The Resilience of New Orleans:
Urban and Coastal Adaptation to Disasters and Climate Change

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Abstract

New Orleans is like many historic port cities around the world - a place sited on vulnerable grounds 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. In spite of the great ecological and economic value of wetlands, the United States has lost half of its original wetlands. 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 and exacerbated by sea-level rise and natural disasters. This situation, while draconian, is not unlike many other 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, and governance. 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 discussed.

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Background and Introduction

Coastal Louisiana Background

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 restoration efforts have recently been planned (Everglades reference).

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 40% of the coastal wetlands in the contiguous U.S., but are experiencing 80% of the coastal wetland loss (6, 7) as shown in Figure 1. The causes of this wetland loss include cumulative natural and human-induced impacts (7-13). 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, 14). 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 Delaware (7, 15). 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, 10, 16).

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) lost oil and gas infrastructure; (3) lost 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 (LCWRTF 1993). These resources provide more fishery landings than any other coterminous U.S. state (6, 17)(USDOC 1996; CPRA 2008), the largest fur harvest in the U.S. (6, 18), 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.

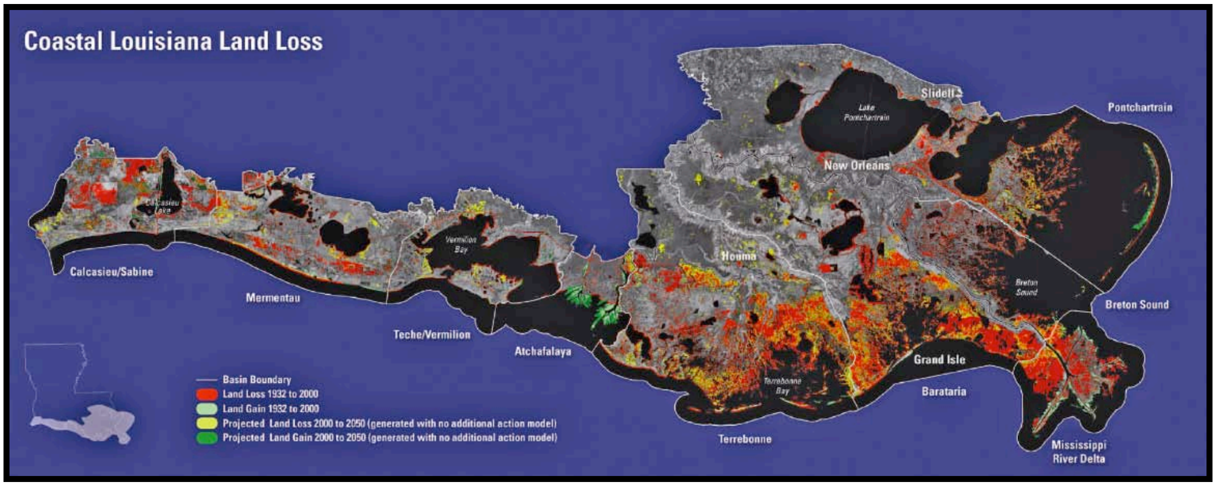

Figure 1. Existing and projected coastal wetland loss and land gain in coastal Louisiana. Historical rates range from between 25-35 square miles per year (19).

New Orleans Background

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 still widespread hope (or perception of hope) that it was still possible to restore and retain the historic wetland footprint of coastal Louisiana. The immensity of the problem was further "realized" in the early 21st century when Hurricanes Katrina and Rita resulted in approximately 200 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 one 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 enhancing the natural processes to the best extent possible, to rebuild with the expectation of future flooding and to cluster populations in the areas safest from natural disaster. The knowledge that climate change-related relative sea level rise of 3-10mm per year (20) in the next 50 years only exacerbates this vulnerability and the need to reside in the least vulnerable zones, whenever possible. In fact, 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, many former distributaries of the Mississippi River, so that they can remain above sea level and minimize risks associated with flooding and storm surge.

Carrying Capacity of Coastal Louisiana

The reality is that human populations worldwide, including New Orleans, will continue to populate in areas that are vulnerable to natural disasters and periodic flooding – some of it severe. In a white paper in 2006 (discussed later in this paper), Campanella focused on the opportunities that high ground could provide in New Orleans if prioritized for residential development, with the knowledge that Louisiana's coastal wetlands will continue to degrade for years to come before a state of no net loss (or even net gain) is achieved (21). A similar analysis of the "carrying capacity" of Louisiana's entire coastal system should be performed. How do we, in fact, establish a new recommendation for "carrying capacity" based on a sustainable or realistically maintainable urban and coastal landscape?

Since Hurricane Katrina, numerous articles and reports have been published that mesh the theoretical underpinnings of coastal science, engineering, architecture, and landscape architecture, 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 coastal Louisiana (6, 16, 21-29) . Most of these articles recommend maximizing incorporation of natural 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 at 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.

New Orleans Urban Assessment

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 (21), unutilized 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.

Specific opportunities would include prioritization of above sea level areas that are currently unoccupied/underdeveloped for residential use (over commercial/industrial use) with densities (units per acre) consistent with New Orleans trends as well as the shift from 3.5 to 2.5 residents per unit on average between 1960 and 2005 (30). We estimate New Orleans' additional carrying capacity above sea level is between 8,900 residents at 5.5 units/acre (using 2005 mean population density) and 20,630 at 9.2 units/acre (using 1960 mean population density).

Coastal Louisiana Rural Implications

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 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 (described previously). Current plans are to restore as much of this marsh as quickly as possible with a combination of restoration of natural delta building, marsh creation from use of dredged material, water control structures, and hard structures (e.g., dikes and levees) (6, 22) as shown in Figure 2. 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 more proximate to more densely populated areas.

Like the study conducted by the CBR for New Orleans, if one is to prioritize areas 1 foot above sea level or higher for residential occupation, available space is limited in coastal Louisiana. While a larger regional levee system in south Louisiana is proposed to provide 100-year protection for about 120,000 rural residents in Louisiana rural coastal areas (31), thousands of residents are left outside of protection systems. For the Delta lobe (e.g., Boothville-Venice) residents, these lands will ultimately be sacrificed with marsh creation (e.g., through beneficial use of dredge material) being prioritized for degraded marsh in Barataria, Terrebone, and Breton Sound basins, in particular. So far, relocation is based primarily on voluntary actions of residents (6) and this must be re-examined carefully in terms of design, planning, and policy so that vulnerability and litigation are mitigated and/or precluded.

Levee Infrastructure Costs and Uncertainties

The construction cost estimates for proposed urban protection (New Orleans metropolitan area) and regional levee systems (Figure 2) 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 increased construction costs each year due to the increased 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 Levee system (Figure 2) 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.

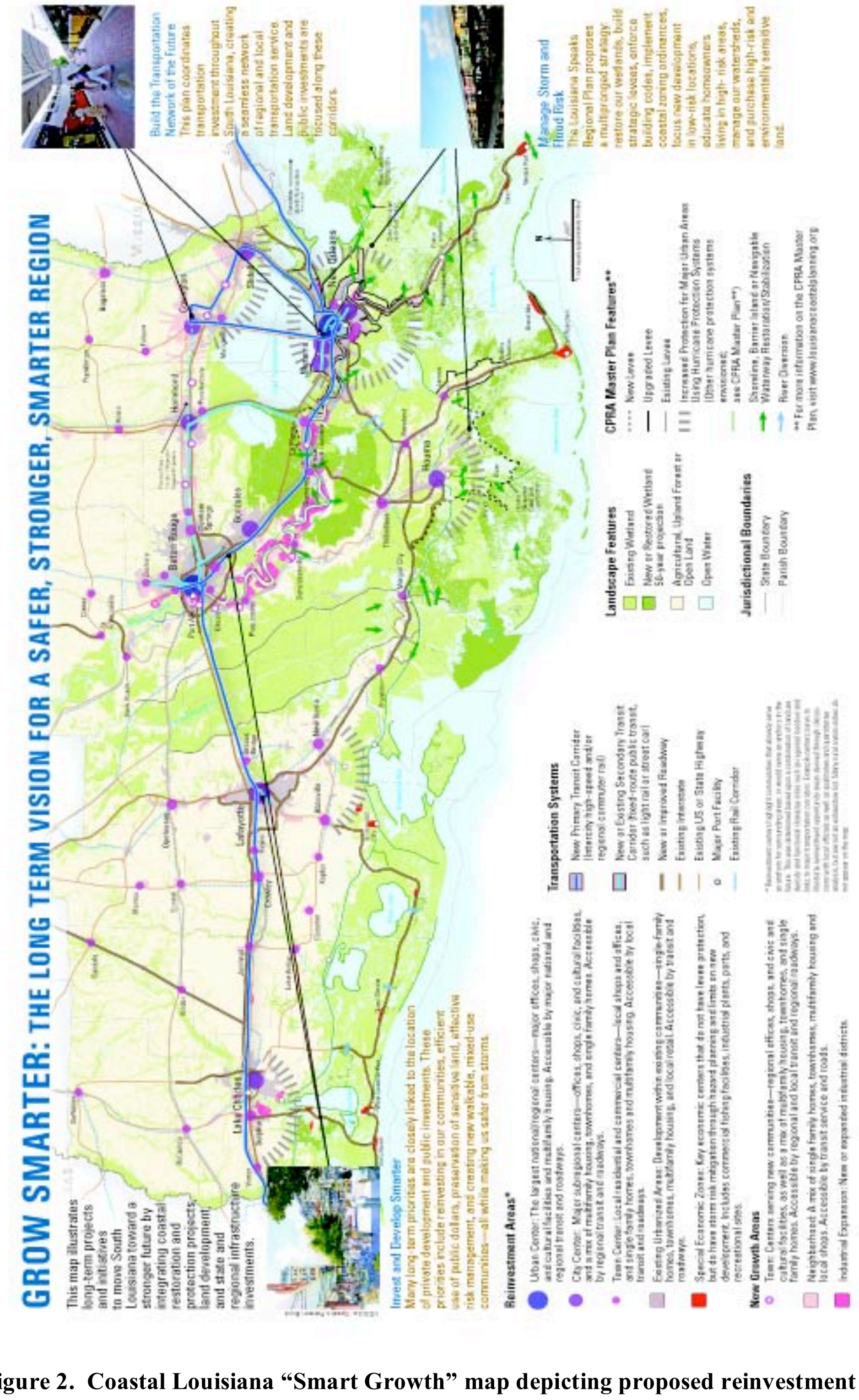

Figure 2. Coastal Louisiana "Smart Growth" map depicting proposed reinvestment and growth areas; transportation and landscape features; and Coastal Planning and Restoration Authority proposed 100-year enhanced levee systems and coastal restoration areas (from (22).

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. The recent 500-year flooding events in the Mississippi River Basin came just 15 years after a similar 500-year event in 1993 (32). 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.

Even with these estimates, an examination of the appropriateness of continuing to prioritize particular rural and urban regions to include residential uses is warranted. Any increase in actual costs (unless accompanied by a concomitant relative increase in protected population) will only exacerbate this discrepancy in protection cost per resident and will ultimately make certain design levels cost prohibitive.

Table 1. Cost projections and 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)	(31, 33, 34) (35)
Area Protected	115,616 acres (Orleans Parish)	550,990 acres	(34)
Residential Pop. Protected	1-1.3 million (320,000 in Orleans Parish est.)	120,000	(36)
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 (35) Assumes 12.69 multiplier on earlier estimates based on new contingencies (35)

Land Use Challenges and Opportunities

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. 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 (37). 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.(37)

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 (37).

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).

Land Policy Opportunities

Even with the challenges described above, there are several land policy opportunities in coastal Louisiana. 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. Practices that would promote sustainable development include compact development, context-sensitive streets, community-centered schools, preservation of open space and natural resources, increased transportation options, walkable neighborhoods mixed land uses, energy efficiency, "green" architecture, neighborhood scale storm water management, water efficiency, brownfield redevelopment, waste management, waste-to-energy/biomass management, 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 (28). While these recommendations were not initially put into practice by New Orleans' municipal governance due to sociopolitical and jurisdictional concerns, among other reasons, the New Orleans Office of Recovery and Coastal Protection and Restoration Authority have subsequently endorsed them.

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 (22). This fund would allow the State to acquire rights 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 (38). 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 (38). 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.

Conclusions

The fate of New Orleans and other port cities worldwide is increasingly vulnerable 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, the future design of the natural and built environment, in order to be sustainable, must also be floodable due to periodic flooding and increased vulnerability to storm surge (and because relative sea level rise and the coast's adaptability to this change is much less than we thought a year ago). Therefore, while regional plans must be practical, given chronic vulnerabilities of this integrated urban and natural system; opportunities exist for creative structural and non-structural interventions and policies described above.

The $4 billion initial investment in CPRA-recommended regional levee systems (including the 72-mile Morganza-to-Gulf levee) is a risky and expensive investment that could ultimately lose time, money, property and life. 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) Evacuation of thousands of rural inhabitants in the next 10-20 years - particularly those in vulnerable coastal areas outside of the proposed levee protection system.
2) Evacuation 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, 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. Social governance is tantamount of this process with governmental accountability. 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.

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