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A Community-Informed Framework for Quantifying Risk and Resilience in Southeast Louisiana

Scott A. Hemmerling, Colleen M. McHugh, Christine DeMyers, Harris C. Bienn, Allison DeJong, Jessica Parfait, and Erin Kiskaddon

Produced for and funded by:

WALTON FAMILY FOUNDATION

Foundation for Louisiana
At work for resilient communities.

MARCH 2020

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SUGGESTED CITATION

Hemmerling, S. A., McHugh, C. M., DeMyers, C., Bienn, H. C., DeJong, A., Parfait, J., Kiskaddon, E. (2020). A community-informed framework for quantifying risk and resilience in southeast Louisiana. Baton Rouge, LA: The Water Institute of the Gulf.

INTEGRATING APPLIED RESEARCH | LINKING KNOWLEDGE TO ACTION | BUILDING PARTNERSHIPS

Acknowledgements

This project was made possible by the generous support of the Walton Family Foundation and the Foundation for Louisiana. These organizations have long been at the forefront of the fight to protect Louisiana's coastal communities and represent a huge component of what makes these communities as resilient as they are. Special thanks have to go to Kristin Tracz from the Walton Family Foundation and Liz Williams Russell from the Foundation for Louisiana. Without their vision and insight, this project would not be what it is.

The project team would also like to thank the members of our technical advisory committee. Janice Barnes, Colette Pichon Battle, Jeannette Dubinin, Dakota Fisher, Robert Habans, Devyani Kar, Nina Lam, Josh Lewis, Earthea Nance, Allison Plyer, Mat Sanders, Liz Russell Williams, and Clint Willson gratefully shared their expertise and time at various points throughout the study. Special thanks go out to Nina Lam's graduate students who took the time to meet with us and learn about the project. Your enthusiasm for the project reminded us why we do the work we do!

The project team would also like to acknowledge Greg Baecher and Denise Reed. The idea of merging engineering principles with social science principles may not be a new concept, but those early conversation back in 2015 provided the inspiration for this project. The team also recognizes the contributions of Jeff Hebert. Without his vision, this project would not be what it is. The Water Institute's Alyssa Dausman and Hugh Roberts provided key insight and recommendations and Berva Noone offered much needed editorial advice.

Finally, we would be remiss if we did not acknowledge the residents of Morgan City and Berwick, who took time out of their busy days to meet with us and provide the valuable local knowledge that proved so invaluable to this research. Monica Mancuso from St. Mary Excel has been a tireless advocate for the residents of Morgan City and was instrumental in bringing the community to the table. To the Port of Morgan City, Mayor Grizzaffi of Morgan City, and Mayor Arthur of Berwick, thank you for taking the time to meet with us provide your insights. To the students of the Berwick High School, Central Catholic High School, and Morgan City High School, we offer our special thanks. You represent the future of Coastal Louisiana and your insights provided a unique lens through which to view community resilience. I hope we, in some small way, were able to inspire you.

The opinions, findings, and conclusions expressed in this report are those of the authors and any errors are solely the responsibility of the authors.

Executive Summary

Coastal communities face increasing threats from storm events, riverine flooding, sea level rise, land loss, subsidence, and other hazards. Climate change, in many cases, intensifies these events. A community's underlying social support systems as well as decisions about land use and infrastructure can alter the economic, environmental, and social consequences of these hazards. Communities of color, Indigenous peoples, and vulnerable populations, such as low-income households and the elderly, often face disproportionate risk to coastal hazards. Furthermore, the factors that comprise a community's risk and resilience look different across different communities and require a deep understanding of local systems and priorities to fully unpack. The complexity of addressing future risks and planning for an uncertain future is exemplified in southeast Louisiana, the geographic focus of this study, where state agencies and nongovernmental partners are battling the existential crisis of coastal land loss, preparing for more extreme future storm events, and working with communities to develop a shared understanding of risk and vision for the future in light of those risks. Coastal scientists, planners, and policy makers in Louisiana and in coastal regions around the world need to make informed and strategic decisions, grounded in sound science and data, about how and where to invest limited resources to reduce risk and strengthen resilience. Unfortunately, the quantitative tools and models that decisionmakers use to plan and prioritize investments often fall short of capturing the complexity of risk and sufficiently measuring the components of community resilience, especially the nuances of local conditions and the social aspects that may be difficult to quantify.

To address this gap, this study integrates the multi-attributed aspects of coastal risk—economic, social, and environmental—into a unified coastal resilience assessment framework using a consistent set of quantitative metrics. In order to capture the unique local character and priorities that comprise community resilience across different geographies within the region, we have developed a rigorous, replicable process for gathering and incorporating qualitative local knowledge into our quantitative data model. Additionally, we have incorporated a racial equity lens into our analysis, recognizing that communities of color and Indigenous peoples are not inherently vulnerable because of their demographics, but often experience greater risk from hazards because of a history of structural and environmental discrimination. We ran a correlation analysis to identify disparities in risk rather than treating race and ethnicity as an inherent social vulnerability in the model.

This report outlines our research process and initial findings and concludes with a set of recommendations for how coastal scientists, planners, and policy makers can apply this research to decision making. Ultimately, this study provides additional quantitative support for planning approaches that are holistic, grounded in local community knowledge, and intentional in addressing social and racial inequities. Decisionmakers can use the data model developed through this research for a range of applications in coastal planning projects—including benchmarking and agenda-setting, plan evaluation, and prioritizing investments.

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Image Credit: Colleen McHugh

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> "Everyone in the parish makes use of these areas, people are going out on their time away from work, their vacation time, their hunting, their fishing, their recreation, the boating, just enjoying the area, it's everybody's."
> -Grand Bayou tribe member, February 2019

Introduction

Communities and the critical industrial infrastructure that support robust economic activities face increasing threats from coastal land loss, storm events, riverine flooding, sea level rise, and subsidence. These factors, enhanced by climate change, act separately and interactively to endanger people, structures, and habitat (Baecher et al., 2015). The National Research Council has called on the federal government to work closely with state agencies to establish national objectives and metrics for reducing coastal risk and to develop a comprehensive, integrated national coastal risk assessment (NRC, 2014). Such a risk assessment could serve as a basis for states and localities to assess their level of resilience, including current life-safety, social, economic, and environmental vulnerabilities and to evaluate the costs and benefits associated with alternative risk management plans.

In the literature on environmental disasters, resilience is a well-established concept that is generally used to explain "the ability to prepare and plan for, absorb, recover from or more successfully adapt to actual or potential adverse events" (National Academy of Sciences, 2012). In recent years, the concept of resilience has quickly become an established component of environmental policy agendas around the world. At the same time, as the usage of the term has become more widespread, confusion over what resilience is and the purpose it serves has increased. Resilience has increasingly become a popular buzzword among academics, government agencies, industry, consulting firms, international finance organizations, non-governmental organizations, and community groups. It has become more common for researchers to set aside the decades-long history of resilience studies and derive their own concepts of resilience (Cretney, 2014). For example, the U.S. Army Corps of Engineers has proposed three variants of resilience in reference to coastal storm damage reduction (Table 1). In their view, while acknowledging that other systems are important and should be investigated, only engineering resilience is measurable (Schultz et al., 2012). However, the concept of resilience as it is understood today is derived from early psychology and ecology studies and there is a long history of transdisciplinary research focused on the quantification of resilience. Acknowledging this scientific basis of resilience and its transdisciplinary nature, measuring it, and utilizing it in decision making allows the research contained herein to explore and quantify resilience from an engineering or built environment perspective as well as social and ecological environments. This increases its viability in solving complex social-ecological problems such as those experienced by residents of coastal Louisiana.

Recognizing the complexity of resilience and the difficulties in establishing a consistent basis for measuring resilience that includes all key dimensions, the National Academy of Sciences (2012) proposed the development of a suite of metrics organized around what they perceived as the critical dimensions of resilience:

- Indicators of the ability of critical infrastructure to recover rapidly from impacts;
- Social factors that enhance or limit a community's ability to recover, including social capital, language, health, and socioeconomic status;
- Indicators of the ability of buildings and other structures to withstand earthquakes, floods, severe storms, and other disasters; and
- Factors that capture the special needs of individuals and groups, related to minority status, mobility, or health status.

While many existing models of resilience profess to be integrated by including information about infrastructure, physical systems, and social systems, often some of these elements are represented more strongly in the models than others (Cutter et al., 2013). The State of Louisiana, for example, has approached the concept of resilience in two different ways, which will be explored in this research. The first approach focuses on risk reduction and is a primary focus of Louisiana's Coastal Master Plan for a Sustainable Coast (the Master Plan), a science-based protection and restoration plan to reduce the exposure of residential and non-residential properties to storm surge and coastal flooding (Coastal Protection and Restoration Authority of Louisiana, 2017). This approach includes recognizing that, in some cases, residents will likely need to move out of areas with high flood risk. The second approach that Louisiana has taken revolves around reducing the susceptibility of communities to risk using urban and regional planning tools. The Louisiana Strategic Adaptations for Future Environments (LA SAFE) plan is a regional effort that focuses on holistic community techniques for reducing risk, including community-building to reduce future susceptibility to harm (Louisiana Office of Community Development & Foundation for Louisiana, 2019).

Table 1. Variance of resilience in reference to coastal storm damage reductions (Schultz et al., 2012).

Resilience Concept	Definition	Emphasis	Quantitative Measures	Estimation of Measures
Ecological resilience	The ability to resist being forced into an alternate state.	How the system functions are performed.	The force needed to push a system into an alternate steady state.	Theoretical. Not estimated in practice because of uncertainty in thresholds.
Engineering resilience	The ability to resist and recover from disturbance.	Functional performance.	Functions of the rate at which pre-disturbance performance levels are recovered.	Quantified in practice using simulation models or data on past performance.
Community resilience	The ability to preempt and avoid mishaps in organizations through learning and adaptation.	The ability to adapt, reorganize, or develop new functions specifically conditioned on the disturbance.	None known.	Conceptual. Not estimated quantitatively.

Flooding in Baton Rouge, Louisiana in 2016

While the Master Plan and LA SAFE may differ in the way that they approach adaptation to risk, both require data-based decision support tools and models to enhance the planning and decision-making process (McAllister, 2016). With this in mind, the research presented herein developed a suite of integrated data models to measure systems-level resilience. These models utilized quantitative measures of risk and incorporated aspects of engineered, ecological, and social systems vulnerability.

This current study recognizes the need for a systems-based approach that is able to incorporate aspects of both physical exposure and susceptibility of communities and the surrounding environment to harm. The theoretical resilience framework developed herein makes the linkage between the physical and social environments explicit. The more communities depend on infrastructure, for example, the more exposed they are to its failure and the more critical that infrastructure is to community resilience(Atzl & Keller, 2013). Similarly, the more susceptible these communities are to the impacts of a hazard event, the greater the likelihood of suffering adverse consequences. This theoretical framework developed herein serves as the basis upon which data collection and analysis were conducted.

Finally, this research acknowledges that there are aspects of resilience that are not readily captured by secondary data sources and quantitative data models. Aspects of inherent resilience, for example, are strongly tied to personal experiences with hazards and vary between communities and over time (Colten et al., 2012). The resilience framework begins to remedy this by developing a rigorous and replicable scientific method that will allow community engagement to become a part of the standard process of quantitative resilience assessment. For coastal protection and restoration to meaningfully impact community resilience, the planning process needs to strike an effective balance between science-driven processes and engagement with residents who are especially vulnerable to risk or likely to be affected by policy actions (Hemmerling, Barra, et al., 2020). The stakeholder engagement methodology developed for this research can effectively scale-up local perspectives and integrate the results of qualitative analysis into a geospatial framework that can be used for statewide decision making. By acknowledging that resilience is experienced and acted upon at an individual level and offering an effective means of analyzing local knowledge, this research provides a valuable tool for planners and decisionmakers who need to prioritize how best to allocate limited resources. This community-informed process will also assure that that decisions are made in a more socially just and equitable manner.


Flooding in Baton Rouge, Louisiana in 2016. Image Credit: US Coast Guard

"I don't think that we can actually do a piecemeal—this is a system and we have to protect this system. You can't just say I'm going to pick up this and let this go because it's all interconnected. When we talk about areas of importance. We have to look at when projects are being designed, it has to be multiples it can't be one thing here one thing there."
-Grand Bayou tribe member, February 2019

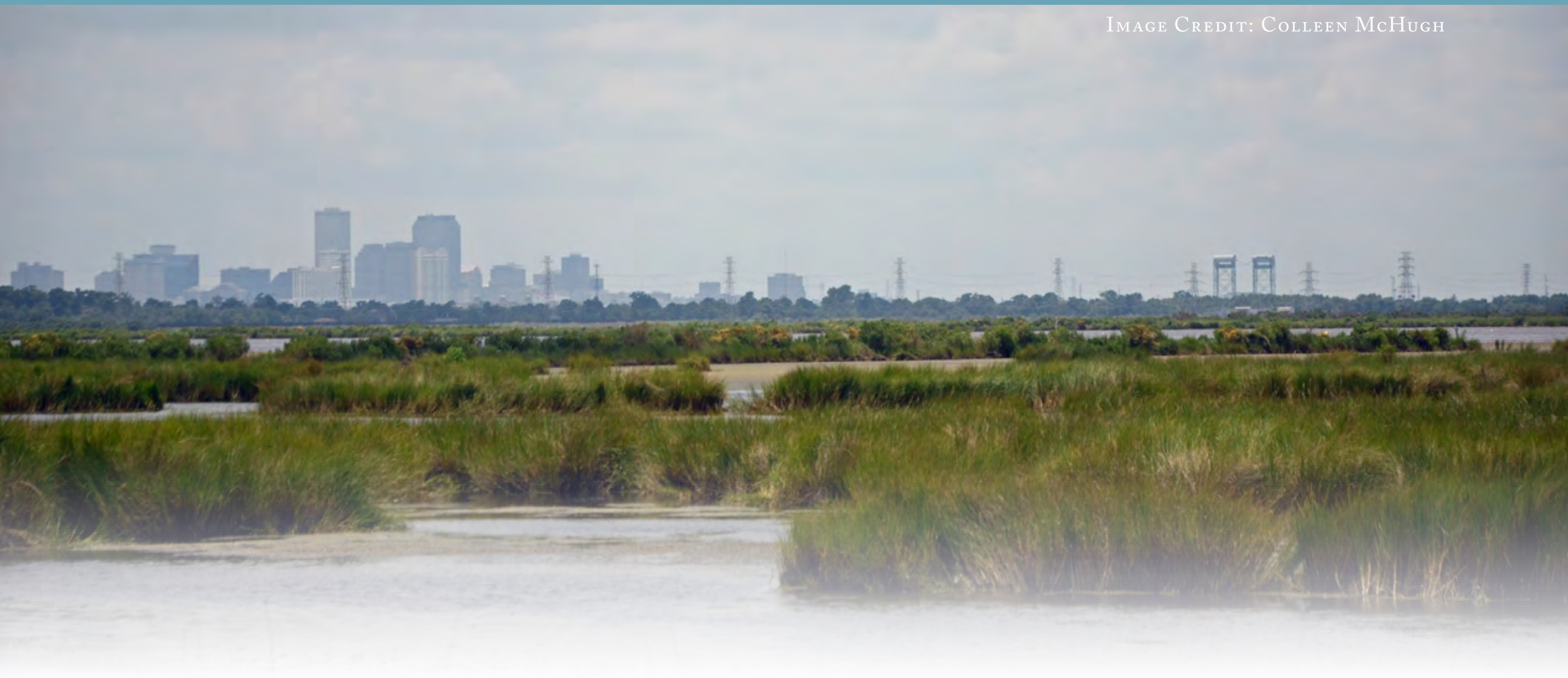


Image Credit: Colleen McHugh

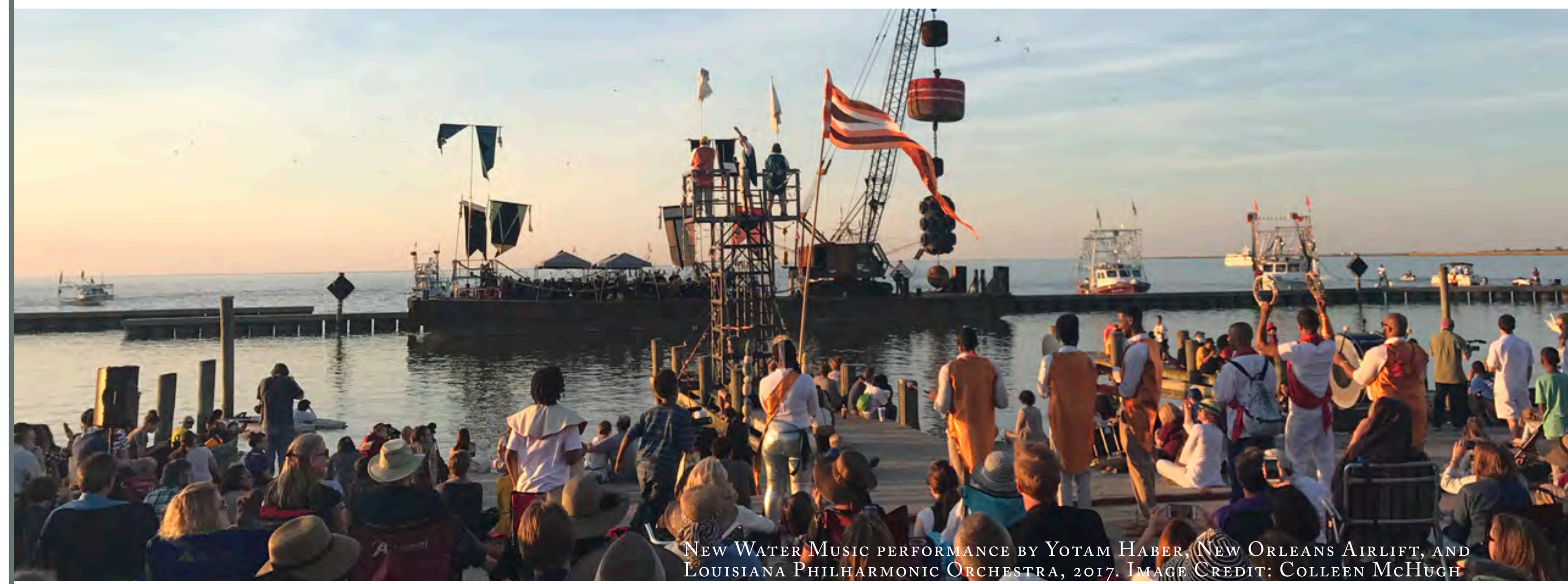
Chapter 1

What is a Resilient Community?

Coastal regions around the world have experienced record levels of population growth during the twentieth century and into the twenty-first. The last two decades of the twentieth century alone saw coastal populations in the United States increase by 28 percent. Counties located along the Gulf of Mexico have experienced growth far exceeding this national average, with a total population increase of 45 percent during this same time period (Crosset, 2005). While a combination of social and economic factors has largely driven this coastward migration, the construction of extensive structural flood protection systems has encouraged populations to move ever closer to the interface of land and water where the impacts of coastal storms and the risk of storm-induced inundation are heightened. The proximity to the open water enhances the risks of tropical weather impacts and coastal flooding. The limited land area in coastal regions also restricts the construction of road networks, which in turn limits the options for evacuation during storm events (Hemmerling, 2017). This is nowhere more evident than in coastal Louisiana where leveed areas reach deep into the coastal marshes and human development exists atop the narrow ridges and natural levees of the state's coastal zone. Strikingly, residents of the small rural communities residing in the area are often crowded together on the limited high ground in density levels approaching that of the greater New Orleans area (Laska et al., 2005). This presents unique challenges for residents and policy makers alike.

These challenges are compounded by a number of unprecedented natural and human-induced changes to the environment which have further increased the risks faced by coastal residents. While some environmental changes can have direct impacts on coastal residents, such as immediate loss of life or property resulting from hurricanes and other tropical storm events, others can be indirect, impacting the social and ecological systems upon which communities depend, such as agriculture or fisheries (Lenton, 2013). Coastal land loss represents a slow-moving, yet significant, environmental crisis facing residents of Louisiana. The U.S. Geological Survey has reported that coastal Louisiana has suffered a net loss of approximately 1,883 square miles of land and wetlands from 1932 to 2010 (Couvillion et al., 2011). This deterioration of the vital shoreline protection zone places coastal communities at increased risk from the impacts of storms and the effects of climate change such as accelerated sea level rise and increased frequency and intensity of extreme tropical weather events (Laska et al., 2005). Additionally, this zone represents a vital ecological link between communities and the benefits provided by local ecosystems. The loss of these vital coastal ecosystems would have long-lasting effects on the traditional economic activities, such as fishing, hunting, and trapping, which have been at the core of Louisiana's coastal culture, as well as a vital economic engine for the region and the nation at large.

For environmental change to alter human systems in any significant way, there must be a resultant impact on human wellbeing. Human wellbeing relies on a complex web of interconnected institutions, infrastructure, and information that make up the fabric of a place (ARUP & The Rockefeller Foundation, 2015). Louisiana has a vibrant working coast and is a center of economic activity and opportunity for many coastal residents. It also possesses a unique cultural heritage that ties residents to the land. Generations of Indigenous peoples, Acadians, Isleños, African Americans, and Asians have lived and worked in Louisiana's coastal zone. But the coast is also a perilous place where system shocks and slow moving crises have combined over time to force change in local communities, even if this change is only experienced at a multigenerational scale (Hemmerling, 2017).



New Water Music performance by Yotam Haber, New Orleans Airlift, and Louisiana Philharmonic Orchestra, 2017. Image Credit: Colleen McHugh

Many coastal communities have found the means to persist in place despite repeated disruptions in the form of hurricanes, floods, oil spills, and ongoing threats resulting from coastal land loss and sea level rise (Colten et al., 2018a). However, without meaningful adaptation, the effects of these stresses may continue to compound to the point where a community fails to rebound and residents are unable to persist any longer, resulting in social breakdown, physical collapse, or economic deprivation (ARUP & The Rockefeller Foundation, 2015).

Community resilience provides a different perspective on the relationships that societies have with their environmental setting. In places where constant change becomes the new normal, the role of crises in maintaining or eroding community resilience cannot be understated. Adaptations to change are the adjustments that society make to fortify its resilience and to incorporate lessons learned after a disaster. Resilience focuses on enhancing the performance of a system in the face of multiple hazards, rather than preventing or mitigating the loss of assets due to specific events (ARUP & The Rockefeller Foundation, 2015). In this way, resilience can be considered as a process that develops, grows, and perpetuates between disruptive events (Hemmerling, 2017). It is this historical component of resilience that promotes the development of long-term adaptations to changing environmental conditions, allowing communities to develop inherently resilient qualities through time.

What is Resilience?

Resilience is a concept that addresses the complex interactions between human, natural, and built environments. It is variously defined as the degree of change a community can tolerate while maintaining its basic ability to function (Bruneau et al., 2003). Current resilience thinking is derived from early studies of social-ecological resilience (Holling, 1973). One key aspect of social-ecological resilience is that resilience refers to systems rather than individual units. The systems approach focuses on how much disturbance a natural or human community can absorb before it changes its structure or reaches a critical tipping point. For this reason, it is necessary for researchers to fully understand the complex interactions of the human, natural, and built environments, recognizing that change in any of these environments will result in changes across the entire system. Such an understanding also recognizes the existence of a zone of "stable functioning" within which a system can absorb change while still maintaining its essential functioning (Cretney, 2014). Building on these ecological concepts and applying them to human environments, the National Academy of Sciences more specifically defines resilience as the ability of a system, community, or society to prepare and plan for, absorb, recover from, and more successfully adapt to adverse events in a timely and efficient manner, including through the preservation and restoration of essential basic structures and functions (National Academy of Sciences, 2012). This definition recognizes the complexity of resilience and the difficulties in establishing a consistent basis for measuring resilience that includes all key dimensions (Box 1).

Box 1

Measuring Community Resilience

A community's level of resilience can be determined by its vulnerability and adaptive capacity in the face of various hazards. In the aftermath of any hazard, vulnerabilities that exist in any community characteristic (such as the social, natural, or built environment) may result in changes across the entire community, ultimately resulting in a range of consequences.

HAZARD: Any natural or social threat to infrastructural, social, or ecological system.

VULNERABILITY: The extent of an infrastructural, ecological, or social system's susceptibility to harm. Susceptibility to harm subsequently affects the ability of a system to function before, during, or after a hazardous event. Social vulnerability refers to the ability of certain sub-populations (or demographic groups) to prepare for or recover from a hazardous event.

ADAPTIVE CAPACITY: the extent to which a community can learn from the losses incurred from a hazard and adapt to reduce future damage.

The degree of resilience possessed by a community and its residents is an important asset for buffering the effects of environmental and ecological stresses. Resilient coastal communities are more likely to be able to prevent hurricanes and other tropical weather events from making the transition from natural hazard event to social disaster (Adger et al., 2005). Enhancing a community's resilience can improve its capacity to anticipate significant multi-hazard threats, to reduce overall the community's vulnerability to hazard events, and to respond to and recover from specific hazard events when they occur (Colten et al., 2008a). The ability of a community to recover from repeated disruptions suggests a degree of inherent resilience comprised of practices that coastal residents deploy to cope with disruptions and that are retained in their collective memory (Colten et al., 2012). As the rate and intensity of natural hazard events continue to climb, however, a loss of resilience and population migration becomes an increasingly likely response, driven by the physical risks and hazards and the policy responses to these hazards (Dalbom et al., 2014). While coastal residents do experience a disproportionate level of risk relative to noncoastal residents, it is the policy responses that may ultimately determine the degree of resilience in the region.

Community-Informed Coastal Modeling: Mapping a Pathway to Resilience

Historical trajectories of environmental, political, and economic change ultimately help determine how communities will respond to and recover from hazard events and other social stresses. Inherent in this concept is the idea that place matters when it comes to resilience. There is no one-size-fits all means of building resilience. Different historical contexts most certainly result in different levels of resilience, even in communities sharing similar geographies. Efforts to effectively move the needle on resilience will require an approach that addresses all aspects of resilience, from reducing physical exposure to lowering social vulnerability to increasing capacity to respond and adapt. Perhaps most importantly, such an effort will need to incorporate qualitative data on public perceptions of value and risk because resilience, at its core, is dependent on human decision making. This requires a dramatic reframing of how resilience is conceptualized and modeled in coastal planning efforts. As noted by the Army Corps of Engineers, framing an evaluation of resilience in terms of community resilience rather than engineering resilience changes the nature of the analysis. Technical issues of structural and functional reliability become less important and social, political, and psychological issues become more important (Schultz et al., 2012). Essentially, they are talking about how social, ecological, and engineering factors are weighted in resilience assessments. This represents a distinct challenge and opportunity for coastal scientists to move forward in a more transdisciplinary manner.

Modelers and computer scientists working in the fields of artificial intelligence and artificial neural networks recognize the transdisciplinary nature of their research and that the accuracy of their models requires knowledge of computer science as well as psychology, neurophysiology, physics, mathematics, and a multitude of other natural and social sciences (Jain et al., 1996). Scientists working to develop artificial neural networks have continued to evolve their models by continuously incorporating new developments from these other disciplines. Work in resilience has inexplicitly tended to move in the opposite direction, focusing on numerical models that rely on types of data that are more directly quantifiable in terms of physics and mathematics and discarding those data that do not easily fit within existing models. While numerical models have become increasing sophisticated in their ability to predict levels of physical exposure to any number of coastal hazards, they cannot account for how this exposure is experienced. Community resilience outcomes of decisions made based solely on these models remain largely unknown.

This research does not purport to develop anything as rigorous as artificial intelligence. What it does do is take a first important step in synthesizing qualitative and quantitative social science data with numerical modeling data to develop a more comprehensive and meaningful model of community resilience. While computer models can effectively handle numerical and symbolic manipulations of large volumes of data, they do not inherently deal with the types of perceptual problems involved in human decision making (Jain et al., 1996). At its core, community resilience is the result of human decision-making processes. By integrating public perceptions data and numerical modeling, this research acknowledges the complex nature of resilience. Decisions that increase resilience in an urban neighborhood may not increase resilience in a small rural town. Further, decisions that improve resilience in a rural fishing community may not increase resilience in a rural agricultural community.

If a goal of coastal scientists, planners, and policy makers is truly to build a more resilient coast, it is imperative that they not shy away from the complexities of human experience. In much the same way that artificial neural networks seek to model human behavior on an individual level, models of resilience should attempt to model this experience at a community scale or at the very least, recognize and account for the fact that resilience is inherently built upon human decision making. If the educational system in a community is failing or if residents are unable to find gainful employment, no amount of levee construction or new flood gates will increase community resilience in a substantial way. Residents with the means to leave will seek out new opportunities in other places. In much the same way, if an area is not protected from coastal hazards and residents experience severe repetitive losses, these same residents will likely seek out safer locations to live, regardless of the social amenities that they are leaving behind (Box 2).


"Tying sacks of oysters, Olga, Louisiana" 1938.
Image Credit: Russell Lee

"This is all a productive oyster area right here [pointing to map]. This used to be and this used to be right here. This is wiped out right now because of a crevasse. These are historical oyster reefs that are irreplaceable. The crevasse is up here below Pointe a la Hache."
-Oysterman, Lower Plaquemines Parish, February 2019

Coastal Louisiana. Image Credit: NASA Worldview

BOX 2

COASTAL LOUISIANA:

What is at Stake?

Coastal Louisiana has a rich and diverse cultural history with traditions dating back centuries, most of which revolve around the unique ecology and resources of the coast. First settled by Indigenous inhabitants thousands of years ago, the area is home to some of the oldest human-made structures in the world. Louisiana was later settled by Acadians from Canada and Europeans, who brought enslaved Africans, all of whom reshaped the unique culture of the region. Attracted by the abundance of natural resources and the mouth of the Mississippi River, an essential trade corridor even today, Louisiana became and remains a hub of cultural exchange. In the early days of establishment, the coast provided an abundance of seafood, furs, and virgin cypress, which have since been harvested to near extinction in the state. The seafood industry continues to thrive as the nation's top provider of shrimp, oyster, blue crabs, crawfish, and alligators (Coastal Protection and Restoration Authority, 2017). In more recent history, the discovery of oil and gas has attracted many more people and provided supplemental employment to fishermen who were experts at navigating the waterways. By incorporating the industry into existing cultural norms and because the oil and gas industry employs so many people in Louisiana, the industry has become inextricably linked to the culture, perhaps best exemplified by Morgan City's Shrimp and Petroleum Festival.

While Louisiana contains an abundance of natural resources that supports a wide range of coastal industries and workers, it also experiences a wide range of environmental and anthropogenic hazards. Human activities, including the construction of levees that inhibit the deposit of sediment, the dredging of canals, and the deforestation of the wetlands, have had pronounced negative impacts on the coastal landscape. When combined with land subsidence and globally high levels of eustatic sea level rise, this landscape alteration has resulted in devastating levels of coastal land loss in the twentieth and twenty-first centuries. With this land loss, interior communities are becoming increasingly vulnerable to storm surge and tidal flooding.

Furthermore, while the oil and gas industry has proven to be a tremendous source of economic wellbeing for coastal residents (Hemmerling, Carruthers, et al., 2020), it also represents a source of physical and economic risk. Louisiana's coastal zone is home to a large number of facilities associated with the production, transportation, and processing of oil and gas. Though disasters like the Deepwater Horizon Oil Spill are rare, regular exposure to toxic environments pose health risk, often disproportionately impacting low income and minority residents (Hemmerling & Colten, 2017). Despite the potential negative consequences, the oil and gas industry employs more than 260,000 people in Louisiana and the severance tax on oil production funds necessary public services. This also means that fluctuations in global oil prices can significantly impact the state's economy. Recent decades have seen coastal communities go through a number of boom and bust cycles, highlighting the inherent precariousness of overreliance on coastal industries.

Today, Louisiana has become a gumbo of cultural traditions from around the world mixed with Indigenous traditions and language unique to the coastal landscape of the state. While Louisiana's abundant natural resources are important nationally and globally, the state's rich culture and history, which attracts millions of tourists each year, should be seen as equally important. Further, with climate change and sea level rise projected to significantly impact coastal communities globally, Louisiana is in a unique position to provide leadership and innovation in coastal management and resilience that can serve as a model for other at-risk areas.

Marsh birds, LA

Mississippi River, LA

New Orleans, LA

Lafayette, LA

Top left image by Allison DeJong. All others by Colleen McHugh

Outline of this Research

The primary objective of this research is to develop a holistic approach to integrated coastal risk mapping by incorporating local aspects of social and economic vulnerability into established risk assessment frameworks. The goal is to develop a practical trans-local methodology that can be adapted and utilized in various social and biophysical areas nationwide. Such a methodology can be used by state and local governments as a diagnostic tool to quantify community resilience and assess the effectiveness of investments in impacting a community's overall level of resilience across social, built, and environmental systems.

Many community resilience assessment tools already exist. However, there have been limited advancements in tools that: (1) account for change across geographic spaces and emergency scenarios over time; (2) adequately integrate environmental indicators of resilience; and (3) involve community participation in the development and application of the tool (Sharifi, 2016). The integrated coastal risk mapping framework developed and tested in the remainder of this report uses a novel combination of publicly available data and community engagement to quantify the interactions among infrastructure, environment, and society that drive the consequences of hazards and to assess the relative effects of different types of coastal planning investments.

Chapter 2 focuses on development of a quantitative coastwide resilience index that can be used to compare relative resilience at the block group level. The development of this index relies upon a modified hazards-vulnerability-consequence model of risk that includes a full spectrum of vulnerabilities, including social, ecological, and built environment. Within this framework, the impact of hazard events on the integrated built and social system is modulated by two factors: the physical exposure of locations (including the functional performance of its protective infrastructure) and the preparedness of the communities. The integrated risk mapping approach treats these modulators as overlays to the systems characteristics that comprise the integrated system vulnerability. The consequences of a hazard event are quantified in three dimensions: uncertain economic, environmental, and social impacts. While the data used in the development of this index included numerical model outputs and social vulnerability data developed for Louisiana's Coastal Master Plan (Coastal Protection and Restoration Authority of Louisiana, 2017; Hemmerling & Hijuelos, 2017; Johnson et al., 2013), the data model itself is modular, allowing for incorporation of a wide range of data inputs. The data framework is piloted and assessed using southeast Louisiana as a case study.

Chapter 3 explores how the lived experiences and collective memories of a community can directly impact the level of resilience possessed by that community. Local conditions and history have a direct impact on how hazards, vulnerabilities, and consequences are experienced and acted upon by community members. As a result, coastal protection and restoration projects may increase resilience in some communities but not in others. To fully understand the inherent resilience of communities requires an extensive understanding of local knowledge which

Lower Plaquemines Workshop, Louisiana

can only be gathered through qualitative research. The coastwide data model developed in Chapter 2 is enhanced here using local knowledge in order to derive a quantitative community-informed coastwide resilience index for southeast Louisiana. Qualitative data collection methods were piloted in the community of Morgan City, Louisiana.

Chapter 4 examines the history of public engagement in coastal planning followed by current correlations between community vulnerability, race, and ethnicity. The historical overview of public engagement in the coastal planning process highlights the current need to bridge the gap between state-level coastal decision-making and local-level communities who experience the results of those decisions. Much of the previous research on social vulnerability, including seminal work by Cutter and the social vulnerability index utilized in Louisiana's Coastal Master Plan (Cutter et al., 2003; Hemmerling & Hijuelos, 2017), recognized race and ethnicity as a distinct social vulnerability. This current research recognizes that racial and ethnic minority groups are more vulnerable to environmental hazards but that this vulnerability is not due to any inherent racial or ethnic characteristic. Rather, this research views these vulnerabilities as being directly linked to underlying social and economic condition that developed over time. The indices created in Chapters 2 and 3 were designed to be actionable and as a result do not include race and ethnicity as variables that can be changed to impact resilience. Chapter 4 subsequently explores the relationship between the indices and race and ethnicity.

In closing, Chapter 5 explores the utility of this research to inform coastal planning. It is critical that findings from community resilience assessments be translated into practical adaptation strategies (Sharifi, 2016). To this end, the outputs of this analysis can be used to show how measures designed to reduce the exposure and susceptibility of human populations and engineered systems to coastal hazards can improve the resilience of these systems and alter the consequences of hazards. By taking a holistic view of social vulnerability and involving local communities in the process of defining their own resilience-related challenges and opportunities, the integrated coastal risk mapping framework represents a step forward in quantitative risk mapping, ensuring that plans and decisions derived using the framework can more effectively minimize future losses for a full range of stakeholders and provide equitable access to the benefits of coastal planning investments.

Chapter 2

Mapping Multi-Attributed Risk & Resilience in Coastal Louisiana: A Regional Approach

The decade following Hurricane Katrina produced a number of large-scale coastal and riverine flood risk assessments. A great many of these have focused on modeling and mapping storm surge and flood hazards, often incorporating a quantitative analysis of economic risks and consequences. These risk assessment frameworks often take an engineering approach to address economic damages, only incorporating societal risk information that can be quantified and made to fit into existing quantitative frameworks. The general challenge in developing a more integrated coastal resilience assessment lies in finding ways to combine disparate datasets. Such an assessment requires a solid theoretical basis as well as methods and applications that will allow for the processing, interpretation, and communication of large amounts of risk information and data at different scales and in different locations (Assmuth & Hildén, 2008). This challenge is compounded by the fact that some data are difficult to quantify.

Information that cannot be easily quantified is often disregarded and not included in existing risk assessment frameworks (Assmuth & Hildén, 2008). This often includes measures of social vulnerability and community resilience. The impacts of hazard events are made more severe by preconditions of social vulnerability, conceptualized as the potential for harm to the wellbeing of human populations. Harm (or negative consequences) can be thought of as deaths, injuries, pain and suffering, disruptions of activities, family life, community functioning, and the loss of economic activities and services (Colten et al., 2008). While various investigations have dealt with some of these elements, there is a need to systematically incorporate societal factors into existing risk assessments in order to provide a more comprehensive picture of risk and resilience.

The present study integrates these multi-attributed aspects of coastal risk—economics, social, and environmental—into a unified coastal resilience assessment framework using a consistent set of quantitative metrics. While many existing models of vulnerability and risk profess to be integrated, including information about infrastructure, physical systems, and social systems, often some of these elements are represented more strongly in the models than others (Cutter et al., 2013). This framework makes the linkage between these disparate components explicit by adapting the traditional hazard-vulnerability-consequence perspective of risk assessment to incorporate aspects of social vulnerability and resilience (Figure 1). In engineering terms, integrated system vulnerability is a product of the geography of the hazard itself (exposure), inherent system characteristics (fragility), and adaptive capacity (performance persistence). This more holistic approach to integrated coastal risk mapping provides a practical tool that can be adapted and utilized in various social and biophysical areas nationwide.

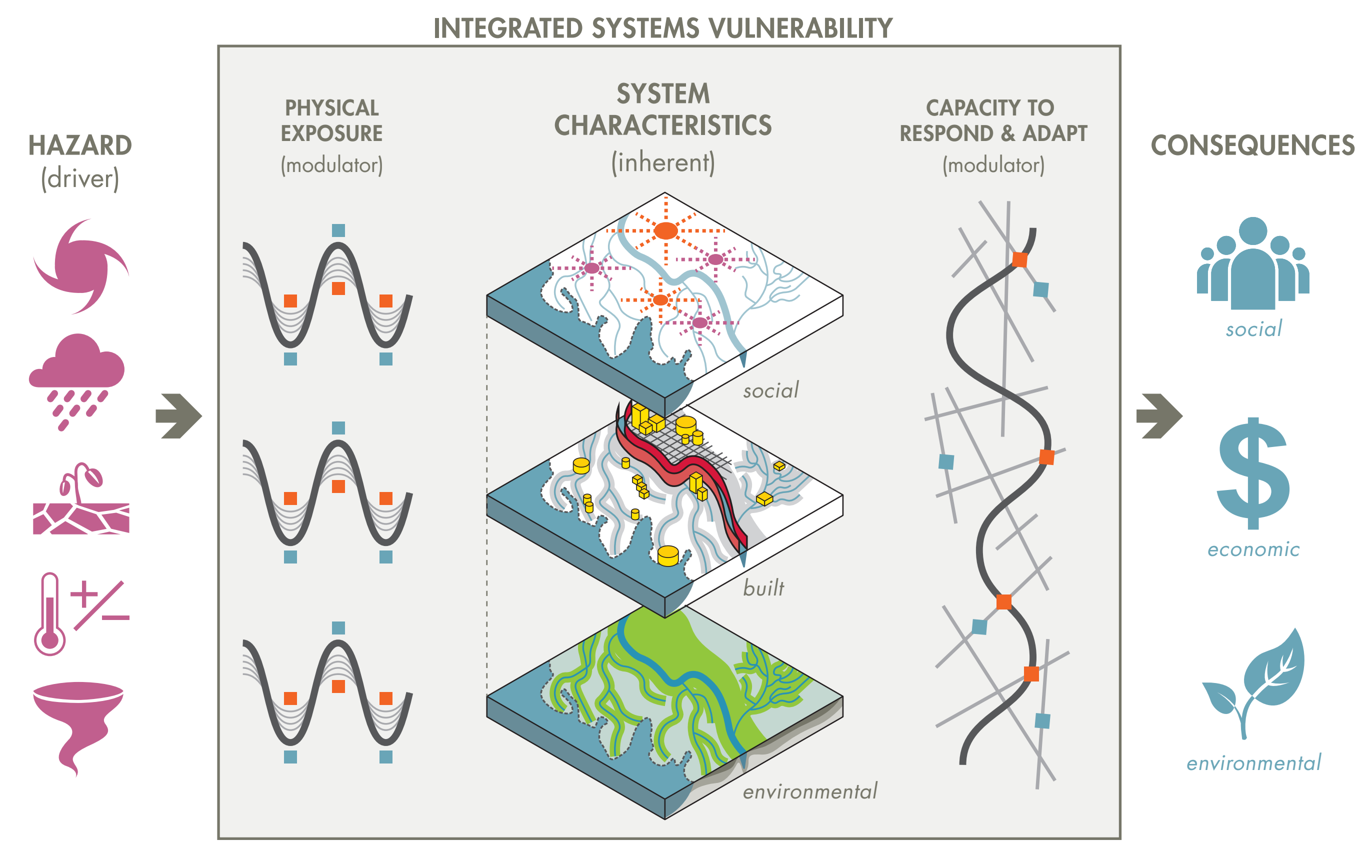


Figure 1. Conceptual diagram of the integrated risk mapping model framework.

Impacts of Hazards in Coastal Louisiana

At its most basic, a hazard can be thought of as a threat to human life and property. Put another way, there are no hazard impacts unless humans, their possessions, or their activities are involved. Traditionally, natural hazards researchers have viewed hazard events in terms of the direct effects they have on the human population, such as immediate loss of life and property. Viewed in this way, these events appear to be singular occurrences that provide an immediate shock to the human environment from which the population recovers and adapts. In many cases, however, the situation is much more complex than the literature would seem to indicate (Hemmerling, 2007). Hazards arise from the interaction between social, technological, and natural systems (Cutter, 2001). It is this interaction that forms the basis of a more integrative approach to hazards research, one that focuses on the entire mosaic of risks and hazards that impact an area. When technological hazard zones are combined with other technological and natural hazard zones, it becomes possible to define localized regions of higher and lower potential risk. The resultant "hazards of place" model describes hazards not only in terms of technological and natural risks, but also of local mitigation efforts (Cutter & Solecki, 1989). The mosaic of risks, or hazardscape, can be a landscape of many hazards within a region, or it may consist of comparisons of one type of hazard between regions (Cutter, 1993).

Southeast Louisiana is one of the most vulnerable coastal areas in the United States, facing recurring threats from coastal hazards, including large-scale, rapid-moving disasters such as hurricanes and storm surges and slow-moving disturbances such as land subsidence and sea level rise (Cai et al., 2016). In addition, the region supports nearly one-third of the nation's offshore oil production, which must be processed by an extensive network on onshore infrastructure. This presents a potential for release of air and water pollutants (Hemmerling et al., 2020). To assess a comprehensive suite of hazards impacting coastal Louisiana, this research utilized a hazardousness of place model. To fully gauge the resilience of coastal Louisiana, it is imperative to provide a full summary of the hazards that coastal residents face.

This research develops a hazardousness of place model to examine locations of significant cumulative hazards in coastal Louisiana[1]. Many of the hazards examined (see Box 3) are concentrated along the coastal fringe. This includes hurricanes and land loss. Other hazards, such as extreme rainfall, are more widespread over the study area. Industrial and technological hazards are also widespread over the study area. Temperature-related hazards are concentrated in urban areas, likely the result of the urban heat island effect. Taken cumulatively (Figure 2), we see some unique patterns emerge. Most strikingly, Lafourche and Terrebonne Parishes stand out, locations along both Barataria Bay and Terrebonne Bay, stretching up to the Mississippi River, through St. Charles and Jefferson Parishes. Beyond this large cluster of hazards, several locations along the region's waterways stand out, including the Mississippi River, Bayou Lafourche, and the Gulf Intracoastal Waterway (GIWW). Louisiana's waterways represent important locations for the oil and gas industry as well as locations where natural hazards such as riverine and coastal tidal flooding are concentrated.

[1] For a full description of the methods underlying this hazards analysis, see Risk and Resilience in Coastal Louisiana: Analytical Methodology for Assessing Hazards, Vulnerability, and Consequences.

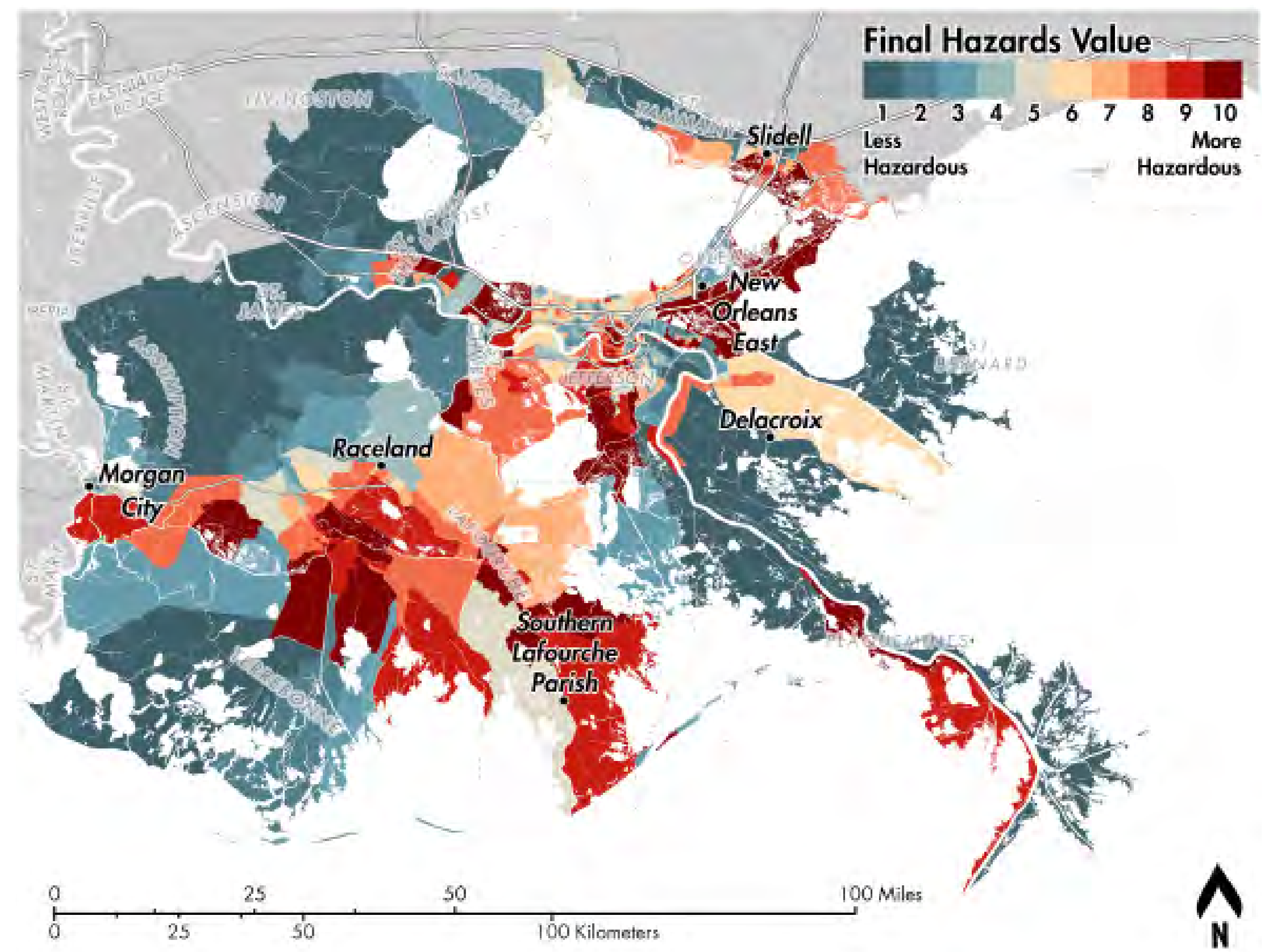


Figure 2. Cumulative ranking of potential impact for all documented hazards events across southern Louisiana.

BOX 3

Mapping Hazards in Coastal Louisiana

The hazards included in this assessment effort were extrapolated from geospatially enabled point, line, or polygon data, then interpolated to create a decadal index of continuous hazard surfaces for the 1980 to 2010 reference period. The average value of a unique hazard within every census block group located in a National Oceanographic and Atmospheric Administration (NOAA) coastal shoreline or coastal watershed parish was estimated using a simple geostatistical routine commonly known as zonal statistics. Decade specific zonal hazard values were then aggregated into an average value for the entire time period (1980 2010) and standardized using the average and standard deviation of the whole NOAA coastal parish modeling domain. These standard scores (termed z-scores) served as one of the primary inputs into follow-on deterministic statistical analysis. All hazard surfaces created by this analytical framework were then averaged and re-standardized to create a final hazard surface.

1. HURRICANES

Hurricanes and tropical storms are quickly rotating systems characterized by a central area of low pressure, partitioned atmospheric circulation at lower altitudes, strong winds, and a generally tentacular arrangement of thunderstorms extending outward from the convective center. In coastal Louisiana, tropical storms are significant drivers of coastal flooding, land loss, and population migration (Hori & Schafer, 2010; Roth, 2010; Stone et al., 1997).

2. EXTREME RAINFALL EVENTS

Extreme rainfall refers to instances during which the amount of precipitation experienced in a location substantially exceeds normal values. The potential impacts of heavy precipitation include crop damage, soil erosion, and an increase in areal flood risk due to ponding water. Precipitation runoff from already saturated soils can impair water quality as pollutants deposited on land wash into water bodies (Oldenborgh et al., 2017; Stott et al., 2016)

3. TEMPERATURE EXTREMES

Extreme temperature events are naturally occurring hazards affecting nearly every region of the world. Extreme heat has been correlated with amplified human and animal mortality as well as increased incidences of illness, wildfire, drought, and tornadic activity (Smoyer-Tomic et al., 2003). Extreme cold events and prolonged below-average temperatures are similarly linked with an elevated incidence of mortality in susceptible populations and decreased environmental productivity, as well as detrimental impacts to infrastructure and transportation (Deschenes & Moretti, 2009; Yang et al., 2009).

4. DROUGHT

A drought is defined by spatially dependent below-average precipitation resulting in prolonged shortages in local and regional water supply (Wilhite & Glantz, 1985). Droughts can last for months or years and can have a substantial impact on the ecosystem and agriculture of the affected region as well as associated negative effects to the local economy (Wilhite, 2000).

5. TORNADOES

Tornadoes are highly convective columns of air extending from the base of a thunderstorm system toward the ground, with wind speeds reaching nearly 300 miles per hour. Tornados occur as a result of powerful thunderstorms and can appear suddenly and without warning, causing fatalities and neighborhood-scale devastation in a matter of seconds. The damage path from a tornado can be in excess of 1 mile wide and more than 50 miles long (Masoomi & van de Lindt, 2018).

6. COASTAL FLOODING & STORM SURGE

Coastal flooding occurs in areas adjacent to a sea, ocean, or other large body of open water. Typically, coastal flooding occurs as the consequence of extreme tidal conditions resulting from severe weather. Storm surge is the leading cause of coastal flooding and often the greatest threat associated with a tropical storm activity in coastal Louisiana.

7. RIVERINE FLOODING

Riverine flooding occurs when excessive, extended rainfall causes a river to exceed its capacity. The damage from a river flood can be widespread because the overflow affects smaller rivers downstream, often causing water protection features to fail and subsequently inundate adjacent low-lying areas. Louisiana is dominated by riverine hydrology, and associated flooding is a major concern of coastal residents.

8. LAND LOSS

Coastal Louisiana has experienced a globally high rate of wetland loss due in part to a combination of sea level rise, subsidence, saltwater intrusion, and reduced sediment inflow. In the last 100 years, Louisiana lost more than 4,500 square kilometers of wetlands and is predicted to lose an additional 6,000 square kilometers over the next 50 years (Couvillion et al., 2017). The loss of these coastal wetlands represents not only a deterioration of ecological and economic viability, but a loss of the vital shoreline protection zone that insulates coastal communities from the impacts of coastal hazards such as storms and the effects of climate change.

9. OIL AND GAS INFRASTRUCTURE

Coastal Louisiana supports nearly one-third of crude oil production and one-fifth of natural gas production in the United States. While the majority of this production occurs offshore in the Gulf of Mexico, processing oil and gas after extraction is an energy-intensive undertaking requiring an expansive network of land-based infrastructure. Despite the economic benefits associated with oil and gas development, there are negatives related to potentially detrimental impacts to ecological and human health.

Integrated Systems Vulnerability in Coastal Louisiana

Vulnerability is a function of local socioeconomic conditions and the nature of the hazards to which the human population are exposed (Adger et al., 2004). While overall vulnerability is dependent upon exposure to specific hazards, social vulnerability represents the inherent characteristics of a community or population group that influence how it is able to respond to and recover from any number of theoretical hazard events. Many factors contribute to the ability of communities to respond adaptively to changing conditions, and these factors can be represented by any number of indicator variables. Indicator variables are either quantitative or qualitative measures derived from observed facts that simplify the reality of complex situations (Cutter et al., 2010).

This research study explored the integrated vulnerability of coastal Louisiana, recognizing that community resilience relies upon protecting not only vulnerable human populations but the built and natural environment that they rely upon for protection and sustenance. The next step of this research therefore involved identifying the datasets available to represent the assets and variables that comprise the natural and social systems at risk in coastal Louisiana. These may be absolute values (e.g., acres of wetland of a specific type) or scaled indices (e.g., proportion of low-moderate income households). The quantity and quality of available data were assessed in terms of their temporal and spatial extent, the reliability of the data, and their appropriateness for use as indicator variables. Three broad categories of data were explored:

1. **Built Assets –** Relevant critical and essential facilities in coastal Louisiana mapped by census block using Federal Emergency Management Agency HAZUS data, InfoUSA, and other relevant datasets. For the purposes of this research, critical facilities are broadly defined as those that are needed during a disaster while essential facilities are defined as those that a community needs in order to return to full functioning.

2. **Environmental Assets –** Environmental assets in coastal Louisiana mapped using datasets from the Louisiana Department of Wildlife and Fisheries, the U.S. Fish and Wildlife Service, and the U.S. Geological Survey. These datasets include conservation opportunity areas, extent of wetland and habitat suitability for a number of critical species, and scenic rivers, parks, and other recreational spaces.

3. **Social Assets –** Identified parameters in socioeconomic conditions in coastal Louisiana mapped by census block using census data and other relevant administrative data sources. These data focus primarily on social vulnerabilities that affect a society's ability to prepare for and recover from a hazard event. The most widely accepted demographic and social characteristics of residents that make some communities more vulnerable than others include socioeconomic status, age, and special needs, including physical disabilities.

Data for each set of assets were assembled and used to determine the geospatial unit(s) of analysis that best represent spatial patterns and variability of the data while enabling integration among multiple asset types. Once assembled, the asset data were further subdivided into seven resilience dimensions to allow for more refined vulnerability mapping. The five most common dimensions measured by community resilience assessments are environmental, social, economic, built environment, infrastructure, and institutional resilience (Sharifi, 2016). The National Institute of Standards and Technology utilizes these dimensions but expands the social dimension into three separate dimensions of resilience: population and demographics; lifestyle and community competence; and social-cultural capital, for a total of seven dimensions (Renschler et al., 2010). Population and demographics is comprised of a number of static indicators that are most commonly used during social vulnerability assessments (see Box 4). The latter two dimensions are more variable and require additional input from community members about the dynamic (rather than static) characteristics of their community. Lifestyle and community competence metrics measure the extent to which people are involved in politics, can respond constructively to adversity, and can produce effective leaders. Social-cultural capital measures the extent to which people are connected to each other and their environment. Data used in this research to assess the inherent systems characteristics used in the integrated systems vulnerability model were classified into the seven NIST resilience dimensions (Figure 3). One cumulative index was created for each dimension and these were combined using an unweighted additive model.

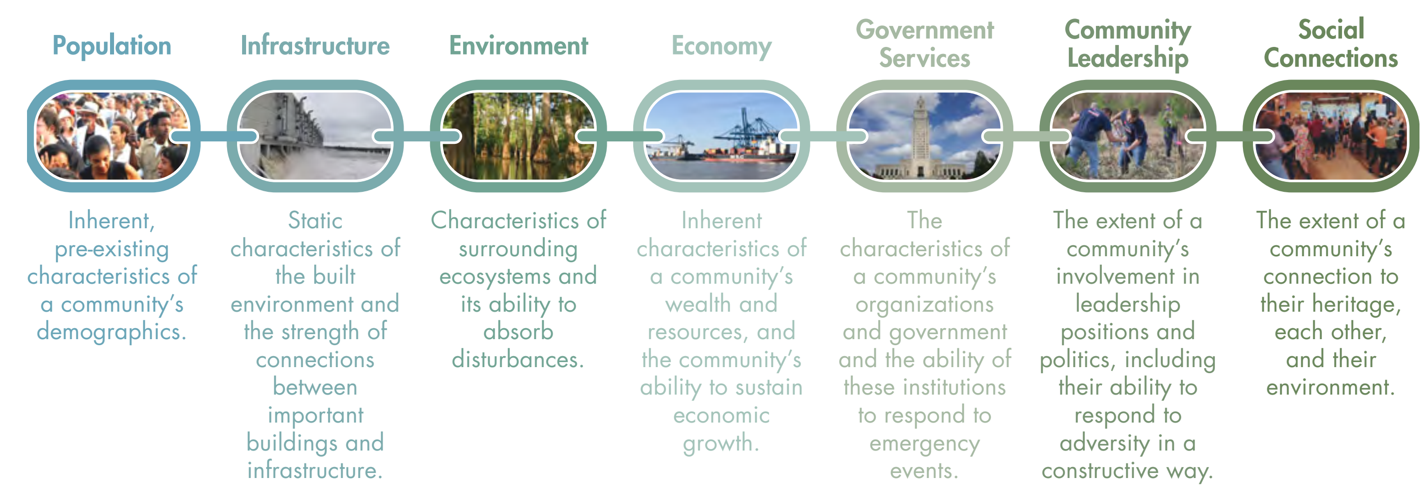


Figure 3. The seven dimensions of resilience used in the development of the integrated systems vulnerability model (adapted from Renschler et al., 2010).

The final integrated systems vulnerability surface (Figure 4) reveals an extremely patchy pattern, with locations of extremely high vulnerability immediately adjacent to locations of extremely low vulnerability. This is most notable in New Orleans and Jefferson Parish, on both the east and west banks of the Mississippi River. Similarly, the north shore of Lake Pontchartrain exhibit similar dichotomies with locations of extreme low vulnerability in St. Tammany Parish border by areas of high vulnerability in Slidell to the east and in Tangipahoa Parish to the west. Strikingly, the coastal fringe of southeast Louisiana, an area previously noted as having a significantly high risk of hurricanes and other tropical events, also has a high level of cumulative vulnerability. Where cumulative vulnerability is the highest, socially vulnerable populations, the critical and essential facilities they rely upon, and the surrounding ecology are particularly vulnerable to hazard events. When such locations coincide with area with locations of heightened physical exposure potential, the possibility of heightened impacts is increased.

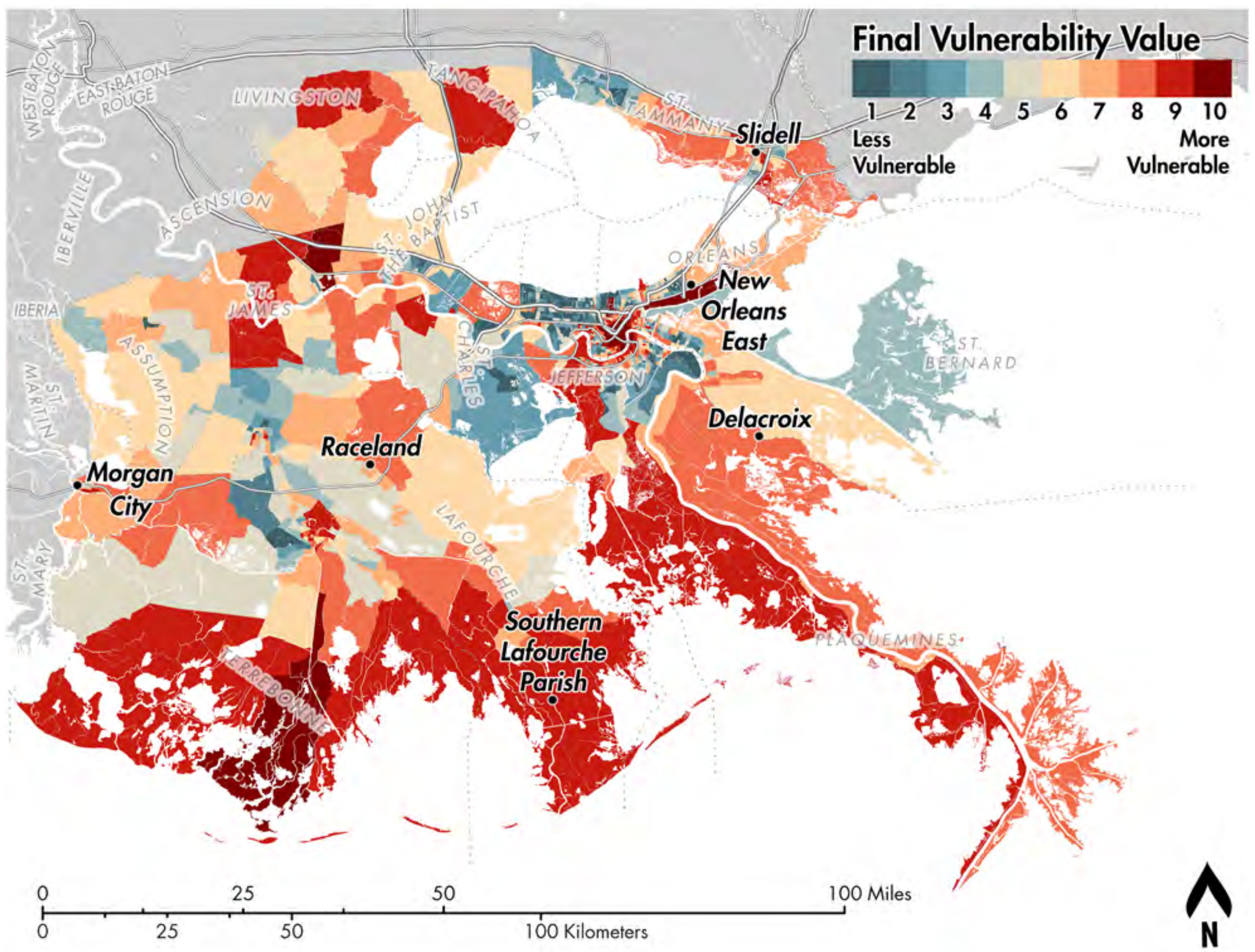


Figure 4. Integrated systems vulnerability ranking for the southeast Louisiana study area.

BOX 4

Methods of Assessing Social Vulnerability

This research utilizes a social vulnerability methodology to examine the underlying socioeconomic, institutional, political, and cultural factors that determine how people within coastal Louisiana respond to a wide range of existing or hypothetical hazard events (Adger et al., 2004). Social vulnerability is a structural condition that affects a society's ability to prepare for and recover from a hazard event. It is a pre-existing property that modulates the effect that the hazard has on communities. The most widely accepted demographic and social characteristics of residents that make some communities more vulnerable than others include socioeconomic status, age, and special needs, including physical disabilities. Additionally, communities that rely on a single economic sector for their livelihoods are more vulnerable than those communities with a diversified economic base (Cutter, 2008). This is especially true of communities that rely economically on natural resources, such as fisheries, for their livelihoods (Hemmerling & Hijuelos, 2016; Jepson & Colburn, 2013; Tuler et al., 2008). We utilized a statistical modeling approach using indicator variables to quantify relative levels of social vulnerability across space and develop a social vulnerability index (Cutter et al., 2003). This approach enables relative vulnerability comparisons between communities and between geographical regions, which can aid in evaluating the susceptibility of communities to future hazardous threats. An enhanced understanding of the factors that determine vulnerability will also aid in identifying actions to reduce vulnerability (Adger et al., 2004).

While much of the current literature utilizes factors related to race, ethnicity, and gender in their assessments of social vulnerability, this research recognizes that these factors in and of themselves do not constitute an inherent vulnerability. Rather, these factors interact with a complex system of social and economic factors that, in many cases, results in these populations experiencing social amplifications of risk. For this reason, this research addresses the specific socioeconomic underpinnings of vulnerability and will then assess how racial and ethnic minorities are positively or negative correlated with these factors. This approach will allow planners to more directly address the socioeconomic inequities that these populations face.

Damage & Recovery from Disasters

There is often a great deal of spatial variation in exposure to coastal hazards. When combined with different levels of inherent vulnerability, different locations may experience uneven responses and levels of recovery. This is often true of different locations occupying the same region. The consequences of hazards can be examined in two very distinct ways: damage from hazard exposure and recovery from exposure (Cai et al., 2016). Damage can be represented by a diverse set of variables, ranging from physical and economic to social and mental. This could include residential and commercial property damage and the amount of debris generated but also mental and emotional damage suffered by impacted residents, signified by increased rates of depression and substance abuse. While indicators of damage represent one end of the spectrum for impacted residents, recovery represents the other. The most commonly used indicator for recovery after a disaster is population change over time (Cai et al., 2016). This indicator reflects a wide range of decisions made by individuals to remain in an area after disturbances (Lam et al., 2016). While population change on its own may not necessarily indicate recovery, it is meaningful when evaluated in the context of exposure and damages from hazard events (Lam et al., 2016). Taken together, damage and recovery estimates have multiple scales of consequences, from remaining in place and suffering health consequences to making the difficult decision to leave one's home or community (Box 5). Understanding these underlying indicators is critical for identifying the places that are resilient to disasters (Cai et al., 2016).

When examined spatially, the consequences of hazard events and the recovery from recent hazard events reveal two very different patterns. The consequences of hazards (Figure 5) unsurprisingly reveal a pattern like that seen in the cumulative hazards map with

Lower Ninth Ward, New Orleans, LA. 2013. Image Credit: Colleen McHugh

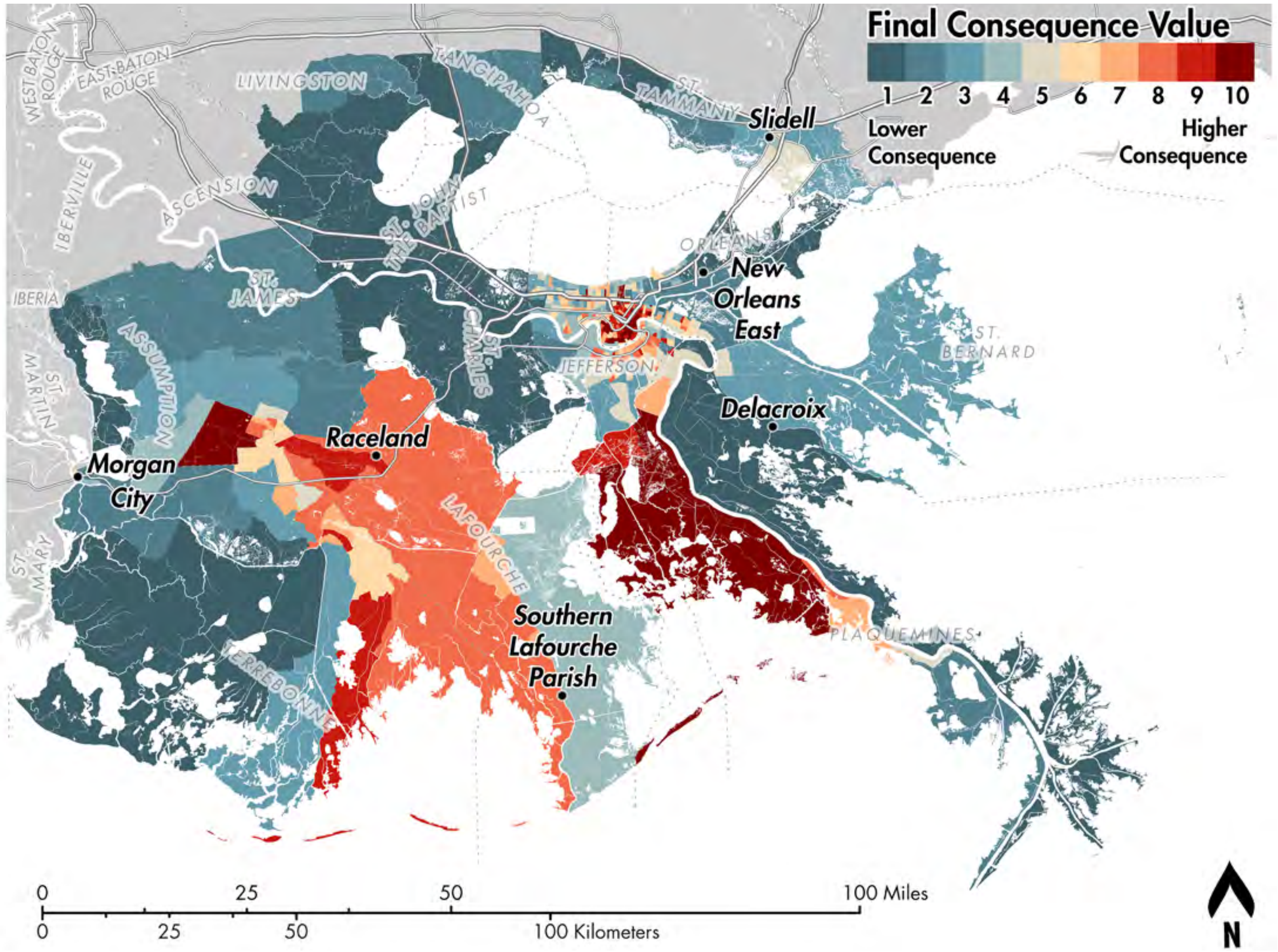


Figure 5. Cumulative ranking of final consequence clusters across southeast Louisiana.

locations along Barataria Bay and Terrebonne Bay, including Terrebonne Parish, the western half of Lafourche Parish, and the west bank of the Mississippi River in Plaquemines Parish. The majority of these consequences appear to be the result of the potential economic consequences of hazards, including unemployment and loss of economic outputs. Given that these locations are heavily reliant on natural resource-based employment such as oil and gas and fisheries, these results are not surprising. Of all the outcomes that comprise the cumulative surface, only mental health outcomes are spread evenly spread across the study area, suggesting that the social impact of hazard events extend far beyond geographic impact areas.

Flooding in Baton Rouge, LA. 2016

The patchiness of the mental health outcomes of hazard events is mirrored in the patterns of recovery. Recovery, assessed in term of population loss and growth, reveals high levels of population loss throughout New Orleans, particularly in New Orleans East in the five years between 2012 and 2017 (Figure 6). Many of the suburban parishes surrounding New Orleans, including virtually the entire circum-Pontchartrain region, have experienced high levels of population growth. Many coastal areas that had previously suffered massive population loss in the aftermath of Hurricane Katrina, such as Plaquemines and St. Bernard Parishes appear to show signs of recovery, with a high percentage of population growth in recent years.

> "[The rate of flood insurance is]… a large reason why people are just moving into mobile homes, not building. And like I said, raising the homes is just not feasible to pay. There's no help there, and they're not gonna do it. And to relocate, you can't sell your home, so they don't have money to relocate either."
>
> - Resident, Plaquemines Parish, February 2019

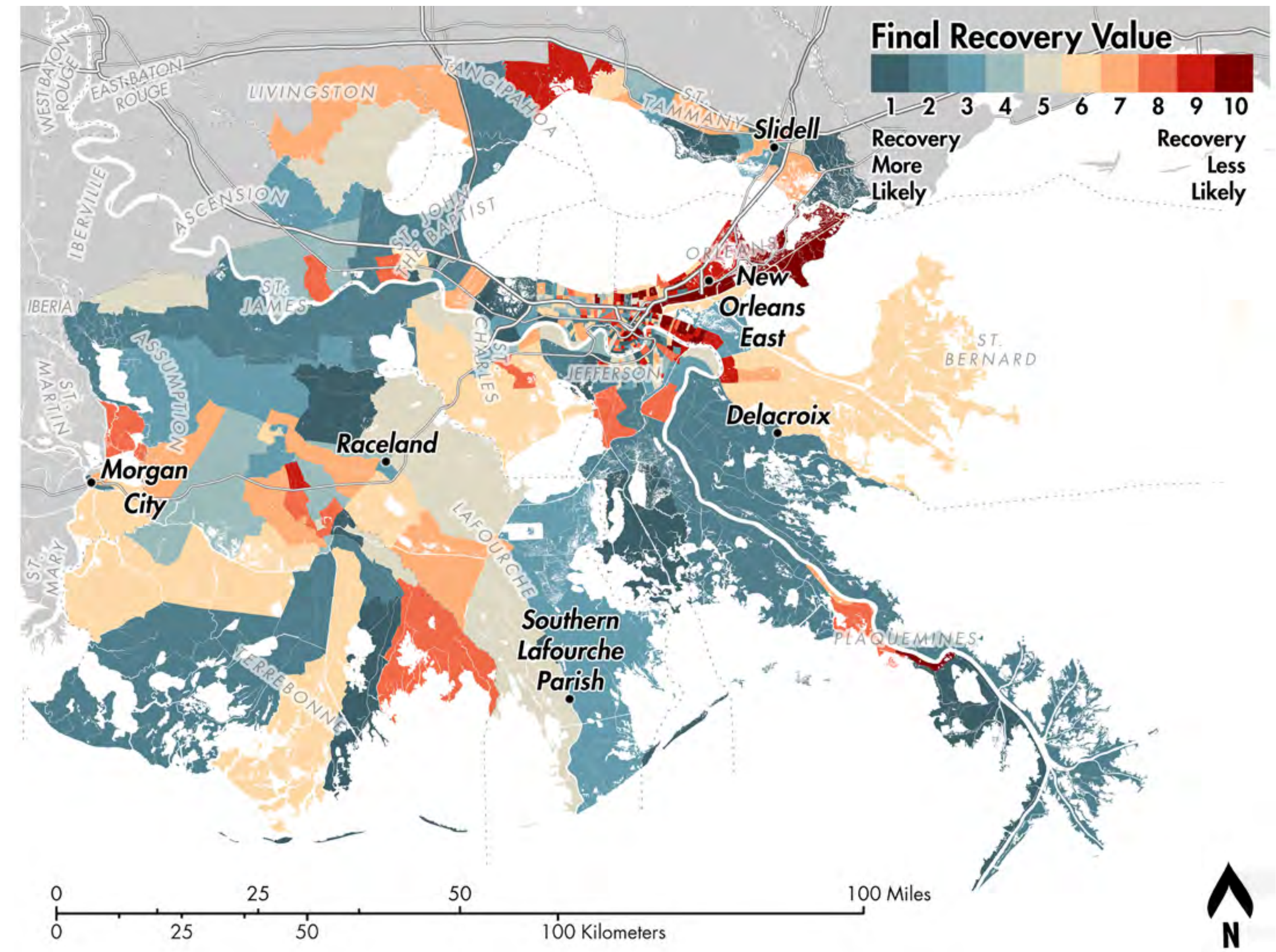


Figure 6. Final recovery clusters represented as deciles. Higher cluster values indicate a higher likelihood of external population migration.

Flooding in Baton Rouge, LA. 2016. Image Credit: US Coast Guard

BOX 5

THE RESPONSE OF THE SYSTEM:

Measuring the Consequences of Hazards Events

Spatial analysis was used to identify and map the locations where communities and assets are at risk from current and modeled coastal hazard events. The physical, economic, and social dimensions of hazard consequence were evaluated through use of the natural hazard analysis program HAZUS, distributed by the Federal Emergency Management Agency. The HAZUS modeling regime considered by this study utilizes a probabilistic hurricane scenario based on all 10-, 20-, 50-, 100-, 200-, 500-, and 1,000-year return period storms included in the HAZUS hurricane database run on a regional census tract basis. Consequence determination utilized a cumulative evaluation of the impact of the four highest intensity storm return periods. The consequence values were then mapped spatially and are visualized in Figure 5 and Figure 6.

1. PHYSICAL CONSEQUENCES

Physical consequence was evaluated based on the average tonnage of debris (wood, brick/concrete, and tree debris) generated by the four highest intensity reoccurrence probabilities aggregated with the average percentage of buildings experiencing damage across the residential, commercial, industrial, education, non-profit, and government sectors. Both average debris generation and average percentage building damage were normalized based on a tract area basis to account for the influence that densely constructed, urbanized census tracts have on the overall NOAA coastal parish valuation. A cumulative combined standard score was calculated through use of the Pearson product-moment correlation coefficient.

2. ECONOMIC CONSEQUENCES

Economic consequences were evaluated based on the average dollar value of employment and output loss across all sectors for all four highest intensity storm return periods. Employment and output loss, estimated in thousands of dollars, were totaled across each sector for each return period and averaged to form an aggregate estimation of consequent monetary loss. As with the physical damage dimension, the resultant aggregate estimate was normalized to remove potential bias from dense urban areas. The results were normalized based on total tract population.

3. SOCIAL CONSEQUENCES

Social consequences were assessed utilizing aggregated estimates of total displaced households and short term shelter requirements. Estimates of these variables were averaged over the four highest intensity return periods and normalized based on the universe of each variable, total tract households for displaced households and total population for short-term shelter requirements. A cumulative combined standard score was determined through use of the Pearson product-moment correlation coefficient.

4. MENTAL HEALTH CONSEQUENCES

Mental health consequences were assessed using data sourced from the Centers for Disease Control and Prevention Behavioral Risk Factor Surveillance System and PolicyMap database. Three mental health factors, each collected in 2017, were aggregated to develop a final mental health consequence value: excessive drinking, days of poor mental health, and incidence of depression. Data were made available at the census tract level and aggregated based on the average valuation for each contributing mental health metric. A final mental health score was determined by taking the average value of each contributing variable.

5. COMMUNITY RECOVERY

Community recovery was estimated using the block group population change rate between the 2008-2012 and 2013-2017 American Community Survey (ACS) 5-year estimates obtained from the U.S. Census Bureau and the National Historical Geographic Information System. Because ACS data are pooled across years, rates of change cannot be calculated on an annual basis. Comparisons over time can only be made on 5-year ACS estimates without overlapping years.

Pulling It All Together: How Composite Data Are Developed

The primary objective of this research was to develop a holistic quantitative method to assess community resilience to a broad range of coastal hazards. The resultant integrated coastal risk mapping model was applied at the block group level and used to understand the interactions among infrastructure, environment, and society that drive system damage and recovery. These data were used to derive a quantitative resilience index that was empirically validated through two statistical procedures: K-means cluster analysis of exposure, damage, and recovery variables to derive the resilience groups and discriminant analysis to identify the key indicators of resilience (Cai et al., 2016). K-means clustering is a method that allows researchers to quickly cluster and identify structures within large datasets. For this research, the three dimensions of resilience (hazards, consequences, recovery) were analyzed using k means clustering to classify each of the block groups into different resilience states. As each of the individual components comprising the hazard, consequence, and recovery values were standardized, each of the individual resilience dimensions themselves were standardized into z-scores to account for the different scales of the three dimensions. Discriminant analysis is a statistical procedure that builds a predictive model for group membership and is composed of a discriminant function based on linear combinations of predictor variables. The goal of this portion of the research was to identify the underlying socioeconomic and environmental characteristics of the southeast Louisiana study area that can be used to predict the community resilience states (Cai et al., 2016). The clustering classification for the composite score of the three dimensions of resilience (hazards, consequences, recovery) determined through the k means clustering process was used as the categorical grouping variable in the discriminant analysis while the principal components derived in the Principal Components Analysis were the independent predictor variables.

When hazards, vulnerabilities, and consequences are combined into a final unweighted resilience surface, the results show, as the input datasets suggested, that the coastal parishes bounding both Barataria Bay and Terrebonne Bay, including Terrebonne, Lafourche, lower Jefferson, and western Plaquemines Parishes are the most at risk, indicative of low levels of resilience. The same holds for cities bounding the eastern shore of Lake Pontchartrain such as Slidell and New Orleans East and rural St. Bernard Parish. Communities along the GIWW, including Morgan City, also exhibit low levels of resilience. Portions of New Orleans including the lake front of Lake Pontchartrain, Jefferson Parish and St. Tammany Parish all show high levels of resilience. Unexpectedly, portions of coastal Terrebonne Parish and the east bank of Plaquemines Parish exhibit high levels of resilience as do rural locations in Assumption and St. Charles Parishes. These results highlight that resilience is multifaceted and can run the gamut of urban, rural, coastal, and noncoastal.

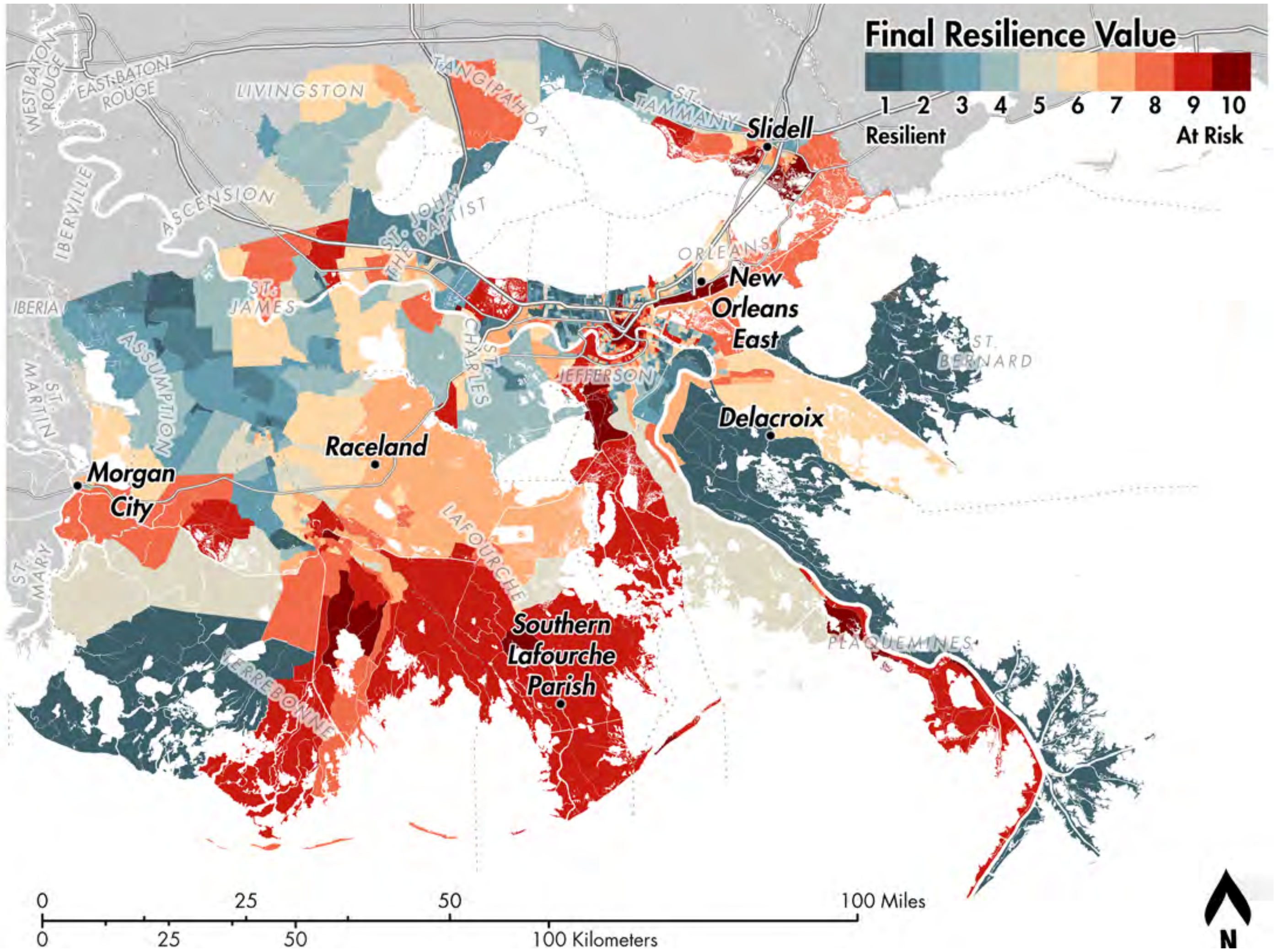
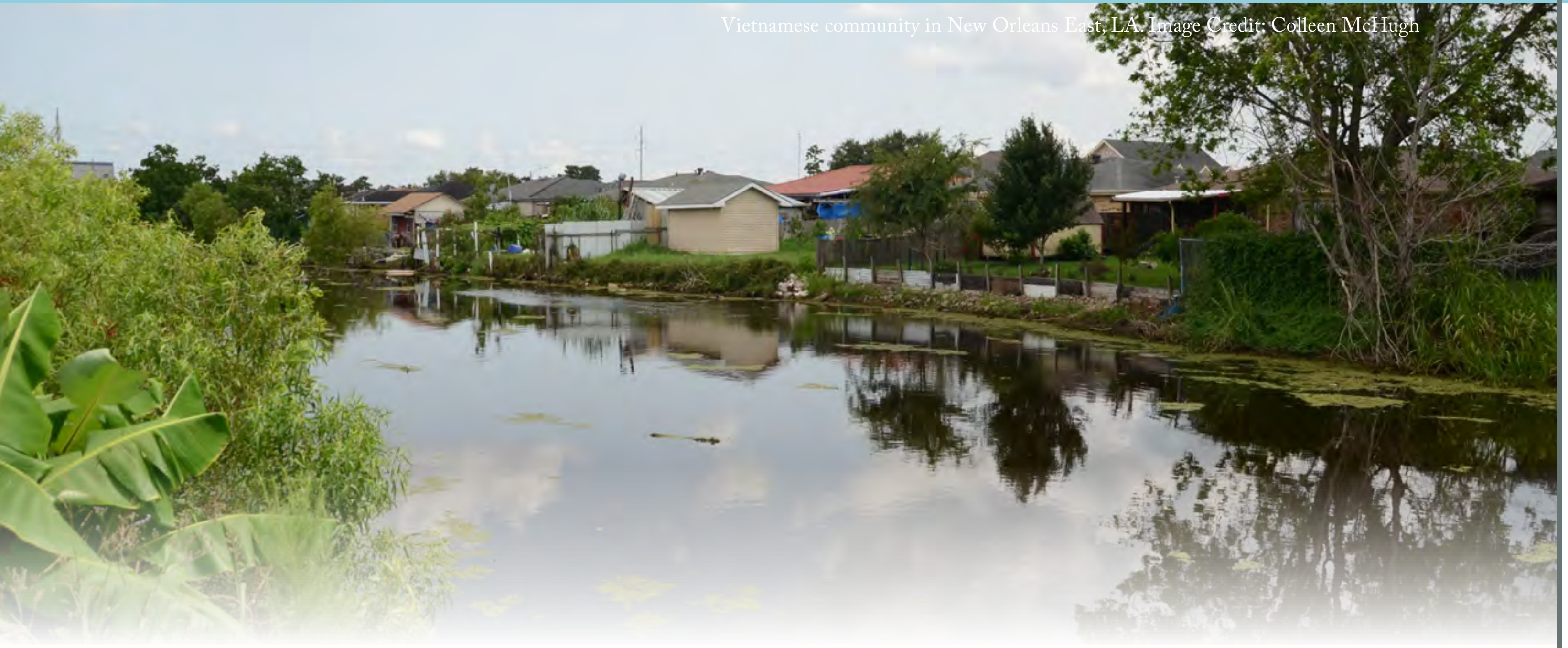


Figure 7. Weighted final resilience score for southeast Louisiana.



Vietnamese community in New Orleans East, LA. Image Credit: Colleen McHugh

Chapter 3

Recognizing the Value of Local Knowledge: Inherent Resilience in Coastal Louisiana

Inherent Resilience in Coastal Louisiana

Beyond the cities of New Orleans and Houma, the Lower Mississippi River delta region of southeast Louisiana consists mainly of low-lying marshes and narrow strips of populated land atop relict natural levees. This region is home to populations of Indigenous peoples, Acadians, Isleños, African Americans, and Asians predominantly living in linear villages where they have endured repeated disruptions in the form of hurricanes, floods, and oil spills as well as ongoing threats resulting from coastal land loss and sea level rise (Colten et al., 2018a; Hemmerling, 2017). Following disasters and other traumatic events, both environmental and economic, many residents have migrated away from highly exposed locations; however, coastal communities and the economic activities that sustain them endure. These communities share two key traits that have allowed them to persist in this changing environment: dedicated attachments to a perilous place and heavy reliance on resource-based livelihoods (Colten et al., 2012). Their ability to recover from repeated disruptions suggests a degree of inherent resilience. Inherent resilience consists of "practices that natural resource-dependent residents deploy to cope with disruptions and that are retained in their collective memory" (Colten et al., 2012). Inherent resilience operates at a local level that is not readily revealed by the quantitative indices and measures generally used to gauge the social vulnerability and resilience of coastal communities. Furthermore, current planning does little to reveal either the local or personal level of hazard impacts and fails to recognize the local networks that can most effectively enhance inherent resilience (Colten et al., 2012). This research begins to remedy this by developing a rigorous and replicable scientific method that will allow community engagement to become a part of the standard process of resilience assessment. The data derived from this community engagement process can be included in the integrated risk model developed in Chapter 2, allowing coastal scientists and planners to effectively scale-up local perspectives and integrate the results of qualitative analysis into statewide decision making. The resultant community-informed integrated risk model directly recognizes that that community resilience is the result of human decision-making processes and can provide decisionmakers with more nuanced information on how certain projects differentially impact local communities and stakeholder groups. This process is further illustrated at the end of this chapter (see Box 6).

Why Local Resilience Matters

While engineers might define resilience as the "joint probability of meeting objectives with respect to functional performance and recovery, given the severity of a particular hazard event (Schultz et al., 2012)," such a definition does not begin to get at what makes communities resilient. A resilient community is far more than one that is protected from hurricanes, floods, and other hazards. Clearly, risk mitigation is a key component of resilience, but a resilient community may also be one with high levels of educational attainment and low levels of crime or one that provides safe spaces for children to play. A resilient community may also be one where we see a diversified economy. Without economic opportunity, younger residents will seek employment elsewhere, which can impact residents across all levels of the economic spectrum. Residents are also tied to communities by more intangible aspects, such as the sense of place that a community exudes or a rich cultural heritage that binds people to place over time. This binding of people to place is community resilience and it is the strength of these binds that determines how resilient a community it. Ultimately, it is community members who are forced to make difficult decisions on whether to stay in their homes or retreat to new locations that are perceived as being safer or able to provide an enhanced quality of life of wellbeing. These decisions may be informed by model results or socioeconomic data in a quantitative index, but such data is but one factor in a complex suite of factors that are often difficult to quantify.

To begin to understand the social impacts of coastal hazards and risk and how this impacts community resilience requires an extensive understanding of local knowledge. The people who live and work in coastal communities are becoming recognized as repositories of valuable

Delacroix, LA. Image Credit: Colleen McHugh

> "I think that historically all of ya'll do a great job, because storms and flooding—just like we had all of the flooding in the Spring—the minds get together and they take care of our environment and our people. So hats off to all of ya'll, I think ya'll do a great job from all of those types of hazards."
>
> -School teacher, Morgan City, February 2020

local knowledge of concentrated community risks that reduce capacity in preparedness, such as issues of safety, health, and education, as well as the critical social infrastructure network that they would access in response and recovery (Curtis et al., 2018). Community members also hold perceptions of risk that shape their preparedness and mitigation activities, such as which places in their community are dangerous and which are thought to be safe. Such local knowledge and environmental perceptions are often geographically explicit and are powerful influences on behavior (Curtis et al. 2018). It is essential that coastal scientists, planners, and policymakers account for these data to form a more complete evidence base in guiding the development of resilient coastal communities (Hemmerling, Barra, et al., 2020). A resilience plan that will benefit the residents of New Orleans may not have the same resilience benefits for residents of Delcroix or Golden Meadow or Grand Bayou. Moreover, decisions made to benefit New Orleans might not even have the same benefit for residents of that city's Ninth Ward neighborhood. By integrating public perceptions data and numerical modeling, this research acknowledges the complex nature of resilience. Moreover, this research acknowledges that projects designed to enhance resilience at a broad regional scale may not have the desired effect at the community scale and provides planners and decisionmakers with a tool that can assess resilience at multiple scales.

Engaging with Residents to Better Assess Inherent Resilience

Despite the scientific rigor behind quantitative, data-based assessments of social vulnerability and community resilience, there are limits to the ability of secondary data sources to capture elements of inherent resilience, particularly at the local level. Challenges to measuring elements of local resilience include accounting for change across a broad range of geographical spaces, accounting for multiple emergency scenarios over time, adequately integrating environmental indicators of resilience, effectively utilizing community participation in the development and application of resilience tools, and translating findings into effective adaptation strategies (Sharifi, 2016). To fully understand the social impacts of coastal hazards and other community-level risk requires an extensive understanding of local knowledge. Many "cultural impacts involving changes to the norms, values, and beliefs" are not quantified and require direct interaction with community members to be documented (King, 2000). Blending qualitative research (interviews and community forums) with quantitative analysis (demographic and economic data) magnifies understanding of the local situation. Qualitative methods allow researchers to effectively field test conclusions drawn from quantitative methods and can identify analytical approaches tailored to specific local concerns.

This research study developed and field-tested a series of unique stakeholder engagement methods designed to gather qualitative data that can be incorporated into a quantitative data framework to assess levels of community resilience in southeast Louisiana. Engagement with local stakeholders provided additional insight and data to ensure the relevance of quantitative variables to a wide range of communities across coastal Louisiana. Additionally, qualitative research was used to identify other factors specific to this region that have not been included in other frameworks and indices. The results of this assessment were used to derive a resilience framework that more fully captures the dynamics of the natural and human systems in coastal Louisiana.

Measuring Local Risk & Resilience in Coastal Communities

Long-time residents of coastal communities will have insights into how their communities and surrounding environs have changed in the aftermath of hurricanes or how these places have gradually transformed as a result of coastal land loss, sea level rise and land subsidence (Curtis et al., 2018). Such knowledge cannot be gleaned from the development of traditional social vulnerability indices and similar quantitative measures but it vital to understanding what makes one community more resilient than another. Indeed, the Interorganizational Committee on Principles and Guidelines for Social Impact Assessment emphasizes that interacting with community members and gauging what is directly of concern to them can add to insights gained from analyzing standard statistical sources (Interorganizational Committee on Principles and Guidelines for Social Impact Assessment, 2003). Despite the rigor behind the development of the integrated coastal risk mapping model, researchers recognize that there are limits to the ability of secondary data sources to fully capture community resilience, particularly at the local level. Challenges to measuring community resilience include accounting for change across a broad range of geographical spaces, accounting for multiple emergency scenarios over time, adequately integrating environmental indicators of resilience, effectively utilizing community participation in the development and application of resilience tools, and translating findings into effective adaptation strategies (Sharifi, 2016). Engagement with local knowledge experts can address many of these challenges. Local knowledge experts that represent a range of differences in cultural heritage, geography, population density, natural resource dependency, and susceptibility to hazards and should be directly engaged through this process. The data captured from these experts can be used to measure the relative importance of individual resilience dimensions in their communities.

"My biggest problem is that I can't go way over here (to shrimp) because I live right here. Why would I want to leave my home? I could have left after Katrina. That would have been very easy for me to do, but I didn't do it.... I don't want to leave my home. Shouldn't have to."

-Shrimper, Lower Plaquemines Parish, February 2019

These workshop methods derived for this research includes a combination of facilitated group conversations, live polling activities, and local knowledge mapping exercises[2]. The acquired data can be analyzed quantitatively and qualitatively and directly input into the integrated risk model to derive a community-informed integrated risk model that more accurately captures issues of local resilience. The workshop methods described here are designed to enhance rather than replace the integrated risk model developed in the previous chapter. This research operates on the assumption that the seven dimensions of resilience are experienced differentially across community types and stakeholder groups. For example, an urban neighborhood will weigh the dimensions of resilience differently than a rural town. In the same way, a rural town reliant on commercial fisheries will weigh the dimensions of resilience differently than a rural town reliant on farming or ranching. Racial and ethnic groups may have their own unique values and vulnerabilities that influence their overall level of resilience. Researchers should also include these groups as a key component of this qualitative research. This will create a more complete evidence base for planners and decisionmakers to operate from.

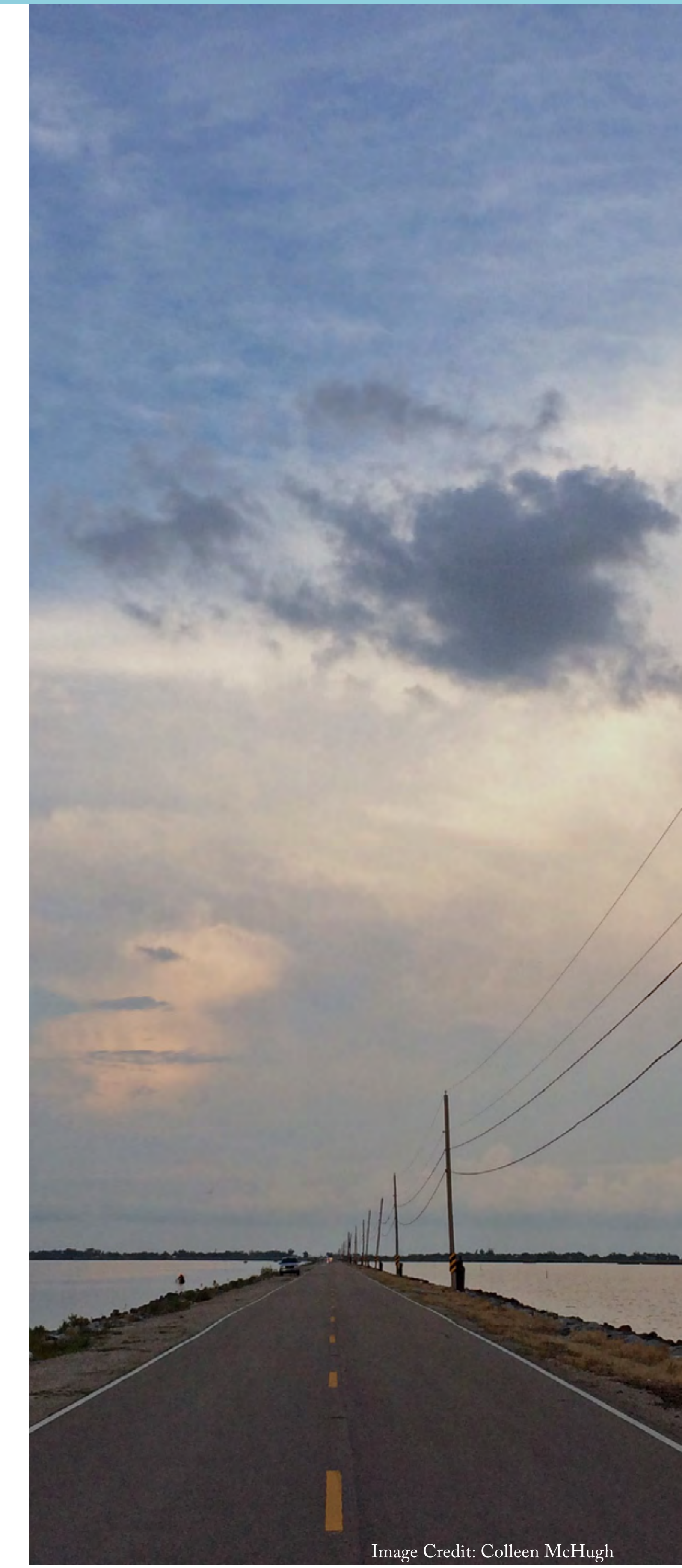


Image Credit: Colleen McHugh

[2]For more detail on the workshop methods developed for this research, see Walton Resilience Project: Workshop Methods technical memorandum.

Group Conversations

Key to the success of these workshops is that researchers acknowledge the value of the knowledge possessed by community members and create a venue for an open and honest dialogue around issues of community resilience. This dialogue should be structured to provide insight into local or regional factors that have not been included in previous resilience frameworks and indices. The qualitative data derived from the group conversations can be used to derive a set of variables that more fully capture the local dynamics of the natural and human systems.

Prior to beginning any more structured activities, workshop attendees should be given an opportunity to discuss what resilience means to them and their community. Conversation prompts should specifically focus on recent and historical hazards that have impacted the area, how the population responded, and how the community has changed as a result. To assure the validity of the integrated risk model, workshop attendees should be also given an opportunity to review and comment on the integrated risk model and the maps developed in earlier phases of research.

All feedback should be collected in a structured, scientifically sound manner. Data derived through the group conversations (and all subsequent workshop activities) should be recorded with the permission of workshop attendees. This will allow the conversations to be transcribed, coded, and transformed into qualitative data that can be analyzed to detect underlying themes in the dialogue.

Local Knowledge Mapping

Many science-driven planning processes rely upon quantitative, geospatial datasets as model inputs and to derive metrics as criteria for evaluating the effectiveness of protection and restoration projects. While these datasets are effective at locating any number of nonresidential, residential, and infrastructure assets at risk within an area, they are not able to specifically identify places that have social or cultural value to residents and communities (Hemmerling et al., 2020). The social and cultural values of a place are often key anchor points for community resilience. Identifying these assets are integral to defining local resilience. Local knowledge mapping is an approach that aims to encourage community member participation in sharing knowledge and perceptions of a given area and has been shown to provide an effective means of incorporating community and traditional ecological knowledge into a coastal protection and restoration framework (Curtis et al., 2018). Local knowledge mapping typically involves having local stakeholders mark locations on paper maps and discuss the meaning behind such places. The data collected during local knowledge mapping exercises can be used to create a geospatially explicit baseline dataset allowing researchers to incorporate local knowledge into an assessment of ecological restoration projects.

Live Polling Activities

After identifying community risks and hazards and discussing the various dimensions of community resilience, workshop participants should be asked to assess how they believe their community ranks in each of the seven dimensions of resilience. This can be accomplished using online polling software or a series of posters, depending on the engagement venue and the personal comfort level of workshop attendees. Workshop attendees should rank their community by placing markers on a non-numeric scale ranging from “vulnerable” to “resilient” for each of the seven dimensions (Figure 8). While the research team fully recognizes that these terms are not necessarily inversely related in the scientific literature, field testing of the live poll indicates that this terminology is the most effective and easy for non-scientists to understand. The influence of each dimension will either pull a community's adaptive capacity toward resilience or make it more vulnerable to a negative future outcome (Jurjonas & Seekamp, 2018). Once all group members place their markers, facilitators should reveal the results and ask participants to explain why they feel their community is more vulnerable or more resilient for that particular resilience dimension. This facilitated group discussion will provide additional depth and qualitative detail to the live polling results.

Once the results for all the dimensions of resilience are reviewed with the community members, the results should be collated the data gathered through this process quantified. Descriptive statistics for each of the resilience dimensions can be calculated and used to provide local weighting to the integrated coastal risk mapping model developed in Chapter 2.

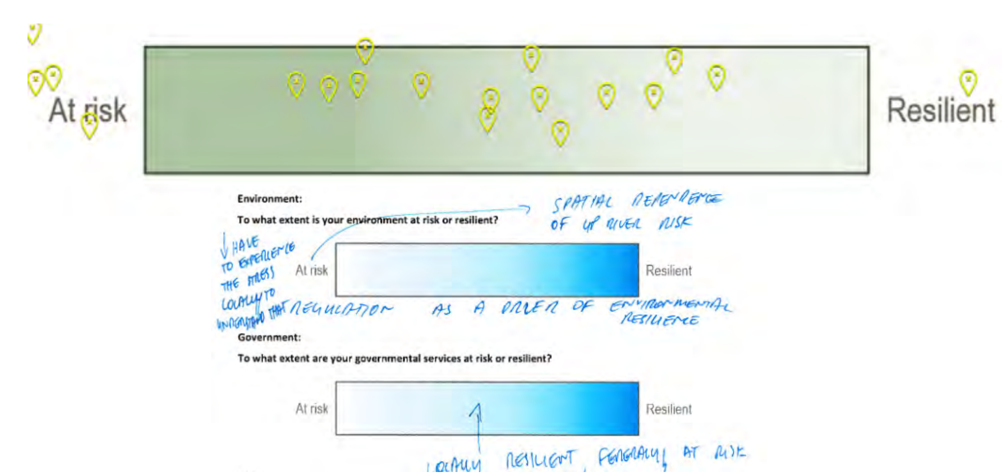
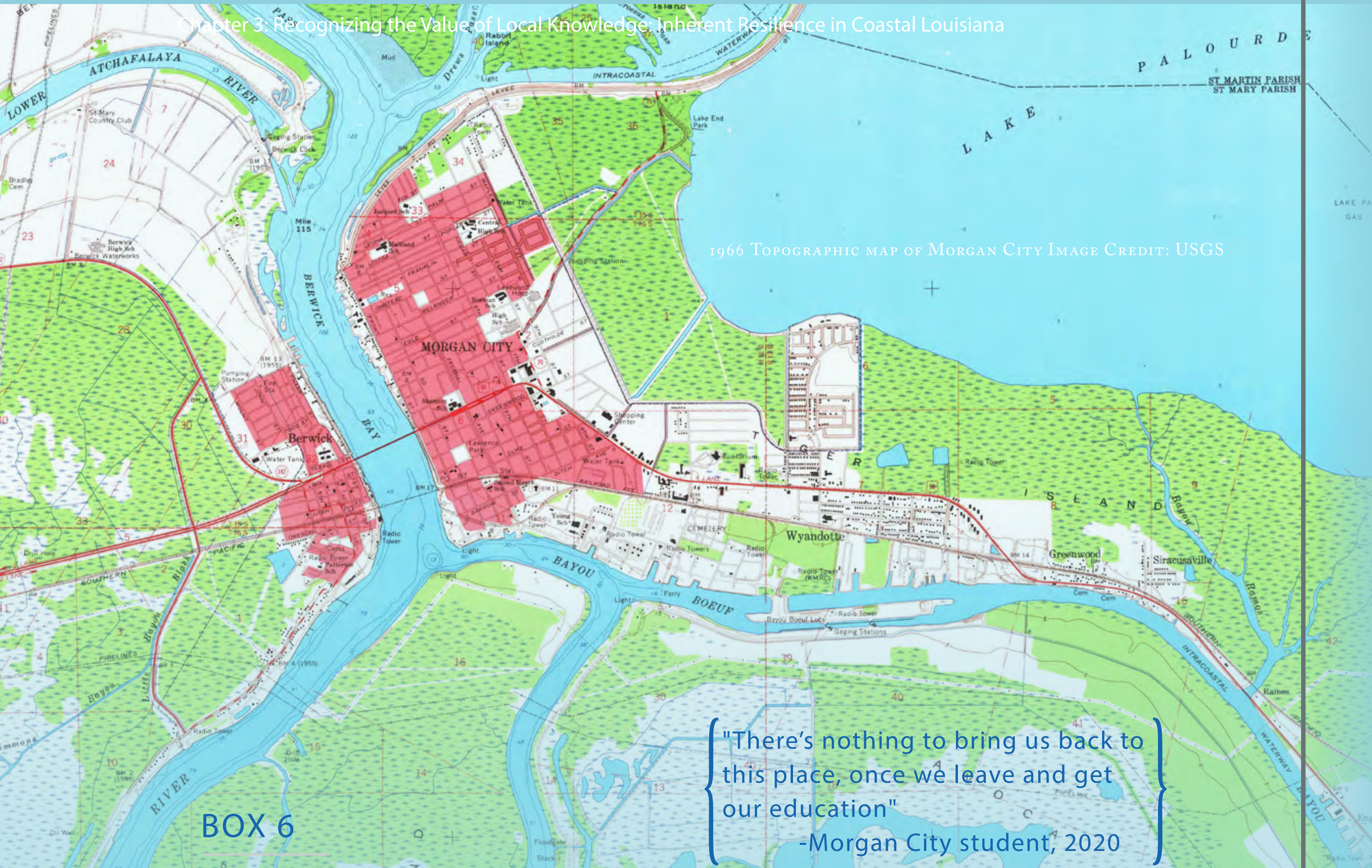


Figure 8. Example of electronic and paper poll responses collected during a community polling activity.



1966 Topographic map of Morgan City Image Credit: USGS

"There's nothing to bring us back to this place, once we leave and get our education"
-Morgan City student, 2020

BOX 6

WHEN PHYSICAL AND ECONOMIC RISKS COLLIDE:

Morgan City, Louisiana

The community of Morgan City is located in the Acadiana region of south Louisiana in eastern St. Mary Parish. The city is part of the Morgan City-Bayou Cane-Thibodaux Metropolitan Statistical Area. According to the U.S. Census Bureau, there are 11,221 people residing in Morgan City, 73.8% of whom are white. African Americans make up the largest minority group in Morgan City with 20.4% of the total population, followed by Indigenous peoples at 1.1% and Asians at 0.3% of the population. In addition, some 8.4% of the population is of Hispanic origin. Median household income is $42,483 with an annual per capita income of $24,582, significantly below the national averages of $57,652 and $31,177, respectively.

Morgan City has a total area of 6.25 square miles and sits at an average elevation of 7 feet above sea level. The city is surrounded by water on all sides, delineated to the west by the Atchafalaya River, to the north by Flat Lake and Lake Palourde, and to the south by Bayou Shaffer and the Avoca Island Cutoff canal. The terrain surrounding the city is predominantly flat with naturally occurring bayous and manmade canals throughout. The area to the south of Morgan City is predominantly stable marshland crosscut by numerous waterways flowing south into Atchafalaya Bay and the Gulf of Mexico.


Image Credit: LA Sea Grant College Program, LSU (CC BY 2.0)


Morgan City, Louisiana. 2019. Image Credit: David Wilson (CC BY 2.0)

Image Credit: Colleen McHugh


Morgan City, Louisiana, 2019

Water dominates this region and is the primary natural influence on the human population residing therein. The city exists as a manmade fastland and is protected on all sides by either levees or floodwalls. Despite the structural protection the city enjoys, over the last quarter of the twentieth century, residents of the parish filed $6.9 million in National Flood Insurance Program flood loss claims, with Morgan City accounting for $1.1 million of these claims (Laska et al., 2005). Even though St. Mary Parish was not directly in the paths of either Hurricane Katrina or Hurricane Rita, most of St. Mary Parish south of Highway 90 was submerged (Roth, 2010). The commercial fisheries infrastructure also experienced a high level of economic damage from the two storms.

The wider Atchafalaya watershed system is one of the most heavily sediment-laden watersheds in coastal Louisiana, and the Atchafalaya delta and west-adjacent Wax Lake delta are among the few areas in coastal Louisiana currently experiencing a net land gain. However, the resultant sediment, while providing physical benefits in terms of land building, has placed the city at economic risk as its large port struggles to keep the river channels dredged to the required depth. This risk compounds the already vulnerable economy of city, which has struggled since the oil bust of the 1980s.

Developing a Community-Informed Integrated Risk Model

The workshop methods were field tested in Morgan City, Louisiana, a coastal community located at the junction of the Atchafalaya River at the GIWW Given its location on two principal water navigation routes, Morgan City is an important hub for industrial and commercial activities. Morgan City is emblematic of many small cities located in Louisiana's coastal zone that are heavily reliant on natural resources and exposed to a number of coastal hazards. Given the history of Morgan City in recent years (see Box 6), it is not surprising that residents view the economy and population of Morgan City as the most vulnerable aspects of the community (Figure 9). The results of qualitative research conducted in Morgan City found that residents recognize that the fluctuations associated with the oil and gas industry and the loss of industries such as platform fabrication have reduced their levels of community resilience. They also recognize that the loss of a strong economic base has led to a situation where many younger, college educated residents are leaving Morgan City in search of jobs and more community amenities. At the same time, residents recognize that, while they are risk from riverine flooding, their location in one of the few land building areas in Louisiana provides them with a higher degree of environmental resilience than other areas of the coast. They also recognize the work of parish leadership and the Port of Morgan City to try and both protect residents from hazards and foster economic growth in the region.

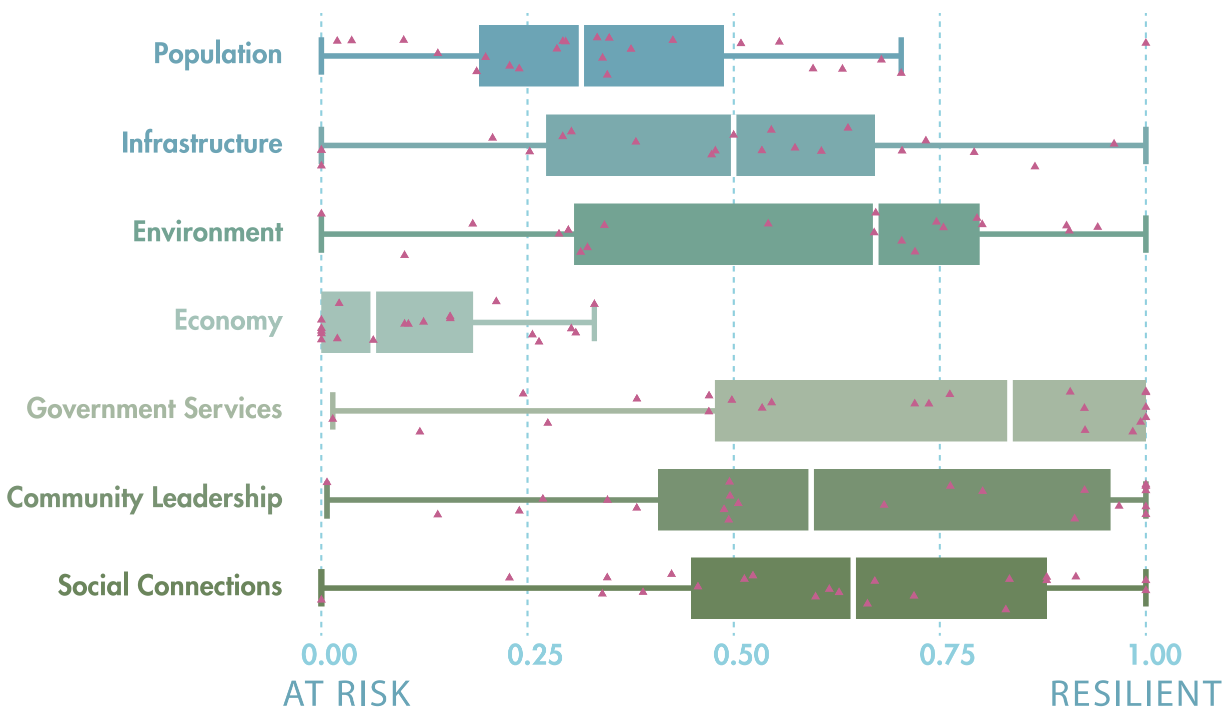


Figure 9. Local resilience weighting scores identified by workshop participants in Morgan City, Louisiana.

Table 2. Descriptive statistics derived from resilience dimension scores identified by local stakeholders in Morgan City, Louisiana.

Variable: Risk or Resilient	n	Mean ± Standard Deviation
Community Leadership	23	0.633 ± 0.3
Economy	23	0.105 ± 0.1
Environment	24	0.566 ± 0.3
Government Services	26	0.712 ± 0.3
Infrastructure	23	0.471 ± 0.3
Population	26	0.341 ± 0.3
Social Connections	24	0.644 ± 0.3

Analysis of these results allowed the research team to incorporate these public perceptions of vulnerability and resilience into the data model developed in Chapter 2. While each of the seven resilience dimensions were weighted equally in this model, the new "community-informed composite resilience model" developed here weighted each dimension based upon the mean values assigned by community members (Table 2). The resultant weighted data model was mapped to revealed previously undetected patterns of local resilience (Figure 10). A comparison of the unweighted and community-weighted resilience scores reveals what much of the literature on the resilience of coastal Louisiana suggests; that there is a high level of inherent resilience in many of the communities located in Louisiana's coastal zone. Recognizing that much of what makes a community resilient is dependent upon inherent factors that are largely intangible, these community weighted values represent a valuable source of local knowledge that planners and policy makers can utilize. The methods presented here represent advances in rigorous, replicable, and accessible forms of collecting local knowledge to inform coastal restoration planning, providing information to agencies and communities about social and cultural factors that need to be considered in the restoration planning process.

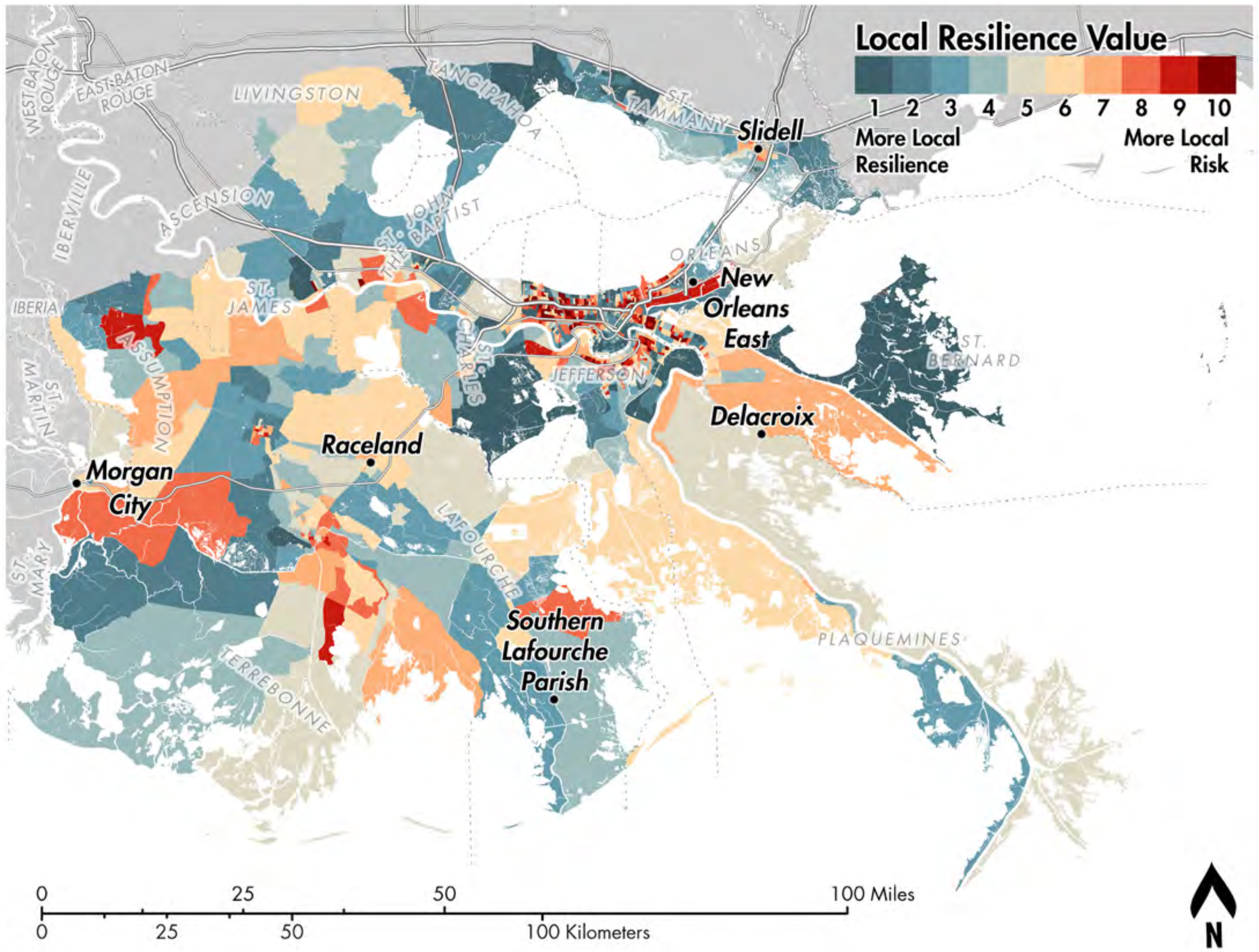


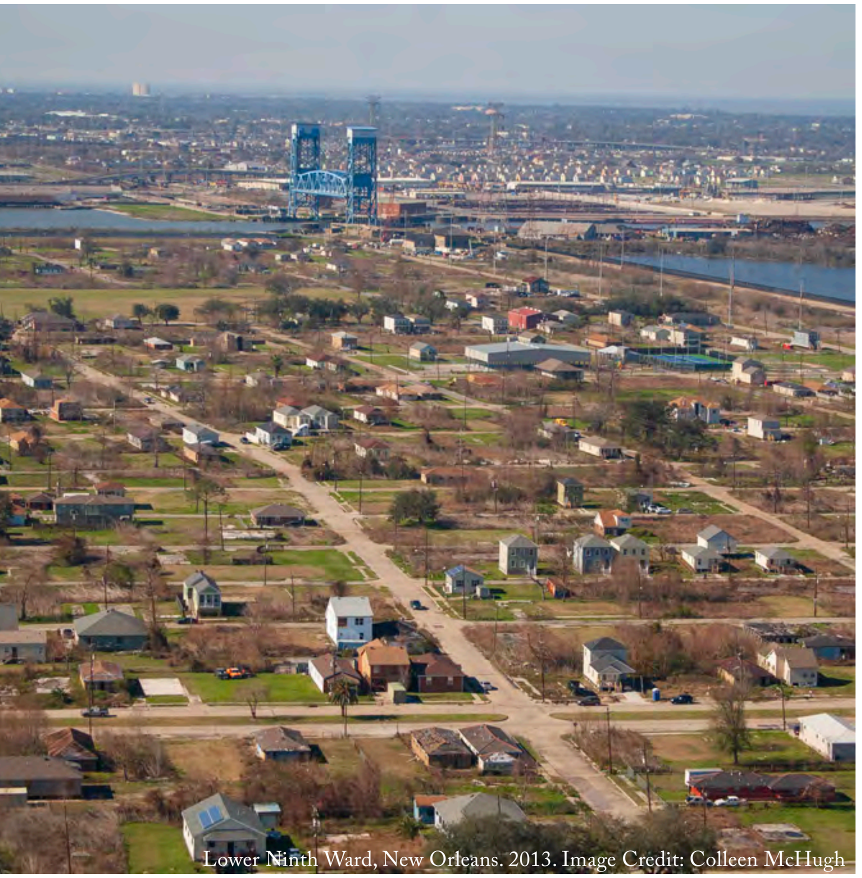
Figure 10. Community-informed resilience score for small, resource-dependent coastal cities in Louisiana, based on research conducted with residents of Morgan City, Louisiana.

Image Credit: Colleen McHugh

Chapter 4
Developing an Equitable Approach to Measuring Community Resilience

The ultimate goal of this project is to provide an effective means of assessing progress toward building more resilient coastal communities. Researchers, planners, and policy makers generally accept the idea that resilience is a positive trait that contributes to sustainability. Recent evidence has shown, however, that the promotion of resilience for some locations may come at the expense of others and that the enhancement of resilience at one scale may reduce resilience at other scales (Leichenko, 2011). This highlights the importance of directly accounting for issues of social and racial equity in coastal resilience planning. Issues of equity are generally linked to quantitative measures of distributive justice and focus on the allocation of costs and benefits resulting from environmental policy, resource management decisions, and environmental modifications (Hemmerling et al., 2020; McDermott et al., 2013). Planning approaches that overlook issues of social and racial inequity run the risk of inadvertently shifting the distribution of risk from one group to another, potentially make some disadvantaged groups even more vulnerable than they were prior to the intervention (Lebel et al., 2009).

This research recognizes that the purely distributive focus of some quantitative data frameworks obscures the role that social structure and institutional context play in determining current settlement and risk patterns (Foster, 1998). For rural *and* urban communities that are socially vulnerable, it is not only geography but histories of marginalization that continue to exacerbate environmental inequalities. In rural areas in coastal Louisiana, for example, Indigenous communities have experienced a history of displacement, segregation, and political disenfranchisement which has led to them being disproportionately impacted by environmental change (Dalbom et al., 2014). In many urban areas, deeply rooted histories of racism and classism, upheld by a lack of economic diversification, has exacerbated environmental inequities for many African Americans. Such inequities are often evidenced through disproportionate exposure to hazard events but also in unequal recovery from disasters. The recovery process after Hurricane Katrina, for example, constituted a "second-order disaster" for many low-income African American residents (Adams, 2013). While this research does not purport to provide solutions to deeply rooted issues related to race and inequity, it does directly address and provide a means to include these issues in the coastal planning process.


Lower Ninth Ward, New Orleans. 2013. Image Credit: Colleen McHugh

Issues of equity are addressed here in two broad ways. The first is through the promotion of meaningful engagement with coastal communities and the inclusion of underserved residents in the development of the data outputs of this research. As detailed in Chapter 3, this research acknowledges that resilience is experienced differently between communities and amongst stakeholder groups. This is also true of racial and ethnic minorities. The methods used to construct the community-informed integrated risk mapping model specifically requires the direct input of underserved communities[3]. This research also intentionally addresses issues of social and racial inequity in a second way by assessing the correlation between race, ethnicity, and social vulnerability. The research team took the specific track that race and ethnicity in and of itself does not constitute an inherent vulnerability.

[3]For more detail on the communities and population groups to be engaged in this ongoing research, see Walton Resilience Project: Workshop Methods technical memorandum.

Stakeholder Engagement in Social Equity

Since the 1970s, coastal planning has gradually evolved from a piecemeal approach to a more comprehensive, systems-based approach based upon science-driven numerical models. While the extent of local involvement in coastal protection and restoration planning has also evolved during this time (Table 5), the level of impactful public engagement and social science research in this process has continued to lag behind the advancements made in other sciences (Hemmerling et al., 2020). One reason for this is that social science data, both qualitative and quantitative, has traditionally been viewed as being much less amenable to quantification in a manner typical of engineering or ecological data (Schultz et al., 2012). As a result, most numerical models do not sufficiently incorporate local knowledge into their design or applications. These predictive tools are mainly developed to answer scientific or management questions from research groups or government entities that likely do not reside in these vulnerable regions and likely do not fully grasp the on-the-ground implications of coastal hazards (Meselhe et al., 2020). As a result, despite extensive public outreach efforts made on the part of state planning agencies, many coastal residents still feel disenfranchised by what they perceive to be a repetitive and ambiguous public engagement process that often leaves them feeling fatigued, frustrated, and ignored by policymakers and coastal planners (Carruthers et al., 2017). The stakeholder engagement processes developed for this research begins to remedy this situation by directly involving community members and their local knowledge in the production of coastal science.

Community members are unique sensors of the environment, both human and natural. The knowledge possessed by residents can provide planners and decisionmakers with a means of anticipating, understanding, and attempting to alleviate unequal impacts before they occur (Hemmerling et al., 2020). This research recognizes that local conditions and history have a direct impact on how hazards, vulnerabilities, and consequences are experienced and acted


Bayou St. John, New Orleans. Image Credit: Colleen McHugh

upon by community members. Racial and ethnic minorities, in particular, experience environmental change far differently than the population writ large (Adams, 2013; Dalbom et al., 2014; Jessee, 2020). It follows that protection and restoration projects, as well as projects designed to increase community resilience, are likely to be experienced differently as well. To fully understand how environmental change is experienced at the community level requires an extensive understanding of the local situation which can only be gathered through community-based research. The methods developed for this study enables the collection of local knowledge from a full spectrum of community types and stakeholder groups, including minority populations. The methods for this study also provide a means for including these data in the development of quantitative data models. This integration of qualitative and quantitative data represents an important advancement in the coastal planning process.

"All of these things that have been implemented so far have been clouded with politics. The trust is not there to believe their science or their engineering design, because we know that from past experience, everything that they've done has always been—like follow the dollar. The consideration of the communities in place has not been primary. It's always been."
- Grand Bayou tribe member, February 2019


Image Credit: Colleen McHugh

Table 3. The evolution of public involvement in coastal planning and policy (adapted from Hemmerling, Barra, et al., 2020).

Timeframe	Policy or Plan	Extent of public involvement in coastal planning
1970-1980s	Several	Comments could be made on early coastal policy reports in a traditional public input process, but there was no community involvement in the design of projects.
1989	CWPPRA	As wetlands policies became more comprehensive, they depended on project nominations from community members and stakeholders before project design began. Projects, however, were limited in scope and geography.
Mid 1990s	CWPPRA	Policies still depended on project nominations from community members and stakeholders. Prioritized projects became larger in scope to address coastwide issues.
1997-2002	Coast 2050	Repeated meetings with concerned residents were included in the planning process. The coastal plan presented a unified vision and began to integrate scientific advances.
2005-2007	CPRA CMP	This plan involved extensive public comment periods, public meetings, stakeholder meetings, and presentations. Public comment period is made after plans are drafted.
2012-2017	CPRA CMP	At the outset of the planning process, CPRA held ten regional community meetings. Master Plan framework development team included federal, state, and local governments, NGOs, business and industry, academia, and coastal communities. Public input and local knowledge is not included as a part of the best available science.

CWPPRA Coastal Wetlands Planning, Protection and Restoration Act.
CPRA CMP Coastal Protection and Restoration Authority's Coastal Master Plan.

Race, Ethnicity, & Social Vulnerability

Much of the previous research on social vulnerability, including seminal work by Cutter and the social vulnerability index utilized in Louisiana's Coastal Master Plan (Cutter et al., 2003; Hemmerling & Hijuelos, 2017), recognized race and ethnicity as a category of social vulnerability. This creates a unique challenge for practitioners using such datasets to measure and reduce levels of social vulnerability in their communities. Population displacement could theoretically be used as a means of quantitatively reducing levels of social vulnerability, shifting vulnerable populations from one geography to another. This current research recognizes that racial and ethnic minorities are more vulnerable to hazards in coastal Louisiana (Dalbom et al., 2014) but that this vulnerability is not due to any inherent racial or ethnic characteristic.

The integrated risk models created in Chapters 2 and 3 were designed to be actionable and as a result do not include race and ethnicity as variables that can be changed to impact overall levels of resilience. However, coastal scientists, planners, and decisionmakers can still acknowledge that social vulnerability is often linked to racial and ethnic characteristics of communities. To provide an effective path forward, this research provides a quantitative means of assessing social vulnerability that intentionally addresses social and racial inequity. By examining the degree to which race and ethnicity are correlated with various vectors of social vulnerability and identifying locations where this correlation is most pronounced, this research identifies locations where targeted investments in building resilience can also reduce social and racial inequities.

As part of the development of the integrated systems vulnerability component of the integrated risk models, the research team developed an index to assess the social vulnerability of coastal Louisiana[4]. For reasons previously stated, this index did not include race and ethnicity variables in its construction. Principal components analysis was used to identify a suite of composite indicators of social vulnerability for the southeast Louisiana study area. A Pearson product-moment correlation coefficient was computed to assess the relationship between African American, Asian, Hispanic, and Indigenous communities and composite social vulnerability indicators (Table 4). The results show that when examined across the entire study area, overall social vulnerability is significantly correlated with high levels of African American and Asian residents. Strikingly, the African American population is also highly correlated with all eight of the constituent components of social vulnerability.

The Asian population correlates most strongly with the level of natural resource dependence, most likely fisheries employment, followed by the number of non-English speaking residents and young children present in their communities. Despite these vulnerabilities, the correlation between the Asian population and socioeconomic status is positive overall. Note, that as with all of these correlations, the results are for the entire study area and that there may be local variations when examined at smaller scales.

While the correlation between the Hispanic population and overall social vulnerability is not significant, there are significant correlations between several of the constituent components of social vulnerability, primarily natural resource dependence. There is also a strong *positive* correlation with socioeconomic status. This, combined with a significant negative correlation between the Hispanic population and the number of elderly residents, suggests that much of the Hispanic population tends to reside in working class areas with high levels of residents working for the oil and gas industry.

Finally, as with the Hispanic population, the Indigenous population is not significantly correlated with overall vulnerability at the study area scale. It is important to note that past

Image Credit: Colleen McHugh

[4]For a full description of the methods used to develop the Social Vulnerability Index, see Risk and Resilience in Coastal Louisiana: Analytical Methodology for Assessing Hazards, Vulnerability, and Consequences

research has found that this population is highly vulnerable (Dalbom et al., 2014; Hemmerling, 2007). The discrepancy between this research and earlier research is likely due to the scale of analysis. The Indigenous population is highly concentrated in rural communities in Lafourche and Terrebonne Parishes, which may skew the correlation results. Nevertheless, the results do show that this population tends to correlate strongly with rural areas with low levels of educational attainment, which is typical of rural communities with a large number of offshore oil workers.

Table 4. Correlation between race, ethnicity, and social vulnerability, including composite social vulnerability and the eight constituent components of social vulnerability.

Social Vulnerability Component	African American	Asian	Hispanic	Indigenous Peoples
Composite Social Vulnerability	0.612**	-0.125**	0.005	0.036
Low Socioeconomic Status	0.715**	-0.177**	-0.072**	0.011
Educated Urban Populations	-0.089**	0.006	-0.069*	-0.141**
Aging Populations	-0.078**	-0.052	-0.170**	0.027
Non-English Speaking, Migrant Populations	-0.180**	0.067*	-0.125**	0.329**
Families with Children	0.110**	0.061*	-0.026	-0.058*
Natural Resource Dependent Communities	-0.119**	0.394**	0.628**	0.038
Civically Engaged Communities	0.130**	0.033	0.059*	-0.191**
Isolated and Dependent Populations	-0.092**	0.012	0.081**	0.024

* Correlation is significant at the 0.05 level.

** Correlation is significant at the 0.01 level.

This chapter has outlined the rationale for the inclusion of socially oriented methods in the integrated risk mapping model—to promote more equitable resilience outcomes in the coastal planning process. Because this model considers equitable outcomes to be driven by institutional context and the distribution of costs and benefits, it includes (1) input from engagement processes with coastal communities and (2) correlations between distinct variables, race/ethnicity and indicators of social vulnerability. The brief historical overview of public engagement in the coastal planning process highlights the current need to bridge the gap between state-level coastal decision making and local-level communities who experience the results of those decisions.

Additionally, the correlations summary outlines the ongoing social vulnerabilities experienced by African American, Asian, Hispanic, and Indigenous communities. Equitable resilience outcomes resulting from this portion of the risk mapping model could thus include (1) coastal residents' increased levels of involvement and trust in the coastal planning process, and (2) a suite of indices of a given community's resilience that can directly transfer to practical and socially responsible planning recommendations. By considering equitable outcomes in research design, data collection, and data analysis, this integrated risk mapping model is designed to work with the coastal planning process to foster progress toward building more resilient communities.

Image Credit: Colleen McHugh

Conclusions:

Implications for Planning

Applying Lessons Learned to Planning & Decision Making in Coastal Louisiana

The results of this research provide multiple tangible lessons learned for planning and decision making in southeast Louisiana and beyond. While these recommendations are largely consistent with best practices promoted through urban and regional resilience planning efforts across the country, this research provides additional quantitative support for planning approaches that are holistic, grounded in local community knowledge, and intentional in addressing social and racial inequities.

An Integrated Approach to Risk Reduction and Resilience

Risk reduction for an entire community often relies on structural protection, such as levees or floodgates, and nonstructural protection, such as home elevations or buyouts. These measures are designed to reduce exposure to hazards like hurricanes. The analytical methods developed and demonstrated in this report show that *structural and nonstructural risk reduction approaches alone will not automatically measurably improve the resilience of a community*. Community resilience is ultimately based on human decision making. While public perceptions of risk can clearly influence the degree of resilience possessed by a community, social and economic factors may represent far more meaningful drivers of change. To significantly improve a community's resilience, investments should address the multifaceted aspects of resilience by examining the underlying systems within a community, reducing exposure to hazards, and improving the community's ability to adapt and recover. Investing in both quality of life improvements—health and safety, a strong and diversified economy, coordinated and capacious infrastructure— and risk reduction will provide far more tangible benefits for community resilience than either aspect alone.

Impacting a community's overall resilience requires investing across social, built, and environmental systems and ensuring that all investments have co-benefits. For example, an infrastructure investment can improve a community's ecological health, capacity to evacuate or respond to hazards, reduce physical exposure to hazards, and reduce isolation and improve economic activity and job access.

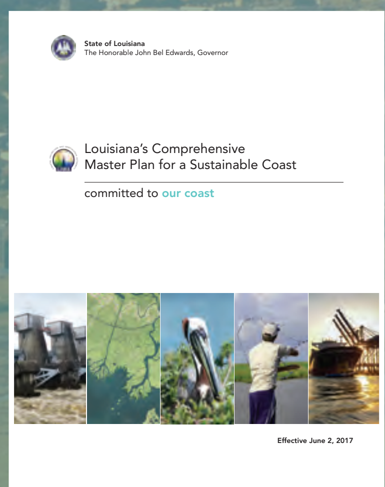
These types of investments could be planned, coordinated, and integrated at all scales – local, regional, state, and federal. Statewide planning efforts, such as CPRA's Coastal Master Plan, encompasses structural plans, nature-based solutions, and non-structural programs (Box 7). These activities should be coordinated across all state agencies, linking the structural and non-structural protection investments with state investments in preparedness, economic diversification, education, transportation, and public health. Regional and local plans and projects could also be developed in alignment with these long-range efforts to improve resilience outcomes.

Policy and investment levers that impact physical exposure, inherent system characteristics, and the capacity to adapt and respond can be coordinated together to maximize the benefit to community resilience. These levers also show that investments must be made across the entire framework, not just one system, to meaningfully reduce consequences and improve resilience (Figure 11).

Gulf Intracoastal Waterway West Closure Complex. Image Credit: Colleen McHugh

BOX 7

Coastal Louisiana Resilience Planning



COASTAL MASTER PLAN

In response to the state's crisis of rapid coastal land loss, the Louisiana Coastal Master Plan identifies and prioritizes $50 billion in projects that are designed to build and maintain land, reduce flood risk, and support ecosystems. Led by the Coastal Protection and Restoration Authority (CPRA), the planning process is grounded in scenario modeling of 10-year and 50-year future predicted land loss and threat from a storm surge event if no projects are completed (Future Without Action) and if all projects are completed (Future With Action). The Coastal Master Plan is updated every five to six years. The most recent 2017 edition includes 124 projects that would build or maintain more than 800 square miles of land and reduce expected damages by more than $150 billion over the next 50 years.

LA SAFE

The LA SAFE planning process, led by the Louisiana Office of Community Development (OCD) and Foundation for Louisiana (FFL), released *Our Land and Water: A Regional Approach to Adaptation* in April 2019. This plan, built on an extensive community engagement process that included over 75 public meetings in four parishes, contends with the inescapable facts that Louisiana's landmass is physically shrinking while the state's population is shifting. The LA SAFE approach combines the communities' vision, best planning practices, and current and future environmental conditions to outline strategies across five categories: water management; housing and development; transportation; education, economy, and jobs; and culture and recreation. This planning approach complements the state's Coastal Master Plan efforts to upgrade structural and non-structural protection in the coastal zone by investing in community systems. By working with communities to develop a shared understanding of risks and a vision for the future in light of those risks, the LA SAFE strategies are an example of plan alignment that can improve overall community resilience.

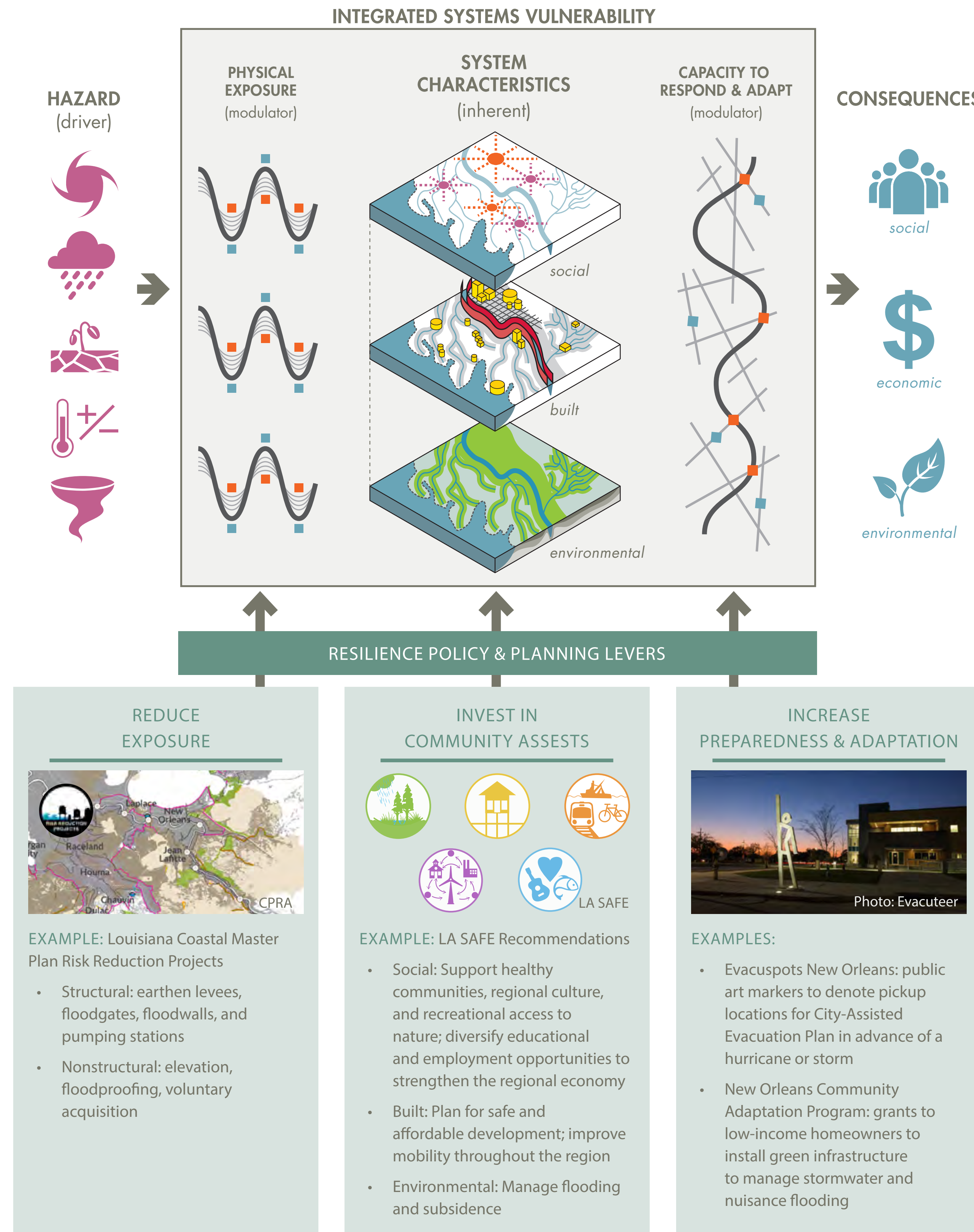


Figure 11. Policy and investment levers.

Importance of Community-Informed Metrics & Place-Based Planning Approaches

Each community understands their own strengths and challenges and the unique factors that contribute to their own resilience. No community is identical to another. This is particularly true in coastal Louisiana, which possesses a unique cultural heritage that ties residents to the coast. Generations of Indigenous peoples, Acadians, Isleños, African Americans, and Asians have all lived and worked in communities large and small, scattered across Louisiana's coastal zone. Just as one community's physical characteristics and infrastructure can reduce exposure to hazards, another community's underlying social infrastructure can help speed recovery and adaptation. The modeling framework outlined in this report shows how important it is to examine the underlying factors of a community's resilience when planning investments in physical, social, or natural systems.


Lower Mississippi River Physical Model, LSU Center for River Studies

Plans that drive investment, whether in individual projects or large-scale regional or state programs, should account for this variability between communities' resilience. Community priorities and knowledge, both about the specific ways in which they are resilient to hazards as well as their underlying strengths and vulnerabilities, can and should be incorporated into plans. When these kinds of statewide planning efforts and programs are flexible and can adapt to community priorities, more sensitive implementation can occur.

Equitable Planning to Address Disparities in Risk & Resilience

In many planning efforts, there is a tendency to consider resilience as a static quality of communities. In reality, the level of resilience possessed by a community is constantly changing based upon any number of internal and external factors (Hemmerling, 2018). To effectively plan for resilience, it is necessary to account for the historical forces that have shaped current conditions. In some cases, these forces have been environmental, including any number of natural and technological hazards that have impacted the region (Colten, 2009). In other cases, however, these forces are social and include such complicated issues as racial discrimination and environmental inequity. Resilience is experienced differently across different racial and ethnic groups (Cutter et al., 2006). If a goal for coastal scientists and planners is to enhance community resilience, they need to acknowledge and account for the deeper environmental development history that contextualizes both disaster impacts and recovery (Brand & Baxter, 2020). Hazard events impact social landscapes and often unequally affect people of color. Planning efforts that seek to enhance community resilience must acknowledge and account for the presence of environmental inequities when they exist. Decisions to invest in risk reduction and community adaptation measures should be made with full knowledge of any disparities underpinning the current conditions to avoid unintentionally exacerbating them.

Planning efforts that seek to address racial and ethnic disparities in risk and resilience can be a contributing element in statewide planning efforts. The LA SAFE plan, *Our Land and Water: A Regional Approach to Adaptation*, describes how a person's race is an influencing factor on socioeconomic status. As a result, the geography of risk is often unequally experienced across racial and ethnic lines. The relationship between elevation and the cost of homeownership and insurance is a prominent example. Homes located on safer, higher ground areas are generally more expensive while those located in lower-lying areas are less expensive. However, insurance costs in lower elevation areas are higher, which prevents low income families from building equity in their homes. LA SAFE's planning process acknowledges that the geographies of risk and race may change as residents move from high-risk areas further inland to safer ground. The plan's strategies were developed intentionally with communities to prepare for this outcome, building housing and creating services that "rectify the social, economic, and geographic inequality they faced previously." (Louisiana Office of Community Development, 2019).


Image Credit: Colleen McHugh

How to Use This Data in Planning & Decision Making

This research directly builds on previous planning efforts developed by the state of Louisiana for its Coastal Master Plan. The hazards and consequence data incorporated numerical model output developed for the Master Plan (Johnson et al., 2013). The Social Vulnerability Index that the Water Institute developed for the 2017 Coastal Master Plan (Hemmerling & Hijuelos, 2017) is a key component of the integrated systems vulnerability model developed herein. This index was used to understand how well projects in the plan address risk in socially vulnerable communities. This index is included in the Coastal Master Plan online data viewer. The analysis of this study improves upon that effort by incorporating a more holistic picture of vulnerability and social, economic, and environmental consequences.

The comprehensive hazard, vulnerability, and consequence data model developed through this research was designed to serve as a useful input for planning and decision-making exercises. This data model is intentionally modular and flexible so that it can analyze the impacts of various hazards and be incorporated into a range of planning frameworks, models, and tools for decision making. Coastal planners and resilience practitioners are increasingly referencing engineering models of hazards and consequences, social vulnerability assessments, and community input to scope projects, prioritize investments, and develop comprehensive strategies that not only reduce exposure but also address the underlying issues that make some communities more vulnerable than others. This research brings those elements together into a comprehensive and quantitative model so that decisionmakers can compare "apples to apples" when identifying the variables that impact their communities' overall resilience the most and allows for an understanding of how changes—positive and negative—may alter that resilience. While the research developed here is specific to southeast Louisiana, the approach and lessons learned are transferrable to the rest of the state, the Gulf Coast, and other regions around the country.

Potential applications for this analysis include the following activities inherent in coastal planning projects:

> "I think there are a lot of people who sleep easier at night, even during hurricane season when a hurricane gets in the Gulf, if their house is elevated a foot, two feet above the base flood elevation."
> - Resident, Houma
> (Davis et al., 2019)

Benchmarking & Agenda-Setting

Communities, regions, and state government can use this data as a diagnostic tool to develop a baseline assessment of the current state of comprehensive resilience in communities in the region. This benchmarking can help communities communicate a comprehensive understanding of risk to residents and stakeholders and to demonstrate how that risk is a composite of physical exposure, social vulnerability, and capacity to respond and adapt. Decisionmakers can also compare risk and resilience across geographies and community types to understand who is most at risk and where. Planners and decisionmakers can also identify primary issues of concern across the region and within specific communities. This benchmarking analysis allows decisionmakers to set data-driven policy and programmatic agendas and begin to develop comprehensive strategies for improving community resilience.

Plan Evaluation

For coastal, risk, and environmental planning exercises driven by scenario modeling, the data developed through this research can help planners more comprehensively measure the impacts and evaluate the consequences of projects included in the plan.

For example, with the Louisiana Coastal Master Plan, this data could be used to evaluate how effective the "Future with Action" scenario is in improving overall community resilience and reducing social and environmental consequences (in addition to the existing economic consequences of structure damage already included in the plan). In this way, CPRA, other state agencies, and partner organizations can better understand which communities are positively and negatively impacted, any unintended biases that exist in project prioritization, ways to improve plan development, and gaps that can be addressed through investments in other areas and coordination across agencies and plans.

Prioritizing Investments

Planners and decisionmakers at the local and state level can use this data model to identify and evaluate which policy and project investment levers are most important to coastal communities and will have the most impact in reducing risk and improving resilience for a specific geography or across the overall region. This analysis can be incorporated into existing data-driven project evaluation models and tools or be developed into a new evaluation process.

Louisiana is already using innovative evaluation models for coastal projects. The Coastal Louisiana Risk Assessment Model (CLARA), for example, measures flood risk and structural damage as a result of hurricanes and is used to evaluate potential flood risk reduction projects for inclusion in the Louisiana Coastal Master Plan (Fischbach et al., 2017). CLARA was originally developed by the RAND Corporation for the Coastal Master Plan and has been updated for each successive plan update. The CLARA model is a quantitative simulation of storm surge flood risk that has been updated for multiple types of ecological and policy concerns, such as improving asset inventories to accurately account for risk or improving outputs to inform local community planning. The data developed through this research could directly augment the CLARA model, incorporating social vulnerability and more comprehensive dimensions of community resilience into the project prioritization process. Similarly, this data could be expanded upon and used to evaluate and prioritize projects as part of watershed management and hazard mitigation planning efforts.

Image Credit: Colleen McHugh

Mapping Resilience Changes from Investment Scenarios

One of the most powerful aspects of this data model is its ability to assess how multiple investment pathways can combine to synergistically impact overall levels of resilience. While investing in risk reduction can have an impact on levels of community resilience, this investment alone may not be enough to effectively “move the needle” in building resilience. When this investment is combined with social planning project, the impacts on overall resilience may become more pronounced. A community that has been losing population for decades due to a lack of economic opportunities or a failing school system, for example, will not become resilient overnight because of investment in structural protection. However, if this investment is combined with an economic development plan or investment in early childhood education, more residents might choose to remain in that community or previous residents might be enticed to return. The following examples show how theoretical investments across multiple policy and planning levers can combine to significantly improve overall levels of community resilience in southeast Louisiana.

In the first scenario, significant investments in structural protection measures (levees, floodwalls, floodgates, and pumps) reduce hurricane hazards by 25%, and significant investments in nonstructural protection (elevations, buyouts, floodproofing) reduce riverine flood hazards by 25%. Resulting model outputs show the overall change to coastwide resilience as relatively unchanged or minimally increased in most areas, suggesting that reducing exposure alone may not be sufficient (Figure 12). While this example examines changes across the study relative to the coastwide average, it is important to note that the impacts of these investments may be experienced differently at the community scale. The results might look significantly different for communities with below average levels of social vulnerability and above average levels of physical or environmental vulnerability. Both scales of analysis produce valid results that can be used to inform planners and decisionmakers.

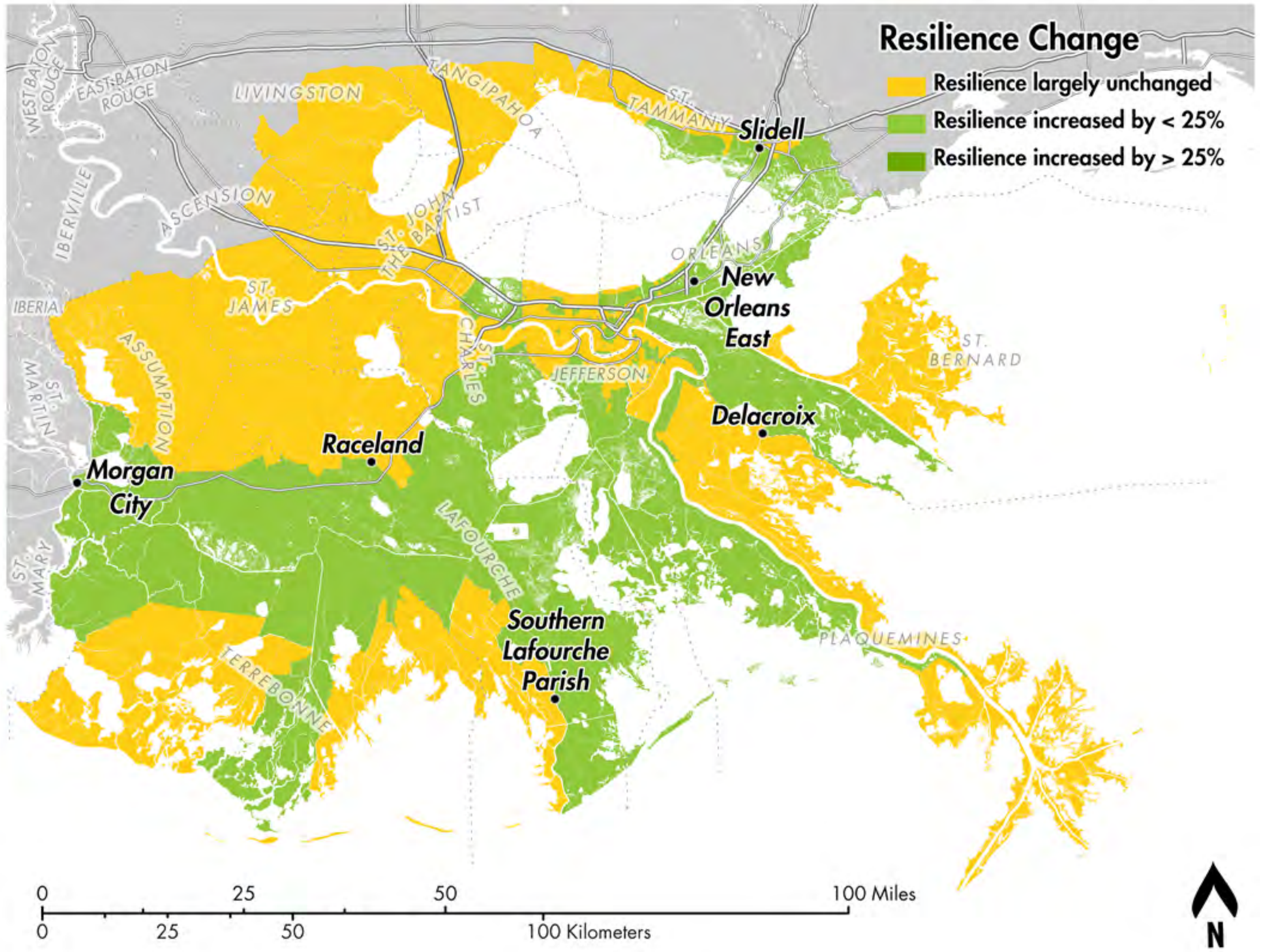


Figure 12. Consequences for community resilience after significant investment in structural protection measures in southern Louisiana (scenario 1).

In the second scenario, the model assumes that the same level of structural and nonstructural investment in made. In addition, this scenario also assumes that significant investments are made in social planning and protecting critical and essential facilities. For this scenario, we assume that this investment results in a highly significant 50% reduction in both social vulnerability and physical infrastructure vulnerability. Accomplishing such a reduction would likely require dedicated action across multiple policy areas to significantly improve incomes, educational attainment, health, the local economy, transportation, and critical infrastructure. The results of this scenario reveal that, overall, the level of resilience for locations across the study area are significantly improved (Figure 13).While the scenario used for this example took a very broad brush approach to reducing vulnerability, the model as designed is able to assess the impacts of investments at any scale, from impacting a single variable to broadly change a suite of variables. By implementing the methods presented herein, decision makers will have access to new sources of data to help inform future plans and policies. This comprehensive approach could result in measurable overall risk reduction and improved community resilience for communities across southeast Louisiana.

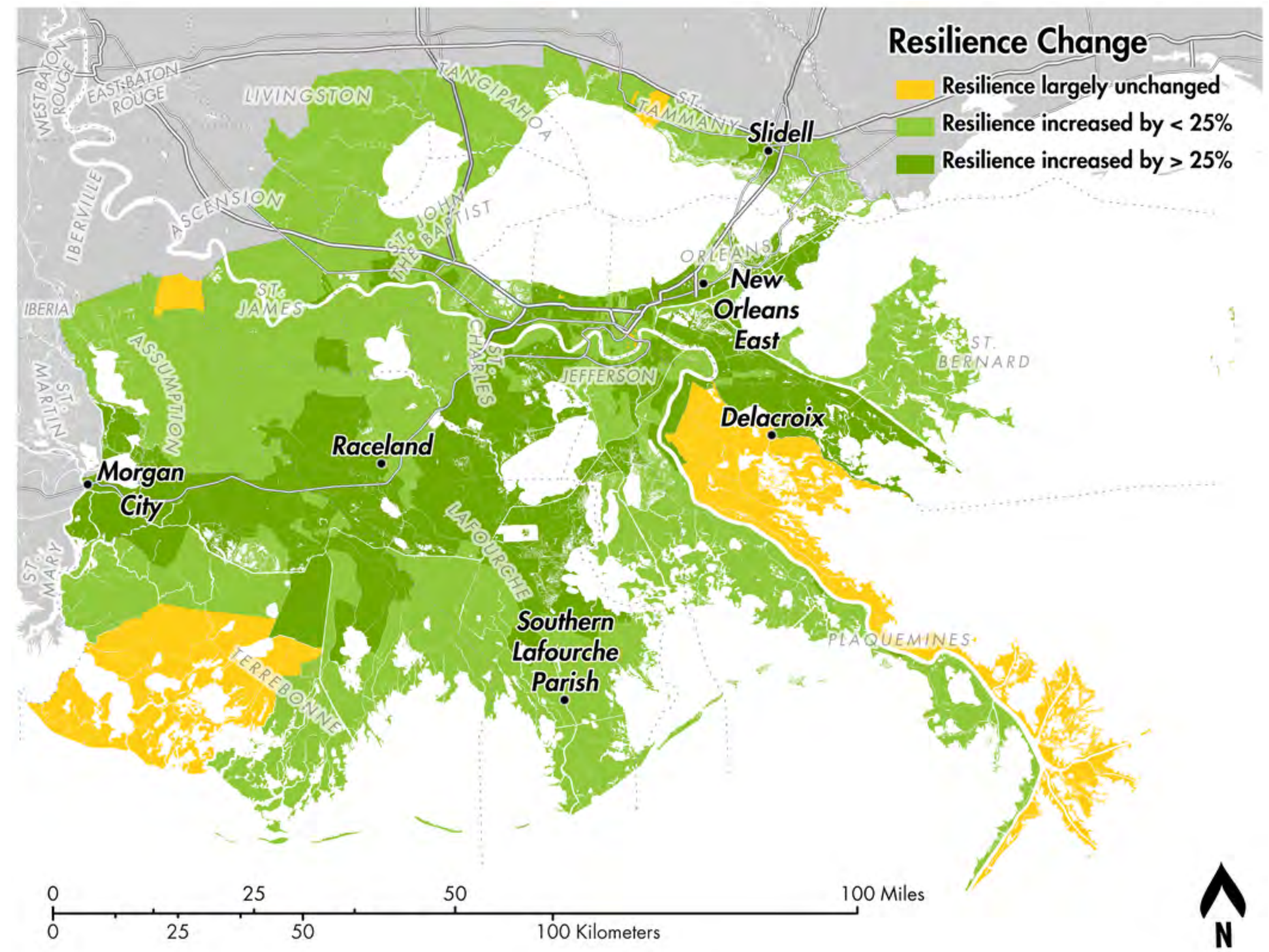


Figure 13. Consequences for community resilience after significant investment in structural protection as well as in social and built community assets in southern Louisiana (scenario 2).

This demonstration of two investment scenarios and the subsequent anticipated changes in community resilience shows the potential power of this mapping tool and analysis. Investments in resilience planned and coordinated across state agencies, parishes, and programs result in improved overall community resilience. The quantitative analyses visualized in these theoretical scenarios shows that investing in social and economic plans as well structural and non-structural risk reduction result in a measurable increase in resilience.

The impacts of coastwide planning efforts, whether to reduce physical risk or enhance social and economic wellbeing, are often experienced far differently at the local or community level. Incorporating local knowledge and experiences into coastwide planning frameworks provides granularity to show how resilience is experienced at these smaller scales. The pilot workshop held in Morgan City, Louisiana in the winter of 2020 utilized a series of stakeholder engagement techniques designed to elicit local knowledge that would provide necessary data inputs to the overall quantitative framework for measuring resilience. The local weights derived from this workshop account for community perceptions of risk and resilience and the lived experiences of residents who have witnessed and experienced first-hand, the impacts of hazards in their community. The outputs of this research more accurately express the relative importance of each of the seven resilience dimensions to the community. Additional workshops conducted in the same manner in other communities can provide additional qualitative insights and quantitative weights for the data model and show the variations across communities and stakeholder groups in how they experience risk and resilience. The more qualitative data that is added to the model, the greater the ability of the model to address the local impacts of risk and resilience. Adjusting the quantitative framework in this way is critical for understanding how regional-scaled or coastwide investments in risk reduction may be experienced in local communities.

The methodology demonstrated in this report can be applied to any number of local, coastwide, and statewide planning efforts. From the comprehensive all-hazards-in-one-place approach piloted here to an assessment of a single small-scale hazard event, this process is readily transferable to any geography and any scale. Yet, the true power of this methodology is its recognition that local stakeholders are a data repository when it comes to assessing and quantifying community resilience. The data model developed herein can be used without local knowledge expert input and can quickly identify and assess the overarching impacts of coastal planning efforts on resilience. When local knowledge is included in the model, however, previously unseen patterns of risk and resilience become apparent. This research is a powerful tool designed to bring this critical information into planning, modeling, and decision support tools throughout Louisiana and beyond.

Image Credit: Colleen McHugh

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"If you were to go to community members and say, 'We're gonna elevate your house, and we're gonna pay for it,' they'll say, 'Absolutely.' Everyone will be on board."
- Resident, Houma (Davis et al., 2019)

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