



GULF STATES POLICY INSTITUTE

A study by RAND Infrastructure, Safety, and Environment

CHILDREN AND FAMILIES
EDUCATION AND THE ARTS
ENERGY AND ENVIRONMENT
HEALTH AND HEALTH CARE
INFRASTRUCTURE AND
TRANSPORTATION
INTERNATIONAL AFFAIRS
LAW AND BUSINESS
NATIONAL SECURITY
POPULATION AND AGING
PUBLIC SAFETY
SCIENCE AND TECHNOLOGY
TERRORISM AND
HOMELAND SECURITY

The RAND Corporation is a nonprofit institution that helps improve policy and decisionmaking through research and analysis.

This electronic document was made available from www.rand.org as a public service of the RAND Corporation.

Skip all front matter: [Jump to Page 1](#) ▼

Support RAND

[Browse Reports & Bookstore](#)

[Make a charitable contribution](#)

For More Information

Visit RAND at www.rand.org

Explore the [RAND Gulf States Policy Institute](#)

View [document details](#)

Limited Electronic Distribution Rights

This document and trademark(s) contained herein are protected by law as indicated in a notice appearing later in this work. This electronic representation of RAND intellectual property is provided for non-commercial use only. Unauthorized posting of RAND electronic documents to a non-RAND website is prohibited. RAND electronic documents are protected under copyright law. Permission is required from RAND to reproduce, or reuse in another form, any of our research documents for commercial use. For information on reprint and linking permissions, please see [RAND Permissions](#).

This product is part of the RAND Corporation technical report series. Reports may include research findings on a specific topic that is limited in scope; present discussions of the methodology employed in research; provide literature reviews, survey instruments, modeling exercises, guidelines for practitioners and research professionals, and supporting documentation; or deliver preliminary findings. All RAND reports undergo rigorous peer review to ensure that they meet high standards for research quality and objectivity.

TECHNICAL REPORT

Coastal Louisiana Risk Assessment Model

Technical Description and 2012 Coastal Master Plan Analysis Results

*Jordan R. Fischbach • David R. Johnson • David S. Ortiz
Benjamin P. Bryant • Matthew Hoover • Jordan Ostwald*

Sponsored by the Coastal Protection and Restoration Authority of Louisiana



GULF STATES POLICY INSTITUTE

A study by RAND Infrastructure, Safety, and Environment

This research was sponsored by the Coastal Protection and Restoration Authority of the State of Louisiana and was conducted in the RAND Gulf States Policy Institute and the Environment, Energy, and Economic Development Program within RAND Infrastructure, Safety, and Environment.

Library of Congress Control Number:

ISBN: 978-0-8330-7708-0

The RAND Corporation is a nonprofit institution that helps improve policy and decisionmaking through research and analysis. RAND's publications do not necessarily reflect the opinions of its research clients and sponsors.

RAND® is a registered trademark.

© Copyright 2012 RAND Corporation

Permission is given to duplicate this document for personal use only, as long as it is unaltered and complete. Copies may not be duplicated for commercial purposes. Unauthorized posting of RAND documents to a non-RAND website is prohibited. RAND documents are protected under copyright law. For information on reprint and linking permissions, please visit the RAND permissions page (<http://www.rand.org/publications/permissions.html>).

Published 2012 by the RAND Corporation
1776 Main Street, P.O. Box 2138, Santa Monica, CA 90407-2138
1200 South Hayes Street, Arlington, VA 22202-5050
4570 Fifth Avenue, Suite 600, Pittsburgh, PA 15213-2665
RAND URL: <http://www.rand.org>
To order RAND documents or to obtain additional information, contact
Distribution Services: Telephone: (310) 451-7002;
Fax: (310) 451-6915; Email: order@rand.org

Summary

Motivated in part by the devastating effects of Hurricanes Katrina and Rita in 2005 and Gustav and Ike in 2008, planners and policymakers in the State of Louisiana have updated *Louisiana's Comprehensive Master Plan for a Sustainable Coast* (the “Master Plan”). The resulting Master Plan proposes a range of structural protection and coastal restoration projects to reduce storm surge flood risks to coastal communities and address other objectives to help create a more sustainable coast over the next 50 years. To support this process, the Coastal Protection and Restoration Authority of Louisiana (CPRA) convened a set of modeling teams to provide analytical support and help improve understanding of how coastal conditions might change in the future and how they could be improved through new investments in protection or restoration.

CPRA asked RAND to create an analytical model, the Coastal Louisiana Risk Assessment (CLARA) model, to estimate flood depths and damage that occur as a result of major storms. CLARA made it possible to systematically evaluate potential projects for inclusion in the Master Plan on the basis of how well they reduce flood damage in Louisiana's coastal region.

CLARA's outputs are inputs for the separate, RAND-developed Planning Tool, which assesses the overall benefits and costs of proposed protection and restoration projects, taking into account uncertainty regarding future conditions.

Overview of the CLARA Model

Theory

CLARA's structure is based on the principles of quantitative risk analysis. Risk is typically described as the product of the *probability* or *likelihood* of a given event occurring—in this case, the annual probability of storm surge flooding at different depths—and the *consequences* of that event—the damage that results from the flooding. This formulation can be refined when applied to storm surge flood risk because engineered systems designed to prevent flooding may fail, introducing a new dimension of uncertainty.

The likelihood of flooding can be divided into two components: the *threat* or *hazard*, which represents the underlying probability that a surge-producing storm will occur, and the *vulnerability* of hurricane protection infrastructure (e.g., levees, pumps, gates) to partial or complete failure given that a storm surge event occurs. The resulting three-part characterization of flood risk—threat, vulnerability, and consequences—serves as the basic organizing principle for CLARA (U.S. Army Corps of Engineers [USACE], 2009b; Morgan and Hen-

tion, 1990; Fischbach, 2010). The consequences of flooding can include all possible impacts, including direct or indirect economic damage or losses, loss of life, and environmental damage. In our framework, references to flood risk are best understood as *flood risk to structures, physical infrastructure, and other local economic assets*.

Inputs

CLARA uses two types of information to estimate flood depths and resulting damage:

- **Estimated peak storm surge and wave heights that occur as a result of hurricanes.** CLARA uses estimated surge and wave heights from 40 simulated storms across the Louisiana coast selected to best represent the range of possible coastal flooding threats. The model also accounts for *subsidence* over time, the natural sinking of the land compared with sea level, and *rising sea levels* that could result from the effects of global climate change.
- **Data that characterize the hurricane protection system.** One of the key decisions to be made as part of the planning process was where to construct or improve levees, floodwalls, and other structures to protect Louisiana from storms. These structures define which areas are protected from hurricanes and which areas are not.

RAND conducted the CLARA modeling after other teams working in support of the Master Plan had run their models and produced the necessary input data. For example, the Storm Surge/Wave Team provided estimates of surge elevation over the course of each storm for the 40 simulated storms in both unprotected and protected areas. The Storm Surge/Wave Team also provided estimates of significant wave heights in unprotected areas and wave characteristics along the structural elements to facilitate the calculation of *overtopping*—water that enters the protection system because of waves or storm surge spilling over the crest of a protective structure. Other data inputs, including land elevation, geotechnical and construction characteristics of levees and floodwalls, connecting interior heights between hydrologic basins, and an inventory of economic assets, were provided to RAND by CPRA, the USACE, and other CPRA modeling teams.

Outputs

Risks are estimated in terms of damage in dollars that results from surge-based flood events caused by Category 3 and higher storms. We measure damage from flooding in two ways. First, we use *exceedance probabilities*, which are statistical estimates of the flooding and damage expected to recur with a certain probability in each year. For example, the 1-percent or 100-year flood exceedance is the flood depth that has a 1-percent chance of occurring or being exceeded in each year. This is commonly referred to as the *1-in-100* or *100-year flood*. We calculate flood and damage exceedances at three levels: 50 year (2-percent chance), 100 year (1-percent chance), and 500 year (0.2-percent chance). We also measure flood damage using *expected annual damage* (EAD). EAD is the average damage from Category 3 and higher storms projected to occur in a single year, taking into account both the effective damage from such a storm and the overall likelihood of a storm of this intensity occurring in a given year.

Certain types of assets, including strategic assets (e.g., oil and gas infrastructure) and culturally significant and historic properties, were not included in damage estimates because of a lack of data regarding the value of these assets. In these cases, 50-, 100-, and 500-year flood

depth exceedances were provided directly to other CPRA modeling teams to determine the number of properties in each category flooded at each exceedance interval.

Assumptions

Flooding is a result of a complex set of factors, so by necessity CLARA simplified what actually occurs. For example, when considering the possibility that portions of hurricane protection systems might fail, we considered only peak storm surge that occurs during a storm, ignoring the period of buildup and withdrawal. We also made assumptions that dramatically simplify the patterns of flooding if a system breach occurs. We assumed that floodgates used to seal off protected areas are closed properly prior to a storm. Pumping scenarios are simplified and pumps are assumed to be on, off, or operating at 50-percent capacity. These and other assumptions were carefully tested for their influence on our results.

Time Period, Three Scenarios, and Geographical Scope

CLARA results from our final analysis of the Master Plan are presented for current conditions (2012), as well as in two future time periods: 2036 (25 years from present) and 2061 (50 years from present). We describe results from three scenarios that were used for the entire Master Plan modeling effort: the *moderate*, *moderate with high sea-level rise (SLR)*, and *less optimistic* future scenarios.

The study area and northern boundary were adopted directly from the recent USACE Louisiana Coastal Protection and Restoration analysis, which divided the Louisiana coast into a series of five Planning Units and approximately 1,000 Planning Subunits (USACE, 2009a) also known as “basic hydrologic units” (BHUs). The northern boundary of this area roughly follows Interstates 10 and 12; storm surges are not expected to affect areas to the north of these highways.

CLARA labels each BHU as *unprotected*, *semiprotected*, or *protected* (USACE, 2009a). Unprotected areas have no levees, floodwalls, or other barriers to prevent flooding due to storm surges. Semiprotected areas have levee or floodwall protection, but these protection structures do not fully enclose the population at risk. As a result, storm surge could “run around” the structures and flood the area from behind. Protected areas have hurricane protection that is fully enclosed in a ring, defining an artificial hydrologic unit composed of one or more adjoining BHUs that is distinct from the exterior area. Key protected areas include the portions of Greater New Orleans enclosed within the Hurricane and Storm Damage Risk Reduction System (HSDRRS) built by the USACE.

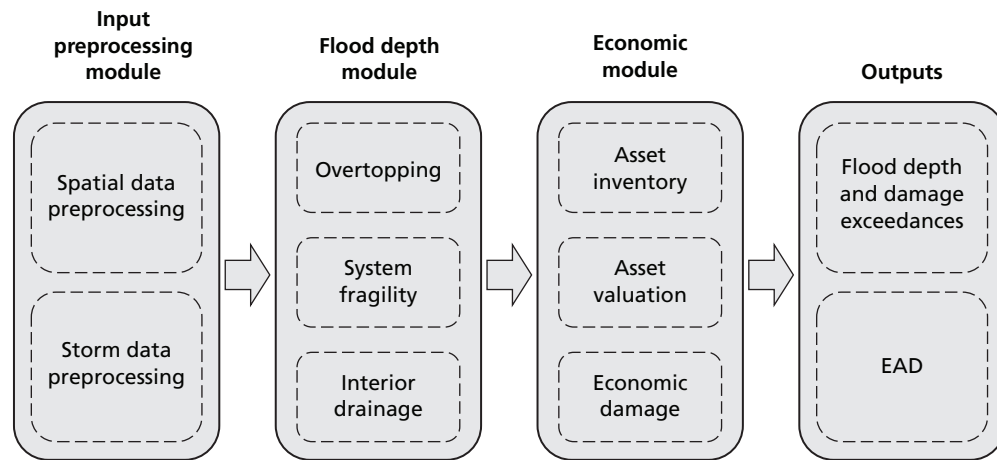
CLARA’s Analytical Structure

The structure of the CLARA model is illustrated in Figure S.1.

In the **input preprocessing module**, CLARA uses information about the study region and generates flood depth estimates in unprotected and semiprotected areas and storm hazard conditions for a sample of hypothetical storms. It also records surge and wave conditions along protection structures.

CLARA then estimates the volume of water that flows over structures into protected areas—i.e., it estimates flood depths in the **flood depth module** with particular focus on storm surge or wave overtopping and system fragility. CLARA handles system fragility by

Figure S.1
CLARA's Analytical Structure



RAND TR1259-S.1

bracketing between two extreme cases: one in which protection systems never fail and one in which breaches result in interior inundation up to the level of surge that initiated the breach.¹

CLARA also equalizes the flood depth among adjacent protected areas. If one neighborhood in New Orleans lies next to another neighborhood and the first neighborhood floods, the adjacent neighborhood will also flood unless some barrier separates them. The elevation of the connections among BHUs is determined using a high-resolution digital elevation model (DEM)—including embankments, roads, and other structures—compiled and provided by the Wetland Morphology Team.

The depth of the flood directly determines the amount of damage that occurs, so flood depths are inputs to the **economic module**. In this step, CLARA values the assets at risk from flooding and estimates damage. Damage is estimated by census block at the 50-, 100-, and 500-year damage exceedances. Damage depends on the inventory of assets, so we build an inventory of assets (for example, homes, roads, and agricultural buildings and crops) within each census block and place a value on the assets and their contents. Values depend on characteristics that vary by asset type. Single-family homes are valued at replacement cost per square foot, which in turn depends on a number of factors. In general, our model bases values on the Federal Emergency Management Agency's (FEMA's) Hazards–United States (Hazardus)–Multi-Hazard (Hazardus-MH) model, 2010 census data, and Louisiana-specific data provided by the Louisiana Coastal Protection and Restoration project.

In addition to damage to property, CLARA estimates the costs borne by victims who are displaced by flooding.

A key challenge was estimating potential future damage from flooding over the 50-year time horizon of the Master Plan. Patterns of settlement and economic growth will alter the kind and value of assets that could be damaged in a flood. We developed several scenarios of

¹ A structure suffers a *seepage failure* when water flows through soil under the levee or floodwall. A *slope stability failure* occurs when forces exerted by the floodwater against the levee or floodwall are greater than what the structure can resist. An *overtopping failure* occurs because of erosion of the protected side of the levee or floodwall from the rushing surge water.

future economic growth and the level of urbanization in coastal areas to provide a range of estimates of the future value of assets.

CLARA outputs are the damage exceedances and EAD.

Results of the CLARA Analysis and Contributions to the Master Plan

RAND's initial analysis with CLARA helped compare and rank projects for inclusion in the Master Plan based on flood depths and damage in dollars in a "future without action" to protect coastal Louisiana and in a future with the final Master Plan in place, in two time periods and two scenarios: 2012 (current conditions) and 2061 (50 years from present) in the *moderate* and *less optimistic* future scenarios, respectively. These scenarios reflect different assumptions regarding future SLR, coastal land subsidence rates, and other key uncertainties about the future. The moderate scenario assumes low to moderate SLR and subsidence rates, while the less optimistic scenario uses much higher assumptions.

Then we evaluated the combined damage reduction benefits from Master Plan investments in new or upgraded protection structures, nonstructural risk reduction projects, and coastal restoration in these same years and scenarios and also included an additional interim time period, 2036 (25 years from present), and additional future scenario, termed the *moderate future with high SLR*. This scenario matches the assumptions for the moderate scenario, except that it includes additional SLR over time.

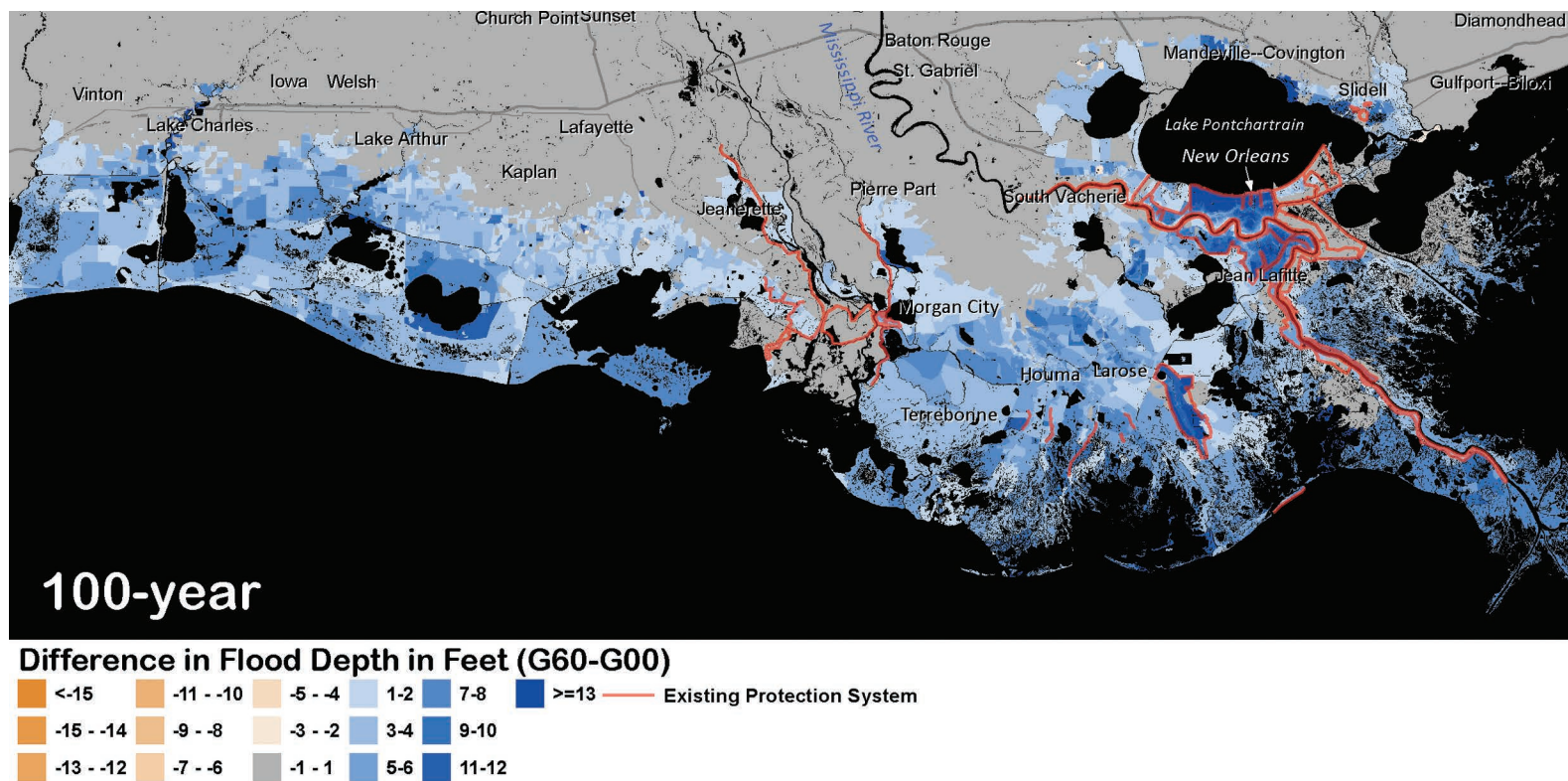
What Might We Expect in a Future Without Action?

In general, risk and damage results from the final Master Plan analysis show that storm surge flood damage represents a major threat to coastal Louisiana, and if no action is taken, this damage can be expected to grow substantially in the future. Figure S.2 illustrates the potential increase in flood depths over 50 years in a future without action.

Flood depths and damage outcomes both worsen over time in a future without action, with the amount of increased flood damage varying substantially by Master Plan scenario and with the assumed structural reliability of the New Orleans HSDRRS in future years. When we consider the potential for failures of the protection system, damage estimates increase substantially for New Orleans in some Master Plan scenarios. Results produced in the CLARA analysis may overstate this damage because of simplifying assumptions, but results nevertheless indicate that considering system fragility is critical to understanding the potential benefits and trade-offs associated with future protection system investments.

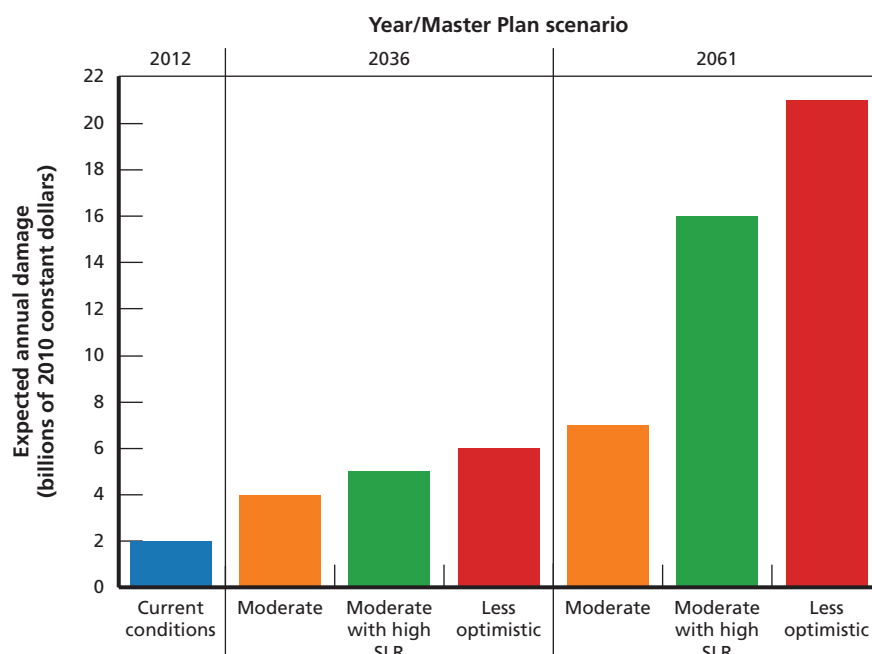
As Figure S.3 illustrates, EAD in the other Master Plan scenarios is not as large as in the less optimistic scenario, reaching \$7 billion in the moderate scenario and \$16 billion by 2061 in the moderate scenario with high SLR. In Greater New Orleans, 2061 EAD in the moderate scenario is \$1.5 billion, compared with \$6.9 billion in the moderate scenario with high SLR and \$12.4 billion in the less optimistic scenario. That means that the performance of the Greater New Orleans HSDRRS is responsible for about 78 percent of the difference in EAD between the moderate and less optimistic scenarios. The dramatic increase in EAD is thus driven by the impact of higher SLR and land subsidence on the fragility of existing protection systems; less severe, more frequent storms become more likely to cause catastrophic levee failures in protected areas with highly concentrated assets than in the moderate scenario.

Figure S.2
Estimated Change in Flood Depth from 2012 to 2061, by Census Block, at the 100-Year Flood Exceedance (Less Optimistic Scenario)



RAND TR1259-S.2

Figure S.3
Estimated Expected Annual Storm Surge Flood Damage in the Future
Without Action, by Year and Master Plan Scenario



RAND TR1259-S.3

What Might We Expect in a Future with Master Plan Projects in Place?

The Master Plan helps to reduce flood damage in many areas of the coast through a combination of structural and nonstructural risk reduction investments and coastal restoration projects. For instance, Figure S.4 illustrates the coastwide reduction in 100-year flood depth in the less optimistic scenario with the Master Plan in place using our default assumptions. The projects associated with the Master Plan are also indicated on the map and include structural protection (in pink), river diversions to rebuild wetlands, and coastal restoration projects.

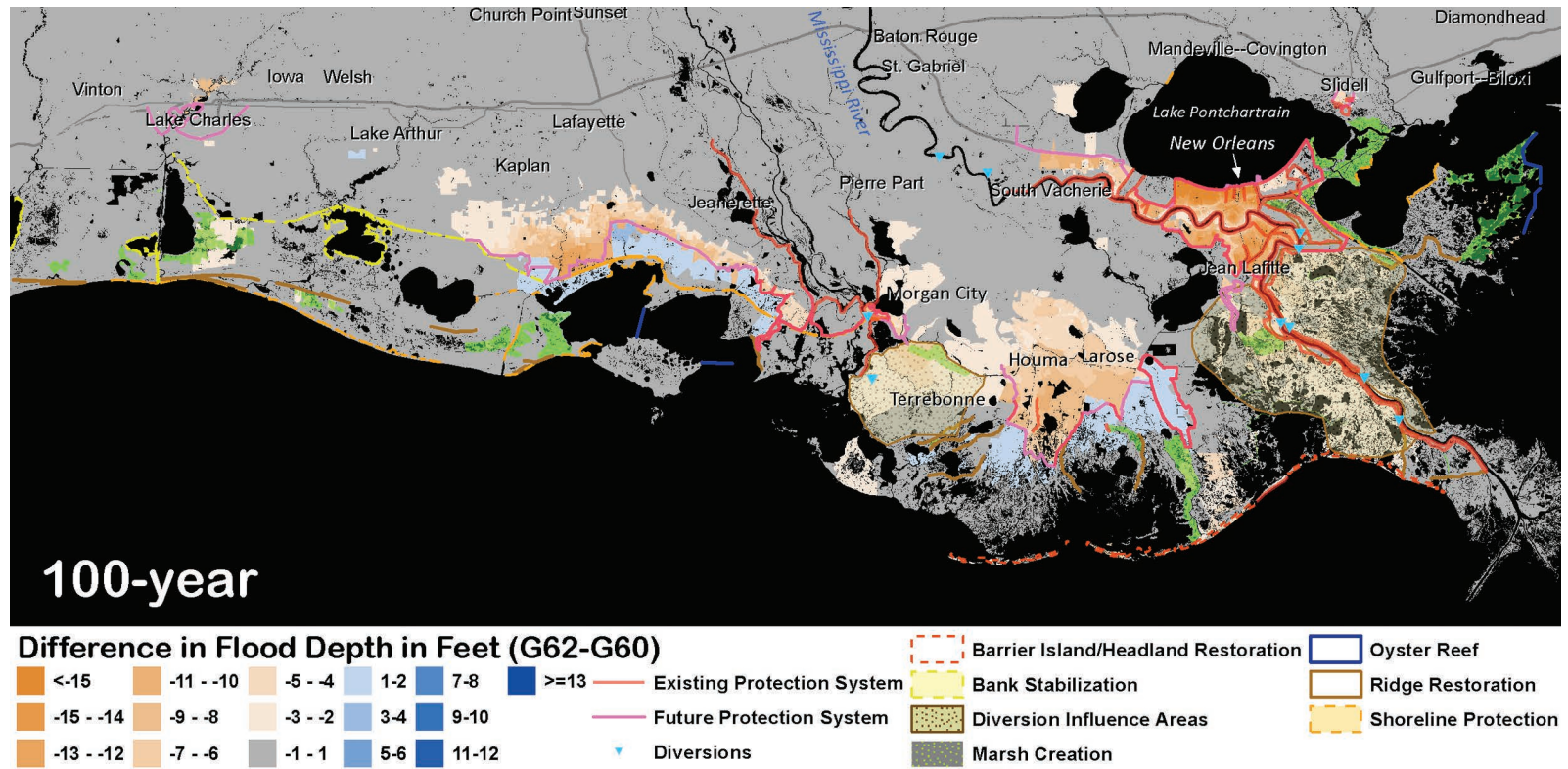
This map indicates the difference in flooding between the Master Plan and the future without action and shows substantial depth reduction (orange shading) in many areas of the coast.

Damage reduction is also notable across all three scenarios (Figure S.5). For instance, in 2061, EAD is projected to increase to between \$7 billion and \$21 billion in the future without action depending on the scenario, but, with the Master Plan in place, this damage level is reduced to between \$3 billion and \$5 billion. This corresponds to a reduction of approximately 60 to 80 percent compared with flood damage level in the future without action.

Different story lines emerge from different areas of the coast. For instance, a large proportion of the coastwide damage reduction occurs in Greater New Orleans after 2032 as a result of new investments that reduce the likelihood of the protection system being breached by waves or storm surges.

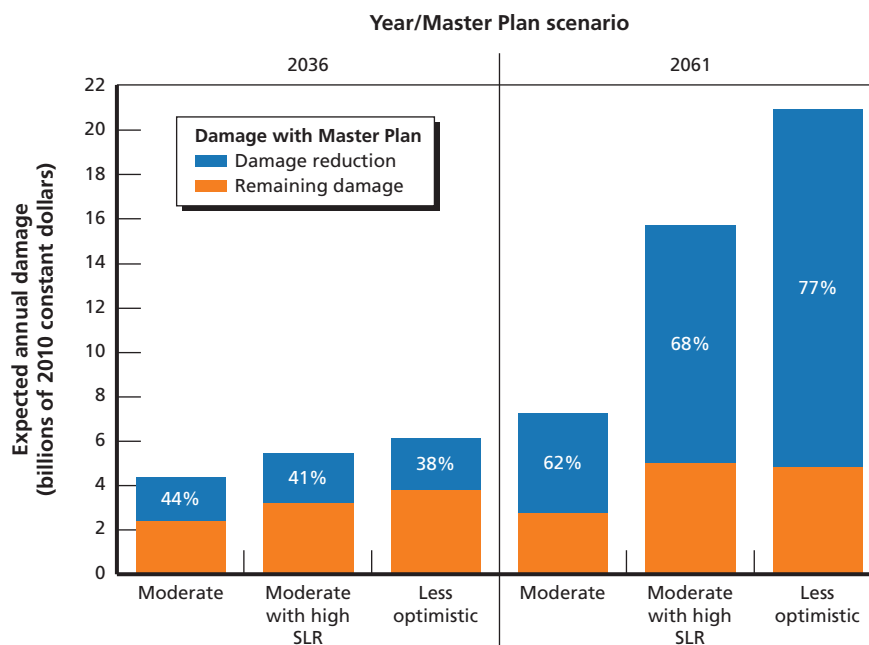
The new Morganza to the Gulf surge barrier, built to an elevation of 20 to 37 feet, provides substantial flood depth reduction and consequent damage reduction in the vicinity of Houma and Terrebonne. The final Master Plan analysis shows that the new alignment could provide substantial risk reduction benefits to Houma and the surrounding Terrebonne ridge

Figure S.4
Estimated Change in 100-Year Flood Exceedance in 2061 for Coastal Louisiana, by Census Block, with the Master Plan in Place (Less Optimistic Scenario)



RAND TR1259-S.4

Figure S.5
Estimated Remaining Expected Annual Damage and Reduction in Expected Annual Damage with the Master Plan in Place, by Year and Master Plan Scenario



RAND TR1259-S.5

communities. Analysis with CLARA shows that Morganza to the Gulf could reduce depths across all three flood exceedances considered, with depth reduction of 2 to 5 feet (50 year), 2 to 7 feet (100 year), and 2 to 11 feet (500 year), respectively. Depth reduction extends for a large area of the coast behind the new alignment, including other portions of Terrebonne Parish and some upland areas.

However, the Morganza to the Gulf levee also displaces surge that previously flooded areas to the north, leading to an increase in surge heights and flood depths for areas exterior to the levee system. In addition, a notable result is that the new levee displaces surge onto the existing Larose to Golden Meadow system, leading to induced flooding on the interior.

Finally, some areas receiving nonstructural investments in the Master Plan, such as the community of Mandeville on the north shore of Lake Pontchartrain, see very limited flood damage reduction from the Master Plan due to the limited range of nonstructural projects considered in this analysis. For these areas, a wider range of risk reduction alternatives may need to be considered to reduce vulnerability to damage from future storm surge events.

Conclusion

Louisiana faces a growing threat from increased future flood risk, but the 2012 Master Plan takes a major step toward protecting the state's vibrant cultural history and economic livelihood for years to come. CLARA was designed to support policymakers in a flexible exploration of options for protection projects. CLARA establishes the capability to perform comparative

evaluations of many options in a rigorous manner while accounting for a wide range of future uncertainties. Its development and use as part of the master planning process produced new methods for estimating flood depths and damage and provided timely information to support Master Plan development. CLARA can also serve as a roadmap for future evaluations of coastal flood damage or damage reduction in Louisiana and other coastal regions.