1 INTRODUCTION

Using New Orleans, Louisiana, USA as the departure point, this paper discusses emergent trends of climate change and hurricanes, along with policies and practice representing adaptive land use, mitigation, and governance. The role of urban form in adapting to and mitigating climate change will be addressed, including an emphasis on natural wetland and water "ecostructures". The New Orleans case study offers information that can inform international sites, particularly historic, vulnerable port delta cities.

1.1 Coastal Louisiana and New Orleans

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 and gas extraction, sea level rise, and nutria consumption of native wetland vegetation.

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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. The immensity of the problem was revisited 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 (CPRA 2007). 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 discussions recommend rebuilding — or relocating — with the expectation of future flooding, clustering populations in areas safest from natural disaster, and enhancing natural processes to the greatest extent possible.

The destruction and increased 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. In consequence, the 220 million acres of wetlands that once existed in the contiguous U.S. have been reduced to about 103 million acres (Watzin and Gossling 1992). 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 (Costanza and Farber 1985). 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 (Cowan and Turner 1988; Turner and Rao 1990; Good et al. 1995). These wetlands represent 30% of coastal wetlands in the contiguous U.S. but are experiencing 90% of coastal wetland loss (CPRA 2007; LCWCRTF 1993; Dahl 2000). The causes of this wetland loss include cumulative natural and human-induced impacts (LCWCRTF 1993; Boesch 1982; Mendelssohn 1983; Titus 1986; Turner and Cahoon 1987; Day and Templet 1989; Duffy and Clark 1989). Beginning in the 18th century and accelerating after the record flood of 1927, the construction of artificial levee systems has eliminated the overbank contribution of sediment of flood flows from the Mississippi River to Southeastern Louisiana (Turner and Rao 1990; Kesel 1989). In addition, during the 19th and 20th 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 caused reductions in new accretion and freshwater inflow, led to increases in saltwater intrusion and wave energies on a fragile interior marsh substrate, and destroyed emergent vegetation which would otherwise bind sediments and produce organic matter. By 2050 it is projected that Louisiana will have lost more than one million acres of coastal wetlands, an area larger than the State of Delaware (LCWCRTF 1993; Meffert et al. 1997). 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 (CPRA 2007; Titus 1986; Lopez 2005; NCMGCEC 2006).

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 (CPRA 2007; LCWCRTF 1993). These resources provide more fishery landings than any other coterminous U.S. state (CPRA 2007; USDOC 1994), the largest fur harvest in the U.S. (CPRA 2007; Coreil 1994), 21% of the nation’s natural gas supply (CPRA 2007; LCWCRTF 1993), and protection for waterborne cargoes representing 25% of the nation’s total exported commodities (CPRA 2007). Because many of these benefits and services are of national interest, the entire country, not just Louisiana, stands to lose a vast economic resource.

1.2 Climate Change Implications

With expectations of climate change-related relative sea level rise of 3-10 mm per year in the next 50 years (Törnqvist et al. 2008), the vulnerability of the New Orleans metropolitan area and the rest of coastal Louisiana will only be exacerbated, leading to an increased need for people 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 (Törnqvist et al. 2008; Day and Giosan 2008; Marshall 2008).

Despite these recent and dire predictions, 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, priori-
tizing 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, those that remain above sea level but on the ridges of the former Mississippi River distributaries will 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. Given these relocations, the State has an opportunity to re-examine future land use priorities in 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.

2 THE ECOSTRUCTURE HYPOTHESIS

Specific crosscutting research questions addressed in this paper (adapted from ICLEI — Local Governments for Sustainability Urban Biosphere Programme) are:

1. What are the main ecological drivers of change at the 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?

For purposes of this research, the definitions of adaptation and mitigation are consistent with the Intergovernmental Panel on Climate Change (IPCC) Fourth Working Group (IPCC 2007):

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.”

The hypothesis is that restoring and enhancing ecosystem services (i.e., “ecostructure”) of urban systems in the context of regional natural systems with appropriate jurisdictional oversight and local governance increases the ability of these urban systems to adapt to and mitigate the effects of climate change.

3 METHODOLOGY

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

Since many of the most significant indicators of actual implementation of large-scale adaptation and mitigation measures are not yet available, a quantitative model is not proposed in this paper for linking social and governmental actions with resultant adaptation and mitigation outcomes. Rather, a qualitative review of peer-reviewed, popular, and government reports regarding urban and coastal restoration and planning are synthesized with a particular emphasis on relevance to climate change adaptation and mitigation. For example, while the Wetland Value Assessment (WVA) methodology behind selection of priority wetland restoration projects is well established (providing a common metric of average annualized habitat units (AAHUs), these assessments are prospective in nature for an average project “lifetime” of twenty years of accrued benefits (LCWCRFT 1993; Meffert et al. 1997). 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. It is possible, however, to perform a qualitative review of cumulative expected outcomes.

This paper thus provides a qualitative review on the adaptation of urban form in New Orleans to date, with a particular focus on ecostructural approaches, and extrapolates this information to recommended future land use and other practices that can be applied to cities with similar conditions internationally.
CHAPTER 18

4 ECOSYSTEM AND POLICY ADAPTATION

4.1 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).

With regard to the first crosscutting research question described earlier in this paper, the main ecological driver of enhanced resilience on both regional and local scales is restoration and preservation of coastal wetland habitats. 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 (CPRA 2007; LRA 2007; CPRA 2009). The most interior marshes have been prioritized for conservation and restoration because of the ecological benefits (e.g., habitat for fisheries, support of indigenous plant and animal life) and storm surge protection they provide to the more densely populated areas, including New Orleans, and oil and gas exploration and transportation infrastructure. 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.

Campanella (2007) has assessed vacant parcels and lots in Orleans parish in order to calculate the potential incremental increase in residential carrying capacity of areas above sea level in New Orleans (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 is 115,000 more than the 185,000 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 over the next 50 years (Törnqvist et
al. 2008), residential development should be the priority use for higher elevations, with lower elevations reserved to support fisheries, storm surge protection, and other ecosystem services. If one is to prioritize areas 1 foot above sea level or higher for residential occupation, for example, available space is limited in the deltaic plain of coastal Louisiana to primarily levees and ridges along rivers, bayous and former distributaries of the Mississippi River. 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 (Walsh 2007), 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 with an eye to both vulnerability and litigation exposure.

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

Of necessity, human populations worldwide will continue to occupy urban areas that are vulnerable to the impacts of slow variables (e.g., sea level rise, periodic flooding, etc.) and threshold events (e.g., natural disasters) – some of which will be 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 variables. These natural and socioeconomic indicators, including rising seas, compacting deltaic landscape, population decline, suburban sprawl in below sea level areas, coastal wetland loss, and economic decline (Campanella, Etheridge and Meffert 2004), combined to make the city increasingly vulnerable. 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 that storm, or a similar shock, not struck the city 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 (NCGMCEC 2006). 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 (NCGMCEC 2006). 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 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 (CPRA 2007; LRA 2007; Laska and Morrow 2006; Lopez 2007; Costanza, Mitsch and Day 2006; Blakely 2007; Rodiek 2007; Meffert 2008; Törnqvist and Meffert 2008). Most of these articles emphasize both adaptation and mitigation, recognizing 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 ecostructural processes in community-based planning and design and minimizing deleterious environmental impacts of built infrastructure elements. While specific recommendations vary among 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;

3. Implement flood control, disaster preparedness, and 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 architectural 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.

With regard to the second crosscutting research question described earlier in this paper, 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. Cumulatively, these interventions will increase human well-being and safety, reduce vulnerability, and enhance adaptation and mitigation to climate change. 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
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 recreation 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.

### 4.3 Scale Mismatches in Social-Ecological Planning and Land Use Governance

With regard to the third crosscutting research question described earlier in this paper, the sustainable governance of the urbanized New Orleans metropolitan region must rely on both hard structures (e.g., levees and floodwalls) surrounding the city and the multi-parish enhancement of natural wetland
habitats (e.g., through natural delta building) on a multi-decadal temporal scale. Systematic planning interventions in coastal Louisiana are complicated by mismatches between the natural boundaries of the problem at hand and those of the jurisdictions having the requisite regulatory authority or planning capacity. Figure 1 shows four of the five 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 tends 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 1
Planning Units in Southeast Louisiana of the State’s Coastal Protection and Restoration Authority Master Plan (outlined with solid lines).

Each unit includes one or more of the 9 major hydrologic basins in coastal Louisiana with Units One, Two, Three-A, and Three-B being delineated by the Mississippi River, Bayou Lafourche, and Bayou du Large (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 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 1). 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.

The foundation for examination of 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 (NOLA 2009), and other recommended flood risk adaptation activities (e.g., land swaps and voluntary structural elevations).

Regarding the New Orleans-specific documentation above, Goody Clancy (Boston, MA) was contracted by the City of New Orleans to develop a Comprehensive Master Plan (CMP) and Comprehensive Zoning Ordinance (CZO) that, if adopted, would have the force of law. As of the summer of 2010, the final CMP had been submitted to the City Planning Commission and CZO public meetings and development were in progress. Guiding principles and key features of the plan are summarized in Table 1. This planning process has also established a Sustainable Systems Working Group (SSWG) with a research and community outreach process completed in the summer of 2009. “Sustainable” recommendations in the Master Plan will contain the following elements (GCA 2008):

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 CMP includes a general recommendation that the City of New Orleans create a "climate plan" that addresses how the city should respond to global warming (NOLA 2009). 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 (Lopez 2005) (Figure 2). This strategy includes coastal wetlands and barriers, levees and pumps, internal drainage improvements, and land use planning and regulation.

FIGURE 2
Multiple lines of defense concept (adapted from graphic produced by the Lake Pontchartrain Basin Foundation, from the CPRA Master Plan)
TABLE 1
Guiding Principles and Key Features of the Draft New Orleans Master Plan

<table>
<thead>
<tr>
<th>Guiding Principles</th>
<th>Master Plan Key Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>• The future of New Orleans must be shaped by an honestly optimistic assessment assessment of its risks and opportunities.</td>
<td>• A 1-in-500 year minimum level of protection from storms</td>
</tr>
<tr>
<td>• Geography and water shape value and culture as well as drive risk.</td>
<td>• A city that does not have to evacuate (except under extraordinary circumstances)</td>
</tr>
<tr>
<td>• New Orleans cannot survive as a viable community if it must evacuate frequently</td>
<td>• A city planning for current risks and future risks — specifically those associated with rising seas</td>
</tr>
<tr>
<td>• A 1-in-100 year level of flood protection is essential but not adequate and is less than the City ad the Nation were committed to prior to Hurricane Katrina</td>
<td>• A city that views water as an asset</td>
</tr>
<tr>
<td>• The levees, pumps, and wetlands the City currently relies on are all that can be expected for the foreseeable future.</td>
<td>• Land use and water management practices that reduce risk, enhance land values and increase resilience to water, storms and other environmental hazards</td>
</tr>
<tr>
<td>• The State Master Plan and Corps of Engineers plans are not a substitute for effective action at the City since the authorization, funding and construction process for bold and effective action on next generation storm protection, coastal restoration, and climate change will be measured in decades — time the City does not have.</td>
<td>• Plan for, and reduce, subsidence at the city level.</td>
</tr>
<tr>
<td>• New Orleans can increase its near term protection and resilience by how it chooses to live with its levees, pumps, and wetlands.</td>
<td>• Plan for, and manage, interior hydrology and storm water to reduce flooding risk.</td>
</tr>
<tr>
<td>• No part of the City is immune from risk, though risks are not uniform across the City. Plan for water, not against it.</td>
<td>• Encourage regional cooperation and planning.</td>
</tr>
<tr>
<td>• No part of the City should be left out of its recovery and redevelopment, but the timing and nature of recovery and redevelopment does and will vary.</td>
<td>• Support and advocate for improvements to long range storm protection system</td>
</tr>
<tr>
<td>• It is not possible to immunize the City from risk; we must make it resilient to risk.</td>
<td>• Support and advocate for coastal conservation and restoration at the State and federal levels.</td>
</tr>
</tbody>
</table>

While the Master Plan/Comprehensive Zoning Ordinance (CZO) project provides an opportunity to include this approach to resilience in the vision for New Orleans future, the structural and non-structural land use provisions needed for most of this lie outside the jurisdictional boundaries of Orleans parish and are subject to a fragmented and uncoordinated land use planning and governance structure for implementation. The recent escalating costs of restoration and levee protection, along with the decline in the price of domestic oil and 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.

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. In the face of the dramatic wetland loss and relative sea level rise occurring in many parts of deltaic Louisiana, this may make only the thin ridges flanking the Mississippi River, various bayous in rural coastal Louisiana, and the 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 a systemic infrastructure plan with improved agency coordination and investments that increase 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 in response to the series of community meetings convened as a part of the master planning process, 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) to hold more water in the city with more canals and retention ponds and to repair/improve pumps and levees (Clancy 2008). However, low public support exists on instituting a comprehensive water management system or to use parks or vacant land for water storage, due to concerns about flooding, mosquito-borne disease, and a prevailing notion that the best way to manage water is to keep it outside of the city’s boundaries. These seemingly contradictory impulses have not been resolved into a citywide recommended master plan or strategy.

Further complicating the transition from residential use to a more natural ecostructure (e.g., water, green space, urban forest, etc) in areas of the city where a low percentage of residents are returning is a lack of public trust in government and developers. Maps produced in the immediate aftermath of Hurricane Katrina by the Urban Land Institute (ULI) and the Bring New Orleans Back Commission’s (BNOBC) Urban Planning Committee depicted portions of low lying residential areas converted into wetlands or green space (Figure 3) at a time prior to the development of the Road Home Program, which provided for voluntary buyouts and restoration grants to homeowners. Thus, conversions to uses other than residential are generally not only seen as decreasing the market value of surrounding residential property, but also as potential plots to deny residents the right to return to their former homes.
In both the ULI and BNOBC cases, these maps and proposed land uses were met with public hostility. The City government did not endorse these recommendations and, instead, encouraged residents to repopulate the entire city. As of the summer of 2009, nearly four years after Hurricane Katrina, the City has numerous areas where less than 50% of residents have returned (GNOCDC 2009). Green and Olshansky evaluated the extent to which New Orleans homeowners exercised the “buyout” options in the Road Home program (i.e., selling their property to the Louisiana Land Trust and not returning to their pre-Katrina property). As depicted in Figure 4, numerous significant clusters of sellers have emerged from this voluntary program. Not surprisingly, all of these clusters are in lower lying areas of the city that were impacted the most from the flooding in the aftermath of Hurricane Katrina and are, in several cases, in the same regions of the city where the BNOBC Urban Planning Committee recommended land use changes to encourage open park land (Figure 3).
The Lower 9th Ward offers a promising case study in New Orleans where community-based planning efforts have explored a number of rebuilding and land use strategies that embrace sustainability concepts. As early as June 2006, the Lower 9th Ward and Holy Cross Neighborhood produced a “sustainable restoration” plan which served as the foundation for its contribution to the Unified New Orleans Planning process (HCHDL9W 2006). Key concepts examined in the plan include structural improvements (e.g., energy efficiency and renewable energy) and open/degraded space ecostructural interventions (e.g., cypress swamp restoration, urban forestry) that promote safety, survivability and, ultimately, carbon neutrality. For example, the lower elevation impacted areas of the Lower 9th Ward, the community is supporting restoration of the adjacent Bayou Bienvenue to provide storm surge protection, wastewater assimilation from the neighborhood’s water treatment plan, carbon sequestration, and recreational services. For residential areas with little reoccupation of homes and a high percentage of those participating in the State’s buyout option, ideas ranging from urban farming, urban forestry, and community gardens and parks have been proposed.

If a new residential use does not materialize for these “buyout” properties throughout the city, a land use change and new “active” use would likely increase the market value for surrounding repopulated parcels in those neighborhoods.
and would be most fortuitous. But whether these clusters will see significant permanent land use changes incorporating water and/or park systems remains to be seen. 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. To that end, the ability for the City and its residents to see water as not only a threat, but also an asset (i.e., living with water — not against it) will be a critical evolution from current prevailing norms.

5 LAND USE CHALLENGES AND OPPORTUNITIES

5.1 Natural Versus Engineered Systems

Engineered structures like levees and floodwalls are at odds with the natural delta-building processes that created Louisiana’s coastal zone. However, given the human settlement patterns in Louisiana’s deltaic plain, urban and regional levees and floodwalls continue to be planned in combination with targeted, more natural freshwater and sediment diversions in unpopulated areas to maintain as much ecostructure as possible. The construction cost estimates for proposed urban protection (New Orleans metropolitan area) and regional levee systems (Figure 10) 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 2). While costs for the Orleans metropolitan levee system have generally ranged from $3.5 billion - $9.5 billion (protecting approximately 1 million current residents), costs for the proposed regional coastal levee (protecting approximately 120,000 current residents), originally estimated at $4.5 billion, could double. This could further escalate up to ten-fold if costs for the Morganza-to-the-Gulf (MtG) Levee system increase from the original $882 million estimate to $10.77-11.2 billion, as tentatively proposed by Arcadis Corp — a contractor for the Army Corps of Engineers.
TABLE 2
Cost Projections for Repair of New Orleans Metro Area and Regional Coastal Levees and Corresponding Residential Populations

<table>
<thead>
<tr>
<th></th>
<th>New Orleans Metro Area</th>
<th>Southeast Louisiana</th>
<th>Reference(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Repair/Construction Cost</td>
<td>$3.5-9.5 billion ($7.2 billion)</td>
<td>$4-5 billion ($882 M for Morganza to Gulf (MtG) 72-mile section)</td>
<td>(Walsh 2007; ENS 2006; Jonsson 2007)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$10.7-11.2b for MtG (perhaps lower at $1.4-$1.5b if 30% increase)</td>
<td>(Schleifstein 2008)</td>
</tr>
<tr>
<td>Area Protected</td>
<td>115,616 acres (Orleans Parish)</td>
<td>550,990 acres</td>
<td>(Jonsson 2007)</td>
</tr>
<tr>
<td>Residential Pop. Protected</td>
<td>1-1.3 million (320,000 in Orleans Parish est.)</td>
<td>120,000</td>
<td>(BIMPP/GNOCDIC 2008)</td>
</tr>
<tr>
<td>Construction cost/resident (not including long-term maintenance)</td>
<td>$2,692-$9,500</td>
<td>$33,333-$41,667</td>
<td>Uses 2006/2007 estimate above.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$43,333-$54,167</td>
<td>Assumes 30% cost overrun based on Governor’s Office statement (Schleifstein 2006)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$423,000-$528,750</td>
<td>Assumes 12.69 multiplier on earlier estimates based on new contingencies (Schleifstein 2008)</td>
</tr>
</tbody>
</table>

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 (Paulson 2008). As shown in Table 2, even if construction costs remain at their original estimates with the aim of protecting 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.

The Louisiana Speaks Regional Plan for south Louisiana developed by Calthorpe Associates is a recent attempt by the State of Louisiana to apply smart growth and New Urbanist approaches to 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 (LRA 2007). While this plan demonstrates success in incorporating restoration of coastal wetlands, 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 (Adelson 2009).

5.2 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 (NAE/NRC 2008; NAE/NRC 2009).

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 (54):

1. Comprehensive flood planning and risk management for the New Orleans metropolitan region will be based on a combination of structural and non-structural 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; and
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 (Kahan et al. 2006). 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 (Kahan et al. 2006).

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 (NAE/NRC 2009). 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 (Kahan et al. 2006).

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, all having differences in preference for different measures. The benefits and costs of various strategies are poorly understood, 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., rate of sea level rise and subsidence) and performance of restoration and protection structures (e.g., levees built on unstable soils) make the success 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 of homes and property buyouts of vulnerable residents in coastal Louisiana as proposed in the CPRA master plan is of concern (CPRA 2007).

5.3 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 1 at the southern extreme of the LaFourche-Terrebonne delta. For centuries, UHN settlements were physically and culturally integrated with a vibrant healthy ecosystem that sustained and protected their settlements. This deep connection with natural ecosstructure is eloquently expressed by historian Daniel D’Oneny who wrote “Understanding the Houma without acknowledging their relationship to waterways is like trying to understand a shadow without acknowledging the existence of light”.

The tension between coastal communities’ cultural connection to a delta system and its rapid erosion is a common phenomenon in vulnerable deltas in both the developed and developing world. Thus, the experiences of the UHN, because they live on the most rapidly eroding delta in the world, provide lessons for other deltaic communities. For generations, European colonization, warfare, disease, land dispossession, and coastal erosion have threatened the UHN. During the 20th century, the 16,000 members of the UHN were faced with declining livelihoods and displacement due to accelerated coastal erosion, saltwater intrusion, and the decline of the Barataria-Terrebonne Estuary. Estimates suggest that Hurricanes Katrina and Rita in 2005 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 (Yoachim 2008).

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 a core of trained members of the Houma nation available to serve as first responders in 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, including land trusts, are emerging as the most critical tools (Meffert, Etheridge and Tate 2009).
5.4 Easements, Mitigation Land Trusts, and Severance of Surface/Mineral Rights

Even with the best science and engineering informing the optimal balance of ecosstructure and hard structures for Louisiana’s urban and coastal planning, the implementation of land use interventions (and legal consequences) remains the biggest challenge the State of Louisiana faces on adaptation and mitigation measures. Jurisdictional challenges are exacerbated by the high proportion of private property ownership in Louisiana’s coastal zone (80%) and 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 reducing population vulnerability and maintaining healthy, viable communities.

The carbon sequestration benefits of Louisiana’s coastal wetland and forested habitats is emerging as an increasingly significant driver in exploring various land use policies that promote restoration and conservation of these private and public lands. For example, an acre of restored bottomland hardwood in the lower Mississippi floodplain sequesters up to 300 tons (average of 100 tons) of carbon dioxide over the next 100 years (Wayburn 2009). In addition, the highly productive fresh to brackish marshes of Louisiana’s coastal zone contain some of the highest amounts of soil organic carbon in the United States, and thus also represents great potential for carbon sequestration (Markewich and Russell 2001).

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 and the general public prior to 2007 (Urban Design Committee 2006). 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 (CPRA 2007; CPRA 2009; NOLA 2009).

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 (Emmer et al. 2007). 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 were 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 (LRA 2007). 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 successful precedents for this approach with Louisiana’s coastal restoration efforts. For example, on property with State-owned surface rights, the State can allow a landowner access 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, exceptions have been granted 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 landowners, 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, some entities will 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 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 step towards large-scale restoration at non-prohibitive cost and time-consuming implementation.

6 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 expected 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” (Törnqvist and Meffert 2008). Regardless of how this particular city will be rebuilt, New Orleans and its deltaic surroundings offer an opportunity to adapt 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. More specifically, New Orleans physical viability into the 21st century depends, to a large extent, on the ecological health of its surrounding coastal wetlands in terms of the resultant economic and storm surge protection values of these habitats. Conversely, the justification for large-scale restoration of these habitats lies with the goods and services these wetlands provide the world and the protection they give to densely populated areas and strategic port systems. New Orleans, in this sense, is an urban and natural laboratory that can provide new knowledge and understanding with applicability to larger 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 policies and practices in the developing world, utilizing natural processes and resources whenever possible for climate change adaptation. As evidenced by discussions earlier in this paper of the vast amounts of research and planning that have 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 (Halsnaes and Verhagen 2007).

Of particular relevance are delta regions and their urban center, increasingly vulnerable to SLR and storm surges like Dhaka, Bangladesh, and its GBM river system (Figure 5). Cities like Dhaka can benefit from lessons learned in coastal Louisiana not only in terms of climate change adaptation (and related restoration of delta systems for storm surge protection) but also, indirectly, in terms of urban poverty alleviation. This latter benefit, although perhaps not immediately intuitive, is due to the fact that the vast majority of new immigrants to Dhaka come from Bangladesh’s rural areas, with many of these immigrants migrating north from the delta regions because of their rapid erosion. While the body of peer-reviewed literature related to climate change impacts on the GBM system is expanding in recent years (Ali 1999; Brouwer et al. 2007; Erwin 2009; Karim and Mimura 2008; McDougall 2007; Mirza, Warrick and Ericksen 2003), 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 the Mississippi River are 600,000 cubic feet per second (cfs) on average and 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. (Karim and Mimura 2008) The coastal zone of Bangladesh comprises 19 administrative districts encompassing a land area of 47,201 km² (Figure 6) compared to Louisiana’s 19 coastal parishes with 21,448 km² of designated coastal zone area. A three-foot rise in sea levels could inundate nearly 20% of Bangladesh’s territory — proportionately on the same scale as 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. (Karim and Mimura 2008).
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 km²) compared to Louisiana’s 2M coastal zone residents (93.3 residents per km²). 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 (Lewis 2009), 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 (Campanella 2007).

Similar comparative practices can be examined in terms of predicting vulnerability to increasingly intense tropical storms and providing maintenance and restoration of these natural coastal habitats that furnish 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 (Karim and Mimura 2008; AMS 2008). 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 to predict a 12 foot storm surge for Bangladesh that would go 20-50 miles inland (Society AM 2008). After communicating this prediction to Bangladesh’s disaster office (their equivalent of FEMA), they were able to evacuate 3.2 million residents. Although 3,500 casualties still occurred, countless lives were saved.

Bangladesh has the Coastal Greenbelt Project to slow down surge waves and stabilize coastal land (afforestation project) (Erwin 2009). However, Bangladesh’s 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 (Halsnaes and Verhagen 2007). 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) also have significant impediments to long-term economic development. This is because significant GDP losses result from short-term climate change impacts and preclude investments in long-term economic adaptation measures (Hallegatte and Hourcade 2005).
FIGURE 5
The Coastal Regions of Bangladesh and Major Rivers in the Western Coastal Zone (reprinted from Karim and Mimura 2008 with permission from Elsevier)
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 resulting in hundreds of billions in total damage to the Gulf coast, and more than $150 billion from Hurricane Katrina alone (Hallegatte 2008), 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 the next four years from a combination of state and federal sources (Kirkham 2009), the current master plan will cost up to $100b (CPRA 2009). 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 (Sengupta 2009). 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 whose delta-building capacity has been enhanced in Louisiana’s Atchafalaya River and Wax Lake deltas (CPRA 2007; LCWCRTF 1993).

7 CONCLUSIONS

Through qualitative analysis and synthesis of available literature, this paper used the City of New Orleans and its surrounding Louisiana coastal wetlands as a case study to examine the following hypothesis: restoring and enhancing ecosystem services (i.e., “ecostructure”) of urban systems in the context of regional natural systems increases the ability of these urban systems to adapt to and mitigate the effects of climate change. In addition, climate change adaptation and mitigation of these complex systems required both regional appropriate jurisdictional oversight and local governance.

What are the main ecological drivers of change on regional and local scales that impact urban resilience following a disaster and adaptation to climate change? 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 threats that face them and can survive as long as they are adaptable and live with these prevailing gradual environmental trends (e.g., coastal erosion, sea level, rise, and subsidence) and systemic “shocks” (e.g., hurricane storm surge damages). New Orleans and coastal Louisiana are worth restoring and conserving because of the vast tangible and intangible economic, ecological, and cultural values intrinsic to their ecosystems and human communities. These include a significant vibrant and culturally rich population in New Orleans as well fisheries, oil, gas and other infrastructure elements in coastal Louisiana.

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? Based on our findings, Louisiana’s coastal wetlands have limited ability to maintain elevation relative to rising sea level and to sustain the ecosystem services described above. Thus, the future design of the natural and built environment must also accommodate periodic flooding and increased vulnerability to storm surge (Day and Giosan 2008). 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.
What are the spatial, jurisdictional, and temporal scales required to ensure sustainable governance of urban systems? The Louisiana coastal master plan is an ecologically-based strategy that seeks to protect local urban developments like New Orleans and sustain critical regional fisheries and port economies in the face of anticipated relative sea level rise and potential increased storm intensities associated with climate change. This strategy is multi-decadal with large-scale restoration project timelines being 20 years or greater. The spatial scale of the State’s master plan is the entire coastal zone including the deltaic plain of the Mississippi River and the adjacent western coastal habitats, thus involving numerous parishes, cities, and towns that must coordinate their governance boundaries with corresponding hydrologic basin management strategies for success.

The prevailing practices in place on the urban, regional, and statewide scales have largely relied on adaptive measures. Many opportunities for mitigation remain including 1) increased GHG sequestration through ecosystem services provided by the restoration of natural delta processes and wetland creation, 2) GHG regulation of oil and 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 spatial and temporal scale and limited in terms of restoring large-scale natural processes.

There is reason for optimism that there will be an increased emphasis on climate mitigation and adaptation at both the city and coast-wide scales. On the local urban scale, New Orleans’ Comprehensive Master Plan advocates implementation of mitigation measures described above within its jurisdictional boundaries and advocating for them on a regional scale. The State of Louisiana is also advocating large-scale coastal restoration and other structural and non-structural adaptation measures.

The challenge remaining ahead rests primarily on two issues – limited funding and land use policy implementation on the local urban and regional coastal scales. 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, while potentially providing near-term protection from flooding for the Houma urbanized area and its residents, could ultimately lose time, money, ecosystem services, property and life, if large-scale coastal wetland restoration
projects are not also prioritized. In other words, these regional levee systems will not be stable if their surrounding natural wetlands are not stable. 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 and maintenance of ecosystem services. 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.

Delta habitats are among the most fertile lands in the world and can continue to provide fisheries, agricultural products, and other ecosystem services to their coastal rural and urban communities and the rest of the world. In the case of the many urbanized and engineered delta systems worldwide, maximizing the natural processes that created these dynamic systems in the first place may also prove the cheapest and most practical way to protect their human populations from the effects of climate change into the next century. These inextricable links between the natural and built environments are at the core of ecostructure solutions in the New Orleans case study and, with appropriate attention to institutional differences, have application to similar deltaic regions worldwide.
While the original “ecostructure” hypothesis in this paper remains neither proven nor disproven, it is a question for which an answer will play out in the decades to come as the large-scale efforts to restore natural delta building are implemented and thereafter have a chance to perform successfully. The 2010 Deepwater Horizon oil spill in the Gulf of Mexico, despite its near-term and potential long-term threat to this fragile ecosystem, further supports the value of natural processes in sustaining deltaic habitats. The Mississippi/Atchafalaya rivers and related freshwater diversion projects have been successful tools for keeping the oil out of these habitats in the first place. This event has also catalyzed the development of a recovery plan that increases support for rapid implementation of these restoration projects, and supports accelerated investments in renewable energy options for the region, thus also helping to mitigate climate change.

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