Climate Change and the Resilience of New Orleans: the Adaptation of Deltaic Urban Form

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Executive Summary

Human populations worldwide continue to populate coastal areas that are vulnerable to the near and long-term effects of climate change. New Orleans, Louisiana, USA, is like many historic deltaic cities around the world, a place sited on vulnerable ground that exploited the interface of land and water at a time when waterborne transportation accounted for nearly all long-distance human movement and trade. Modern New Orleans is located on a subsiding deltaic landscape and is surrounded by a rapidly eroding coast and rising seas. Louisiana leads the nation in terms of the number of coastal wetland acres lost, experiencing up to 80% of the nation's loss due to anthropogenic and natural causes, including sea-level rise and hurricanes, exacerbated by climate change. This situation is not unlike many other deltaic and coastal settlements, and, thus offers lessons, experiences, technologies, and test beds for human coastal environments worldwide.

This paper focuses on emergent trends and ecosystem "shocks", including climate change and hurricanes, along with resultant policies and practice that represent ecosystem adaptation, social-ecological learning, adaptive land use, mitigation, and governance. The role of urban form in adapting to and mitigating global warming will be explicitly addressed. A review of current structural and non-structural urban and coastal land use challenges and opportunities, with a special focus on the integrated New Orleans and coastal Louisiana ecosystems, will be of particular value to urban planners and local institutions dealing with climate change at the metropolitan scale.

This paper cuts across all five of the URS research clusters summarized in the URS2009 Concept Note, with a particular emphasis on Cluster 3 (Role of Institutions, Governance, and Urban Planning). The foundation for analysis includes the flood advisories established by the Federal Emergency Management Agency (FEMA) after Hurricane Katrina, the proposed resettlement and land use proposals developed through the Unified New Orleans Plan (UNOP) and other relevant urban/regional plans, the recent investments through the Louisiana Recovery Authority in targeted reinvestment areas established by New Orleans' Office of Recovery and Development Administration (ORDA), the Comprehensive Master Plan for New Orleans currently under development, as well as the status of other recommended flood risk mitigation and adaptation activities (e.g., land swaps, voluntary structural elevations).

Financial mechanisms to reduce risk and maximize conservation and restoration that are examined include easements and conservation and mitigation trust funds that would allow the State or another third party to acquire fee ownership or surface rights to high-risk lands or acquire permanent conservation easements. Given the prevalence of private property ownership in coastal Louisiana, this would allow potential sellers the option for retention of underlying mineral rights (through legal severance of surface and underlying rights) and, thus, enhance the potential for voluntary relocation to less vulnerable areas. There are precedents of success in this approach with Louisiana's coastal restoration efforts. For

example, the State can allow a landowner access to property to which the State owns surface rights for private oil & gas exploration purposes with the caveat that it be maintained and closed in a manner that does not disturb natural and built elements of the conservation or restoration intent.

Areas of open water in Louisiana's coastal zone also present interesting land policy opportunities in terms of restoration and conservation. State claimed "water bottoms" in Louisiana include all waterways (e.g., bays, bayous, rivers, etc.) that were susceptible of commercial navigation at the time of statehood, in 1812. In addition, in terms of former coastal wetland areas already degraded and converted to open water, the State of Louisiana sometimes acquires servitudes of these water bottoms for the construction of channels and other structures, which may include rights of public navigation. Similar to the legal severance indicated above, this pre-existing servitude option could be utilized for the State to access water bottoms "created" through wetland degradation for the purpose of restoration without severance of mineral rights of a private landowner who has legal ownership of the former land.

Land policy interventions that are examined extend to the coordination and expediting of restoration and protective measures for critical landforms, including the urbanized metropolitan area, bays, shorelines, and peninsulas of urbanized and rural areas of the southeast deltaic plain of Louisiana, which includes New Orleans. Recommended approaches should broadly address practices that would promote sustainable development, including restoration of large-scale natural ecosystem processes, accepted smart growth principles, and the ways in which urban management can support the resilience of cities in the face of climate change.

New Orleans, like many urban centers worldwide, has to date relied more heavily on adaptation, including structural improvements, than mitigation measures in response to climate change and increased vulnerability to storm and flooding events. Mitigation measures including increased greenhouse gas (GHG) sequestration through wetland creation, decreased GHG emissions from oil and gas industry, and increased investment in renewable energy, are gaining greater support on local and regional levels and, thus, offer opportunities for increased mitigation policies and practices. The New Orleans and coastal Louisiana case study offers information that can inform international case studies, including those in the developing world, particularly historic, vulnerable port cities and deltaic systems which are explored in this paper.

Introduction

Coastal Louisiana and New Orleans

The destruction and vulnerability of wetlands has reached a critical level worldwide. Over the last 200 years, wetlands in the United States have been drained, dredged, filled, leveled, and flooded for urban, agricultural, and residential development. Because of these activities, the 220 million acres of wetlands that once existed in the contiguous U.S. have been reduced to about 103 million acres (1). These losses are important because wetlands are among the most highly productive ecosystems on Earth, and provide a variety of economically important products and services (2). Scientists have recognized the need to restore or replace lost wetlands. Until recently, most wetland restoration efforts were relatively small, but a few large-scale restoration efforts (50,000 acres and larger) have been implemented.

Nowhere in the United States are wetland losses greater than in Louisiana. Louisiana's coastal zone was formed by sediments deposited during a series of 16 major Mississippi River deltaic episodes over the past 7,000 years, creating a region of coastal wetlands covering 3.3 million acres of the state (3-5). These wetlands represent 30% of the coastal wetlands in the contiguous U.S., but are experiencing 90% of the coastal wetland loss (6-8) as shown in Figure 1. The causes of this wetland loss include cumulative natural and human-induced impacts (7, 9-14). Beginning in the eighteenth century and accelerating after the record flood of 1927, the construction of artificial levee systems has eliminated the overbank contribution of sediment as a result of flood flows from the Mississippi River to Southeastern Louisiana (4, 15). In addition, during the nineteenth and twentieth centuries, navigation channel dredging, oil and gas exploration and production, land reclamation, and the construction of commercial and industrial facilities further damaged the coastal region in terms of primary and secondary wetland losses. These activities have reduced new accretion, reduced freshwater inflow, increased saltwater intrusion, increased wave energies on fragile interior marsh substrate, and destroyed emergent vegetation which would otherwise bind sediments and produce organic matter. Projecting the current land loss rate, by the year 2050 Louisiana will have lost more than one million acres of coastal wetlands, an area larger than the Sate of Delaware (7, 16). In addition, the Gulf of Mexico will continue to advance inland as much as 33 miles during this period, transforming previously productive wetlands into open water and leaving major towns and cities, such as New Orleans and Houma, exposed to open marine forces of the Gulf of Mexico (6, 11, 17, 18).

If the coastal land loss trend continues, Louisiana will sustain major economic and social losses including: (1) damages, control costs, and insurance claims from floods and hurricanes; (2) oil and gas infrastructure; (3) private land and residences; (4) commercial seafood production; (5) commercial hunting and trapping; (6) recreational hunting and fishing; (7) shipping; (8) channel and river maintenance; (9) drinking water; (10) water quality improvements; and (11) employment. When one accounts for functional values, infrastructural investments, and biologic productivity, Louisiana's coastal wetlands value exceeds $100 billion dollars (6, 7). These resources provide more fishery landings than any other coterminous U.S. state (6, 19), the largest fur harvest in the U.S. (6, 20), 21% of the nation's natural gas supply (6, 7), and protection for waterborne cargoes representing 25% of the nation's total exported commodities (6). Since many of these benefits and services are of national interest, the entire country, not just Louisiana, stands to lose a vast economic resource.

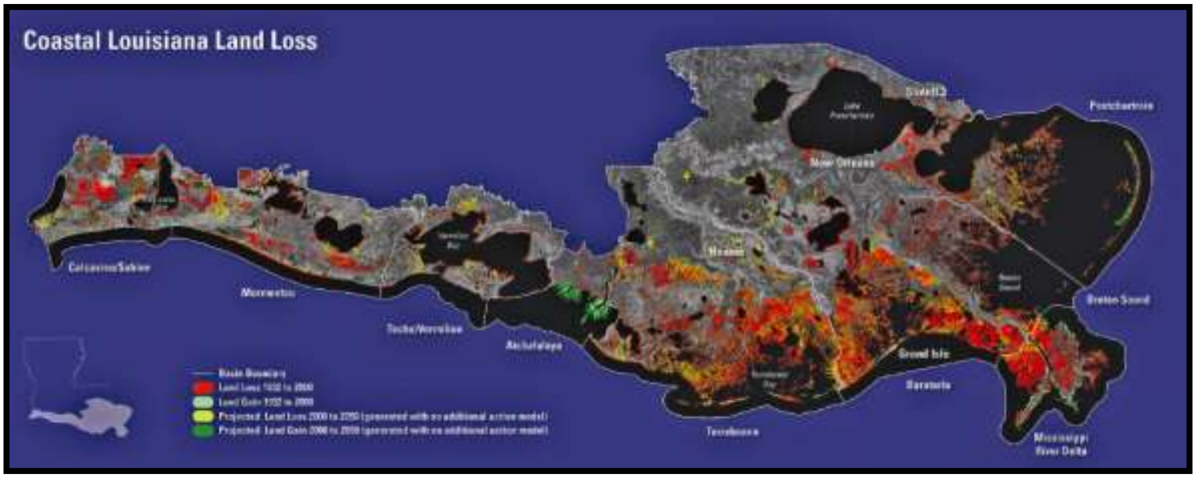


Figure 1. Existing and projected coastal wetland loss and land gain in coastal Louisiana. Historical rates range from between 25-35 square miles per year (21).

For most of the 20th century, New Orleans was sustained paradoxically by enhanced drainage of its delta subsurface along with increased efforts on managing land and water at its perimeter and regional environs (e.g., levees and floodwalls). At the same time, coastal Louisiana was experiencing one of the highest coastal wetland loss rates in the world due to the combined and exacerbating effects of seasonal sediment deprivation from the Mississippi River levees, natural compaction and subsidence, subsidence from oil & gas extraction, sea level rise, and nutria consumption of native wetland vegetation.

The continued loss of wetlands and increased vulnerability of New Orleans was widely discussed and debated among many scientists, engineers, and policy-makers for decades before Hurricane Katrina. Until the 21st century, there was widespread hope that it was still possible to restore and retain the historic wetland footprint of coastal Louisiana. The immensity of the problem was further understood in the early 21st century when Hurricanes Katrina and Rita resulted in approximately 217 square miles of wetland conversion (loss) to water statewide, 117 square miles of which was due to Hurricane Katrina (6). Around metropolitan New Orleans, where the wetlands have historically formed a critical storm surge buffer, the loss of coastal marshes in that particular year was so great that it represented about 50 years of projected wetland loss.

Much has been written and debated about how and where New Orleans residents should repopulate. Many of these opinions, recommendations, reports and papers recommend rebuilding—or relocating-- with the expectation of future flooding, clustering populations in the areas safest from natural disaster, and enhancing natural processes to the greatest extent possible.

Climate Change Implications

The knowledge that climate change-related relative sea level rise of 3-10mm per year (22) in the next 50 years only exacerbates the vulnerability of the New Orleans metropolitan area and the rest of coastal Louisiana and the need to reside in the least vulnerable zones, whenever possible. When one accounts for both subsidence endemic to Louisiana's deltaic coast and global sea level rise, recent estimates of relative sea level rise project the Gulf of Mexico will be anywhere between 2-6 feet higher in the next century (22-24), with a three-foot rise depicted in Figure 2.

Despite these recent and dire predictions, the fact is that, with the exception of populated areas in New Orleans that are below sea level, urban and rural populations of Louisiana's coastal zone have long existed with the natural flooding propensity of the region – with many small towns in the deltaic plain, in particular, prioritizing residential land use along the limited levee areas of bayous and former distributaries of the Mississippi River, so that they can remain above sea level and minimize risks associated with flooding and storm surge. The problem now is that many of the small rural towns in coastal Louisiana that have been able to sustain themselves near sea level for the past century will succumb to sea level rise during the next century and, for those that remain above sea level but on the ridges of the former Mississippi River distributaries no longer have the wetland buffers that have historically protected them from diurnal fluctuations of sea level, intermittent storms, and less frequent but increasingly catastrophic hurricane/tropical storm surges. For many of these towns, residential relocations are inevitable. And, given these relocations, the State has an opportunity to re-examine future land use priorities for the delta plan and implement both structural and non-structural interventions that will maximize the productivity of these systems while minimizing economic and cultural losses and social justice dilemmas.

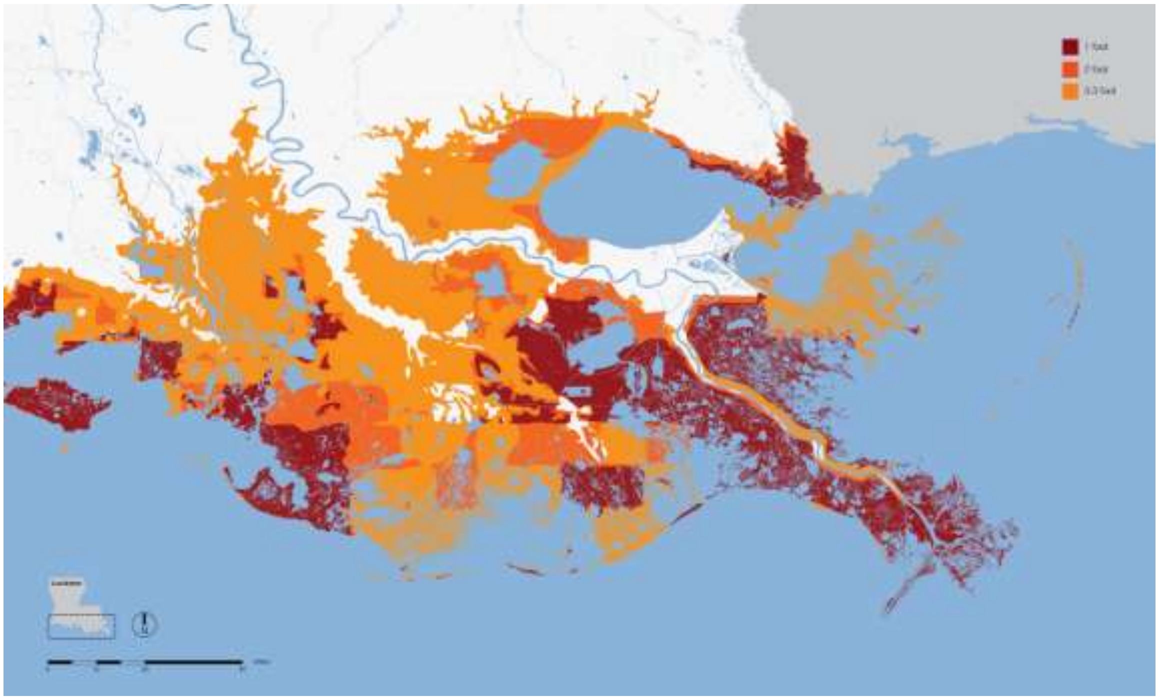


Figure 2. Predicted Louisiana deltaic coastline comparing current extent of coast with 1 to 3.3 feet relative sea level rise predictions by 2100 (graphic by Jonathan Tate).

Hypothesis

Our hypothesis for the case studies evaluated in this paper is as follows:
Maximizing natural ecosystem services of urban systems in the context of regional natural systems with jurisdictional oversight and local governance maximize the ability of these urban systems to adapt to and mitigate the effects of climate change.

Specific crosscutting research questions addressed in this paper have been adapted from the UNESCO Urban Biosphere Programme and include:
1) What are the main social-ecological drivers of change on global, regional, and local scales that impact urban resilience following a disaster and adaptation to climate change?
2) What is the role of ecosystem services and land use transformation in promoting human well-being and safety, reducing vulnerability, and enhancing adaptation and mitigation to climate change?
3) What are the spatial, jurisdictional, and temporal scales required to ensure sustainable governance of urban systems?

We define adaptation and mitigation consistent with the Intergovernmental Panel on Climate Change (IPCC) Fourth Working Group (25):

Adaptation is defined as "initiatives and measures to reduce the vulnerability of natural and human systems against actual or expected climate change effects. Various types of adaptation exist, e.g., anticipatory and reactive, private and public, and autonomous and planned. Examples are raising river or coastal dikes, the substitution of more temperature-shock resistant plants for sensitive ones, etc."

Mitigation is defined as "technological change and substitution that reduces inputs and emissions per unit of output. Although several social, economic and technological policies would produce an emission reduction, with respect to climate change, mitigation means implementing policies to reduce Green House Gas (GHG) emissions and enhance sinks."

Methodology

The methodology for our analysis is one that is a synthetic descriptive assessment of large-scale ecosystem restoration, flood protection, jurisdictional advocacy and oversight, and land policies that promote adaptation and mitigation of New Orleans and its contextual regional ecosystem. Given the nascent nature of New Orleans' recovery from Hurricane Katrina and coastal master plan implementation, our primary sources of information are peer-reviewed when available, and from more popular literature when peer-reviewed or government documents are not available.

Similarly, since many of the most significant indicators of actual implementation of large-scale adaptation and mitigation measures are not yet available, we do not propose a quantitative model linking social and governmental actions with resultant adaptation and mitigation outcomes in this paper. For example, while the Wetland Value Assessment (WVA) methodology behind selection of priority wetland restoration projects is well established (which establishes a common metric of average annualized habitat units (AAHU's)), these assessments are prospective in nature for an average project "lifetime" of twenty years of accrued benefits (7, 16). Furthermore, as discussed later in this paper, the projects that have been determined to have the greatest benefits in terms of large-scale adaptation and mitigation have not yet been implemented due to lack of land policy resolution and funding, so there is no available information yet on the efficacy of these projects.

Our aim in this paper is to provide both a qualitative and quantitative review on the adaptation of urban form to date and extrapolate this information to recommended future land use and other practices and apply this to cities with similar conditions internationally.

Ecosystem and Policy Adaptation

Ecological/Coastal and Urban Form Comparisons

Just as ecologists examine ecological systems in terms of their carrying capacity of keystone species, one can examine urban and other coastal human settlements in terms of their residential carrying capacity. So how do prevailing gradual environmental trends (e.g., relative sea level rise and coastal wetland loss) and acute threats (e.g., hurricanes and flooding) impact urban and rural coastal carrying capacity in Louisiana? The pre-Katrina trend was already one of dramatic historical wetland loss since these regions are the vestiges of former Mississippi River delta lobes and are thus subject to the natural compaction and deterioration of these habitats which has been exacerbated by relative sea level rise and other anthropogenic interventions (e.g., leveeing the Mississippi River, oil and gas exploration, wetland conversions to agriculture and other development). Current plans are to restore as much of this marsh as quickly as possible with a combination of adaptation and mitigation measures including restoration of natural delta building, marsh creation from use of dredged material, water control structures, and hard structures (e.g., dikes and levees)(6, 26, 27). The most interior marshes have been prioritized for conservation and restoration because of the ecological services they provide combined with the storm surge protection they provide to the areas more densely populated, including New Orleans. The most prominent occupied landscape feature currently identified for abandonment is the modern (aka "bird's foot") delta of the Mississippi River. Plans call for this land/marsh material to be utilized for restoration/re-creation of marsh that is located proximate to more densely populated areas.

In a summer 2007 report published by the Tulane/Xavier Center for Bioenvironmental Research (CBR) entitled "Above-Sea-Level New Orleans", under research conducted by Campanella (28), vacant parcels and lots in Orleans parish were assessed such that the incremental increase in residential carrying capacity of New Orleans' above sea level areas could be calculated (beyond those properties already identified as blighted which are under the jurisdiction of the New Orleans Redevelopment Authority). By this estimate, New Orleans could accommodate roughly 300,000 residents above sea level (in 1960 this area held a peak population of 306,000), which are 115,000 more than the 185,000 currently residing above sea level in 2006.

Given the knowledge that deltaic cities like New Orleans will likely experience 3-10mm per year of relative sea level rise in the next 50 years (22), residential development must be prioritized for higher elevations while other ecological (e.g., fisheries) or other provisional (e.g., storm surge protection) ecosystem services can be prioritized for lower elevations. If one is to prioritize areas 1 foot above sea level or higher for residential occupation, for example, available space is limited in coastal Louisiana (Figure 2). While a larger regional levee system in south Louisiana is proposed to provide 100-year protection for about 120,000 rural residents in Louisiana coastal areas (29)**,** thousands of residents are left outside of protection systems. For the Delta lobe (e.g., Boothville-Venice) residents, these lands will ultimately be abandoned with marsh creation (e.g., through beneficial use of dredge material) being prioritized for degraded marsh in Barataria, Terrebonne, and Breton Sound basins, in particular. So far, relocation is based primarily on voluntary actions of residents and this must be re-examined carefully in terms of design, planning, and policy so that vulnerability and litigation are mitigated and/or precluded.

Ecosystem and Land Use Adaptation to Climate Change and Disaster: Chronic Perturbation v. System "Shocks"

The reality is that human populations worldwide will continue to occupy urban areas that are vulnerable to slow variables (e.g., sea level rise, periodic flooding, etc.) and thresholds (e.g., natural disasters) – some of it severe. As a deltaic city, New Orleans has always been situated in a dynamic landscape. After achieving its peak urban population in the early 1960's, in the 40 years before Hurricane Katrina, New Orleans was experiencing trends in multiple slow variable indicators that, in combination, worked to make the city increasingly vulnerable – rising seas, compacting deltaic landscape, population decline, suburban sprawl in below sea level areas, coastal wetland loss, and economic decline (30). In terms of most of these indicators, Hurricane Katrina provided a shock to the New Orleans urban ecosystem that advanced its state half a century into what its future would have been had Hurricane Katrina, or a similar shock, not struck the city at all during that period. Thus, New Orleans provides valuable clues for strategic planning of vulnerable deltaic cities worldwide.

The Gulf of Mexico of the United States has an ongoing history of natural disasters. A major hurricane has hit the Gulf Coast every year since 1994 with 26 named storms and 14 hurricanes in 2005 (18). One of the reasons that Hurricane Katrina caused so much damage is that more than 10 million people currently live in coastal counties and parishes along the Gulf of Mexico – 3.5 times the population that lived in these counties in the 1950's (18). Since Hurricane Katrina, numerous articles and reports have been published that mesh the theoretical underpinnings of coastal science, engineering, architecture, landscape architecture, and urban planning and design, with basic land use and other germane coastal policies to provide recommendations for future planning of the urban/rural form of New Orleans and its surrounding deltaic landscape (6, 26, 31-38). Most of these articles emphasize adaptation as well as mitigation with recognition that adaptive measures are necessary, given the rapid rate of relative sea level rise and increased salinization of freshwater and brackish coastal marsh habitats. In general, recommendations include maximizing incorporation of natural ecological processes in community-based planning and design and minimizing deleterious environmental impacts of built infrastructure elements. While specific recommendations vary between publications, general concepts include:

1) Work with natural hydrology and propensity for flooding whenever possible and encourage a) building on higher ground with increased residential densities in these areas and b) promoting decreased residential densities in lower ground and/or floodable structures in these areas;

2) Restore natural landscapes (e.g., gradual boundaries/topography between deepwater systems and uplands) with natural processes (e.g., Mississippi River diversions) whenever possible for maximum provision of ecosystem services including storm surge and infrastructure protection and ecological services;
3) Implement flood control disaster preparedness landscape interventions on a neighborhood scale in existing urbanized areas and primary transportation corridors (e.g., terraces; polders; drainage enhancements, including bayous, canals and permeable surfaces);
4) Use sustainable architecture practices (e.g., renewable and efficient energy, decreased flooding propensity, materials reuse, etc.) for both renovation of existing structures and construction of new structures; and
5) Maximize community participation and restore social capital (e.g., diversity, environmental justice, and social networks) at every phase of planning, design, and implementation.

One can examine New Orleans urban and contextual natural habitats in terms of the ecosystem services they provide and, thus, aid prioritization of the interventions described above. Current Tulane University CBR social-ecological research in New Orleans, for example, is testing, forensically and prospectively, whether human interventions in post-Katrina New Orleans have altered the ability of this urban and surrounding coastal ecosystem to provide for ecosystem services. The habitats of interest are the urban forest; developed residential, commercial, and public space; and other built and natural forms as they have existed historically through development patterns and in terms of prospective plantings and other future built and natural interventions. Some of the primary core services endemic to the New Orleans urban/coastal system include:

1) Provisioning services:
   a. Foods (e.g., through urban farms)
   b. Energy (e.g., biofuel production in underdeveloped formerly urban flood-prone regions)
   c. Passive stormwater runoff/infiltration (e.g., vegetative interventions/landscape architecture)
   d. Storm surge protection (e.g., from coastal wetland and barrier island habitats)
2) Regulating services:
   a. Carbon sequestration and climate regulation (e.g., urban heat island effect)
   b. Nutrient dispersal (e.g., from fertilizers utilized in the Mississippi River watershed)
3) Supporting services including waste/chemical decomposition/detoxification (e.g., natural attenuation, phytoremediation)
4) Cultural services including recreational services and ecotourism
5) Preserving services including genetic and species diversity of flora and fauna

Direct and indirect feedback loops for selected indicators link up with changes in human interventions that, in turn, relate to local and political perceptions and support for these services. Services can be evaluated in terms of their ability to provide economic resources that benefit the social network of New Orleans' neighborhoods. By addressing the environmental, economic, and social networks of New Orleans, key indicators of sustainability are addressed.

Scale Mismatches in Social-Ecological Planning and Land Use Governance

Systematic planning interventions in coastal Louisiana are further complicated by mismatches between the natural boundaries of the problem at hand and the lack of of the jurisdictions having sufficient regulatory authority or planning capacity. Figure 3 shows 4 of the 5 coastal ecosystem-based planning units (based on combinations of major watersheds/basins) overlaid on parish-governed jurisdictional boundaries (delineated by different colors of adjacent parishes. Jurisdictional mismatches exist because settlement (and subsequent local governance) in coastal Louisiana tend to straddle the high ground on coastal Louisiana bayou and river levees, while the CPRA hydrologic-based planning units are often demarcated by these same waterways – a condition counterintuitive to most water-shed based planning in areas with greater vertical topography.

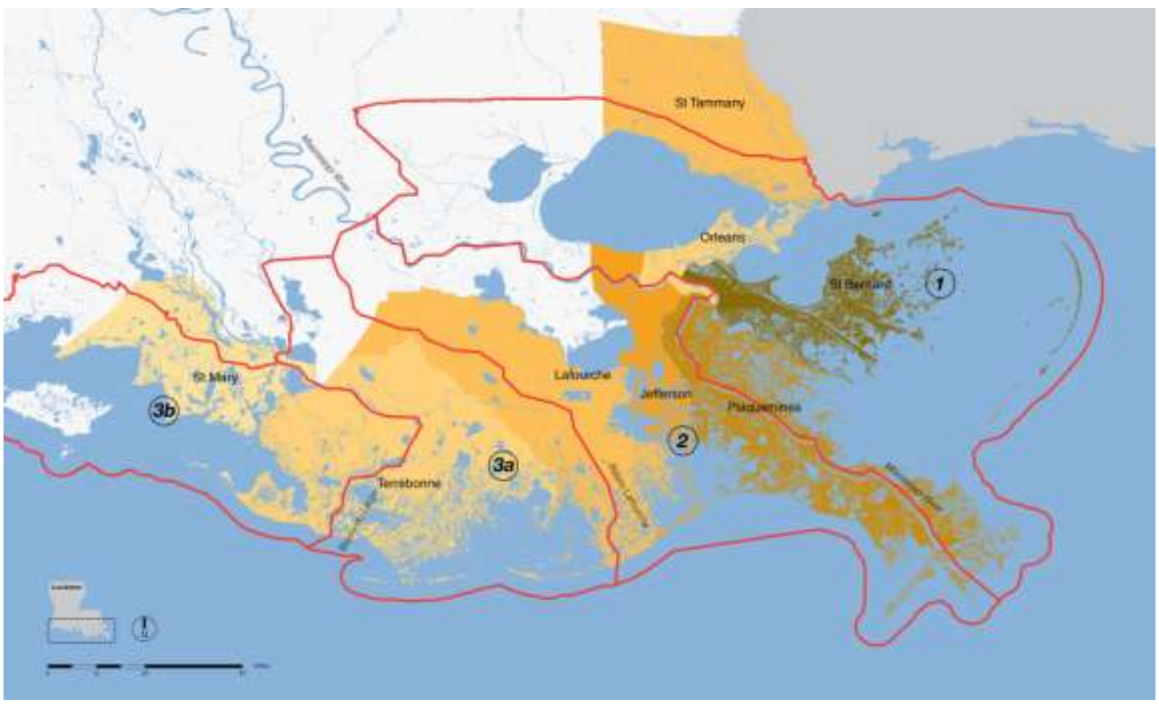
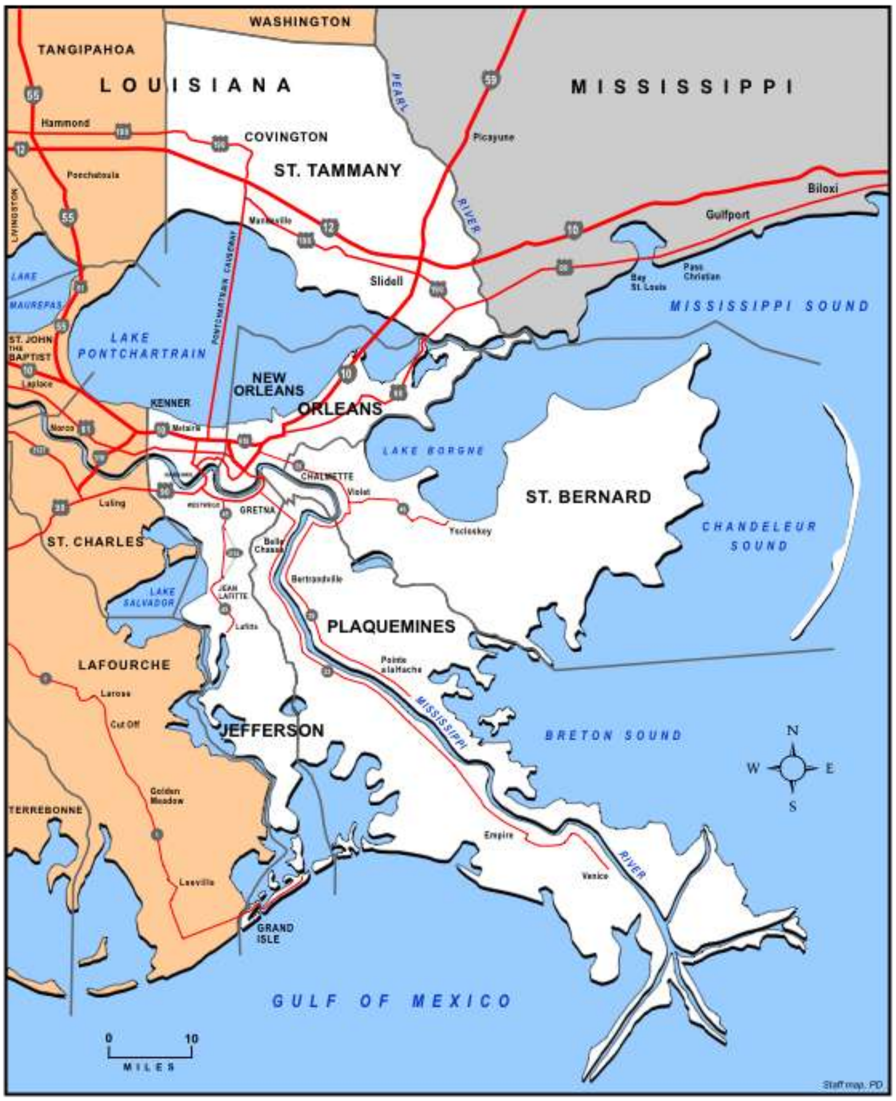


Figure 3. Planning Units in Southeast Louisiana of the State of Louisiana Coastal Protection and Restoration Authority Master Plan (outlined in red). Each unit is a combination of one or more of the 9 major hydrologic basins (watersheds) in coastal Louisiana with Units One, Two, Three-A, and Three-B being largely delineated by the Mississippi River, Bayou Lafourche, and Bayou du Large, respectively (6). (graphic by Jonathan Tate)

In this case, New Orleans as a municipal land use authority has planning and regulatory jurisdiction over only a small fraction of the pertinent area. The official regional planning commission created by the Louisiana legislature for the five parishes around New Orleans (see Figure 4 below) is a policy body without regulatory authority and also falls short in terms of geographic coverage relative to the larger coastal system implicated in planning for coastal ecosystem planning units One and Two (Figure 3). Agencies of the state and federal government are positioned to maintain and protect the larger system and regulate uses that impact coastal waters and wetlands, but may not have the mandate or political will to intervene in land use matters involving private property. These agencies include the Louisiana Office of Coastal Protection and Restoration (OCPR), Louisiana Recovery Agency, Federal Emergency Management Agency (FEMA), the U.S. Environmental Protection Agency, and the U.S. Army Corps of Engineers.



Regional Planning Commission Member-Parishes

Figure 3b. New Orleans Regional Planning Commission planning area (highlighted in white) made up of the 5 Louisiana parishes comprising the New Orleans metropolitan region (http://www.norpc.org/rpc/rpc_brief.html).

The foundation for looking at land use priorities in the New Orleans metropolitan area includes the flood advisories established by the Federal Emergency Management Agency (FEMA) after Hurricane Katrina, the proposed resettlement and land use proposals developed through the Unified New Orleans Plan (UNOP) and other relevant urban/regional plans, the recent investments through the Louisiana Recovery Authority in targeted reinvestment areas established by New Orleans' Office of Recovery and Development Administration (ORDA), the Comprehensive Master Plan for New Orleans currently under development (39), as well as the status of other recommended flood risk mitigation and adaptation activities (e.g., land swaps, and voluntary structural elevations). Our prospective evaluations for this paper include structural and non-structural mechanisms to reduce risk and maximize conservation and restoration and include evaluation of relevant local, regional and international case studies.

Regarding the New Orleans-specific documentation above, Goody Clancy (Boston, MA) has recently been contracted by the City of New Orleans to develop a Comprehensive Master Plan and Zoning Ordinance that, if adopted, will have the force of law. This planning process has established a Sustainable Systems Working Group (SSWG). The research and community outreach process for this effort is due to be complete in Summer 2009 such that "sustainable" recommendations in the Master Plan will contain the following elements (40):

1) Community Facilities and Services
    a. Major components of non-transportation-related infrastructure including water and sewer, electric, gas, and waste disposal
    b. Location, typology and characteristics of key community facilities including schools, libraries, community centers, health clinics, police, fire, courts, and criminal justices
2) Transportation including all roads, bridges, public transit, pedestrian amenities, bicycle, port, and airport infrastructure and systems.
3) Broad aspects of sustainability, environmental quality, and "resilience" as they relate, in particular, to green design, energy efficiency, flood protection, storm water management, hazard mitigation/emergency preparedness, and coastal restoration.

The current draft of the master plan includes a general recommendation that the City of New Orleans create a "climate plan" that addresses how the city should respond to global warming (39). Adaptation and mitigation measures recommended within the next five years to respond to changing global weather patterns include preserving wetlands inside and outside the City's levee system to reduce neighborhood flooding and elevating houses above projected 500-year flood levels (generally three to six feet) following the anticipated 2011 completion of current levee reconstruction efforts. This working group recognizes that the future safety and resilience of New Orleans will depend on "multiple lines of defense" from storm surge and relative sea level rise (17) (Figure 4). This strategy includes coastal wetlands and barriers, levees and pumps, internal drainage improvements, and land use planning and regulation. While the Master Plan/Comprehensive Zoning Ordinance (CZO) project is an opportunity to include this approach to resilience in the vision for New Orleans future, the land use structural and non-structural needs for most of this is outside the jurisdictional boundaries of Orleans parish (as addressed previously) and is subject to a fragmented and uncoordinated land use planning and governing structure for such large-scale implementation. The recent escalating costs of restoration and levee protection along with the decline in the price of domestic oil & gas revenue from Louisiana (which reduces the State's ability to generate matching revenue for coastal restoration and protection projects), is currently stagnating the implementation of the coastal plan.

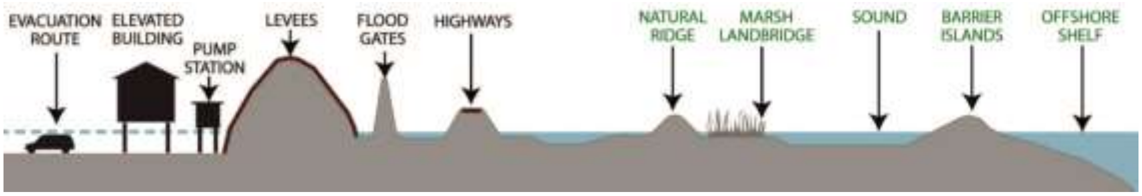


Figure 4. Multiple lines of defense concept (adapted from graphic produced by the Lake Pontchartrain Basin Foundation, from the CPRA Master Plan) (6).

Even with adequate funding and access to land, the construction of more robust levees and wetlands will likely take at least a generation to implement which, in the face of the dramatic wetland loss and relative sea level rise occurring in many parts of deltaic Louisiana may make only 1) the thin ridges flanking the Mississippi River and various bayous in rural coastal Louisiana and 2) dense impounded areas near and below sea level in the City of New Orleans salvageable for human habitation at the end of this century.

The current master planning process in New Orleans parish is dedicated to providing recommendations for sustainable built and natural habitats within the parish boundaries and surrounding parishes. The highest priority for infrastructure is systemic infrastructure plan and agency coordination and investments that improve flood/hurricane resistance. However, a lesser level of support exists to date for investments in high-density areas and a low priority exists to invest in existing flood-resistant areas.

For example, from the public comments received to date, a high priority was placed on adopting the "Dutch system" of water management (as in the "Room for the River" program adopted by the Netherlands government in 2006) (Figure 5) to hold more water in the city with more canals and retention ponds and to repair/improve pumps and levees. However, a low priority has been placed on instituting a comprehensive water management system or to use parks or vacant land for water storage. These seemingly contradictory statements have not yet been resolved into a citywide recommended master plan or strategy(41). However, with maintenance of community engagement, the passive stormwater runoff and retention as well as the aesthetic and recreational ecosystem services of these adaptation measures can lead to greater community support for investments in these interventions.

Figure 5. Prospective rendering of Hoffman Triangle neighborhood in "Mid City" New Orleans which meshes current residential development trends with proposed water management interventions similar to those of the Dutch in low-lying flood prone areas (from "Dutch Dialogues" co-sponsored by Waggonner & Ball Architects and the Ambassador to the Netherlands.

Land Use Challenges and Opportunities

Natural Versus Engineered Systems

The construction cost estimates for proposed urban protection (New Orleans metropolitan area) and regional levee systems (Figure 5) have varied widely and steadily increased since original estimates developed by the U.S. Army Corps of Engineers shortly after Hurricane Katrina. These infrastructure cost uncertainties are the result of changes in construction costs each year due to the fluctuating price in oil, increased concern over stability of existing levee structures, increased costs associated with acquiring suitable building materials (e.g., clay for regional levees), increased costs of likely mitigation (e.g., land buyouts), and other design recommendations based on new predictive models to achieve the 100-year level protection that both these levees are designed to achieve (Table 1). While costs for the Orleans metropolitan levee system have generally ranged from \$3.5 billion - \$9.5 billion (protecting approximately 1 million current residents), the proposed regional coastal levee (protecting approximately 120,000 current residents), originally estimated to cost \$4-5 billion could double, or even increase ten-fold if costs for the Morganza-to-the-Gulf (MtG) Levee system (Figure 6) increase from the original \$882 estimate to \$10.77-11.2 billion, as tentatively proposed by Arcadis Corp – a contractor for the Army Corps of Engineers.

Concern regarding the uncertainties in levee costs are only exacerbated by additional uncertainties regarding their ability to physically protect their respective populations with a 1% probability of flooding in any given year as well as the uncertainties regarding what a 1 in 100-year flooding event really is, given the effects of climate change and other endemic environmental conditions described previously. For example, the recent 500-year flooding events in the Mississippi River Basin came just 15 years after a similar 500-year event in 1993 (42). As shown in Table 1, even if construction costs remain at their original estimates and we aim to protect New Orleans metropolitan residents and Louisiana coastal rural residents, costs will be between:

1) $2,692-$9,500 per resident in the New Orleans metropolitan area and
2) $33,333-$41,667 per resident in the rural areas.

Table 1. Cost projections for repair of New Orleans Metro area and regional coastal levees and corresponding residential populations.

	New Orleans Metro Area	**Southeast Louisiana**	**Reference(s)**
Repair Cost	$3.5-9.5 billion ($7.2 billion)	$4-5 billion [$882 M for Morganza to Gulf (MtG) 72-mile section] $10.7-11.2b for MtG (perhaps lower at $1.4-$1.5b if 30% increase)	(29, 43, 44) (45)
Area Protected	115,616 acres (Orleans Parish)	550,990 acres	(44)
Residential Pop. Protected	1-1.3 million (320,000 in Orleans Parish est.)	120,000	(46)
Construction cost/resident (not including long-term maintenance)	$2,692-$9,500	$33,333-$41,667 $43,333--$54,167 $423,000-$528,750	Uses 2006/2007 estimate above. Assumes 30% cost overrun based on Governor's Office statement (45) Assumes 12.69 multiplier on earlier estimates based on new contingencies (45)

The Louisiana Speaks Regional Plan for south Louisiana developed by Calthorpe Associates (Figure 5) is a recent attempt by the State of Louisiana to apply smart growth and New Urbanist approaches on what is arguably the largest coastal master plan to be developed in modern history in the United States, covering more than 3 million acres of wetland and terrestrial rural and urban systems (26). While this plan demonstrates success in incorporating restoration of coastal wetland, construction of levees, reinvestment in historic communities, investments in new transportation and other infrastructure, and community-based development from tens of thousands of citizens and stakeholders, it implicitly contains a number of challenges:

1) It does not incorporate the latest knowledge of relative sea level rise impacts on Louisiana's deltaic region;
2) It assumes that the integrated coastal wetland restoration projects and large scale levee protection measures will be funded, implemented, and function collectively

to maintain the current level of wetland habit, which is an issue hotly contested and uncertain at best; and

3) It promotes new growth around existing communities that would then warrant the investments in infrastructure described in the plan when, in fact, the population of rural coastal parishes like Plaquemines parish, for example, are continuing to decline, particularly since the hurricanes of the past three years (47).

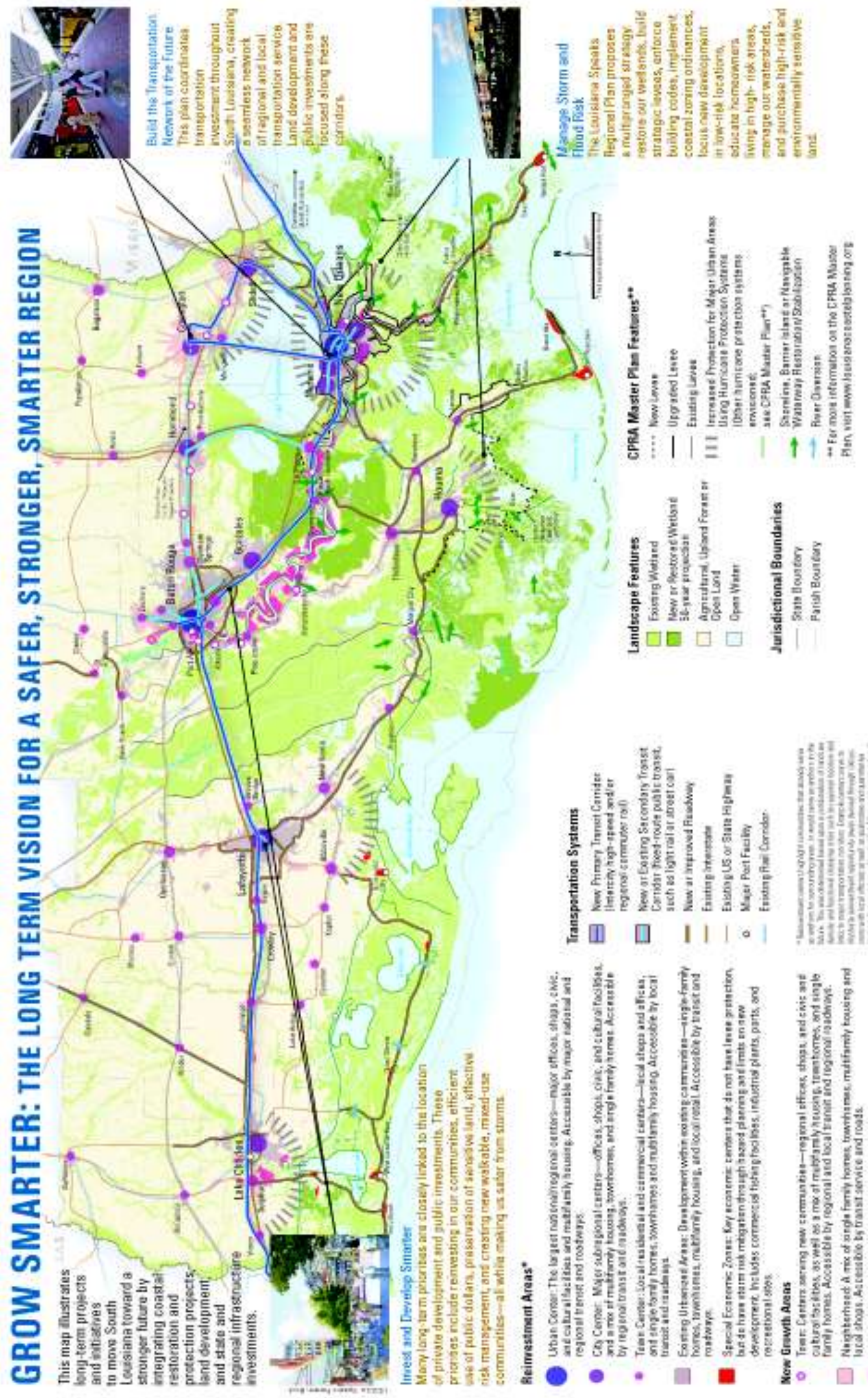


Figure 6. Coastal Louisiana "Smart Growth" map depicting proposed reinvestment and growth areas; transportation and landscape features; and Coastal Planning and Restoration Authority proposed 100-year enhanced levee systems and coastal restoration areas (from (26).

Structural and Non-Structural Measures

How best to prioritize residential, commercial, recreational, and conservation land use in the Gulf Coast region remains an unresolved issue that has been extensively researched and discussed. The Interagency Performance Evaluation Task Force (IPET) was established in October 2005 by the U.S. Army Corps of Engineers to evaluate the performance of the New Orleans hurricane protection system during Hurricane Katrina and to provide assessments of remaining vulnerabilities of the urban and coastal systems (48, 49).

The IPET conducted its evaluations in five areas:

1. Design and status of the hurricane protection system Pre-Katrina;
2. Storm surges and waves generated by Hurricane Katrina;
3. Performance of the hurricane protection system during and after the storm;
4. Social-related consequences of Katrina-related damage; and
5. Risks to New Orleans and the region posed by future tropical storms.

Overarching IPET conclusions regarding structural and non-structural options include (49):

1. Comprehensive flood planning and risk management and risk management for the New Orleans metropolitan region will be based on a combination of structural and nonstructural measures, the latter including relocation options, floodproofing and elevation of structures, and evacuation studies and plans.
2. Better risk communication also must be part of more effective mitigation and an improved state of preparedness.
3. Structural measures such as levees and floodwalls should not be viewed as substitutes or replacements for nonstructural measures, but rather as complementary parts of a multi-tiered hurricane protection solution.

In terms of living with a prevalence of flooding, Kahan, et al. (2006) looked at lessons for the Gulf that could be learned from the experiences of four catastrophic floods in the second half of the 20th century. They suggest that there has been an evolution in thinking about flood management that has taken place in the past 50 years from flood control to integrated water resource management (IWRM). IWRM is a shift from a near-exclusive focus on structural ways of controlling floods (such as building dams, levees and the like) to non-structural flood control systems such as laws and regulations, administrative management and economic levers, and technical measures other than construction (50). The principles of IWRM are

- efficiency to make water resources go as far as possible and achieve the desired level of protection at as little cost as possible;
- equity across different social and economic groups; and
- environmental sustainability, to protect the water resources base and associated eco-systems (50).

The most recent IPET recommendations support a long-term plan for relocation in vulnerable areas, particularly, since the restoration and flood control measures will leave many residents in coastal parishes vulnerable to increased flooding for generations to come. More specifically, IPET supports that the planning and design for upgrading the current hurricane protection system should discourage settlement in areas that are most vulnerable to flooding due to hurricane storm surge. The voluntary relocation of people and neighborhoods of particularly vulnerable areas – with adequate resources designed to improve their safety in less vulnerable areas-should be considered as a viable public policy option (49). When the primary presenting issue is flood protection, non-structural measures are manifested in such examples as zoning to prohibit development of floodplains, flood insurance requirements and limitations, storm surge barriers instead of levees in some places, "land swapping" to relocate residents into lower-risk (e.g., higher or better protected) areas, and even returning some of the land to the water (50).

One of the challenges of non-structural approaches to flood control in the Gulf region is that there are many different actors, including the Federal and state governments, local governments, engineers, the private business sector, and communities. Both within and among these actors, there are differences in preference for different measures. The benefits and costs of various strategies are poorly understood—not only by the actors themselves but also by the people who would analyze various alternatives, particularly given uncertainties in regional economic growth.

Another major issue is the heavy reliance on structural approaches to reduce flood risk versus non-structural (e.g., zoning, planning, easements, etc) measures. With regard to structural approaches, the science and engineering uncertainties regarding environmental trends (e.g., sea level rise and subsidence) and performance of restoration and protection structures (e.g. levees) make the performance of these approaches highly speculative. In addition, uncertainty about the future level and distribution of protection and restoration will continue to affect investments in the built and natural environment and the individual and collective decisions that ultimately shape the scope of reconstruction. Non-structural measures to consider are also not well defined and there is a general lack of awareness of available options, and what the experiences have been when various measures have been attempted in similar and dissimilar situations worldwide. Furthermore, the high reliance on voluntary participation structure-raising and buyouts of vulnerable residents in coastal Louisiana as proposed in the CPRA master plan is of concern (6).

United Houma Nation Case Study of Adaptation and Mitigation

One promising case study of community-based adaptation and mitigation to climate change in Louisiana is that of the United Houma Nation (UHN). The UHN constituents lie primarily outside levee protection systems described above and within the coastal area depicted in Figure 3. Prior to 2005, the 16,000 members of the United Nation were faced with declining livelihoods and displacement due to continued coastal erosion, saltwater intrusion, and the decline of the Barataria-Terrebonne Estuary. Estimates suggest that Hurricanes Katrina and Rita directly affected over 7,000 tribal members with nearly half of these displaced. Hurricane Katrina left over 1,000 tribal members homeless in small settlements through lower Plaquemines, St. Bernard, and Jefferson Parishes and the storm surge from Hurricane Rita inundated lower Lafourche and Terrebonne parishes devastating 4, 000 homes of tribal members (51).

Following the storms, the UHN mobilized to provide immediate relief and support in the form of shelter, food, and necessities to members. With recovery efforts continuing, there is recognition within UHN tribal communities that to survive, members must have their homes elevated or relocate inland to higher ground. Perhaps the greatest concern of the Houma people is community cohesion. While the needs of individual Houma citizens are addressed, the tribe is very concerned that the historic Indian communities are themselves at risk. Indigenous existence is based on a connection between people and place (in this case, a physical and cultural connection to water natural resources) and this is the foundation of all that is indigenous culture. So, for the UHN, the immediate needs must be balanced against the long-term sustainability and survivability of the community. In the near-term, the UHN has begun to develop an emergency response plan with the intent to be certified as a Community Emergency Response Team by the Department of Homeland Security with the hope to have a core of trained members of the Houma nation available to serve as first responders in emergencies who can get back into their communities.

In terms of long-term adaptation to climate change, the UHN is embarking on a relocation strategy that is among the first for coastal communities in the United States to date. The hope for the UHN will be to identify new lands that maintain their connection to water while reducing their vulnerability to periodic and disaster-related flooding through non-structural and structural measures. While the mechanism for land acquisition and assemblage is still being researched, land policy options like land trusts are emerging as the most critical tools (52).

Easements, Mitigation Land Trusts, and Severance of Surface/Mineral Rights

The implementation of land use interventions remain the biggest challenge the State of Louisiana faces on adaptation and mitigation measures, largely due to the high proportion of private property ownership in Louisiana's coastal zone (80%) and the laws that tend to favor private property owners. The amount of science and engineering-related research conducted in the Louisiana coastal zone is vast relative to that often conducted in developing countries. While uncertainty and debate will continue over the ability of large-scale habitat restoration and levee construction to protect urban and rural settlements from the effects of climate change, there is general agreement on the basic natural ecological functions that are key to reduce population vulnerability and maintain healthy, viable communities.

Even with the legal challenges described above, there are several land policy opportunities in coastal Louisiana that can provide for large-scale adaptation and mitigation while preserving the rights of Louisiana's citizenry. As described above, land policy opportunities extend to the coordination and expediting of restoration and protective measures for critical landforms, including bays, shorelines, and peninsulas of urbanized and rural areas of coastal Louisiana. Sustainable development practices include compact development, preservation of open space and natural resources, neighborhood scale storm water management, water efficiency, Brownfield redevelopment, and overall smart growth principles. Recommendations including these were included in the reports submitted to the City of New Orleans governance and the general public prior to 2007 (53). While these recommendations were not initially put into practice by New Orleans' municipal government due to sociopolitical and jurisdictional concerns, among other reasons, the New Orleans Office of Recovery and Development Administration and Coastal Protection and Restoration Authority have subsequently endorsed many of them (6, 27, 39).

Although not yet implemented in Louisiana, "rolling easements" are one viable near-term adaptive land policy in coastal Louisiana. Rolling easements are easements placed along shorelines that prevent property owners from "holding back the sea" but still allow them to develop their land (54). In other words, these easements do not restrict further development or redevelopment of private property until it erodes, such that the government would compensate them for their eroded land if it is to be used for the public good (e.g., for coastal restoration). Although rolling easements do not aggressively address long-term mitigation strategies, they can be a useful near-term strategy that obtains early buy-in from the private land owners for a future public land use with minimal near-term costs and no initial limitations on development of non-eroded land.

One of the more creative financial mechanisms to reduce risk and maximize conservation and restoration is the State Conservation and Mitigation Trust Fund, recommended by the Louisiana Speaks Initiative and supported by the Louisiana Recovery Authority (26). This fund would allow the State to acquire fee ownership or surface rights to high-risk lands or acquire permanent conservation easements. Given the prevalence of private property ownership in coastal Louisiana, this would allow potential sellers the option for retention of underlying mineral rights (through legal severance of surface and underlying rights) and, thus, enhance the potential for voluntary relocation to less vulnerable areas. There are precedents of success in this approach with Louisiana's coastal restoration efforts. For example, the State can allow a landowner access to property to which the State owns surface rights for private oil & gas exploration purposes with the caveat that it be maintained and closed in a manner that does not disturb natural and built elements of the conservation or restoration intent.

Although severance of surface and mineral rights provides for a useful alternative to complete property transfer, these mineral rights certainly complicate the acquisition of land rights in south Louisiana. Given Louisiana's relative abundance of natural gas and oil reserves in its coastal region, the subsurface mineral rights are often more valuable than most other practical surface land use rights, particularly when these properties are not at or adjacent to population centers and/or land ridges or levees. Therefore, the extent to which mineral rights can be retained by a property owner while surface rights are utilized for coastal habitat conservation or restoration enhances the ability to implement these projects. While Louisiana law does not generally allow for permanent severance of surface rights from mineral rights, there have been exceptions in the cases where that severance would promote coastal restoration, protection, or conservation efforts.

Given the high private property ownership rate in coastal Louisiana and that large scale restoration efforts involve a multitude of properties and land owners, even if the majority of land rights are to be acquired through direct purchase, lease, or donation, it is highly likely that, for any given project, there will be entities who refuse to enter into those agreements. For these properties, there will be no other option than eminent domain proceedings. Until recent legislation, Louisiana was the only one of the 50 United States that allowed compensation for "full extent of loss" in the case of eminent domain, which effectively fatally crippled most projects that involved any uncooperative landowner. However, with Constitutional Amendment #4-Act 853 of the 2006 Regular Session (SB 27 by Senator Reggie Dupre), compensation for this expropriation for flood control or coastal restoration is now defined at the fair market value, which is a expediting step towards large-scale restoration at non-prohibitive cost and time-consuming implementation.

Water-Bottom Opportunities

Areas of open water in Louisiana's coastal zone also present interesting land policy opportunities in terms of restoration and conservation and economic activity. State claimed "water bottoms" in Louisiana include all waterways (e.g., bays, bayous, rivers, etc.) that were susceptible of commercial navigation at the time of statehood, in 1812 (55). The Louisiana oyster industry, for example, is a model where public seed grounds on State-owned water bottoms are leased to private parties to jointly promote natural resource management in support of oyster fisheries just as privately-owned water bottoms might be (56). While financial losses in this industry from Hurricane Katrina are estimated to be $44.5 million dockside and $296.5 million retail (57), these financial losses are based on anticipated declines in oyster productivity in the years immediately following disaster and, thus, are near-term opportunity costs as part of a longer-term cyclical level of productivity that can be maintained as long as healthy water-bottom ecosystems are maintained.

In addition, in terms of former coastal wetland areas already degraded and converted to open water, the State of Louisiana sometimes acquires servitudes of these water bottoms for the construction of channels and other structures, which may include rights of public navigation (55). Similar to the legal severance indicated above, this pre-existing servitude option could be utilized for the State to access water bottoms "created" through wetland degradation for the purpose of restoration without severance of mineral rights of a private landowner who has legal ownership of the former land.

Applications of the New Orleans Case Study to the Developing World

The rapidly growing urbanized regions in low-lying coastal settings worldwide face numerous habitat, infrastructure, and non-structural challenges due to sea-level rise in the next century and beyond. However the severity and timing of adverse impacts will vary, depending on endemic conditions including topography; local relative sea-level issues (e.g., with subsidence adding to vulnerability); and the probability of natural disasters, including major storms, tsunamis, and other phenomena.

Within this context, New Orleans is often described as "a canary in the global warming coal mine" (38). Regardless of how this particular city will be rebuilt, New Orleans and its deltaic surroundings offer an unprecedented opportunity to transform both a coastal urban center and its inextricably-linked surrounding natural ecosystem such that natural ecosystem functions and economic goods and services can work together to the best extent possible. New Orleans, in this sense, is an urban and natural laboratory that can only provide new knowledge and understanding once comparable conditions confront larger mega-cities like Shanghai, Tokyo, and New York City and similar regional deltaic forms in the developing world including, but not limited to, the Mekong Delta in Viet Nam and the Ganges/Brahmaputra/Meghna (GBM) river and deltaic systems.

In this paper, we argue that the New Orleans, Louisiana case study can be used as a model system in a developed country that can help inform policy and practice in the developing world. As evidenced by discussions earlier in this paper of the vast amounts of research and planning that has focused on gradual environmental degradation and post-disaster recovery of New Orleans and the Gulf of Mexico coast, coastal Louisiana is a "data-rich" urban and ecological case study that can help inform scientific understanding and land use planning in more "data-poor" developing countries that are experiencing similar global threats. Global climate change does not discriminate between the post-industrialized and developing nations in the world, other than in the level of vulnerability they exhibit and differences in investment capacity and priorities (58).

Of particular relevance are delta regions and their urban center, increasingly vulnerable to SLR and storm surges like Dahka, Bangladesh, and its GBM river system (Figure 7). While the body of peer-reviewed literature related to climate change impacts on the GBM system is expanding in recent years (59-64), a thorough comparative analysis of Louisiana and Bangladesh trends and options for future adaptation has not yet been published.

Coastal Louisiana and Bangladesh are on the same order of magnitude but with Bangladesh exceeding Louisiana in almost every metric of resource abundance and vulnerability. Flows of Mississippi River [600,000 cubic feet per second (cfs) average] are about one-third of the GBM combined flow (1,511,750 cfs average). Whereas Louisiana's coastline is 639 km along the northern Gulf of Mexico, Bangladesh's coastline is 710 km along the Bay of Bengal. (62) The coastal zone of Bangladesh comprises 19 administrative districts encompassing a land area of 47,201 km^2 (Figure 8) compared to Louisiana's 19 coastal parishes with 21,448 km^2 of designated coastal zone area. A three-foot rise in sea levels could inundate nearly 20% of Bangladesh's territory – a percent on scale with that of Louisiana. As mentioned earlier, the 9mm per year of relative sea level rise in Louisiana is greater than the 4-7 mm per year being experienced in Bangladesh's coastal zone. (62).

In terms of human vulnerability, Bangladesh and Louisiana vary depending on whether one is assessing coast-wide or urban exposure. In terms of overall human vulnerability, Bangladesh exceeds Louisiana with 14M people residing in its coastal zone (541 residents per km^2) compared to Louisiana's 2M coastal zone residents (93.3 residents per km^2). However, in terms of urban centers, while both Dhaka and New Orleans are relatively flat, Dhaka's average elevation is 4M (between 1 and 14m) while the vast majority of New Orleans is less than 4M in elevation (65), with 50% of Orleans parish being below sea level, making New Orleans' urban infrastructure even more vulnerable to the near term effects of climate change, in particular relative sea level rise (28).

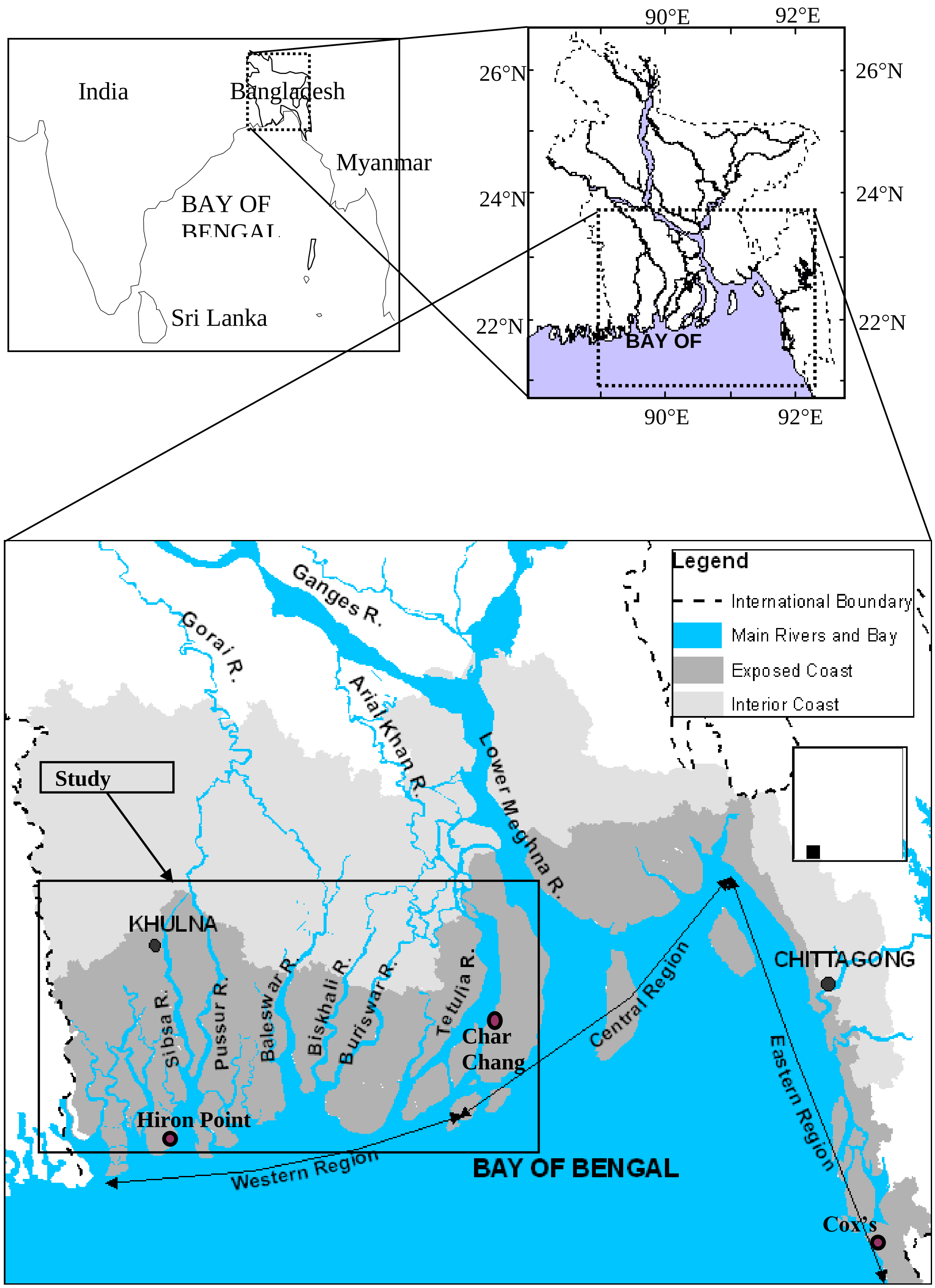


Figure 7. The coastal regions of Bangladesh and major rivers in the western coastal zone (reprinted from Karim and Mimura 2008 (62) with permission from Elsevier).

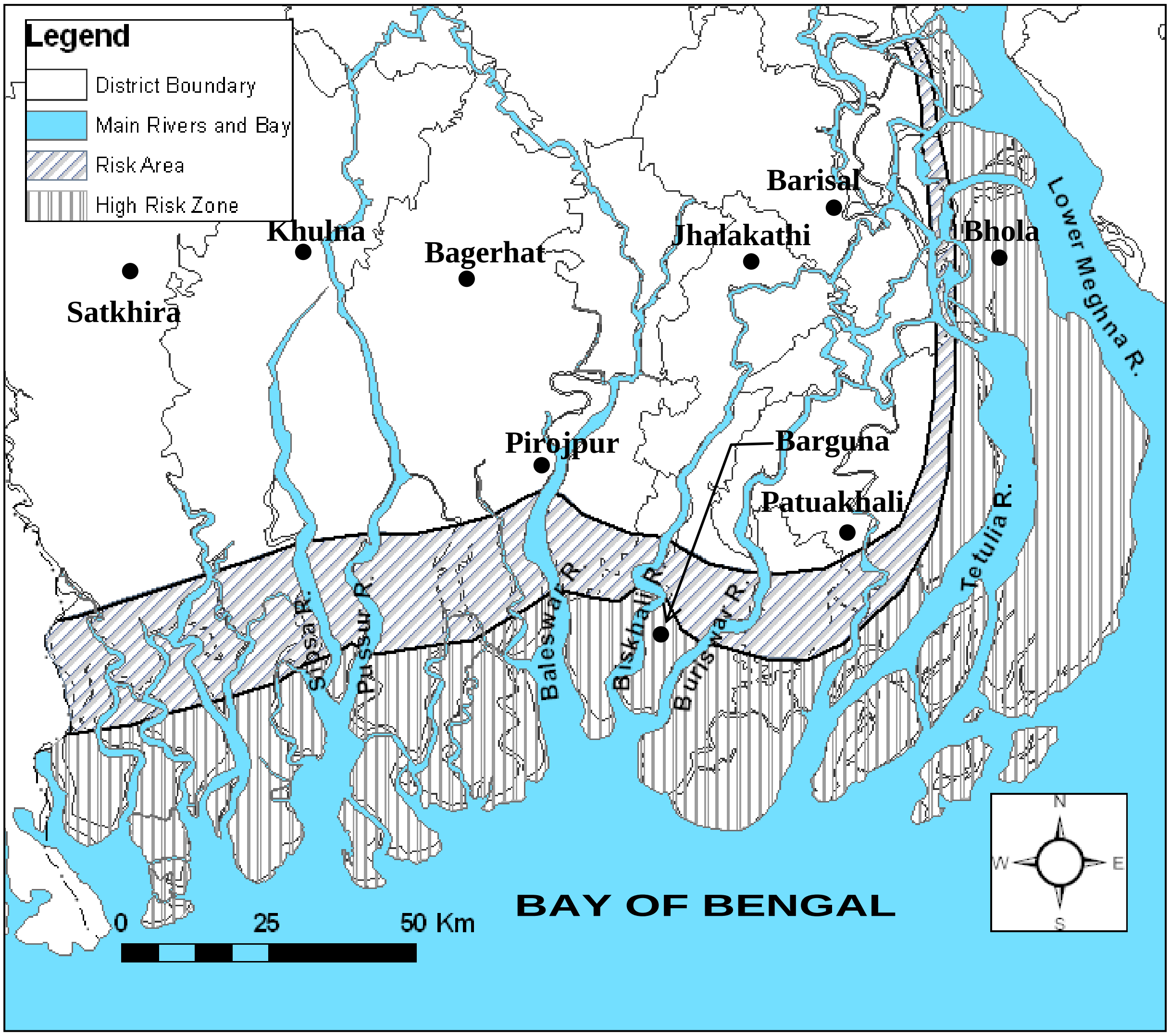


Figure 8. Flood risk map and planning districts for coastal Bangladesh (reprinted from Karim and Mimura 2008 (62) with permission from Elsevier)

Similar comparative practices can be examined in terms of predicting vulnerability to tropical storms with increasing intensity as well as coastal restoration efforts that provide maintenance and restoration of these natural habitats that provide storm surge protection and other ecosystem services. US and Japanese models, for example, have been used to enhance storm surge predictive capacity of Bangladesh in recent years (62, 66). Recently, when cyclone SIDR was forming in the Bay of Bengal on November 12th, 2007, a storm surge modeler, Dr. Hassan Mashriqui, at Louisiana State University used his Gulf Coast "data-rich" model for Louisiana for storm surge prediction for Bangladesh to predict a 12 foot storm surge that would go 20-50 miles inland (67). After communicating this prediction to Bangladesh disaster office (their equivalent of FEMA), they were able to evacuate 3.2 million residents. There were still 3,500 casualties in Bangladesh, but countless lives saved.

Bangladesh has the Coastal Greenbelt Project to slow down surge waves and stabilize coastal land (afforestation project) (61). However, Bangladesh development priorities also include more immediate concerns regarding poverty alleviation: expanding energy access to the poor, increased food production as well as adaptive measures against flooding, coastal erosion, saltwater intrusion, and droughts (58). Thus, as modeled by Hallegatte and Hourcade, developing countries that have a high prevalence of natural disasters (e.g., increased flooding and/or intensity of storms), have significant impediments to long-term economic development since significant GDP losses result from short-term climate change impacts and preclude investments in long-term economic adaptation measures (68).

In this sense, although the general quality of life is higher than developing countries, coastal Louisiana is similarly challenged in terms of investments in long-term adaptation. With four major storm surge-related flooding events in the past three years with hundreds of billions in total damage to the Gulf coast, and more than $150 billion from Hurricane Katrina alone (69), Louisiana may not be able to raise necessary funds to maintain its current level of natural functioning. For example, although the State of Louisiana has increased its restoration and flood control needs with investments at $1.4 billion over next four years from a combination of State and federal sources (70), the current master plan will cost up to $100b (27). Even with these financial limitations, there are lessons learned in terms of Louisiana's Mississippi River freshwater and sediment diversion projects that can be applied to increasingly flood prone delta systems. Case studies have emerged in Beel Bhaina, for example, where water and sediment from the Ganges is now diverted into shallow lands prone to flooding and saltwater intrusion to promote natural wetland accretion and offsets to erosion exacerbated by sea level rise (71). In some places in coastal Bangladesh, sediment-laden river water sped up by a series of man-made dams and channels has actually gained land over the last 35 years, much like the sediment rich waters who's delta-building capacity has been enhanced in Louisiana's Atchafalaya River and Wax Lake deltas. (6, 7)

Conclusions

The fate of New Orleans and other delta cities worldwide is one of increasing vulnerability during the next century and beyond. However, these communities have always been proximate to the natural periodic and catastrophic challenges that face them and can survive as long as they are adaptable and live with these prevailing environmental "slow-change" variables and systemic "shocks". New Orleans and coastal Louisiana are worth restoring and conserving because of the vast tangible and intangible economic and cultural values intrinsic to their ecosystems and communities, including significant population densities in New Orleans and oil & gas and other infrastructure elements in coastal Louisiana. However, based on our recent understanding of the limited ability of Louisiana's coastal wetlands to maintain elevation relative to rising sea level, the future design of the natural and built environment, in order to be sustainable, must also accommodate periodic flooding and increased vulnerability to storm surge. (23) Regional plans need to incorporate both adaptation and mitigation to address the chronic vulnerabilities of this integrated urban and natural system; opportunities exist for creative structural and non-structural interventions and policies described above.

Like most urban centers worldwide, the prevailing practices in place on the urban, regional, and statewide scale have largely relied on adaptive measures. Many opportunities for mitigation remain including 1) increased GHG sequestration through restoration of natural delta processes and wetland creation, 2) GHG regulation of oil & gas industries in the State, and 3) GHG reductions through increased use of renewable energy sources. However, most of these measures remain early in development and are largely voluntary and market-driven on local, state and federal levels. Coastal restoration projects implemented to date are largely smaller in scale and limited in terms of restoring large-scale natural processes.

There is reason for optimism of increased emphasis on mitigation on the urban and coast-wide-scales. On the urban scale, New Orleans' draft master plan is exploring implementation of mitigation measures described above within its jurisdictional boundaries and advocating for them on a regional scale. The State of Louisiana is advocating large-scale coastal restoration and other structural and non-structural adaptation and mitigation measures.

The challenge remaining ahead rests primarily on two issues – limited funding and land use policy implementation on the urban and regional coastal scale. While the State has a long record of rapid implementation of takings of land for the purpose of adaptive measures like levees and pumps, its record on takings or other creative land use options that maintain private landownership for large scale coastal restoration adaptive measures is limited. From this perspective, the science and engineering behind citywide and coast-wide adaptation is well-studied, whereas the legal and financial hurdles require much more investments in decision-making and policy.

The $4 billion initial investment in CPRA-recommended regional levee systems (including the 72-mile Morganza-to-Gulf levee) is an expensive adaptation investment that could, while potentially providing near-term protection from flooding for the Houma urbanized area and its residents, could ultimately lose time, money, ecological services, property and life, if large-scale coastal wetland restoration projects are not also prioritized. Because of the existing and future likely prospects of funding for large-scale levees, coastal restoration, and other flood protection, more institutionalized investments in non-structural measures to protect Louisiana's coastal communities is critical. Specific potential actions that should be examined carefully include:

1) Relocation of thousands of rural inhabitants in the next 10-20 years - particularly those in vulnerable coastal areas outside of the proposed levee protection system (e.g., UHN members described previously).
2) Relocation of up to 120,000 rural (e.g., Buras) and potentially urban (e.g., Houma) inhabitants in areas marginally protected by regional levee systems and increasingly at risk due to sea level rise and disasters in the next 50-75 years.

3) Re-examination of "permanent" versus "temporary" structures for lodging or other longer-term residences in these vulnerable areas so that regional economies can be maintained.
4) Implementation of a State Conservation and Mitigation Trust Fund to promote conservation easements and/or land buyouts and including the option of separation of land, mineral or other rights associated with currently owned private property.

To accomplish this, scientists and engineers must work closely with designers, economists, planning practitioners, community representatives, and political leadership at the conception of demonstration projects and policy development. Lawmakers, planners and architects must not only seek out the best and worst case studies to inform their practice but embrace the scientific and engineering underpinnings for the most sound application. Urban systems like New Orleans can ultimately be more resilient to gradual and catastrophic events, and therefore more sustainable, when their contextual natural and social environments are resilient as well. These inextricable links between the natural and built environments that are core solutions for the New Orleans case study, combined with the wealth of data for this urban/coastal region, will have applications to similar deltaic regions worldwide.

Acronyms

AAHU	Average Annualized Habitat Unit
CBR	Tulane/Xavier Center for Bioenvironmental Research
CFS	Cubic Feet per Second
CPRA	Louisiana Coastal Protection and Restoration Authority
CZO	Comprehensive Zoning Ordinance
FEMA	Federal Emergency Management Agency
GBM	Ganges/Brahmaputra/Meghna
GHG	Green House Gas
IPCC	Intergovernmental Panel on Climate Change
IPET	Interagency Performance Evaluation Task Force
IWRM	Integrated Water Resource Management
LCWRTF	Louisiana Coastal Wetland Restoration Task Force
MA	Massachusetts
MtG	Morganza to Gulf Levee System
OCPR	Louisiana Office of Coastal Protection and Restoration
ORDA	New Orleans Office of Recovery and Development Administration
SSWG	New Orleans Sustainable Systems Working Group
UNOP	Unified New Orleans Plan
UHN	United Houma Nation
URS	Urban Research Symposium
WVA	Wetland Value Assessment

References

1. Watzin MC & Gosselink M (1992) *The Fragile Fringe: Coastal Wetlands of the Continental United States,* (Louisiana Sea Grant College Program BR, LA; U.S. Fish and Wildlife Service, Washington, D.C.; National Oceanic and Atmospheric Administration, Rockville, MD).
2. Costanza R & Farber SC (1985) *The Economic Value of Wetlands in Louisiana: Final Report* (Baton Rouge, LA), (Louisiana Department of Natural Resources CMD).
3. Cowan JJ & Turner R (1988) Modeling Wetland Loss in Coastal Louisiana: Geology, Geography and Human Modifications. *Environmental Management* 12(6):12.
4. Turner RE & Rao CY (1990) Relationships Between Wetland Fragmentation and Recent Hydrologic Changes in a Deltaic Coast. *Estuaries* 13(3):10.
5. Good B, *et al.* (1995) *Louisiana's Major Coastal Navigation Channels* (Baton Rouge, LA), (Louisiana Department of Natural Resources CRD).
6. (CPRA) CPaRAoL (2007) Comprehensive Coastal Protection Master Plan for Louisiana.
7. (LCWCRTF) LCWCaRTF (1993) *Coastal Wetlands Planing, Protection and Restoration Act, Louisiana Coastal Wetlands Restoration Plan: Main Report, Environmental Impact Statement and Appendices* (Baton Rouge, LA), (U.S. Environmental Protection Agency USACoE, U.S. Fish and Wildlife Service, National Marine Fisheries Service, Natural Resources Conservation Service, and Louisiana Department of Natural Resources).
8. Dahl TE (2000) *Status and trends of wetlands in the coterminous United States 1986 to 1997* (U.S. Department of Interior, Washington, DC), (U.S. Department of the Interior FaWS).
9. Boesch DF (1982) *Modifications in Louisiana, causes, consequences and options. Proceedings of a Conference on Coastal Erosion and Wetlands* (Washington, DC), (U.S. Fish and Wildlife Service BSP).
10. Mendelssohn IA, Turner R, & McKee KL (1983) Louisiana's eroding coastal zone; management alternatives. *Journal of Limnology and Society South Africa* 9:13.
11. Titus JG (1986) Greenhouse effect, sea level rise, and coastal zone management. *Coastal Zone Management Journal* 14(3):25.
12. Turner RE & Cahoon DR (1987) *Causes of wetland loss in coastal central Gulf of Mexico, Technical Narrative* (New Orleans, LA), (U.S. Department of the Interior MMS).
13. Day JW & Templet PH (1989) Consequences of seal level rise: implications from the Mississippi Delta. *Coastal Management* 17:7.
14. Duffy WG & Clark D (1989) *Marsh Management in Coastal Louisiana: Effects and issues. Proceedings of a Symposium* (Baton Rouge, LA), (U.S. Fish and Wildlife Service RaDaLDoNR, Coastal Management Division, Biological Report).
15. Kesel RH (1989) The role of the Mississipi River in wetland loss in southeastern Louisiana, U.S.A. *Environmental and Geological Science* 13:11.

16. Meffert DJ, *et al.* (1997) *The 1997 Evaluation Report to the U.S. Congress on the Effectiveness of Louisiana Coastal Wetland Restoration Projects in accordance with the Coastal Wetlands Planning, Protection and Restoration Act, Public Law 101-646, Title III or "Breaux Act"* (Louisiana Department of Natural Resources, Baton Rouge, LA), (Force LCWCaRT).
17. Lopez JA (2005) *The Multiple Lines of Defense Strategy to Sustain Louisiana's Coast* (New Orleans, LA), (Foundation LPB).
18. NCMGCEC (2006) Taking a Longer View: Mapping for Sustainable Resilience. ed Constraints NCtMGCE (Regional Plan Association, the University of Texas at Austin, and EDAW), p 12.
19. (USDOC) USDoC (1994) *Fisheries of the United States, 1993. Current Fishery Statistics No. 9300. M. C. Holliday, O'Bannon, B.K., eds.* (Rockville, MD), (National Oceanic and Atmospheric Administration NMFS).
20. Coreil PD (1994) *Wetlands functions and values in Louisiana* (Baton Rouge, LA), (Louisiana State University CES).
21. Barras J, *et al.* (2003) *Historic and predicted coastal Louisiana land changes: 1978-2050* (U.S. Geological Survey, National Wetlands Research Center, Baton Rouge, LA), (Report USGSOF).
22. Tornqvist T, *et al.* (2008) Mississippi Delta subsidence primarily caused by compaction of Holocene strata. *Nature Geoscience* 1(March 2008):4.
23. Day JW & Giosan L (2008) Survive or subside? *Nature Geoscience* 1(March 2008):2.
24. Marshall B (December 14, 2008) Losing Louisiana. Times-Picayune, p 5.
25. IPCC (2007) Climate Change 2007: Synthesis Report, Annex II Glossary. eds Baede APM, van der Linden P, & Verbruggen A), p 30.
26. (LRA) LRA (2007) Louisiana Speaks Regional Plan: Vision and Strategies for Recovery and Growth in South Louisiana. Main Report and Appendices. Baton Rouge, LA).
27. (CPRA) CPaRAoL (2009) *Draft Fiscal Year 2010 Annual Plan: Ecosystem Restoration and Hurricane Protection in Louisiana* (Baton Rouge, LA).
28. Campanella R (2007) Above sea-level New Orleans: the residential capacity of Orleans Parish's Higher Ground. ed Meffert DJ), p 8.
29. Walsh B (April 10, 2007) White House opposes Morganza levee project. The Times Picayune, p 2.
30. Campanella R, Etheridge D, & Meffert DJ (2004) Sustainability, survivability, and the paradox of New Orleans. *Urban Biosphere and Society: Partnership of Cities*, ed Alfsen-Norodom C, B. Lane (Annals of the New York Academy of Sciences, New York, New York), Vol 1023.
31. Laska S & Morrow BH (2006) Social vulnerabilities and Hurricane Katrina: An unnatural disaster in New Orleans. (Translated from English) *Marine Technology Society Journal* 40(4):16-26 (in English).
32. Authority CPaR (2007) *Integrated Ecosystem Restoration and Hurricane Protection: Louisiana's Comprehensive Master Plan for a Sustainable Coast* (Baton Rouge, LA).
33. Lopez J (2007) Status of coastal planning in Louisiana. in *NOGS Log* (New Orleans Geological Society : New Orleans, LA, United States, United States), p 7.

34. Costanza R, Mitsch WJ, & Day JW (2006) Creating a sustainable and desirable New Orleans. (Translated from English) *Ecological Engineering* 26(4):317-320 (in English).
35. Blakely EJ (2007) Urban Planning for Climate Change. *Lincoln Institute of Land Policy Working Paper* (Product Code: WP07EB1):25.
36. Rodiek J (2007) Landscape planning in hazardous zones, lessons from Hurricane Katrina, August 2005. (Translated from English) *Landscape and Urban Planning* 79(1):1-4 (in English).
37. Meffert DJ (2008) The Resilience of New Orleans: Urban and Coastal Adaptation to Disasters and Climate Change. in *Lincoln Institute of Land Policy Working Paper* (Lincoln Institute of Land Policy, Cambridge, MA), p 12.
38. Tornqvist T & Meffert DJ (2008) Sustaining coastal urban ecosystems. *Nature Geoscience* 1(December 2008):3.
39. NOLA (2009) *Draft Executive Summary: New Orleans master plan and comprehensive zoning ordinance* (New Orleans), (Administration CPCaOoRaD).
40. GCA (2008) Sustainable Systems Working Group Draft Goals and Policies. in *New Orleans Master Plan and Comprehensive Zoning Ordinance* (Goody Clancy Architects, New Orleans), p 9.
41. Clancy G (2008) Citywide Forum 3 Small Group Summary Findings. ed Orleans CoN (New Orleans Master Plan and Comprehensive Zoning Ordinance, New Orleans), p 6.
42. Paulson A (June 20, 2008) Floods Engulf Archaic Levee System. The Christian Science Monitor, p 3.
43. (ENS) ENS (March 31, 2006) New Orleans Levee Repair Price Triples. Environmental News Service Newswire, p 5.
44. Jonsson P (Can a "Leaky Levee" Save the Louisiana Coast? The Christian Science Monitor, p 2.
45. Schleifstein M (June 17, 2008) Flood project's cost estimate explodes. The Times-Picayune, p 3.
46. BIMPP/GNOCDC (2008) The Greater New Orleans Index: Tracking Recovery of New Orleans and the Metro Area. ed Center BIMPPGNOCDNew Orleans, LA), p 53.
47. Adelson J (January 2, 2009) Recovery jobs spur metro migration. Times-Picayune, Section Metro, p 2.
48. NAE/NRC (2008) Fourth report of the National Academy of Engeineering/National Research Council Committee on New Orleans regional hurricane protection projects: review of the IPET Volume III. ed Projects CoNORHP (National Academy of Engineering and National Research Council, Washington, DC), p 19.
49. NAE/NRC (2009) The New Orleans Hurricane Protection System: Assessing Pre-Katrina Vulnerability and Improving Mitigation Preparedness. ed Projects CoNORHP (National Academy of Engineering and National Research Council, Washington, DC), p 41.
50. Kahan JP, M. Wu, S. Hajiamiri, D. Knopman (2006) From Flood Control to Integrated Water Resource Management: Lessons for the Gulf Coast from

flooding in other places in the last sixty years. in *RAND Corporation Occasional Paper*, ed Institute RGSP (Rand, Santa Monica, CA), p 46.
51. Yoachim A (2008) How safe, how soon? Executive Framework. (Tulane Institute on Water Resources Law and Policy, New Orleans, LA), p 7.
52. Meffert DJ, Etheridge D, & Tate J (2009) United Houma Nation: draft strategic plan technical document. ed Meffert + Etheridge LNew Orleans, LA), p 20.
53. Urban Design Committee BNOBCB (2006) Report to Mayor Nagin's Bring New Orleans Back Commission: Action Plan for New Orleans. ed Wallace Roberts and Todd; Urban Design P, Sustainability, and Housing SubcommitteesNew Orleans, LA).
54. Emmer RE, Wilkins JG, Schiavinato LC, Davis M, & Wascom M (2007) Hazard mitigation and land use planning in coastal Louisiana: recommendations for the future. ed Program LSGC (Louisiana State University, Baton Rouge, LA), p 68.
55. (SLO) LSLO (2008) State Land Office (SLO): Database. in *State Lands and Water Bottoms*, ed Louisiana Department of Administration SLO (State of Louisiana, Baton Rouge, LA), pp Disclaimers, Metadata, Data Categories, and Downloadable GIS Data.
56. Dyer CL & Leard RL (1994) Folk Management in the Oyster Fishery of the U.S. Gulf of Mexico. *Fok Management in the World's Fisheries*, ed McGoodwin CLDaJR (University Press of Colorado, Niwot, CO), pp 55-89.
57. McGuire T (2006) Louisiana's Oysters, America's Wetlands, and the Storms of 2005. *Amercan Anthropologist* 108(4):692-705.
58. Halsnaes K & Verhagen J (2007) Development based climate change adaptation and mitigation - conceptual issues and lessons learned in studies in developing countries. *Mitigation Adaptation Strat Glob Change* 12:20.
59. Ali A (1999) Climate change impacts and adaptation assessment in Bangladesh. *Climate Research* 12:8.
60. Brouwer R, Akter S, Brander L, & Haque E (2007) Socioeconomic vulnerability and adaptation to environmental risk: a case study of climate change and flooding in Bangladesh. *Society for Risk Analysis* 27(2):14.
61. Erwin KL (2009) Wetlands and global climate change: the role of wetland restoration in a changing world. *Wetlands Ecology Management* 17:14.
62. Karim MF & Mimura N (2008) Impacts of climate change and sea-level rise on cyclonic storm surge floods in Bangladesh. *Global Environmental Change* 18:11.
63. McDougall D (2007) Stemming the tide. in *Ecologist* (Ecologist), p 5.
64. Mirza MMQ, Warrick RA, & Ericksen NJ (2003) The implications of climate change on floods of the Ganges, Brahmaputra and Meghna rivers in Bangladesh. *Climatic Change* 57:32.
65. Lewis D (2009) Strategic Retreat: an adaptation plan for developed coasts susceptible to sea level rise. ed Design HGSo (Harvard Graduate School of Design, Cambridge, MA), p 27.
66. AMS (2008) LSU Warns Bangladesh Ahead of Monstor Cyclone's Storm Surge. *American Meteorological Society* February 2008:1.
67. Society AM (2008) LSU Warns Bangladesh Ahead of Monstor Cyclone's Storm Surge. *American Meteorological Society* February 2008:1.

68. Hallegatte S & Hourcade J (2005) Why economic growth dynamics matter in assessing climate change damages: illustration on exreme events. *Elsevier Science*:25.
69. Hallegatte S (2008) An adaptive regional input-output model and its application to the assessment of the economic cost of Katrina. *Risk Analysis* 28(3):21.
70. Kirkham C (April 19, 2009) Money to restore coast is cresting. The Times-Picayune, Section Front Page, p 2.
71. Sengupta S (March 20, 2009) In Silt, Bangladesh Sees Potential Shield Against Sea Level Rise. New York Times, p 3.