over on a commercial airliner, I was struck by the extent of these linear or chevron-configured terraces in the Chenier Plain. The terraces are constructed from material excavated from adjacent water bottoms and are intended to limit shoreline erosion by restricting the fetch of waves and to eventually revegetate the ponds. Marsh terracing has been employed for over 30 years, but there has been very little evaluation of its efficacy in the scientific literature, beyond studies of the habitat value provided for aquatic resources and birds.[125] It merits further scientific assessment.

The ICM modeling conducted for the 2017 Coastal Master Plan projected land losses without action in the Mermetau Basin over 2015–2065 to be 121,027 acres under the Low environmental scenario (Table 2).[28] It was 97% and 285% greater under the Medium and High environmental scenarios, respectively. With the more realistic sea-level rise assumed in the Low scenario, the projected losses resulted primarily as a result of inundation collapse of saline (41%), brackish (10%), marshes, salinity collapse (35%),and marsh edge erosion (13%). Losses due to salinity collapse mainly came during the third and fourth decade of the fifty-year planning horizon, with marsh collapse mostly coming later. For the Calcasieu/Sabine Basin, projected losses were 43,467 acres under the Low scenario and 179% and 603% greater under the Medium and High scenario. Most losses came during the last 20 years of the fifty-year period and resulted from inundation collapse of saline (59%) and brackish (35%) marshes, according to the simulation.

A substantial number of restoration projects included in the 2017 Coastal Master Plan are located in the Chenier Plain, although most are slated to be undertaken after the first decade of the planning horizon (Table 7). One of the immediate, keystone projects is an effort to isolate the Calcasieu Ship Channel through gates, locks, and sills intended to limit saltwater intrusion into the adjacent marshes. It would also reduce storm surges and dissipate waves eroding shorelines of Lake Calcasieu. Other near-term projects address marsh creation and shoreline protection in the lower Mermentau Basin and protection of the Gulf shoreline east of the Calcasieu River. Longer-term projects focus entirely on marsh creation, mostly in the Calcasieu/Sabine Basin.

Continued →

Table 7. *Restoration projects in the Chenier Plain included in the 2017 Coastal Master Plan.*[1]

Project type	Number	Description	Period	Cost ($m)
Hydrologic restoration	03a.HR.02	Calcasieu Ship Channel	1-10	262
Marsh creation	03a.MC.03p	East Rainey	1-10	102
	03a.MC.07	Freshwater Bayou North	1-10	226
	03a.MC.09b	Freshwater Bayou South	1-10	87
	004.MC.01	South Grand Chenier	11-30	1,813
	004.MC.04	Mud Lake	11-30	197
	004.MC.07	West Rainey	11-30	271
	004.MC.10	Southeast Calcasieu	11-30	374
	004.MC.13	Cameron Meadows	11-30	120
	004.MC.16	East Pecan Island	11-30	472
	004.MC.23	Calcasieu Ship Channel	11-30	117
	004.MC.102	White Lake	11-30	436
	004.MC.107	West Sabine Refuge	11-30	403
	004.MC.19	East Calcasieu Lake	31-50	1,070
	004.MC.103	Little Chenier	31-50	59
	004.MC.104	Calcasieu Lake West Bank	31-50	337
	004.MC.105	West Brown Lake	31-50	580
	004.MC.107	West Sabine Refuge	31-50	251
Shoreline protection	03b.SP.01	Freshwater Bayou	1-10	72
	004.SP.03	Freshwater Bayou Canal	1-10	15
	004.SP.05a	Gulf	1.10	495

For the Mermentau Basin, the ICM model simulation estimated a reduction in net land loss with the Plan of only 27,993 acres, 23% less that under a future without action (Figure 20).[28] Most of this is due to the avoidance of salinity collapse of wetlands. For the Calcasieu/Sabine Basin, the projected net reduction in loss is more substantial at 14,510 acres, or 33%, most of which are due to avoidance of inundation collapse of marshes. Once again, the Plan is ineffective in reducing marsh edge erosion in either basins.

The ICM model was employed to assess two additional, innovative projects in the Chenier Plain.[28] Expanding a lock providing drainage from the Rockefeller Wildlife Refuge provided few benefits that could be captured in the ICM framework. Diverting small quantities of fresh water from the Red River into the upper Mermentau River reduced summer time peak salinities in the Mermentau Basin.

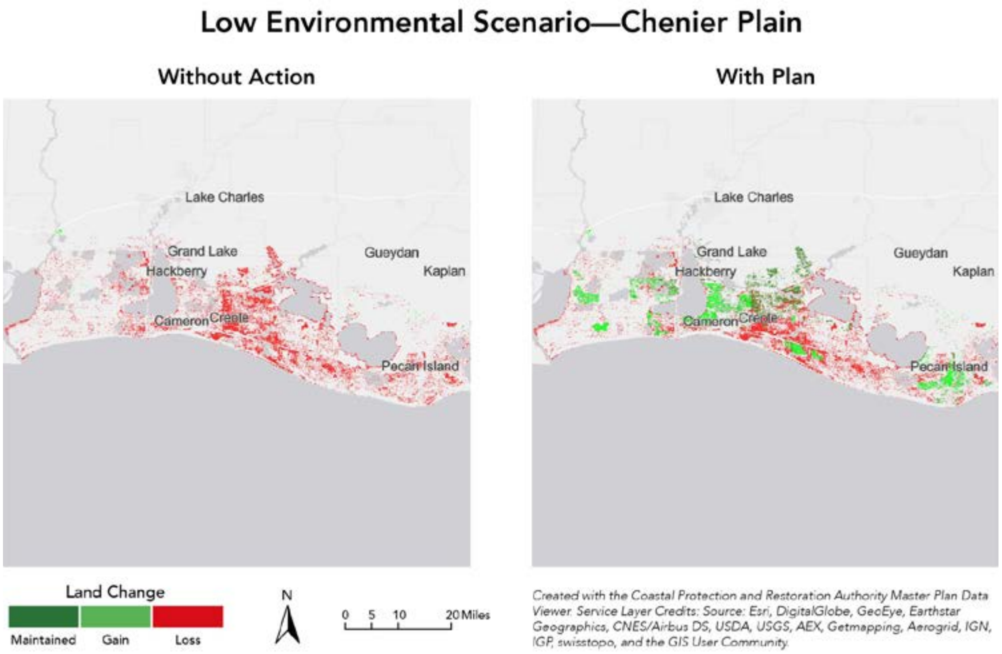

Figure 20. *Land lost, gained and maintained after fifty years in the Chenier Plain, with and without the restoration projects included in the 2017 Coastal Master Plan.*

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Vision

Sustaining the Chenier Plain will be challenging because it is stranded from supplies of sediments that built it in the first place. It was largely built when the large, undammed river was discharging nearby and Gulf levels were stable. Neither of which conditions now exist. While mud from the Atchafalaya river plume is building up along its eastern Gulf shorelines, shorelines along the rest of the plain are eroding. More importantly, channelization and hydrologic modifications have greatly hastened the deterioration of the Chenier Plain's fragile, freshwater and low salinity landscapes. While saltwater intrusion has been stemmed in many cases, drainage of fresh water running off the uplands is now impeded and contributes to wetland loss through prolonged innundation.

The landscape projections included in the 2017 Coastal Master Plan depict the Chenier Plain nearly obliterated under the High environmental scenario with sea-level rise of 83 cm over fifty years, but for the most part in tact under the Low scenario. I have made the case that the Low scenario's assumption of 43 cm is not likely to be exceeded in that time period, but also that a rise of one meter could occur by the end of this century if global warming is not stabilized. So, yes, I can paint a bountiful vision for a wisely managed Chenier Plain over the next fifty years, but beyond that, the future of this unique enviroment depends heavily on the success of the global society in eliminating its net greenhouse gas emissions. This presents a troubling contradiction to the expansion of crude oil and liquified natural gas export facilities in both the Sabine and Calcasieu lakes, which also drive demand for deeper channels that exacerbate saltwater intrusion.

Fundamental to the rehabilitation of the Chenier Plain, the longevity has to be prolonged, along with the repair of the hydrologic disfunctions caused by channelization, marsh mismanagement, and agricultural drainage. This is not a straightforward task, especially in a broad and forward-looking context in which sea-level will be rising and agricultural and other land uses in the watershed will be changing. Hydrologic rehabilitaton will also determine the effectiveness, siting, and design of the many marsh creation projects that dominate the current Coastal Master Plain for the Chenier Plain, estimated to cost over $6 billion just for projects planned after the first decade (Table 7).

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With these thoughts in mind, I suggest the following further considerations for protection and restoration planning for the Chenier Plain:

- **Refine and employ hydrologic models to guide optimal management of water exchanges and flows**. Managing water levels to neither excessively flood nor drain wetlands and to restrain saltwater intrusion and maintain tolerable salinity is a very complex undertaking. Effective controls are required of tidal incursions, including those that could capture sediments from the coastal mudstream, and of freshwater drainage from the Chenier Plain and its watershed. More sophisticated but realistic numerical models, coupled with near-real-time monitoring, could be used to guide smart operational systems.

- **Enhance the capacity for regulated drainage of fresh water from the coastal basins**. Fresh water is both a precious commodity for sustaining the Chenier Plain, especially during droughts, as well as a threat when there is too much. Water draining from southwestern Louisiana and released from large reservoirs in the Sabine River basin results in prolonged inundation of wetlands. As relative sea level rises, the water level gradients to the Gulf decrease, compounding the presently inadequate drainage capacity. Coastal planning should be effectively integrated with the Louisiana Watershed Initiative,[126] which aims to mitigate future flood risks, to include a scheme for providing optimal water resources for the coast.

- **Develop a scheme for transgression of wetlands into agricultural lands**. As relative sea-level continues to rise and accelerate, the freshwater wetlands along the northern edge of the Chenier Plain will spread inland. Unlike many parts of the Mississippi Deltaic Plan, there is a place for them to do so, if allowed. Much of this land is in agriculture, particularly in water-intensive rice cultivation. Because of the sea-level transgression that has been taking place, many rice farmers already confront problems related to saltwater intrusion into wells and to drainage. These problems will only become worse. Obviously there are issues related to property rights and the agricultural economy that will have to be addressed in the development of a rational scheme for retreat.

AN ACHIEVABLE COAST OVER FIFTY YEARS

From a Higher Altitude.

In developing this fifty-year vision for the Louisiana coast, I elected to take a coastal basin-by-basin approach, with focused considerations of each of the six basins, from the Pontchartrain to the Chenier Plain. This is because the circumstances in terms of geology, river influence, and human habitation and use, differ among them in ways that significantly affect their sustainability and the options for rehabilitation. Some basins have been subsiding and deteriorating faster than others while some others can be reconnected to the Mississippi or Atchafalaya rivers more readily. Treatment by basin also allows the integration of various restoration measures — such as sediment diversions, maintenance of barrier islands, and marsh creation — within the context of a specific coastal landscape. In this concluding section, I try to bring the discussions by basin together with an even higher altitude vision for coast.

The future of coastal Louisiana will be determined by the progression of relative sea-level rise, freshwater inflows along with the sediments and other materials they carry, and our ability to adjust the landscape to enhance its longevity and the protection and productivity it provides. Humans can moderate relative sea-level rise regionally by avoiding actions that accelerate natural subsidence and globally by stabilizing Earth's temperature. Freshwater, sediment, and nutrient inflows will be affected by how we manage water and use land throughout the vast river basins and how we distribute outflows while addressing the competing objectives of flood protection, navigation, and sustenance of the landscape. Louisiana's coastal planning fundamentally involves the effective distribution of these flows, but also adjustments to maintain a reasonable stable boundary with the Gulf of Mexico, important landscape features within the coastal zone, and to enhance the longevity of intertidal wetlands.

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Bounded Optimism.

As I stated in the introduction, I purposefully set out to create an optimistic vision, one that assumes all of the most prudent and effective choices were made in restoration, protection, and sustainable societal actions. Yet, this vision has to recognize reality. Net land loss will continue over most regions of coastal Louisiana over the coming fifty years. For the reasons I have provided in this report, I think that the 2017 Coastal Master Plan projections of land loss under the scenario of Low environmental change over the next fifty years (with a rise of Gulf of Mexico waters of 43 cm, or 17 inches) likely represent the worst case. However, this does not mean that coastal land loss does not present a crisis. Timely actions are still needed but restoration measures can be more effective under this slower pace of sea-level rise. At least over the coming fifty years, it is possible to maintain the basic integrity of Louisiana's coastal landscapes, take steps that will help sustain it over the longer term, and even enhance its productivity and value.

Few if any of these prudent and effective choices I refer to will be straightforward and easy. They will require sound technical guidance, appropriate resources, and strong societal and political will. They will require determining how we can protect the places that people live and take steps that may be viewed as threats. They will require heeding the admonition of Lieutenant General Russell Honoré, Louisiana native and hero of Hurricane Katrina rescue, to "don't get stuck on stupid."

In doing research for this report, several prominent Louisiana scientists who have contributed significantly and tirelessly to understanding and addressing the coastal crisis confided that they were not optimistic that society would make those prudent and effective choices because of lack of public acceptance, special interests, or costs. In particular, there is deep skepticism among my Louisiana colleagues about whether global society will act sufficiently and quickly enough to eliminate the emissions of heat-trapping gases that would presage a catastrophic rise in sea level later this century and beyond. They are almost fatalistic about this. I am not, so I am focusing many of my late-career endeavors to do what I can do to affect the reduction in emissions, rather than just adapting to a future that becomes increasingly unmanageable.

Limiting Climate Change is Crucial.

Earlier in this report, I made the case based on current science that stabilizing global heating to less than 2°C above preindustrial levels during this century is necessary to have a reasonable chance of avoiding sea-level rise that would permanently inundate most of the coastal zone of Louisiana sometime early in the next century. International commitments to reduce greenhouse gas emissions sufficient to avoid such dangerous planetary heating have been forged and global and national awareness is ever increasing. I am confident that the hesitancy in our own nation will soon be overcome. Steps that will be taken to reduce and eliminate emissions will be picking up pace and will involve Louisiana whether its citizens, businesses, and political leaders are ready or not. Rather than reject the transition that will eventually take place, Louisiana could instead play a role in the innovative and efficient use of its valuable hydrocarbon resources during this transition. Over the same fifty years covered by the next Coastal Master Plan, the state could also be actively planning an economic and social future as fossil-fuel production and manufacture declines in importance to the state. Because human-induced climate change poses such an existential threat to their state, Louisiana's leaders could, much like leaders of Tuvalu, Kiribati, the Solomons Islands, and other Pacific island nation states, become global advocates for action to limit climate change.

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A Different Working Coast.

Proponents of coastal protection and restoration in Louisiana proudly extoll the fact that their coast is a "working coast," providing many benefits to the nation in form of seafood, energy, and maritime commerce, not just some nature reserve or tourist attraction. While that characterization does not, in my experience, always compel the hoped-for sympathy outside of the Gulf region, it is nonetheless true and important. However, the nature of that work will change; indeed, it must if the coast can be sustained. Oil and gas production in the coastal zone itself has greatly declined and will decline even further. Even offshore production, now at a peak, will decline and could be faced with requirements to strand discovered assets. What role, if any, will oil and gas transshipment facilities, some built for imports and now used for exports, play? As discussed for the Barataria Basin, could infrastructure to support exploration and production be repurposed for sequestering carbon dioxide in deep repositories? Opportunities to produce renewable energy for electricity not only for homes and buildings, but also for industry and transportation, will be explored and developed. They could include offshore wind turbines or solar arrays in the vast coastal zone.

Changes in the work of the coast will go far beyond energy production. Motors of all types will be electrified, affecting the operations of pumps, dredges and vessels of all kind, and thus the expanding restoration industry. Seafood production will shift from hunter-gather modes, such as trawling and dredging, more towards cultivation. Wildlife conservation will adapt to habitat modifications and to changes in stocks and migration patterns resulting from the changing climate. As discussed under the Birdsfoot Delta, one of the most significant adjustments in the work done along the coast will be determined by how the Corps of Engineers will maintain deep-draft navigation into the lower river, which will be affected by deterioration of the delta, energy transformations in global shipping, and the dynamics of world trade. My point is that while we plan for coastal protection and restoration over the next fifty years, it would be foolish to assume that the work done within the coastal zone will remain the same as it has been. Rather, for the reasons mentioned, it is likely to change greatly.

Managing MARB as a System.

Declines in the sediment loads supplied to lower Mississippi and Atchafalaya rivers, nutrient pollution fueling a Dead Zone that can be as large as New Jersey, and the increases in river flooding not caused by greater precipitation but by land uses and channelization are just three of the compelling signs that the future of the coastal Louisiana is challenged by human activities throughout the Mississippi-Atchafalaya River Basin (MARB). While these are outside of the control of Louisiana, there is a clear national need for both analysis and management of the MARB as a system, including future changes in navigation and climate. Yet, attention is generally focused issue-by-issue (nutrient pollution vs. sediment supply) or segment-by-segment (upper basin flooding vs. lower river flood management or barge transportation vs. deep-draft channel maintenance). Whether as the beneficiary or victim of activities within the basin, Louisiana is in a unique position and has every legitimacy to be the advocate and catalyst for managing the MARB as a system.

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Sustaining Bountiful Resources.

The Pelican State, Sportsmen's Paradise, Birdwatchers' Mecca, or the Fertile Fisheries Crescent, such references highlight the exceptional bounty of Louisiana's living resources. Beyond maintaining geography and protecting coastal residents, rehabilitating Louisiana's wetlands and estuaries is also crucial for sustaining these bountiful resources. However, it would be a mistake to view these resources in a traditional or static sense. Rather, how we produce and enjoy these resources will also evolve. Oysters once created massive reefs along the coast. As a result of environmental changes and depletion of stocks and shells, dredging of oysters off the bottom both in seed grounds and on leased bottoms is less productive. Production will shift to rely more on oyster cultivation, as it has already done just about every other place in the world. Similarly, because of global competition and costs, shrimp-trawling efforts have been reduced. Alternate harvest techniques are less costly and lessen the impacts from bottom disturbance and bycatch. River diversions fundamentally needed to sustain the coast will cause shifts in where oysters and shrimp grow and reproduce and various fish species are caught, but could also make room for crawfish and other freshwater-dependent resources. My broader point is that, rather than seeing only the disruptive effects of coastal rehabilitation, we should also seek and develop opportunities to enhance seafood production, recreation, ecotourism, and learning that take advantage of the evolutionary changes in these activities. The objective should be to increase the value of the bountiful living resources.

My bounded optimism about the future of the Gulf Coast of Louisiana is undoubtedly influenced by my heritage and heartfelt feelings about this special place where I grew up and later lived and worked. However, I have developed my vision using my head with the knowledge, objectivity, and wisdom I have managed to accumulate throughout the years as a scientist. I hope it is useful.

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