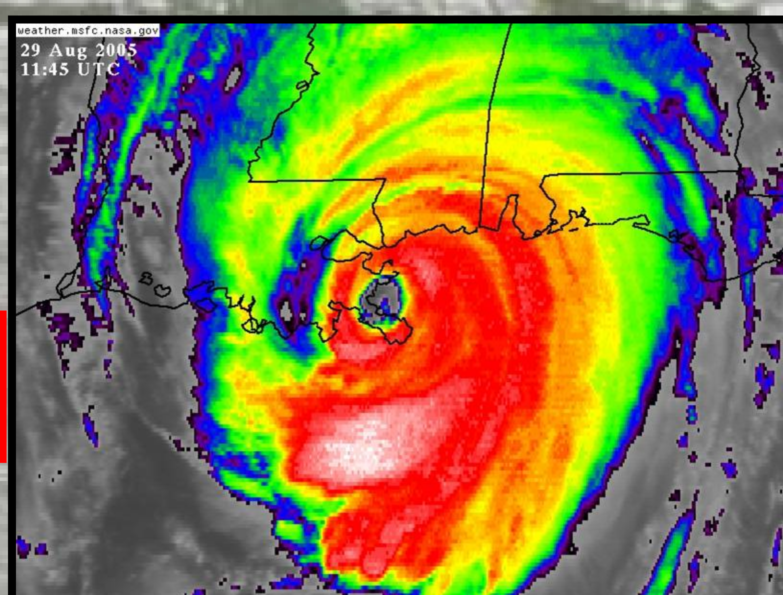
US Army Corps of Engineers®

Performance Evaluation of the New Orleans and Southeast Louisiana Hurricane Protection System

Final Report of the Interagency Performance Evaluation Task Force

Volume VII – The Consequences

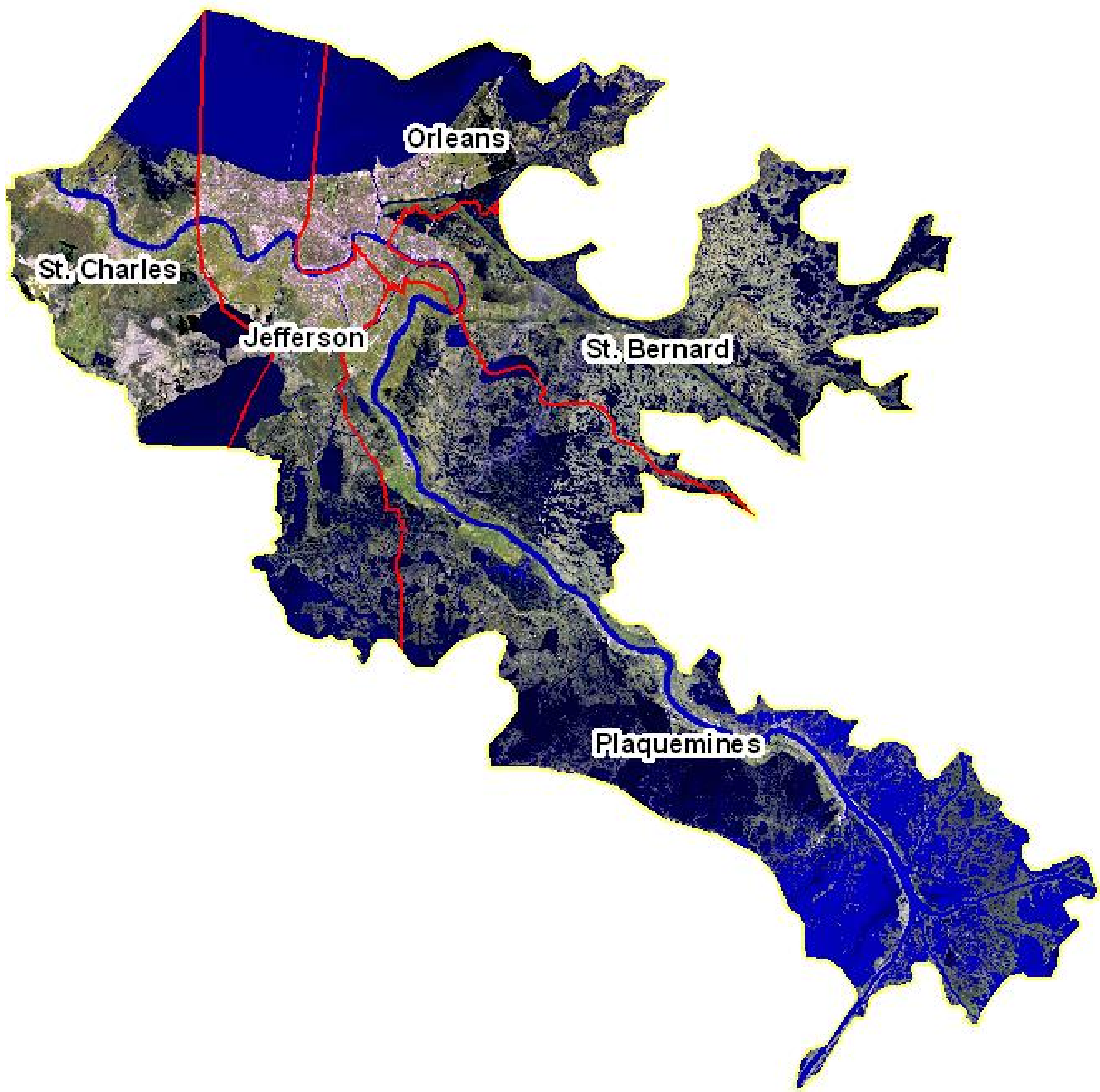
26 March 2007



FINAL

Volume I – Executive Summary and Overview
Volume II – Geodetic Vertical and Water Level Datums
Volume III – The Hurricane Protection System
Volume IV – The Storm
Volume V – The Performance – Levees and Floodwalls
Volume VI – The Performance – Interior Drainage and Pumping
Volume VII – The Consequences
Volume VIII – Engineering and Operational Risk and Reliability Analysis
Volume IX – General Appendices

Volume VII
The Consequences



Contents

Executive Summary 1

Limitations 5

7.0 Contributors 6

Economic Consequences 6
Human Health and Safety Consequences 7
Social and Cultural Consequences 7
Environment Consequences 7

7.1. Summary 9

7.1.1. Objectives 9
7.1.2. Event Scenarios Considered 9
7.1.3. Types of Consequences Considered 11
7.1.4. Results: Katrina with Actual System Performance 11
7.1.5. Implications 13
7.1.5.1. Implications for Public Finance 13
7.1.5.2. Implications for Land Use 13
7.1.5.3. Other Implications 13

7.2. Economic Consequences Assessment Digest 14

7.2.1. Direct Property Damages 14
7.2.1.1. Objective 14
7.2.1.2. Approach 15
7.2.1.3. Damages to Infrastructure 24
7.2.1.4. The Results of Direct Damage Assessment 27
7.2.1.5. Quantifying Uncertainty in Stage-Damage Estimates 30
7.2.1.6. Post-Katrina Stage-Damage 35
References 38
7.2.2. Indirect Impacts 39
7.2.2.1. Objective 39
7.2.2.2. The New Orleans Region Economy 40
7.2.2.3. Regional Economic Forecast 47

7.3. Human Health and Safety Consequences 60

7.3.1. Human Health Effects of Hurricane Katrina 60
7.3.1.1. Objectives and Limitations 60
7.3.1.2. Health and Safety Exposures and Outcomes 62
7.3.1.3. Mental Health Exposures and Outcomes 93
7.3.1.4. Pre-Literature: Studies Currently in the Field or Recently Completed 102
7.3.2. Loss of Life Modeling 104
7.3.2.1. Objective 104
7.3.2.2. Limitations of the Analysis 104
7.3.2.3. Modeling Approach 106
7.3.2.4. Data Requirements 111

7.3.2.5. Analysis...*115*
7.3.2.6. Results..*122*
7.3.2.7. Recommendations for Future Mortality Risk Modeling.............................*123*
References 125

7.4. Social and Cultural Consequences Assessment Digest 138

7.4.1. Objectives..138
7.4.2. Approach 138
7.4.2.1. Units of Analysis..*139*
7.4.2.2. Study Area..*140*
7.4.2.3. Field Methodology...*140*
7.4.2.4. Data *140*
7.4.3. Results 141
7.4.3.1. Local *144*
7.4.3.2. Historical and Cultural Resources...*152*
7.4.3.3. Regional...*152*
7.4.3.4. National *153*
7.4.4. Summary of Social and Cultural Consequences 154
References 156

7.5. Environmental Consequences Assessment Digest...158

7.5.1. Objectives..158
7.5.2. Approach 159
7.5.2.1. Concept Model Development..*159*
7.5.2.2. Data Development and Analysis...*163*
7.5.3. Results: Actual and Hypothetical Katrina Scenarios 167
7.5.3.1. Ecosystem Support..*167*
7.5.3.2. Fisheries (Fish and Invertebrates) *181*
7.5.3.3. Wildlife...*186*
7.5.3.4. Pest Species *189*
7.5.3.5. Special Status Species...*190*
7.5.5. Environmental Consequences of Future Hurricane Events.............................199

References...200

Executive Summary

Metropolitan New Orleans, including the Louisiana Parishes of Orleans, St. Bernard, Plaquemines, Jefferson, and St. Charles, lies primarily below sea level and is highly susceptible to flooding. Hurricane protection and flood control structures, collectively referred to here as "the system," are in place to protect the population, property, communities, markets, institutions, and natural resources within its interior. In Volume VII the consequences of system performance during Hurricane Katrina are examined. Where possible, consequences are tied to interior peak water surface elevation (WSE) measures in each of 27 subbasins (Figure 1) during and after Katrina by quantitative or qualitative measures of diminished health, property, economic opportunity, and ecosystem quality, in loss of life, and in impacts to community infrastructure (social, cultural, and historical).

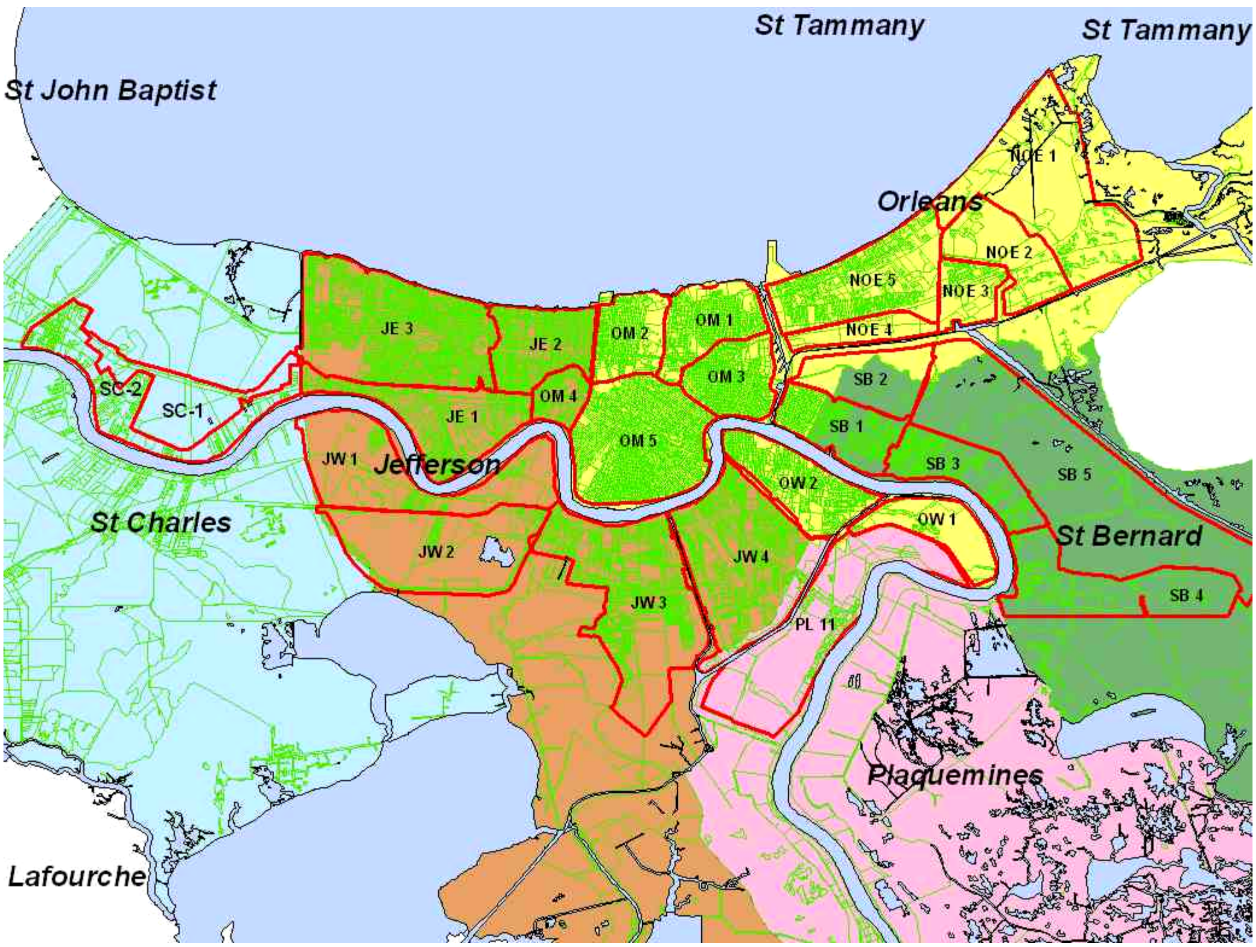


Figure 1. Study area map with subbasin boundaries (OM-Orleans Metro; OW-Orleans West; NOE-New Orleans East; SB-St. Bernard; PL-Plaquemines; JW-Jefferson West; JE-Jefferson East; SC-St. Charles).

It is important to distinguish between a system performance based consequence assessment as reported here and a complete consequence accounting of Hurricanes Katrina and Rita in the gulf region. The system performance based consequence assessment reported in this volume contributes to the overall performance evaluation in the complete volumes of this report. Since the system is only designed to manage flooding in the metro New Orleans basin, wind-based consequences and all direct consequences exterior to the system are excluded from this accounting. A hurricane impact assessment would include the impacts of the high winds and would consider a much larger geography than is reported in this volume.

The analysis represents a continuation of system-wide findings in previous volumes of this report. In earlier volumes, interdependencies were examined between system conditions (Volume III), storm forces on the system (Volume IV), system performance (Volume V), and interior-drainage/pumping-performance (Volume VI). For this volume, the water surface elevation findings reported in Volume VI are directly translated into a consequence assessment. Aside from examining the actual Katrina event, this report examines three hypothetical WSE outcomes that reflect alternative incremental system performance assumptions, each of which would have produced less flooding than what actually occurred. Finally, to facilitate the incorporation of consequence assessments into the risk analysis (Volume VIII), consequence estimates with uncertainty parameters for loss of life and loss of property by study area subbasin are developed for incremental changes of interior WSE, ranging from non-flood outcomes to worst case loss outcomes.

At least 1,118 deaths were recorded in Louisiana following Katrina, the vast majority of which occurred in greater New Orleans, and the region's social infrastructure remains severely diminished. Social consequences of the storm are unparalleled in the modern era of the United States--the poor were disproportionately affected. As of March 2006, over 400,000 fewer peopled resided in metro New Orleans. Direct losses of the tangible wealth in the area amounted to about $21 billion—primarily residential wealth. Most of this damage was the result of failures in the performance of levees, floodwalls, and interior drainage pumps. More than half of the 70 business sub-sectors in the New Orleans area showed a 25-percent or greater decline in employment immediately after Katrina. Overtopping and breaching of the levees and floodwalls caused salt-water contamination of wetlands within the flood protection system and lead to the pumping of toxic chemicals both within and outside the flood protection system. The pace and direction of recovery in the region remains highly uncertain. What follows is a detailed presentation of these and other findings, starting with a brief summary of the scope and procedures for consequence analysis:

Direct Economic Consequences – The economic direct analysis assessed the physical flood damages to property and infrastructure in the greater New Orleans area. For the actual Katrina storm and all hypothetical system performance scenarios, peak WSE estimates for each of the 27 subbasins were reported in Volume VI of this report. The physical damages in each subbasin were estimated by the combination of depth of flooding, depth-percent damage relationships, and the value of the property in the floodplain. Depth of flooding was calculated as the difference between the WSE and ground elevation. Appendix I describes the digital elevation modeling methodology employed to determine these average ground elevations at the census block level. The analysis assembled a structure inventory that identified the property in the greater New Orleans floodplain, organized by census block. Property was categorized by primary usage type and physical characteristics of the structures and was valued at expected depreciated replacement value. Uncertainty in the property values was quantified based on information from previous field surveys of property within the New Orleans area. The next step in this process involved converting peak water stage into flood depths at each census block. Property damage by seven categories was estimated using tables relating the percentage of the depreciated replacement value of each asset damaged at each flood depth. These tables were developed by the U.S. Army Corps of Engineers (USACE) in the late 1990s for the New Orleans area with separate tables for different types of structures and contents. Aside from the Katrina scenario estimates, alternative WSE values ranging from a no-census block flooding depth to maximum loss exposure depths, by 1-foot increments were also computed. This resulted in a separate stage-damage relationship for each census block for each of the damage categories. The final step was to aggregate each of the stage-damage relationships by drainage subbasin. Uncertainty arising from ground elevation model errors and variability in elevation across each census block was quantified and used to adjust the stage-damage values. These stage-damage values, along with their uncertainty boundaries, were used in the risk and reliability analysis reported in Volume VIII of this report.

Indirect Economic Consequence – In concept, the indirect economic consequence analysis comprises all economic consequences not covered by the direct economic consequences analysis; however, the spatial and market resolution of the indirect analysis was far less detailed than the direct economic analysis. Only months after Katrina, a great deal of uncertainty persists about factors important to the recovery of the region. These factors include the response of the local population to disruptions in their lives and livelihoods, the effects on commuters working in the area, and the reactions of investors with ties to the region. Further, forecast of the resilience in the local, regional, and national economy are also sensitive to emerging information, pending policies, and assumptions of future behavior. To examine the recovery and transition process, a limited scope analysis of indirect economic consequences was carried out. This included an examination of the pre-Katrina economic base of metro-New Orleans and the consideration of the anecdotal post-Katrina economic data made available up to May 2006. Finally, economic forecasts of local, regional, and national trends in regional population, labor force, residential and non-residential capital formation, and gross regional product were developed using REMI Policy Insight, a multiregional economic and demographic forecasting model of the U.S. economy.

Human Health and Safety – The assessment of human health and safety consequences involved two parts: 1) identification of human mortality and morbidity resulting from Hurricane Katrina, and 2) loss of life modeling. The assessment of human health effects from Hurricane Katrina relied on a review of the available peer-reviewed literature, including similar-disaster scientific literature, as well as scientific and technical reports, conference papers, government documents, and other literature which are not readily available through commercial channels, to identify currently evident health effects as well as emerging and anticipated future health effects. The loss of life modeling was performed to study the relationship between actual and hypothetical system performance scenarios associated with Hurricane Katrina as well as future flood-related mortality risk from flooding in greater New Orleans. Loss of life modeling involved a two-step process. First, a dynamic simulation model was used to estimate how the population in the flooded area will be distributed vertically in relation to the depth of the flood, assuming no pre-storm evacuation. The model produced estimates of population at risk in three different flood lethality zones. These flood zones were further modified to account for the disproportional impacts to elderly populations. The model assumes that people over the age of 65 are unable to evacuate vertically above the highest habitable levels of structure, while people 65 and under are assumed to be able to evacuate higher to the attics and roofs of structures. In the second part of the modeling process, the vertical distribution estimates of populations at risk are imported into a Monte Carlo uncertainty model that includes distributions for various uncertain parameters, including pre-storm evacuation rates as well as rescue efficiencies and fatality rates by flood zone. Loss of life modeling was performed for two base conditions, one corresponding to pre-Katrina demographic and structural conditions, and one corresponding to post-Katrina demographic and structural conditions (as of June 2006). This modeling procedure produced fatality estimates according to flood elevations for each drainage basin corresponding to both pre- and post-Katrina conditions. Those stage-fatality estimates were incorporated into the risk and reliability assessment reported in Volume VIII and used within Volume VII to estimate potential fatalities under various hypothetical system performance scenarios.

Social, Cultural, Historical – In order that this consequence assessment be comprehensive, an accounting of the flood impacts on the community infrastructure was necessary. This infrastructure included the social, cultural, and historical capital and institutions. These developed and thrived in the neighborhoods, communities, and parishes that were within the hurricane protection system. Neighborhoods, communities, and region-wide institutions, support structures, and historical assets, tangible and intangible, enhanced the quality of life in the greater New Orleans region. These intangible assets did not lend themselves to direct translation of WSE outcomes into social, cultural, and historical impacts. In acknowledgment of this problem, the approach adopted a combination of data analyses, site surveys, and targeted interviews. An extensive research literature was drawn upon to guide the investigation. The study developed a highly detailed typology of institutions and assets describing the social, cultural, and historical infrastructure. The results reported metrics that directly or indirectly describe the assets using different units of measurement. To facilitate an understanding of the stress to the infrastructure, an extensive consideration of the evacuation, rescue, and recovery events is provided. Much of the social, cultural, and historical impacts are long-term and highly uncertain. Reference to appropriate research findings is discussed to anticipate these uncertain impacts.

Environmental – Environmental quality affects markets but the value of the ecosystem is an elusive measure. The ecosystem around New Orleans is both degraded and sustained by natural and human events; hurricanes are a case in point. While hurricanes temporarily reduce certain ecological resources (freshwater fisheries resources, for example), they also sustain natural ecosystems and provide long-term benefits (sustaining estuarine fisheries and threatened and endangered species, for example). To evaluate the impact of system performance on the environment, the evolving processes of the surrounding ecosystem prior to Katrina were first considered. Salient pre-Katrina features of the ecosystem were described and the geography was separated into the inner and outer ecosystem. The outer ecosystem extends beyond the hurricane and flood damage reduction structures but is within the reach of floodwater pumping effects. Drawing from an extensive but uneven statistical record of environmental indicators in the study area, a base condition for comparison was established. After Katrina, assessments by numerous agencies, most notably the U.S. Environmental Protection Agency (EPA) and U.S. Geological Survey (USGS), provided an opportunity to assess environmental impacts of the storm and to identify unresolved issues for further investigation. These assessments were complemented by additional field investigations of the inner-ecosystem wetlands where potential effects were large and little data collection was otherwise expected. The post-Katrina results of these assessments were combined with the results of contaminants fate/transport models. This fate model used floodwater contamination data to evaluate the extent that floodwater pumping contributed to environmental contamination in inner and outer natural ecosystems. The assessment focused on elevated contamination by lead, fecal coliform bacteria, arsenic, DDE, and benzo(a)pyrene , but included other contaminants to the extent information was available. The contaminant fate models included, for Lake Pontchartrain, a three-dimensional (3-D) hydrodynamic model and a 3-D water quality model. A simpler model was used for Violet Marsh. Results from the data analyses and model simulations were reported by ecological resource categories and pest species for both the inner and the outer ecosystems.

Limitations

The nine volumes of this report constitute a performance evaluation of the New Orleans and Southeast Louisiana Hurricane Protection System during Hurricane Katrina and looking forward. Soon after Katrina struck New Orleans it was discovered that the system was severely damaged. This study was sanctioned, in part, to coincide with the urgent repair efforts on the system with a target completion date for both the repairs and this report of 1 June 2006—the official start of the 2006 hurricane season. This date was a major and important factor influencing the approach adopted to produce this volume. To answer the principal question directed towards this effort—"What have been the societal-related consequences of the Katrina-related damage?"—a top priority became a comprehensive classification of potential consequences. Beyond this, other priorities included identifying consequences among those classified to be passed on for the risk analysis, bringing the best available data into the analysis, and limiting analysis of data to findings that are verifiable or sound, transparent, and routinely reproducible. Hard decisions about limiting the scope were made, and three important limitations of those decisions require special mention.

Important data exist that would greatly enhance the information and analysis reported in this volume. With more time, many of these data could have been made available, but this time was viewed too costly to achieving the overall goals in this volume. One example is the micro-data that are compiled for the Bureau of Labor Statistics Quarterly Census of Employment and Wages (QCEW). Efforts on all sides were made to explore opportunities to use information from these data files in a way that does not violate confidentiality restrictions placed on their use. While it was generally agreed that an appropriate arrangement could be made, the hurdles were prohibitive given the severe time constraints. Ultimately, this report used the publicly released QCEW data products as they were provided to the public, including some special tabulations carried out for Interagency Performance Evaluation Task Force (IPET) by the Louisiana Department of Labor. For future studies, it is believed that the QCEW can be used to improve the estimation of the extent and type of direct property damage in the five-parish area as well as better characterize the nature of business resilience following the storm. Other examples of data not available include complete fatality statistics and the locations of the displaced New Orleans population.

Although identification of potential consequences was a priority of this study, many impacts mentioned in this volume are not dealt with as extensively as they deserved. The report includes an extensive listing of specific and general categories of consequences. However, many of these are not are quantified and many gaps remain. They remain a priority of future research.

Context, discussion, and comparisons to other findings are limited in this report. This was not planned but was due to the short time available for internal verification and replication of IPET reported results. Many of the findings are based on data and analytical resources that became available very late in the study period. In both the social and environmental sciences, context and comparisons are a critical aspect of research reporting and much of this context is self-evident. However, it is important that context not be selective and incomplete—for example, only offered to buttress one's findings—and time constraints have limited the opportunity for comparisons and context.

The overall report of findings in this volume meets the goals set out in Reports 1 and 2 of this project. Its timeliness has allowed the key findings to inform both the risk analysis in Volume VIII and the concurrent rebuilding process that is still ongoing. The information reported in this volume should be viewed as laying the groundwork for answering the very hard questions about future investments in hurricane infrastructure.

This volume presents the results of the consequences assessment conducted as part of IPET. Section 7.1 provides a summary of the objectives and results of the overall consequences assessment. Reviews for the four types of consequences are presented in Sections 7.2 to 7.5. These include the following categories of effects: economic, human health and safety, social and cultural, and environmental. More detailed discussions of the assessment of these four categories of effects are provided in Appendices 1 to 5.

7.0 Contributors

Economic Consequences

- David Moser, Ph.D. — USACE, Institute for Water Resources
- Patrick Canning, Ph.D. — USDA, Economic Research Service
- Ian Mathis — USACE, Institute for Water Resources
- Brian Harper — USACE, Institute for Water Resources
- Norm Starler, Ph.D. — USACE, Institute for Water Resources
- Dennis Robinson, Ph.D. — University of Missouri, Community Policy Analysis Center
- Arnold Waters — USDA, Economic Research Service
- Geoff Hewings, Ph.D. — University of Illinois, Regional Economics Applications Laboratory
- Keven Lovetro — USACE, New Orleans District
- Brian Maestri — USACE, New Orleans District
- Lisa Leonard — USACE, New Orleans District
- David McDaniel — USACE, New Orleans District
- Warren Cashen — USACE, New Orleans District

Internal Reviewers

- Karen R. Polenske, Ph.D. — MIT, Department of Urban Studies and Planning
- Nicolas Rockler, Ph.D. — Consultant
- Thomas Arnold — Consultant

Human Health and Safety Consequences

- Paul Scodari — USACE, Institute for Water Resources
- Gerald Stedge, Ph.D. — Abt Associates, Inc.
- Mark Landry — Abt Associates, Inc.
- Maged Aboelata, Ph.D. — Gannett-Fleming, Inc.
- William Schlenger, Ph.D. — Abt Associates, Inc.
- Giulia Norton — Abt Associates, Inc.
- Deborah Walker, Ed.D. — Abt Associates, Inc.
- Allison Goldberg — Abt Associates, Inc.
- Chad Lewis, Ph.D. — Abt Associates, Inc.

Internal Reviewers

- David Bowles, Ph.D. — RAC Engineers and Economists, Inc
- Tom Burke, Ph.D. — Johns Hopkins University

Social and Cultural Consequences

- Jack Beggs — Optinet Resources (Louisiana State University)
- Susan Cutter, Ph.D. — University of South Carolina
- Tom Denes — URS Corporation
- Joan Exnicios — USACE, New Orleans District
- Jeanne Hurlbert — Optinet Resources (Louisiana State University)
- Pam Jenkins — University of New Orleans
- Brenda Phillips — Oklahoma State University
- Ed Rossman, Ph.D. — USACE, Tulsa District
- John Singley, Ph.D. — USACE, Institute for Water Resources
- Internal Reviewer
- Joanne Nigg, Ph.D. — University of Delaware, Disaster Research Center

Environment Consequences

- Richard Cole, Ph.D. — USACE, Institute for Water Resources
- Barbara Kleiss, Ph.D. — USACE, Engineer Research and Development Center
- Jeff Lin — USACE- Engineer Research and Development Center
- Burton Suedel, Ph.D. — USACE, Engineer Research and Development Center
- Jeffery Steevens, Ph.D. — USACE, Engineer Research and Development Center
- Al Kennedy — USACE, Engineer Research and Development Center
- Sandra Brasfield — SpecPro, Inc.
- Tyler Bowley — USACE, Engineer Research and Development Center
- Herbert Fredrickson, Ph.D. — USACE, Engineer Research and Development Center
- John Furey — USACE, Engineer Research and Development Center
- Chris Foote — SpecPro, Inc.
- Margaret Richmond — SpecPro, Inc.

- Gary Ray, Ph.D. — USACE, Engineer Research and Development Center
- Mark Dortch, Ph.D. — USACE, Engineer Research and Development Center
- Mansour Zakikhani, Ph.D. — USACE, Engineer Research and Development Center
- Sung-Chan Kim, Ph.D. — USACE, Engineer Research and Development Center

Internal Reviewers

- Gordon L. Godshalk, PhD. — Alfred University, Alfred, NY
- Richard. J. Wenning, PhD. — Environ International Corporation, Emeryville, CA

7.1. Summary

7.1.1. Objectives

The consequences assessment focused on answering two main questions:

Katrina Consequences—What are the economic, human health and safety, social and cultural, and environmental consequences of flooding in greater New Orleans caused by Hurricane Katrina?

Potential Risk—Once repairs to the protection system have been completed, what will be the quantifiable risk to greater New Orleans from flooding associated with future possible hurricane and storm events?

Answers to the first question provide a profile of flood-related losses associated with Hurricane Katrina, while answers to the second question provide the IPET Risk and Reliability Assessment Team with information needed to assess risks associated with future possible hurricane and system response events. Consequences were also assessed under other specific what-if scenarios in order to provide a more complete understanding of hurricane-related flood risks in the study area, which includes the five parishes that make up the New Orleans metropolitan area (Orleans, Jefferson, St. Bernard, St. Charles, and Plaquemines).

7.1.2. Event Scenarios Considered

Table 1 summarizes the specific event scenarios for which consequences were assessed. These scenarios correspond to flooding associated with different hurricane/system response events. They include:

- Katrina with actual system performance—representing the actual flooding in greater New Orleans resulting from Hurricane Katrina and associated failure of levees and floodwalls.

- Three hypothetical flooding scenarios are examined to explore consequences of alternative scenarios of flood control and hurricane protection system performance in greater New Orleans. The environmental analysis was based on a rainfall event that is roughly equivalent to resilient pumps and levees, but no overtopping. These are summarized as follows:

    1. Hypothetical Katrina scenario 1 (Resilient Levees) – Levees and floodwalls crest elevations are at their pre-Katrina levels. Katrina overtops portions of the flood protection system, the levees and floodwalls maintain their integrity and do not breach, and interior pumping is as occurred during Katrina.

    2. Hypothetical Katrina scenario 2 (Resilient Levees and Pumps) – Levees and floodwalls crest elevations are at their pre-Katrina levels. Katrina overtops portions of the flood protection system, the levees and floodwalls maintain their integrity and do not breach, and interior pumping is at 100 percent availability.

3. Hypothetical Katrina scenario 3 (Resilient Floodwalls) – Levees and floodwalls crest elevations are at their pre-Katrina levels. Katrina overtops portions of the flood protection system. Overtopped levees incur scour as in Katrina, but the floodwalls maintain their integrity and do not breach, and interior pumping is as occurred during Katrina.

Table 1
Consequences Considered for Alternative Event Scenarios

Event Scenario	Consequences	Base Conditions	
		Pre-Katrina (August 2005)	**Post-Katrina (June 2006)**
Katrina with actual system performance	Economic	Direct (property) damages, including public infrastructure, and indirect impacts on local and regional economies	Not applicable
	Human Health	Number and profile of fatalities and description of actual and potential near and longer term physical and mental health impacts	Not applicable
	Social-Cultural	Description of impacts on communities and institutions	Not applicable
	Environmental	Description of impacts on ecological resources	Not applicable
Hypothetical Katrina scenarios • Resilient levees • Resilient levees and pumps • Resilient floodwalls	Economic	Direct (property) damages, excluding public infrastructure	Not applicable
	Human Health	Number of fatalities	Not applicable
	Social-Cultural	Not evaluated	Not applicable
	Environmental	Description of impacts on ecological resources associated with pumping due to an 8 inch rainfall event	Not applicable
Probabilistic risk scenarios as modeled by the Risk and Reliability Assessment Team	Economic	Probabilistic stage-damage functions provided to the Risk and Reliability Team for use in evaluating economic risk as of August 2005	Probabilistic stage-damage functions provided to the Risk and Reliability Team for use in evaluating economic risk as of June 2006
	Human Health	Probabilistic stage-fatality functions provided to the Risk and Reliability Team for use in evaluating mortality risk as of August 2005	Probabilistic stage-fatality functions provided to the Risk and Reliability Team for use in evaluating mortality risk as of June 2006
	Social-Cultural	Characterization of communities and institutions at risk	Description of impacts on communities and institutions with repeat of Katrina flood conditions
	Environmental	Characterization of ecological resources at risk	Description of impacts on ecological resources with repeat of Katrina flood conditions

In addition, stage-damage functions corresponding to property conditions expected to prevail in June 2006 were developed and supplied to the IPET Risk and Reliability Assessment Team. That team has used the stage-damage functions to estimate residual damage risks in the study area under the future risk scenarios.

7.1.3. Types of Consequences Considered

As shown in Table 1, for each of the three event scenarios, four types of consequences were assessed: economic, human health and safety, social and cultural, and environmental and reported under separate titles in the report. The environmental section addressed only the consequences associated with the condition of wild, publicly owned, ecological resources. Other consequences often considered to be part of the environment were addressed as economic, health, safety, social, and cultural consequences. For example, the economic consequences stemming from changes in fisheries resources are included within other regional economic consequences and the effect of contaminated water on people exposed to it is included in the health and safety section. The assessment of these consequences under the actual and hypothetical Hurricane Katrina scenarios used as the reference point those base conditions (e.g., property and demographic profiles) that existed in August 2005 prior to the arrival of Hurricane Katrina in the study area. Since the probabilistic risk scenarios consider both pre- and post-Katrina residual flood risks, the assessment of consequences under this scenario used two different reference points: 1) those base conditions that existed in August 2005 prior to the arrival of Hurricane Katrina, and 2) those base conditions estimated to exist in June 2006. The specific effects considered within each type for the three event scenarios are outlined briefly below.

7.1.4. Results: Katrina with Actual System Performance

Hurricane Katrina was among the costliest natural disasters in U.S. history. Volume VII presents many economic and social consequences, but it is difficult to characterize the full magnitude of the human suffering it caused. The socioeconomic and environmental consequences reported included:

- Direct Economic Consequences in five parishes:
  1. Direct damages to residential and non-residential capital (commercial, industrial and public buildings) amounted to about $21 billion.
     - 25 percent of residential property value, including autos, was lost to damage.
     - 12 percent of non-residential property value was lost to damage.
  2. Public structures and utility infrastructure damages (roads, transit, drainage, sewage, potable water service, electrical utilities, damages to levees, debris removal, etc.) were about $7 billion.
  3. Most of the direct damages resulted from failures in the performance of levees, floodwalls, and interior drainage pumps.
  4. Even if the hurricane protection system had functioned under the best possible scenario (resilient levees and pumps) there would have been $10 billion of property damages (excluding public utilities).
- Indirect Economic Consequences
  1. Employment in 36 of the 70 sub-sectors examined in metro New Orleans decreased by more than 25 percent immediately after Katrina.
  2. The growth of gross domestic product dropped from 4.1 to 1.9 percent (Third Quarter to Fourth Quarter 2005) in the period coinciding with pre-and-post Katrina and Rita.
  3. The national economy remained resilient after Katrina.

4. Long-term five-parish recovery depends on rate of capital repair and labor force return and prospects remain highly uncertain.

- Human Health and Safety
  1. As of August 2, 2006, 1,118 deaths in Louisiana, the vast majority of which occurred in the five parish area; 135 Louisiana residents remained missing as of that date.
  2. Almost 70 percent of deaths in five parishes were persons aged 61 and over; 45 percent of deaths were persons aged 76 and over.
  3. 346 deaths among Louisiana resident evacuees that occurred in other states have been linked to Hurricane Katrina by the State of Louisiana.
  4. Post traumatic stress is typical to both returning and displaced population.
- Social, Cultural, Historic
  1. Over 400,000 fewer people reside in metro New Orleans as of March 2006.
  2. The social infrastructure of metro New Orleans neighborhoods remains severely diminished.
  3. Primary-secondary school enrollment is down 52 percent in 5 parishes (86 percent in Orleans Parish).
  4. A majority of religious congregations are not back to normal functioning.
  5. A majority of musicians are gone, restaurants are closed; these are unique New Orleans resources; this loss affects economic recovery as well as social and cultural recovery.
- Environmental
  1. Consequences evaluated in this section were limited to wild, publicly owned ecological resources and to environmental costs and benefits that were not associated with economic, health and safety, or social and cultural costs.
  2. The estimated wetland loss of 295 square kilometers caused by Hurricane Katrina is consistent with long-term wetland loss trends—70 square kilometers per year—associated with past water resources and urban development, and, for the most part, was independent of levee overtopping and breaching.
  3. The environmental consequences of levee overtopping and breaching are most associated with saltwater contamination of wetlands within the flood protection system and with contamination by toxic inorganic and organic chemicals within and outside the flood protection system.
  4. Actual floodwater pumping following Hurricanes Katrina and Rita temporarily raised maximum concentrations of fecal contaminants and some metal contaminants to above state (Louisiana) standards, similar to runoff from past major storms, but the total environmental load of contaminants pumped with actual floodwaters exceeded rainwater pumping by an order of magnitude because of the much larger volume of water pumped.
  5. Because of high pre-Katrina concentrations of contaminants in the sediments of habitats receiving pumped floodwaters, the added contribution of contaminants in actual floodwaters was small in comparison.
  6. Of the special-status species in the region, bald eagles and brown pelicans were most likely to be exposed to contaminants pumped into the Pontchartrain-Borgne estuary or into Violet Marsh through contamination of their food species, but,

because of the limited area and increment of additional contamination, the effect on these special status species and other species is expected to be small.

7.1.5. Implications

From a perspective of only months after the storm and with the current knowledge of its consequences to the area, findings in this report provide a basis for drawing some overarching consequence implications. These are summarized below.

7.1.5.1. Implications for Public Finance

Damages to public buildings and infrastructure plus the anticipated costs of debris removal around metro New Orleans cost between $3 billion and $4 billion and these items are typically a city/parish responsibility. Combined five-parish general revenues in the 2001-2002 tax year, including taxes, charges, and both federal and state transfers to the local governments, totaled $3.4 billion, and of this total, property and sales taxes comprise more than one-third of local government general revenues in Louisiana (U.S. Census Bureau 2002, Census of Government, Compendium of Government Finances). The tax base in the five-parishes has been substantially diminished due to the flooding. With many displaced residents awaiting signs of progress in the return of public services before returning, it is not clear how these related conditions can be reconciled.

The Federal government is repairing and enhancing the damaged portions of the hurricane protection system and making the entire hurricane protection system better and stronger by 2010. So far almost $6 billion has been made available to the Corps for this work. So far, Congress has authorized around $100 billion in Katrina related emergency supplemental appropriations. Congress has also authorized the preparation of a report on alternatives to enhance hurricane protection in the region. The construction of such protection could entail the commitment of future federal appropriations in the tens or hundreds of billions of dollars. This represents a potentially large commitment of federal funding to the New Orleans region.

7.1.5.2. Implications for Land Use

Property losses in metro New Orleans were predominantly residential. On a damage per dollar of exposed value basis, residential capital (including autos) was more than twice as likely to be damaged by flooding ($0.254 per dollar of exposed value) than was non-residential capital ($0.120 per dollar of exposed value). This was a direct consequence of residential development in areas that, if flooded, would experience deep flooding. Other things being equal, loss of life during flooding events is expected to be greater the greater the depth of flooding. During a flood where people have advance warning and time to evacuate, those that remain are more likely to stay in their place of residence. If this residence is subject to deep flooding, the fatality rate and total loss of life will be correspondingly high.

7.1.5.3. Other Implications

- Society must be prepared to deal with system failure in order to minimize economic consequences.

- Society must be prepared to deal with consequences even if systems do not fail.
- Society should take steps to minimize potential consequences of both system failure and non-failure scenarios.
- Loss of life and evacuation planning should be an integral part of hurricane protection system planning and design as well as in local planning and operation. Especially vulnerable portions of the population warrant special consideration.
- Social and cultural consequences of failure and non-failure scenarios place stresses on the community infrastructure which affect both quality of life and the pace of disaster recovery. These types of consequences also should be factored into hurricane protection system planning and design as well as local planning and operation.
- Surrounding regional economies and the national economy can absorb and largely offset much of the adverse indirect impacts of a severe flood event with significant losses. This can help facilitate a more timely recovery in the directly impacted region.

7.2. Economic Consequences Assessment Digest

7.2.1. Direct Property Damages

7.2.1.1. Objective

The objective was to measure the direct economic consequences of Hurricane Katrina and of other hurricane system performance scenarios by estimating the damages to property in the greater New Orleans floodplain. Hurricane Katrina floodwaters inundated large sections of the city, damaging and destroying homes, businesses, public buildings (schools, hospitals, churches), and essential public facilities such as roads and utilities.

Within this overall objective, direct property losses from flooding in New Orleans were estimated for the following scenarios:

The actual scenario – Katrina overtops portions of the flood protection system, and the levees and floodwalls are breached.

Hypothetical Katrina scenario 1 (Resilient Levees) – Levees and floodwalls crest elevations are at their pre-Katrina levels. Katrina overtops portions of the flood protection system, the levees and floodwalls maintain their integrity and do not breach, and interior pumping is as occurred during Katrina.

Hypothetical Katrina scenario 2 (Resilient Levees and Pumps) – Levees and floodwalls crest elevations are at their pre-Katrina levels. Katrina overtops portions of the flood protection system, the levees and floodwalls maintain their integrity and do not breach, and interior pumping is at 100 percent availability.

Hypothetical Katrina scenario 3 (Resilient Floodwalls) – Levees and floodwalls crest elevations are at their pre-Katrina levels. Katrina overtops portions of the flood protection system. Overtopped levees incur scour as in Katrina, but the floodwalls maintain their integrity and do not breach, and interior pumping is as occurred during Katrina.

In addition, stage-damage functions corresponding to property conditions expected to prevail in June 2006 were developed and supplied to the IPET Risk and Reliability Assessment Team. That team has used the stage-damage functions to estimate residual damage risks in the study area under the future risk scenarios.

7.2.1.2. Approach

The study team developed a flood elevation-property damage relationship and then applied this relationship to the property at risk of physical flood damages in the New Orleans parishes under the various hurricane system performance scenarios. For this analysis, the New Orleans parishes were divided into drainage subbasins which subdivide the separate ringed levee areas. Figure 2 shows the location of each of the subbasins and Table 2 shows correspondence between the subbasins and the major levee areas. Lower Plaquemines Parish was not included because on limited time for analysis and the late development of GIS files on geographical boundaries.

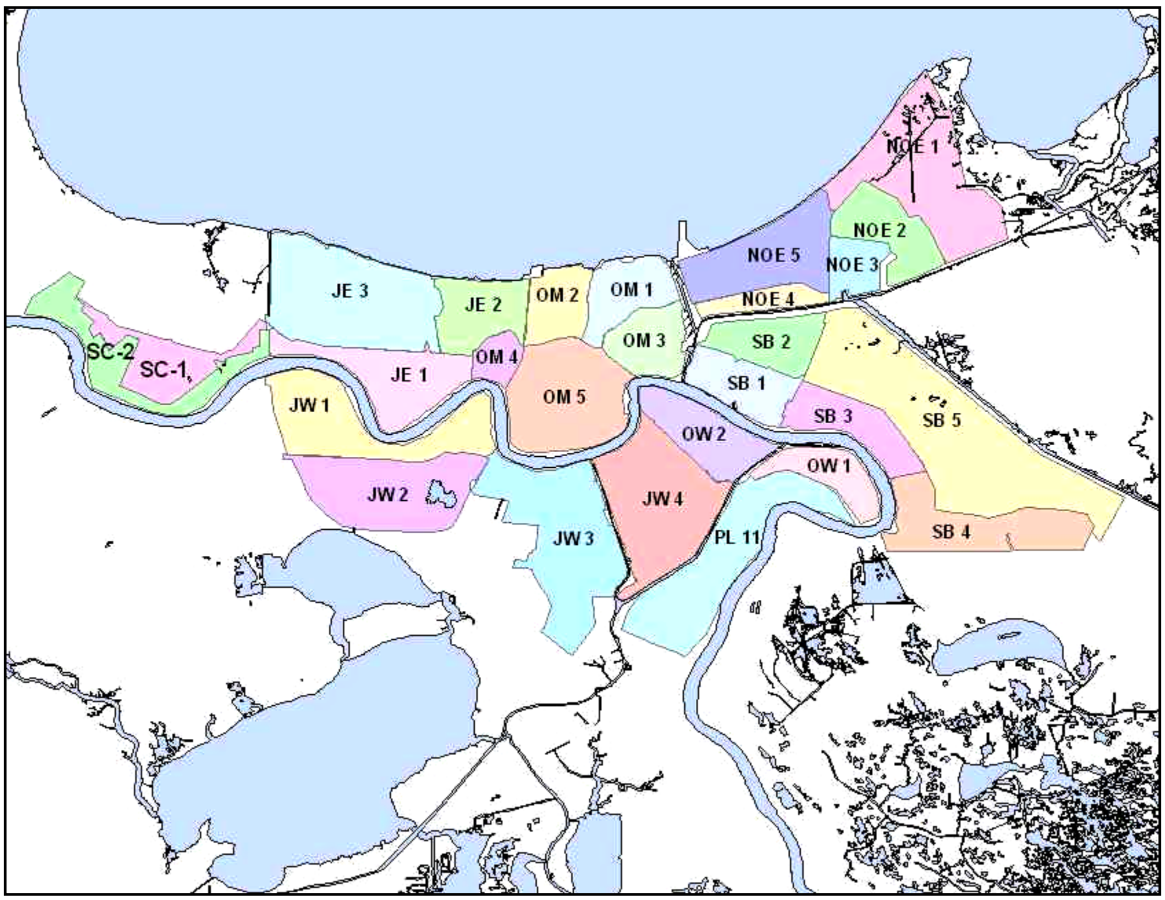


Figure 2. Drainage subbasin map.

Table 2 Drainage Subbasins within Levee Areas	
Drainage Subbasin Symbol	**Levee Area Name**
JE1	Jefferson Parish East Bank E-2
JE2	Jefferson Parish East Bank E-2
JE3	Jefferson Parish East Bank E-2
JW1	Catuouatche W-1
JW2	Catuouatche W-1
JW3	Westwego to Harvey Canal W-2
JW4	Harvey Canal to Algiers Canal W-3a
OW1	Algiers Canal to Hero Canal W-4b
OW2	Harvey Canal to Algiers Canal W-3b
SB1	St. Bernard Parish E-5a
SB2	St. Bernard Parish E-5b
SB3	St. Bernard Parish E-5a
SB4	St. Bernard Parish E-5a
SB5	St. Bernard Parish E-5b
OM1	Orleans East Bank E-3
OM1	Orleans East Bank E-3
OM3	Orleans East Bank E-3
OM4	Orleans East Bank E-3
OM5	Orleans East Bank E-3
NOE1	New Orleans East E-4b
NOE2	New Orleans East E-4b
NOE3	New Orleans East E-4a
NOE4	New Orleans East E-4a
NOE5	New Orleans East E-4a
PL11	Algiers Canal to Hero Canal W-4a

Typically, the Corps develops the inventory at risk structure by structure. In this case, the inventory had to be estimated using a new Geographic Information System (GIS). An existing GIS model (HAZUS-MH) was used as the starting point to determine the property exposed at the census block level.

Property at risk was classified as follows: (1) residential, (2) commercial, (3) industrial, (4) vehicles, (5) public buildings, and (6) infrastructure. This inventory (except for infrastructure, which was handled separately) was adjusted based on New Orleans District and commercially available information. The ground elevation for each block was determined using Digital Elevation Models (DEMs). Existing flood elevation damage curves were applied to the inventory. This yielded an elevation damage relationship aggregated to the drainage subbasin and parish levels. This relationship was converted to 2005 prices from 2002 price levels. A confidence interval for this relationship was estimated for blocks and errors in property value measurement. Figure 3 depicts the approach used to develop stage-damage estimates for calculating property damages.

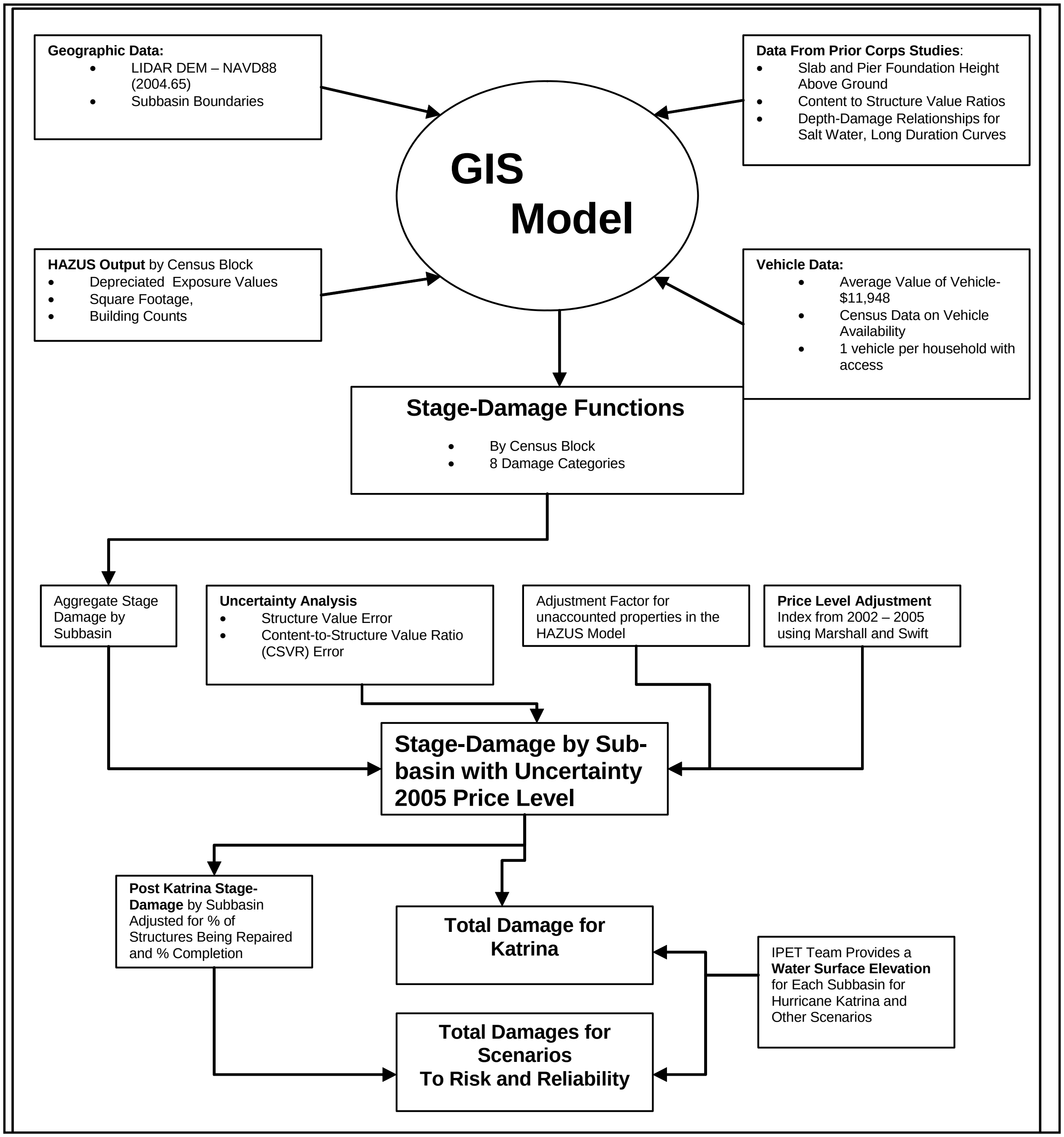


Figure 3. GIS model approach.

7.2.1.2.1. Conceptual Model of Flood Damage Assessment. In a given storm event, the combination of system performance and property in the floodplain determine the level of physical flood damages. The typical flood damage assessment process is diagramed in Figure 4, a schematic representation from FEMA's HAZUS-MH model. The figure shows a combination of five layers that determine the consequences of flooding in a given area.

Layer (a) displays the topographic (ground elevation) data for the study area. When storm surge and rainfall runoff are combined with the ground elevation data, the peak WSE can be calculated and used to determine flood depths across the study area, as shown in layer (b). The location of property and population in the floodplain (c) are overlaid on the areas of flooding to determine (d) flood damages and (e) social and economic consequences. The process of gathering the data for the present analysis is described in the following paragraphs and related to the layers of this schematic for clarity.

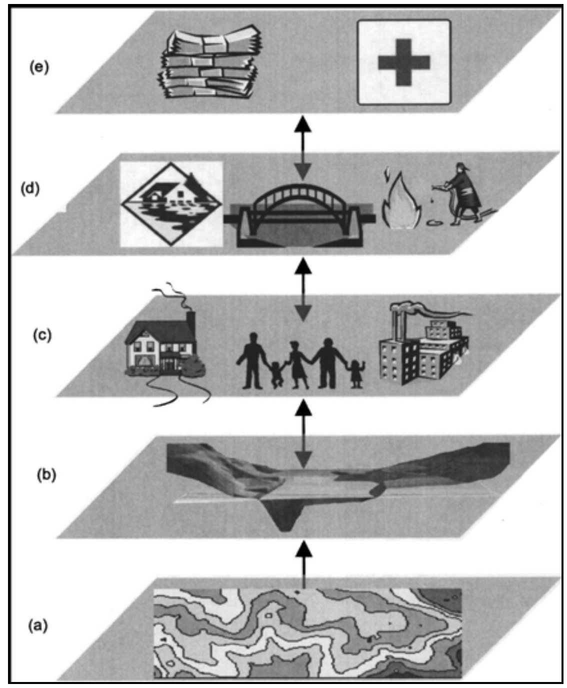


Figure 4. Schematic representation of flood loss estimation. Source: Scawthorn (2006)

Topographic data (a) were provided by the U.S. Army Engineer Research and Development Center (ERDC) in the form of DEMs created with a LIDAR (Light Detection And Ranging) process, an aerial mapping technique used to create topographic maps. The DEMs have been adjusted to the North American Vertical Datum of 1988 (NAVD88) (2004.65 epoch) to be consistent with other elevation data used in the IPET investigation.

Water surface elevations, layer (b), were determined via a combination of simulations with interior flooding models and surveyed high-water marks (HWMs) left behind by the Katrina flooding. Water surface elevations will be further discussed in the results section of the report.

FEMA's HAZUS-MH model was used to develop the structure inventory, layer (c), and members of the IPET team developed a GIS-based model to manage and map the property data to facilitate the calculation of flood damages, layers (d) and (e). These three pieces, (c) through (e), structure inventory through damage calculations, comprise the bulk of the work undertaken in the direct damages assessment, and are explained in detail in this section of the report.

7.2.1.2.2. Structure Inventory. The first pieces of the structure inventory were developed using the HAZUS-MH (MR1, Release 39 copyright 2004) software package. HAZUS-MH is a collection of models developed by FEMA and the National Institute of Building Sciences (NIBS) to estimate potential losses from floods, hurricane winds, and earthquakes. The general building stock component of HAZUS was used to quantify development within the study area. The building stock database identifies, by census block, the square footage, building count, and depreciated exposure value for the residential and non-residential structures in the five-parish area.

The beginnings of the structure inventory were established by aggregating, within HAZUS, the number of square feet in each census block that is identified as residential and non-residential property. The model combines data from the 2000 Census and the Department of Energy

Building Characteristic Reports to allocate the total square footage among six residential occupancy categories:

- Single-family dwellings,
- Manufactured housing/mobile homes,
- Multi-family dwellings,
- Temporary lodgings,
- Institutional dormitories, and
- Nursing homes.

A similar procedure used a Dunn and Bradstreet database to identify the square footage in each of 27 non-residential occupancies, broadly categorized as commercial, industrial, public, and agricultural. Table 3 displays the HAZUS-MH occupancy categories and the eight stage-damage categories into which they were organized.

Once the number of square feet is determined for each occupancy category, the HAZUS model is used to calculate the depreciated exposure value of the property in each census block. The model contains unit replacement costs, at 2002 price levels, for each occupancy category. The unit cost for each category is multiplied by the square footage in the same category to calculate replacement values for the structures in that category. The appropriate measure of economic loss is the depreciated values, so the model uses the average age of the structures in a census block to determine the appropriate depreciation factor from a built-in depreciation schedule. The corresponding depreciation factor is applied to the replacement value to produce the depreciated replacement value for structures in each occupancy category. This process is repeated for all census blocks in the study area to produce a database of depreciated structure values that are exposed to the flood hazard. These values are referred to as depreciated exposure values.

The HAZUS model provided a third piece of information for the structure inventory; a count of structures in each census block, derived from the square footage data and the known mix of occupancies. Therefore, the three contributions of HAZUS-MH to the analysis include the square footage, depreciated exposure value, and estimated building count, sorted by occupancy category and aggregated by census block. Other information is required to complete the structure inventory so that flood damages can be calculated. This other information includes first-floor elevations, foundation type, content values, and construction type (wood, masonry, stucco, steel) for structures in the inventory. These data were developed outside of the HAZUS flood model and were integrated with the HAZUS data in a GIS-based model developed by the USACE, New Orleans District (MVN).

Table 3
HAZUS-MH Occupancy Categories and Depth - Damage Categories

HAZUS-MH Occupancy		HAZUS Definition	Occupancy Example	Stage-Damage Category
1	RES1	Single Family Dwelling	1-Sty/2-Sty/Slab/Pier	Single family
2	RES2	Manufactured Housing/Mobile	Manufactured Housing	Mobile/mfg
3	RES3A	Multi-Family Dwelling - small	Duplex	Multi-family
4	RES3B	Multi-Family Dwelling - small	Triplex/Quads	Multi-family
5	RES3C	Multi-Family Dwelling - medium	5-9 units	Multi-family
6	RES3D	Multi-Family Dwelling - medium	10-19 units	Multi-family
7	RES3E	Multi-Family Dwelling - large	20-49 units	Multi-family
8	RES3F	Multi-Family Dwelling - large	50+ units	Multi-family
9	RES4	Temp. Lodging	Hotel, medium	Multi-family
10	RES5	Institutional Dormitory	Dorm, medium	Multi-family
11	RES6	Nursing Home	Nursing home	Multi-family
12	COM1	Retail Trade	Dept Store, 1st	Commercial
13	COM2	Wholesale Trade	Warehouse, medium	Commercial
14	COM3	Personal and Repair Services	Garage, Repair	Commercial
15	COM4	Professional/Technical/Business	Office, Medium	Commercial
16	COM5	Banks	Bank	Commercial
17	COM6	Hospital	Hospital, Medium	Commercial
18	COM7	Medical Office/Clinic	Med. Office, medium	Commercial
19	COM8	Entertainment and Recreation	Restaurant	Commercial
20	COM9	Theaters	Movie Theatre	Commercial
21	COM10	Parking	Parking garage	Commercial
22	IND1	Heavy	Factory, small	Industrial
23	IND2	Light	Warehouse, medium	Industrial
24	IND3	Food/Drugs/Chemicals	College Laboratory	Industrial
25	IND4	Metals/Minerals Processing	College Laboratory	Industrial
26	IND5	High Technology	College Laboratory	Industrial
27	IND6	Construction	Warehouse, medium	Industrial
28	REL1	Church	Church	Public
29	AGR1	Agriculture	Warehouse, medium	Agricultural
30	GOV1	General Services	Town Hall, small	Public
31	GOV2	Emergency Response	Police Station, Fire	Public
32	EDU1	Schools/Libraries	High School	Public
33	EDU2	Colleges/Universities	College Classroom	Public
34	n/a	n/a	Automobiles	Vehicle

Notes:
1. Residential Single Family Dwellings (RES1) include one- and two-story structures, and slab and pier structures.
2. Private autos were estimated external to HAZUS-MH Program and valued using 2005 prices.

Stratification of Residential Structures by Number of Stories and Foundation Type. The HAZUS output aggregated all single family dwellings into one occupancy category; however, previous Corps studies have determined the relative percentages of homes by number of stories and foundation types. These home characteristics have a bearing on damage results, so the findings of previous studies were used to further stratify the single family home category.

Accordingly, the depreciated exposure values were allocated to one-story and two-story structures, with pier and slab foundations.

Residential and Non-Residential Contents Valuation. Another consideration in the calculation of flood damages is the contents of the structures. For residential structures, the contents include furniture and other belongings, as well as property that may be stored outside of the home. Different floor plans will allow homeowners to distribute their contents differently, thereby altering the potential damage to contents. For example, a two-story home would have furniture and other belongings on the second floor where it would presumably have a lower risk of damage than if all furnishings were on the first floor. A home with a basement may have even more property at risk, depending on the value of items kept in the basement level.

Commercial structures would exhibit similar variances in damage susceptibility depending on the use of the property. For commercial or public structures, the contents would be inventory, equipment, and office furniture. The occupancy category of commercial and public structures will greatly affect the value of the contents. For example, grocery stores, professional offices, manufacturing firms and churches will have contents that serve their primary operations, and the value of those contents in relation to the value of the structure will differ greatly from one entity to the next.

The value of contents for residential (one-story, two-story, mobile homes, and multi-family) and non-residential (seven categories) structures were based on limited field surveys and the experience of a building and insurance expert panel for the Southeast Louisiana (SELA) Flood Control Feasibility Studies in 1996. A representative sample was developed of structures in the floodplain, and an expert panel was assembled to develop estimates of the content values of those structures. Prior to convening the expert panel, interviews were conducted with a sample of homeowners and business owners/managers in each of the categories of residential and non-residential structures. During the interviews, contents of each structure were inventoried and for the residential structures, videotapes were made of the inventoried contents. Expert panels were then convened to review the structure categories under consideration and determine the estimated value of the contents of those structures. A multi-step process was employed to develop estimated value of contents for the structures. First, the panel member developed their own estimate of content value based on a description of the structures characteristics, i.e. number of rooms, bathrooms, square footage, and age of construction. The panelists then viewed videotape of the sampled home inventories. Following the video, the panel discussed a typical contents list for each category of structure based on the inventories and estimated the value of the items on the list. The value of the contents of each structure category were totaled and then compared to the total value of the structure in order to develop contents-to-structure value ratios (CSVRs).

The structure values were developed using the Marshall and Swift Residential Estimator software package. Marshall and Swift estimating tools enable users to develop cost-based appraisals of individual properties. Characteristics of individual structures were entered into the estimator from data gathered during field surveys. The software then provided depreciated replacement values for the structures.

More specific detail regarding the development of the content values can be found in the final report, “Depth-Damage Relationships for Structures, Contents, and Vehicles and

Contents-to-Structure Value Ratios (CSVRs) in support of the Jefferson and Orleans Flood Control Feasibility Studies," dated June 1996.

The CSVRs developed for each of the four residential structure categories and seven commercial structure classifications are shown below:

Residential:		
	One-story	69%
	Two-story	59%
	Mobile home	79%
	Multi-family residence	37%
Commercial:		
	Eating and recreation	114%
	Grocery and gas station	127%
	Professional building	43%
	Public and semi-public building	114%
	Repairs and home use	206%
	Retail and personal services	142%
	Warehouse and contractor services	168%

The GIS model used the CSVRs as a percentage of the total exposure value to determine the total value of the contents for each residential and non-residential occupancy. The commercial CSVRs were assigned to the appropriate HAZUS-MH non-residential occupancy categories.

7.2.1.2.3. Structure Elevation Data. The first-floor elevation is the common reference point for depth-damage functions, so the spatial distribution of the structures in the inventory had to be analyzed to determine estimated first-floor elevations. The first floor elevation of any given structure is controlled by a combination of ground elevation and height of the structure's foundation. Accordingly, the LIDAR DEM data were combined with census block boundaries to determine the mean ground elevation for each census block in the five-parish area. An additional increment was then added to the ground elevation to account for the foundation height. The result was a representative first-floor elevation for the structures in each census block.

The estimated foundation height was not applied uniformly to all structures across the individual census blocks. Information developed in prior USACE studies was used to determine the appropriate foundation height. The foundation height applied to residential structures is based on the results of a first-floor elevation survey conducted by Corps personnel in 1991 for the geographic areas known as traffic zones in Jefferson and Orleans Parishes. A sampling of residential structures by traffic zone was used to estimate the percentage of residential structures with pier foundations and the percentage with slab foundations and to determine the average height of the pier and slab foundations above ground level. The surveys were also used to estimate the percentages of one-story and two-story residential structures in each traffic zone. A similar process was followed in St. Bernard, Plaquemines, and St. Charles Parishes, except that the structures were identified by community rather than traffic zone. Once the foundation heights were segmented by foundation type and structure type, a proportionate share of the single family homes within each census block were adjusted to match the foundation heights found in the field surveys. Mobile homes in each of the five parishes were assigned an average foundation height of

2.0 feet above ground level based on previous studies. Non-residential properties were assigned an average foundation height of 1.5 feet above ground level based on previous field surveys.

7.2.1.2.4. Depth-Damage Relationships. Damages from flooding were calculated for residential and non-residential buildings, their contents, and vehicles based on the depth-damage relationships developed by a panel of building and construction experts in 1996 for the Southeast Louisiana (SELA) Flood Control Feasibility Studies. Saltwater, long-duration (greater than 2 days) depth-damage curves were used to indicate the percentage of the structural value that was damaged at each depth of flooding. Damage percentages were determined for each 0.5-foot increment from 1 foot below first-floor elevation to 2 feet above first floor, and for each 1-foot increment from 2 to 15 feet above first-floor elevation.

The CSVRs developed as part of the depth-damage contracts that supported the Jefferson-Orleans, Atchafalaya and Morganza to the Gulf, and the Donaldson to the Gulf Feasibility Studies were used in the analysis (USACE 1996, 1997, 2006). These ratios were based on data compiled during onsite interviews with homeowners and business owners. The CSVRs were developed for three residential structure categories (one-story, two-story, and mobile home) and eight non-residential structure categories. These ratios were applied to the residential and non-residential structural occupancies used in the HAZUS-MH program.

7.2.1.2.5. Vehicles. Damages to private automobiles were also evaluated and were based on the number of automobiles estimated to have been directly impacted per household. The elevation of each automobile was assumed as the ground elevation near the structure. Automobile damages were then calculated by using the depth of flooding applied to the depth-damage relationships for vehicles.

According to statistics compiled by the Louisiana Department of Motor Vehicles, there are approximately twice as many privately owned vehicles registered in the New Orleans metropolitan area as there are occupied housing units. Census data show that approximately 82 percent of the households in the five-parish area have access to at least one vehicle. However, this percentage was found to be variable across census blocks. For at least some census blocks, Census data showed access to a vehicle as low as 10 percent in Orleans Parish.

In order to estimate flood damages to privately owned vehicles, it was assumed that on average, for each of the households with access to one or more vehicles, one vehicle was left parked at the residence, and the remainder of the vehicles were used for evacuation. The average value of these automobiles was determined to be $11,918 based on the average Manheim auction value of a vehicle adjusted to reflect replacement value at the retail rather than the wholesale level of sales. The depth-damage relationships for vehicles that were developed by a panel of experts for the SELA studies were used to calculate damages at the various levels of flooding. No vehicles were assigned to commercial properties due to insufficient data.

7.2.1.2.6. Stage-Damage Relationships. Inputs to the GIS model have thus far included elevation data, structure inventory and valuation data, and depth-damage relationships. The model used these inputs to generate a stage-damage relationship for each census block. Flood damages are calculated at 1-foot increments from the beginning damage elevation to an elevation where damages for all the structural categories have reached a maximum. In order to insure that this maximum had been reached, the maximum height of a slab foundation or of a pier foundation in each census block was added to the maximum depth of flooding (15 feet) included in the depth-damage relationships. Damages were calculated for seven damage categories including: single-family residential, multi-family residential, manufactured housing/mobile homes, commercial, industrial, public, agricultural, and vehicles.

Adjustments to Stage-Damage Functions. During the analysis, two issues were considered in regards to structure valuations. First, the HAZUS-MH building stock is valued at 2002 price levels. The forthcoming release of a revised version of the model will include 2005 price levels; however, factors were not readily available from HAZUS to index the 2002 to 2005 prices. To compensate for the price level changes, index values from the Marshall and Swift building cost database were used to escalate structure values to 2005 levels.

The second valuation issue is in the accuracy of the general building stock database, which is a national dataset. The national dataset is intended for use in gross assessments of potential hazard damages. These gross analyses are identified as Level 1 studies in the HAZUS documentation. Model developers recommend using region-specific datasets to improve the accuracy of the value estimates. In order to validate the values assigned to the HAZUS-MH residential building stock, the total depreciated exposure value for each census block was compared to the depreciated replacement cost that was calculated by Corps personnel. Corps personnel utilized aerial photography and conducted field surveys to collect site-specific structure characteristics to calculate the depreciated replacement value using the Marshall and Swift Valuation Service. A sampling of city blocks from the actual structure inventories compiled as part of previous feasibility studies in the five-parish area was used in the comparison. For the HAZUS-MH non-residential building stock, a comparison was made for larger areas such as census tracts or portions of a previous study area. The total depreciated exposure value for each census block for residential occupancies and each census tract for non-residential occupancies was compared to the aggregated Marshall and Swift value for the sampled city blocks or tracts, and the difference in the two values was used to calculate confidence intervals for the HAZUS-MH residential and non-residential occupancy data.

The actual depreciated replacement values of residential occupancies calculated using field surveys and the Marshall and Swift Valuation Service for those portions of the five-parish area that were sampled were found to be approximately 16 percent higher than the depreciated exposure values calculated by the HAZUS-MH program. The actual depreciated replacement values of the non-residential occupancies in those portions of the five-parish area that were sampled were found to be approximately 118 percent higher than the depreciated exposure values calculated by the HAZUS-MH program. In order to account for this underestimation, the damages for each stage were increased by approximately 16 percent for residential occupancies and approximately 118 percent for non-residential occupancies.

7.2.1.3. Damages to Infrastructure

7.2.1.3.1. Approach to Infrastructure Damage. Infrastructure damage was an important source of direct economic losses from Hurricane Katrina. This section tabulates (to the extent information was available) monetary costs for damages, measured by the cost of repair or replacement of significant infrastructure assets. As with other investigations for direct damages or costs attributable to Hurricane Katrina within the framework for IPET studies, the area of consideration was primarily limited to the five-parish area of Orleans, St. Bernard, Plaquemines, Jefferson, and St. Charles Parishes.

The impacts to infrastructure from Hurricane Katrina are difficult to estimate for some categories of infrastructure due to the follow-on occurrence of Hurricane Rita. Most impacts from Hurricane Rita were incurred in areas west of the New Orleans metropolitan area with some additional damages imposed by associated rainfall and some reflooding due to weakened levees and previously saturated ground areas. Available information indicates that for the five parishes, infrastructure damages were due mostly to Hurricane Katrina.

A primary objective for IPET studies was to estimate damages based on effects of flooding but acknowledge other effects such as wind and rainfall associated with hurricane conditions. For some infrastructure items, this posed little difficulty, but for others it was extremely difficult or simply not practical. In the case of electrical utilities, a significant loss was due to the downing of utility poles and supported transmission lines plus the destruction of substations. Certainly, some of the loss of utility poles and lines was due to wind alone. In other cases, the saturation of soils compromised the foundational support and led to toppling of aboveground lines.

To provide some context of magnitude of overall hurricane impacts to infrastructure, statistics on electric service were obtained from Entergy, the primary regional electric public utility. Table 4 shows the loss of customer base for each of the five parishes under study. The net total loss of customers (households and businesses) across the five-parish area as of December 2005 was approximately 32 percent compared to the pre-Katrina levels. St. Bernard Parish incurred the greatest loss of neighborhood occupancy measured by percentages with a loss customers using electricity of over 99 percent from the pre-Katrina level. Orleans Parish exhibits the greatest absolute loss with total customers declining by more than 97,000.

Table 4
Impact of Hurricane Katrina Electrical Utility Services – Change in Customer Base

Parish	Total Number of Customers Pre-Katrina	Total Number of Customers as of December 2005	Difference in Customer Base	Percent Loss or Gain in Customer Base
Jefferson Parish	210,025	201,897	8,146	-3.9
Orleans Parish	205,466	97,357	108,109	-52.6
Plaquemines Parish	14,164	6,689	7,475	-52.8
St. Bernard Parish	29,145	178	28,967	-99.4
St. Charles Parish	21,082	20,935	147	-0.7
Total	479,882	327,056	152,844	-31.8

Sources: Entergy (2006); FEMA (2006a).

The dollar value of damage to infrastructure primarily is in terms of full replacement or repair costs in 2005 dollars.

The assessment of infrastructure direct damage followed both a top-down and bottom-up approach for inquiry and data compilation. Top-down inquiries involved internet searches for information in addition to contact with the Federal Emergency Management Agency (FEMA) and various state-level agencies within Louisiana. Bottom-up research involved direct contact with representatives of municipalities and parish governments in addition to contact with companies or entities who own or are charged with management and operation of significant infrastructure assets. Due to the variability of estimates over time as they are corrected or refined, efforts to compile information were iterative with initial estimation followed by subsequent investigation and contact with sources to determine current, more current, or presently available estimates.

7.2.1.3.2. Summary of Katrina Infrastructure Repair Cost. The total infrastructure damages from Katrina for the five-parish area are summarized in Table 5. From the table, Katrina caused an estimated $6.0 to $6.7 billion dollars in damage to infrastructure in the area. The categories with the most damages are levees and floodwalls, roadway networks, and assets of the regional electrical transmission grid. Together, hurricane-related flooding damages to these categories of infrastructure total $3.6 to $4.1 billion dollars.

Table 5
Impact of Hurricane Katrina to Infrastructure by Category

Infrastructure Category	$ Million 2005		
Roads, Pavements, and Bridges	$890	To	$1,119
Railroad Line Access	$48	To	$65
Regional Airport Facilities	$67	To	$73
Electrical Distribution and Transmission Grid	$860	To	$980
Gas (Line) Distribution	$490	To	$515
Drainage, Sewage and Potable Water Services	$690	To	$740
Telecommunications Networks	$290	To	$320
Public Transit (Vehicles and Equipment)	$690	To	$730
Waterborne Navigation	$140	To	$170
Repair to Levee and Floodwall Systems	$1,800	To	$2,000
Total	$5,965	To	$6,712

Note: Estimates for damages or losses primarily limited to flooding in the five-parish area defined for IPET studies with exception of estimates for regional airport facilities and damages to roads, pavements, and bridges which includes damages to interstate bridges and connectors between the city of New Orleans and Slidell, LA.
Sources: FEMA (2006b); NEMIS (2006); LRA (2006); USACE (2006b).

Considerable uncertainty still exists for some categories in Table 4, such as damages to roads and pavements. This is preliminary due to lagging nature and limited availability for some estimates. Roads, pavements, and roadway structures often do not exhibit immediate or obviously significant damage. This damage is revealed some period after the occurrence of inundation as vehicular traffic returns.

An additional damage category is debris removal, although some of this cost may be included as part of the estimated direct property loss. Debris removal, disposal, and containment for the area will require movement of approximately 19 to 20 million cubic yards of material with a total estimated cost ranging from $716 million to nearly $830 million dollars (USACE 2006b).

Available estimates for damages or costs to infrastructure reveal significant impacts due to Hurricane Katrina. The damage to infrastructure will likely slow the recovery of population and business activities.

7.2.1.4. The Results of Direct Damage Assessment

7.2.1.4.1. Aggregated Census Block Stage-Damage to Drainage Basin. After being adjusted for uncertainty and updated to 2005 price levels, the stage-damage relationships developed by the GIS model were used to calculate the flood damages that occurred in the five-parish area as a result of Hurricane Katrina.

The stage-damage relationships developed for each census block were aggregated into one stage-damage relationship for each drainage subbasin in the five-parish area. The locations of the drainage subbasins in the five-parish area are shown in Figure 2.

An example of the resulting stage-damage relationship for an individual drainage subbasin is shown in Table 6. These relationships were estimated for each of the drainage subbasins.

7.2.1.4.2. Actual Katrina Scenario: Direct Property Damages. The estimates of Katrina direct property damage, except for infrastructure, were based on the 27 stage-damage relationships such as shown in Table 6. Appendix 1 contains the stage-damage relationships for all the subbasins. The interior drainage modeling, developed as part of IPET, provided the model stages for each subbasin in the five-parish area. The damages for each drainage subbasin were then combined in order to develop the total damages to the five-parish area. Table 7 shows the estimated average direct flood damage from Katrina by the basic damage categories for each of the flooded subbasins. As context, the exposure value of single family residential property within the five-parish area is estimated to be approximately $52.6 billion so that over 25 percent of this value is estimated to have been destroyed by Katrina.

7.2.1.4.3. Comparison of Katrina Estimates for Direct Property Losses from Hypothetical Scenarios. Table 8 displays the estimated mean damages for each drainage subbasin for Katrina and the three hypothetical levee, floodwall, and pump performance scenarios. Figure 5 shows a comparison of the direct property losses as a percentage of depreciated replacement property value by census block for actual Katrina and hypothetical scenario 2.

7.2.1.4.4. Comparison of Results to Other Published Estimates. In order to assess the accuracy of the model, the flood damages to residential properties calculated using the GIS model were compared to the actual FEMA-insured residential flood losses by zip code in the New Orleans area. To compensate for uninsured flood losses, the actual insured losses were increased by the percentage of uninsured homes that had incurred flood damages. Table 9 displays the total residential flood damages as calculated using the GIS model, the insured flood claims, and adjusted flood claims by zip code in the New Orleans area. The adjusted flood claims are approximately $1.5 billion (10 percent) less than the model estimates; however, the model estimates do not include Plaquemines Parish. The comparison of the published residential flood insurance claims with the model results suggests that the predicted damage estimates reasonably represent other third-party estimates.

Table 6
Example Stage-Damage Relationships for a Drainage Subbasin ($ million 2005)

Water Elevation, ft NAVD88 (2004.65)	Subbasin Name	Single Family Residential	Multifamily Residential	Mobile Home	Commercial	Industrial	Public	Vehicles
-10	JE2	0	0	0	0	0	0	0
-9	JE2	0	0	0	1	0	0	0
-8	JE2	0	0	0	1	0	0	0
-7	JE2	1	0	0	1	0	0	0
-6	JE2	3	0	0	5	0	0	0
-5	JE2	22	3	0	11	2	1	13
-4	JE2	219	61	0	102	7	3	79
-3	JE2	954	318	0	669	50	27	173
-2	JE2	1594	457	1	995	82	41	225
-1	JE2	1826	508	1	1126	100	47	248
0	JE2	2034	560	1	1195	123	49	267
1	JE2	2224	588	1	1226	133	50	283
2	JE2	2401	618	1	1243	138	51	300
3	JE2	2551	651	1	1285	141	53	312
4	JE2	2691	683	1	1336	146	57	323
5	JE2	2854	722	1	1379	153	63	329
6	JE2	3007	749	1	1414	159	76	332
7	JE2	3072	766	1	1444	164	85	333
8	JE2	3105	786	1	1463	168	88	333
9	JE2	3132	821	1	1530	170	91	333
10	JE2	3156	846	1	1573	172	95	333
11	JE2	3174	853	1	1587	173	96	333
12	JE2	3188	858	1	1594	173	96	333
13	JE2	3200	861	1	1597	174	97	333
14	JE2	3208	863	1	1600	174	99	333

Table 7
Estimates of Katrina Direct Flood Losses by Category and Drainage Subbasin ($ million 2005)

Subbasin Name	Water Surface Elevation ft NAVD88 (2004.65)	Single Family Residential	Multifamily Residential	Mobile Home	Commercial	Industrial	Public	Vehicles	Total
JE2	-4.1	199	55	0	93	7	2	72	429
NOE1	3.0	0	0	0	1	8	0	0	9
NOE2	0.8	78	28	0	3	1	0	10	120
NOE3	0.6	255	74	1	35	11	7	27	410
NOE4	7.5	4	2	1	47	3	0	1	57
NOE5	-0.7	3,048	585	1	651	66	51	273	4,674
OM1	2.6	1,600	260	1	86	4	18	160	2,130
OM2	3.2	1,196	191	0	85	7	7	109	1,596
OM3	3.8	1,344	351	0	98	6	10	156	1,966
OM4	2.3	283	10	0	22	3	1	23	342
OM5	2.6	1,379	826	0	664	167	56	284	3,377
SB1	10.5	1,679	326	1	332	45	28	151	2,562
SB3	10.9	1,904	120	15	139	60	15	130	2,384
SB4	11.2	368	15	34	30	6	4	34	492
Total		13,339	2,845	54.7	2,285	394	200	1,430	20,548

Table 8
Comparison of Estimated Mean Losses from Katrina with Hypothetical Scenarios ($ million 2005)

Subbasin Name	Katrina Model		Hypothetical Katrina Scenario 1 (Resilient Levees)		Hypothetical Katrina Scenario 2 (Resilient Levees and Pumps)		Hypothetical Katrina Scenario 3 (Resilient Floodwalls)	
	Water Surface Elevation ft NAVD88 (2004.65)	Property Loss Estimate ($ million 2005)	Water Surface Elevation ft NAVD88 (2004.65)	Property Loss Estimate ($ million 2005)	Water Surface Elevation ft NAVD88 (2004.65)	Property Loss Estimate ($ million 2005)	Water Surface Elevation ft NAVD88 (2004.65)	Property Loss Estimate ($ million 2005)
JE2	-4.1	429	-4.1	429	-7.0	8	-4.1	429
NOE1	3.0	9	2.6	9	2.6	9	3.0	9.1
NOE2	0.8	120	-1.6	105	-7.0	-	0.8	120
NOE3	0.6	410	0.0	400	-0.5	383	0.6	410
NOE4	7.5	7	7.1	57	7.0	57	7.5	57
NOE5	-0.7	4,674	-1.7	4,253	-2.5	3,803	-0.7	4,674
OM1	2.6	2,130	-0.9	1,695	-5.1	133	0.0	1,713
OM2	3.2	1,596	-2.5	962	-5.0	677	-2.7	931
OM3	3.8	1,966	3.1	1,741	2.9	1,674	3.8	1,966
OM4	2.3	342	0.1	150	-1.5	48	0.1	150
OM5	2.6	3,377	-0.8	925	-2.0	785	-0.4	1,204
SB1	10.5	2,562	4.2	1,775	3.9	1,700	10.5	2,562
SB3	10.9	2,384	3.7	1,412	3.7	1,412	10.9	2,384
SB4	11.2	492	6.6	253	6.4	232	11.2	492
Total		20,547		14,164		10,921		17,101

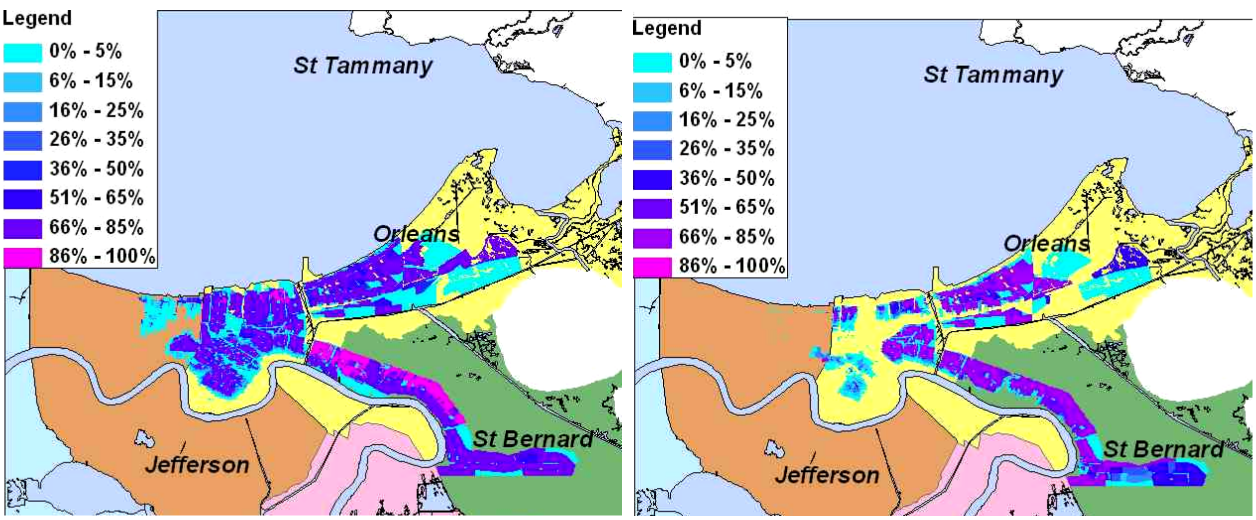


Figure 5. Percent of property damaged (damage/value)--Comparison of model results for Katrina flooding (left) and hypothetical scenario 2, Resilient Levees and Pumps (right).

Table 9
Comparison of Katrina Residential Flood Claims and Model Estimated Residential Losses ($ million 2005)

Parish	Zip Code	Area	Number of Claims	Insured Losses ($ millions)	Percentage of Flooded Homes Insured	Adjusted Losses ($ millions)	Model Estimated Losses ($ millions)
Jefferson	70001	Metairie	5,351	201	81	250	119
Jefferson	70005	Metairie	4,607	264	81	326	178
Jefferson	70121	Jefferson	1,202	14	81	17	42
		Total	11,160	481		594	339
Orleans	70112	French Quarter	439	24	68**	36	47
Orleans	70113	French Quarter	661	22	68**	33	95
Orleans	70115	Uptown	3,726	132	68**	195	323
Orleans	70116	New Orleans	1,535	44	65	67	165
Orleans	70117	9thWard/Bywater	5,393	360	43	838	1,323
Orleans	70118	Carrollton	4,522	249	68**	367	531
Orleans	70119	Mid-City	6,604	518	51	1,016	1,005
Orleans	70122	Gentilly	9,282	961	69	1,393	1,862
Orleans	70124	Lakeview	7,399	1,225	78	1,571	1,389
Orleans	70125	Broadmoor	3,426	366	68**	538	577
Orleans	70126	Eastern New Orleans	7,670	819	77	1,064	1,582
Orleans	70127	Eastern New Orleans	5,358	624	77	810	1,163
Orleans	70128	Eastern New Orleans	5,251	693	77	900	1,095
Orleans	70129	Eastern New Orleans	2,158	220	77	286	405
Orleans	70130	Garden District	844	10	68**	15	0
Orleans	70148	New Orleans	-	-	68**	0	0
		Total	64,268	6,270		9,129	11,563
Plaquemines	70041	Buras	878	82	35	235	*
Plaquemines	70083	Port Sulphur	618	45	35	130	*
Plaquemines	70091	Venice	143	14	35	41	*
Plaquemines	70040	Braithwaite	255	37	35	105	*
		Total	1,894	179		512	*
St. Bernard	70032	Arabi	2,626	313	65	482	377
St. Bernard	70043	Chalmette	8,175	1,114	65	1,714	1,484
St. Bernard	70075	Meraux	2,198	350	65	538	573
St. Bernard	70085	St. Bernard	1,077	135	65	208	126
St. Bernard	70092	Violet	1,775	230	65	355	517
		Total	15,851	2,143		3,297	3,078
Grand Total			93,173	9,073		13,532	14,980

Source: Mietrodt (2006).
Note 1: Asterisk (*) indicates the model value was not estimated for Katrina flooding.
Note 2: The double asterisk (**) indicates value is the average for the parish.

7.2.1.5. Quantifying Uncertainty in Stage-Damage Estimates

7.2.1.5.1. The Approach to Quantifying Uncertainty. The stage-damage estimates were developed for a range of flood elevations for 27 storage areas or drainage subbasins. The highest resolution of measurement of damageable property was the census block. Within each census block, estimates of the number and value of damageable property for residential, commercial, industrial, public, and vehicles were developed. These values were combined with depth-percent damage for each of the occupancy categories to estimate economic losses at each level of flooding within the drainage subbasin. There were several issues within this calculation that contribute to uncertainty in estimated damage at each stage.

The approach to estimating damages is at a much higher level of aggregation than typically used by the Corps in evaluating a flood damage reduction project. Traditionally, Corps economists inventory all structures in the study area. This inventory includes information on the type of structure, its construction, and its use. Each of these is important in selecting the appropriate damage function to apply to predict damages from different levels of flooding. Estimates of the depreciated replacement value for each structure are developed using tools such as Marshall and Swift Residential Estimator. The first-floor elevation of each structure is measured using surveyors, topographic maps, or other methods. Using all of this information, economists develop stage-damage relationships for a range of flood stages. These are aggregated damages from the individual structure damage for each flood stage evaluated. Each of the measurements that are part of this analysis introduces some error. For instance, the method of measuring the spot elevation of each first floor has an error based on the method. The Corps has developed tools and methods to quantify these errors and to combine them in a statistically valid way for this detailed method.

In the case of the IPET study, this detailed evaluation starting at the individual structure level is not feasible. Instead, the analysis starts at the census block. This means that structures and values have been aggregated to that level of resolution. Additionally, depths are representative for the entire census block. The basic approach to identifying and quantifying uncertainties is described below.

7.2.1.5.2. Uncertainty in the Depth of Flooding. The first issue in quantifying uncertainty is the error in the depth of flooding. Depth is based on the difference between a water surface elevation or stage of the water and the first-floor elevation. The first-floor elevation is based on the ground elevation plus the foundation height or first-floor elevation equals ground elevation plus foundation height.

Therefore, several things can contribute to the error in depth of water above the first floor. The accuracy of spot elevation for each point in the census block contributes some error. Each pixel in the raster image of the DEM has a ground elevation. The DEM used is that developed by IPET using the latest LIDAR. Based on communication with the Datum and DEM developers an accuracy of 90 percent within +/- 1 foot was considered reasonable (Garster 2006). Assuming that the error in ground elevation is normally distributed, the error in ground elevation has a mean of zero and a variance of 0.37. This represents a fundamental error that is common to all spot elevations. It is assumed that this error is same for all spot elevations.

A second source of error in ground elevation arises from representing the elevation in a census block by a single value. Because a census block represents a spatial area, the ground elevation is variable across the block. However, the ground elevation must be represented by a single value. For each census block, the mean, minimum, and maximum ground elevation was calculated from the spot elevations extracted from the DEM. This represents an additive error to the underlying ground elevation errors. Ideally, estimates of error in damages could be computed at the census block level using the elevation variability because each census block can have a different range of spot ground elevations. Given the time available, this approach is not feasible. Instead a single average standard deviation is approximated to represent the variability of ground elevation across each census block. The range of spot elevations across each census block is assumed to represent a 99.5 percent confidence interval or approximately six standard deviations.

From the depths computed for Katrina, the average standard deviation was calculated to be 0.82 foot or variance of 0.67.

The variance in the ground elevation for a census block, assuming independence between the two sources of error, is the sum of the variances or

Variance of Error CB Elevation
= Variance Error Spot Elevation + Variance Spot CB Elevation
= 0.37 + 0.67 = 1.04 and
Standard Deviation = $\sqrt{0.37 + 0.67}$ = 1.02 feet.

Note that this value is assumed to be constant across all census blocks.

From the above, the ground elevation for each census block can be represented by a normal distribution with the mean equal to the mean computed from the spot elevations and a standard deviation equal to 1.02 feet.

As noted above, the depth of flooding is the difference between the water stage and the first-floor elevation, where the first-floor elevation is equal to the ground elevation plus the foundation height. The uncertainty in the foundation height adds an additional error in the estimate of flood depth. Estimates of foundation height were based on previous Corps surveys. Two types of foundations are common in the study area: pier and slab on grade. In the computation of damage, these heights and the proportion of structures with each foundation type were used to proportion the census block value of damageable property. However, this uncertainty and its contribution to the uncertainty in flood losses are not quantified. Therefore, the uncertainty in damage is underestimated.

7.2.1.5.3. Uncertainty in Depth-Damage Relationships. In traditional Corps flood damage analysis, the depth of flooding provides the quantity to look up a percentage of value damaged from depth-damage relationships. There are different relationships or curves depending on the type of structure, its construction, and its use. In addition to mean values, confidence intervals around the mean percent damage are established. These error bands typically are established by statistical means based on data and the method for estimating damage. Incorporating this uncertainty was not feasible with the IPET schedule and the nonlinear depth-damage functions. Therefore, this uncertainty and its contribution to the uncertainty in flood losses are not quantified. Therefore, the uncertainty in damage is underestimated.

7.2.1.5.4. Uncertainty in Value of Damageable Property. Another uncertainty that contributes to the uncertainty in flood damage is the value of the damageable property. As noted earlier, flood damages estimated by the Corps are based on depreciated replacement values. The New Orleans District of the Corps has conducted several flood damage reduction studies requiring quantification of the uncertainty in structure values. In general they have relied on commercially available estimating software such as that developed by Marshall and Swift. Based on these previous studies, estimates of the standard deviation of the value, as a percentage of the mean value, were developed. These were then applied to each of the damage categories.

7.2.1.5.5. Resultant Uncertainty. The foregoing describes two types of uncertainty. One type is the uncertainty in the depth of water resulting from each flood stage. The second type is uncertainty in the dollar damage. The first type is effectively the uncertainty in the stage at which damages begin or the zero damage stage. The uncertainty is represented a shifting in the entire stage-damage relationship by the amount of the error corresponding to the desired confidence. For a 90 percent confidence interval, this means shifting the stage-damage curve up by approximately 2 feet, for the upper limit, and shifting it down approximately 2 feet for the lower limit.

The results of the calculation in standard deviation in damages described above can be used to develop a confidence interval for damage at each stage. This incorporates the second type of uncertainty.

Ideally, the uncertainties would be conjoined during the damage computation process. However, as noted above this was not possible. Therefore, the 90 percent confidence interval is approximated by shifting the 5 percent lower limit stage-damage up by 2 feet and shifting the 95 percent upper limit down by 2 feet. Therefore, the confidence interval is only an approximation.

Table 10 shows the uncertainty in the estimated flooding losses from Hurricane Katrina by each drainage subbasin and the total. These values do not include infrastructure damage which from Table 5 represents an additional $4,400 million to $5,600 million.

Table 10
Estimated Direct Property Losses from Flooding from Hurricane Katrina by Drainage Subbasin ($ million 2005)

Drainage Subbasin Name	Water Surface Elevation Interior Drainage Model ft NAVD88 (2004.65)	5% Lower Confidence	Mean	95% Upper Confidence
JE2	-4.1	7	429	3,316
NOE1	3.0	5	9	13
NOE2	0.8	103	120	133
NOE3	0.6	287	410	536
NOE4	7.5	51	57	63
NOE5	-0.7	3,630	4,674	5,154
OM1	2.6	1,789	2,130	2,430
OM2	3.2	1,382	1,596	1,797
OM3	3.8	1,288	1,966	2,419
OM4	2.3	159	342	682
OM5	2.6	1,879	3,377	5,306
SB1	10.5	2,419	2,562	2,658
SB3	10.9	2,153	2,384	2,516
SB4	11.2	434	492	517
Total		15,587	20,547	27,540

Table 11 shows an example of the stage-damage relationship for total property direct damage computed using the uncertainty methodology described above. Note that this does not include infrastructure damage; it cannot be assigned to a particular drainage subbasin yet. The complete flood stage-total damage estimates with uncertainty for all drainage subbasins are shown in Appendix I. These values are what were provided for the risk and reliability analysis.

Table 11
Example 90% Confidence Interval for Direct Damage for a Drainage Subbasin ($ million 2005)

Water Elevation ft NAVD88 (2004.65)	Drainage Subbasin Name	5% LC	Mean	95% UC
-4	JE1	0	0	0
-3	JE1	0	0	1
-2	JE1	0	0	10
-1	JE1	0	1	51
0	JE1	0	9	226
1	JE1	1	49	430
2	JE1	8	218	1,128
3	JE1	47	420	1,530
4	JE1	211	1,093	2,095
5	JE1	410	1,490	2,671
6	JE1	1,058	2,049	3,339
7	JE1	1,451	2,617	3,697
8	JE1	2,004	3,278	4,223
9	JE1	2,564	3,633	4,707
10	JE1	3,217	4,150	5,202
11	JE1	3,569	4,630	5,589

Figure 6 shows a graph of the relationship of stage and flood damage for the Orleans Metro 5 (OM5) subbasin. Notice that, of the uncertainties quantified, the DEM error and error introduced by representing the elevation of a census block by a single value contribute the most. Only at high stages does the uncertainty in value contribute significantly to overall uncertainty. The vertical line shows the estimated Katrina peak stage in the subbasin.

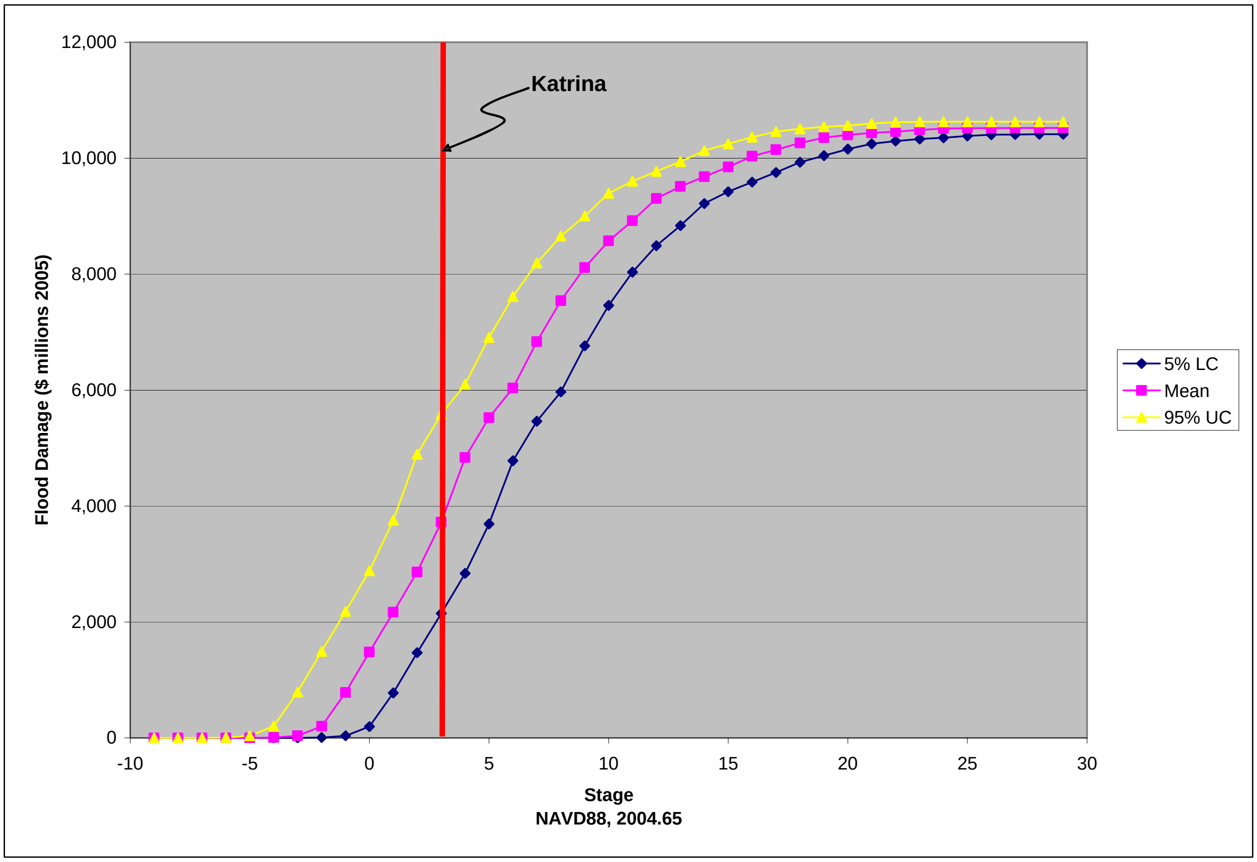


Figure 6. Relationship of stage and flood damage with uncertainty for Orleans Metro 5 (OM5) drainage subbasin—pre-Katrina conditions.

7.2.1.6. Post-Katrina Stage-Damage

7.2.1.6.1. Background. An objective of the direct economic damage analysis is to develop potential stage-damage curves that might represent the flood damage potential as of 1 June 2006. To do this requires accounting for the severity of the Katrina damage and the amount of property loss recovery since Katrina. In some areas flooded by Katrina, where water depths were low, recovery has been almost complete. In other areas, where water depths were high, little recovery or reinvestment has taken place. It is extremely difficult and at the peril of the analyst to make general estimates about the amount of recovery. Nonetheless, some guidance exists in terms of what others have assumed about recovery. The analysis conducted followed the basic parameters provided in the RAND Gulf States Policy Institute (2006) report "The Repopulation of New Orleans after Hurricane Katrina." In developing estimates of repopulation over time, the authors relied on the depth of flooding as the basic determinant of the rate of population recovery. Table 12 shows the recovery rates by depth assumed in the RAND report. The use of these values resulted in an estimate of the March 2006 population of New Orleans of approximately 155,000 people. This is within the range of other estimates.

The June 2006 estimate of potential stage-property damage started with these assumptions. However, the range of depths of flooding was expanded to include more depth of flooding categories while preserving the basic concept.

Table 12
Estimated Repopulation Rates for New Orleans

Period	Depth of Flooding	Repopulation Rate (%)
December 2005	No flooding	65
	<2 feet	20
	2–4 feet	5
	>4 feet	1
March 2006	No flooding	100
	<2 feet	35
	2–4 feet	15
	>4 feet	5
September 2006	No flooding	110
	<2 feet	75
	2–4 feet	25
	>4 feet	10

Source: McCarthy (2006).

Table 13 shows the depth categories and damage recovery rates assumed in developing the June 2006 stage-damage estimates. A RAND category of <2 feet was subdivided into two categories: <1 foot and 1 to 2 feet. Additionally, the >4 feet category was subdivided into three categories: 4 to 6 feet; 6 to 8 feet; and >8 feet. These categories are consistent with those used in social, cultural and historic analysis of the impacts of Katrina the post-Katrina recovery. However, the values of recovery rates are to some degree arbitrary and other rates may be justified. For the estimate of the post Katrina stage-damage functions shown in this section, these rates are used.

7.2.1.6.2. Approach. The post-Katrina stage-damage tables and curves are estimated by the same drainage subbasin definitions as the pre-Katrina values. Additionally, the estimation started with the same census block approach. The Katrina depth grid was used to estimate the depth of flooding for each census block. These depths were used to select the census blocks that incurred damages within each of the categories shown in Table 13. For instance, within the Orleans Metro 5 drainage subbasin, 1535 census blocks had flooding of 1 foot or less while a total of 4400 census blocks were flooded. Table 14 shows the complete estimate of the number of the census blocks flooded by Katrina by depth category.

Table 13
Assumed Property Recovery Rates by June 2006

Period	Depth of Flooding	Property Recovery Rate (%)
June 2006	< 1 feet	95
	1 - 2 feet	50
	2 - 4 feet	20
	4 - 6 feet	5
	6 - 8 feet	1
	> 8 feet	0

From these selected census blocks, damages at each stage were aggregated to the drainage subbasin level for each of the recovery category. This calculation determined the amount of the Katrina damage within each depth category. This was repeated for each of the Katrina flood depth categories.

Table 14 **Number of Census Blocks within Each Drainage Subbasin Flooded by Katrina by Depth Category**						
Drainage Subbasin Name	**Count of Census Blocks within Katrina Flood Depth Category**					
	0-1 foot	**1 to 2 feet**	**2 to 4 feet**	**4 to 6 feet**	**6 to 8 feet**	**> 8 feet**
NOE2	1	2	2	10	19	7
NOE3	7	8	12	8	59	7
NOE4	18	3	0	0	0	0
NOE5	27	31	156	173	371	99
OM1	37	37	107	126	163	361
OM2	24	24	46	56	121	321
OM3	301	136	387	358	219	61
OM4	63	51	72	50	9	1
OM5	1,535	346	871	957	640	35
SB1	31	25	91	153	200	375
SB3	62	32	49	117	173	44
SB4	5	37	62	50	13	0

For some property, recovery from flooding was not necessary, so it contributed its full damage potential to the post-Katrina, June 2006, stage-damage estimates. Table 15 provides a comparison of the pre-Katrina damage potential and the June 2006 damage potential by stage for the OM2. The complete June 2006 flood stage-damage estimates with uncertainty, using this procedure, are provided as Attachment B. These values, including uncertainty, were provided for the Risk and Reliability analysis.

Table 15 **Example Stage-Damage Estimates for Pre- and Post-Katrina ($ million 2005)**			
Subbasin Name	**Water Elevation ft NAVD88 (2004.65)**	**Pre-Katrina Stage-Damage**	**Post-Katrina Stage-Damage June 2006**
OM2	-11	0.0	0.0
OM2	-10	0.0	0.0
OM2	-9	0.0	0.0
OM2	-8	0.0	0.0
OM2	-7	2.0	0.0
OM2	-6	69.9	0.0
OM2	-5	347.6	0.0
OM2	-4	677.1	0.0
OM2	-3	884.1	0.2
OM2	-2	1,040.1	1.8
OM2	-1	1,196.3	4.1
OM2	0	1,260.9	6.9
OM2	1	1,376.7	26.7
OM2	2	1,482.4	44.3
OM2	3	1,573.3	64.0
OM2	4	1,685.3	103.2

Figure 7 shows the pre- and post-Katrina stage-damage with uncertainty for Orleans Metro 5 (OM5).

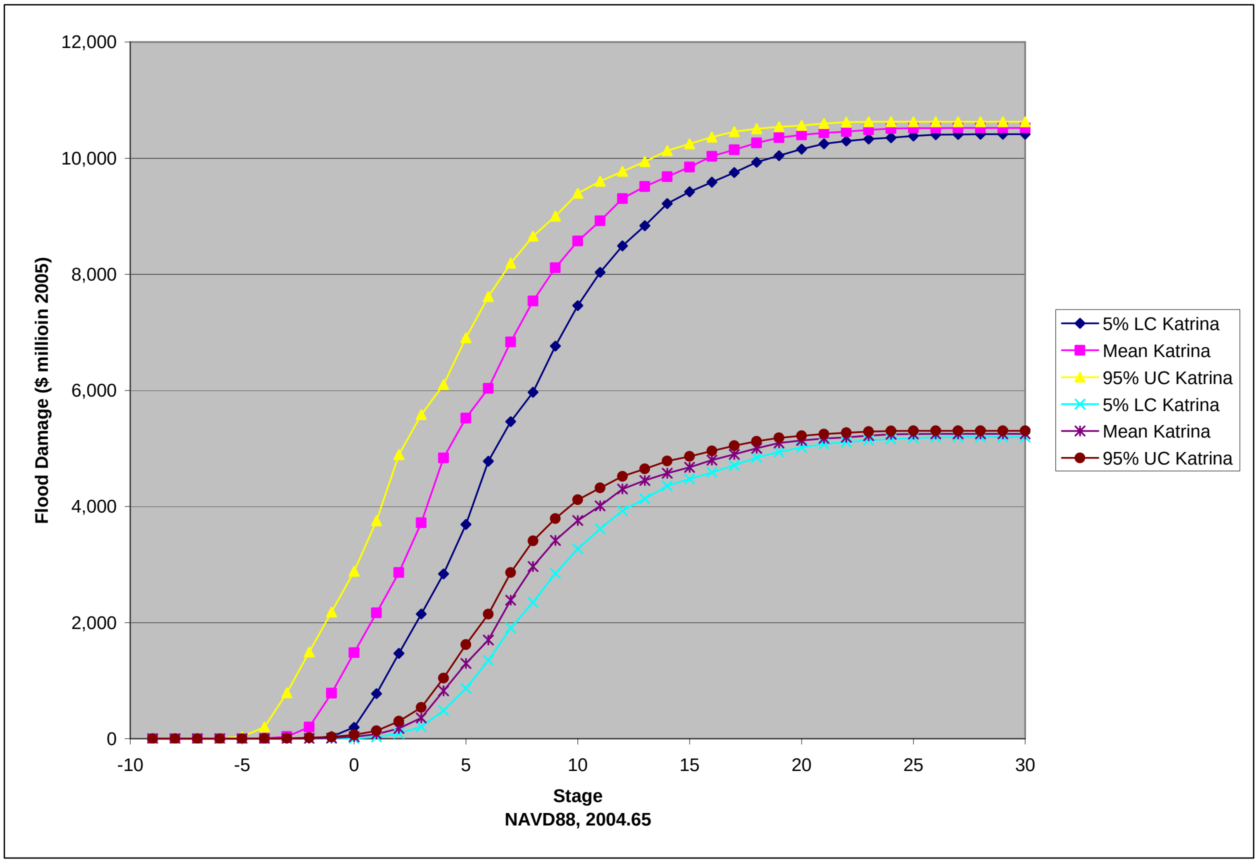


Figure 7. Relationship of stage and flood damage with uncertainty for Orleans Metro 5 (OM5) drainage subbasin—pre- and post-Katrina conditions.

References

Entergy. 2006. Entergy Louisiana and Entergy New Orleans. Cooperative disaster evaluation investigations with the Louisiana Recovery Authority (LRA). November 2005, December 2005, and March 2006.

FEMA. 2006a. "Report on *Current Housing Unit Damage Estimates for Hurricanes Katrina, Rita and Wilma, February 12, 2006.*" Federal Emergency Management Agency (FEMA) and The U.S. Department of Housing and Urban Development Office of Policy Development and Research.

FEMA. 2006b. Summary extracts from the National Emergency Management Information System (NEMIS) for Regions IV and IV.

LRA. 2006. Louisiana Recovery Authority (LRA) Action Team Report for Evaluation of Transportation and Associated Infrastructure Planning, March 2006.

McCarthy, Kevin, D. J. Peterson, Narayan Sastry, and Michael Pollard. 2006. The Repopulation of New Orleans after Hurricane Katrina. RAND Gulf States Policy Institute. RAND URL: http://www.rand.org/

Mietrodt, Jeffry, and, Rebecca Mowbray. 2006. After Katrina, Pundits Criticized New Orleans, Claiming Too Many Residents Had No Flood Insurance. In Fact, Few Communities Were Better Covered. *The Times-Picayune* 19 March 2006.

NEMIS. 2006. Review and assessment of NEMIS Project Worksheet (PW) submittals as provided by parish governments for Plaquemines, St. Charles, St. Bernard, and Jefferson Parishes; various from November 2006 through March 2006.

Personal communication from James K. Garster. 2006. USACE, Topographic Engineering Center, co-lead of the IPET Geodetic Vertical and Water level Datums Team, 16 May 2006.

Scawthorn, Charles F., Neil Blais, Hope Seligson, Eric Tate, Edward Mifflin, Will Thomas, James Murphy, and Christopher Jones. 2006. HAZUS-MH Flood Loss Estimation Methodology I: Overview and Flood Hazard Characterization. *Natural Hazards Review* Vol 7, No. 2, May 1, 2006

USACE. 1996. Depth-Damage Relationships for Structures, Contents, and Vehicles and Contents-to-Structure Value Ratios (CSVRs) in support of Jefferson and Orleans Flood Control Feasibility Studies. Unpublished report. New Orleans District, June 1996.

USACE. 1997. Lower Atchafalaya Reevaluation and Morganza to the Gulf, Louisiana. Feasibility Study. Unpublished report. New Orleans District, May 1997.

USACE. 2006a. Donaldsonville to the Gulf, Louisiana Feasibility Study. Unpublished report. New Orleans District, March 2006.

USACE. 2006b. Personal Communication. USACE. Construction-Operations Division of the New Orleans District, 22 May 2006.

U.S. Census Bureau, 2005. Compendium *of Government Finances: 2002*, 2002 Census of Governments (http://www.census.gov/prod/2005pubs/gc024x5.pdf)

7.2.2. Indirect Impacts

7.2.2.1. Objective

The objective of the indirect economic impact analysis is to examine the pre-Katrina economic base of metro New Orleans, consider the post-Katrina economic data made available up to May 2006, and provide a preliminary assessment of economic impacts brought on by the physical damages to property and dislocation of households in the greater New Orleans floodplain. This examination is important to inform readers about the full nature of economic consequences from the actual performance of the hurricane protection system and the expectations for consequences and risk of future storms in the region. However, many important household, business, and policy decisions have either not yet been made or are still evolving, and their outcomes can have profound impacts on households and markets. Balancing these uncertainties with a need to anticipate potential outcomes, this study will conduct a limited scope economic forecast of population, employment, local investment, and gross regional product based on two ”what-if” scenarios that can be viewed as limiting control scenarios.

7.2.2.2. The New Orleans Region Economy

It is important to provide the regional economic setting for a study of the regional economic effects of Hurricane Katrina. This description of the New Orleans economy focuses on the geographic areas that were most immediately impacted by Hurricane Katrina (call this the New Orleans Region)—the five parishes most affected by the failure of the flood control measures (i.e., Jefferson, Orleans, Plaquemines, St. Bernard, and St. Charles Parishes). Comparative evaluations will be made with Louisiana, with the surrounding states of Alabama, Mississippi, and Texas, and with the nation as a whole.

The economic base description has the following agenda. First, a number of economic trends prior to 2000 are discussed. This provides the trends that shaped New Orleans in its recent history. Next, the economic setting during the most recent period (2001 to 2004) are presented. Last, the extent of the immediate impact of Hurricane Katrina on the economy of New Orleans is demonstrated using very recently released employment data from the U.S. Bureau of Labor Statistics.

7.2.2.2.1. New Orleans Region Economy, 1969 to 2000

Population: Population in the five-parish New Orleans Region grew modestly over the period 1969 to 2000—1.03 million in 1969 and 1.08 million in 2000 (Table 16). This modest growth is also reflected in Plaquemines and St. Bernard Parishes. Jefferson and St. Charles Parishes experienced much faster rates of population growth during the period. However, population in Orleans Parish declined significantly between 1969 and 2000 (from just over 600,000 people to about 480,000).

Personal Income: Personal income is a broad measure of income for an area. It includes net earnings by place of residence, unearned income components (dividends, interest, and rents), and personal current transfer receipts received by residents. Personal income in the New Orleans Region increased substantially from $3.6 billion in 1969 to $28.1 billion in 2000. Each of the five parishes in the New Orleans Region also experienced similar increases in personal income. Income maintenance benefits consist largely of supplemental security income payments, family assistance, food stamp payments, and other assistance payments, including general assistance. As a share of personal income, these benefits nearly doubled between 1969 and 2000.

Per Capita Personal Income: Per capita personal income (PCPI) is personal income divided by population. Growth in PCPI for the New Orleans Region between 1969 and 2000 reflected the growth in personal income (i.e., population remained almost constant during the period): $3,500 in 1969 and $26,050 in 2000. PCPI for Jefferson, Orleans, and St. Charles Parishes were of similar magnitudes as the New Orleans Region as a whole. On the other hand, PCPI in Plaquemines and St. Bernard Parishes were approximately 20 percent lower than the region average in 2000. The per capita personal income of the New Orleans Region was higher than for Louisiana and Mississippi, Alabama, and Texas for both 2001 and 2004 (comparing Tables 16 and 17).

Table 16
Economic Characteristics of New Orleans Region

Region	Area	Item	1969	2000	2001	2004
New Orleans Region	5 Parishes	Personal income ($million)	$3,600.2	$28,136.6	$30,104.9	$32,777.4
		Population (000 persons)	1,030.3	1,080.3	1,071.9	1,058.8
		Per capita personal income (dollars)	$3,494	$26,045	$28,085	$30,958
		Income maintenance benefits ($million)	$41.8	$628.7	$653.2	$843.0
		Income maintenance percent of personal income	1.16%	2.23%	2.17%	2.57%
		Wage and salary disbursements ($million)	$2,756.4	$17,272.0	$17,934.7	$19,586.2
		Wage and salary jobs (000)	433.3	578.6	576.5	565.6
		Wage and salary per worker (dollars)	$6,361	$29,850	$31,111	$34,628
	Jefferson Parish	Personal income ($million)	$1,200.6	$12,616.5	$13,372.9	$14,569.6
		Population (000 persons)	326.0	454.8	452.2	453.1
		Per capita personal income (dollars)	$3,683	$27,742	$29,572	$32,156
		Income maintenance benefits ($million)	$5.2	$173.0	$180.3	$242.2
		Income maintenance percent of personal income	0.43%	1.37%	1.35%	1.66%
		Wage and salary disbursements ($million)	$567.8	$6,363.1	$6,631.4	$7,412.9
		Wage and salary jobs (000)	88.8	229.2	228.9	230.6
		Wage and salary per worker (dollars)	$6,394	$27,757	$28,968	$32,145
	Orleans Parish	Personal income ($million)	$2,073.9	$12,341.8	$13,345.8	$14,453.3
		Population (000 persons)	600.6	483.6	477.6	461.1
		Per capita personal income (dollars)	$3,453	$25,523	$27,942	$31,344
		Income maintenance benefits ($million)	$34.3	$406.3	$421.2	$529.8
		Income maintenance percent of personal income	1.65%	3.29%	3.16%	3.67%
		Wage and salary disbursements ($million)	$1,959.0	$9,050.7	$9,358.5	$9,920.2
		Wage and salary jobs (000)	313.0	292.8	290.7	274.9
		Wage and salary per worker (dollars)	$6,259	$30,910	$32,194	$36,086
	Plaquemines Parish	Personal income ($million)	$72.4	$561.2	$632.0	$715.0
		Population (000 persons)	25.3	26.8	27.0	29.0
		Per capita personal income (dollars)	$2,862	$20,981	$23,401	$24,681
		Income maintenance benefits ($million)	$0.6	$11.5	$11.5	$15.4
		Income maintenance percent of personal income	0.79%	2.05%	1.83%	2.15%
		Wage and salary disbursements ($million)	$86.8	$630.4	$654.0	$668.8
		Wage and salary jobs (000)	12.3	18.3	18.6	16.8
		Wage and salary per worker (dollars)	$7,071	$34,495	$35,242	$39,825
	St. Bernard Parish	Personal income ($million)	$164.3	$1,450.2	$1,538.7	$1,690.4
		Population (000 persons)	49.4	67.0	66.6	65.6
		Per capita personal income (dollars)	$3,328	$21,635	$23,119	$25,754
		Income maintenance benefits ($million)	$0.7	$22.6	$24.4	$33.6
		Income maintenance percent of personal income	0.45%	1.56%	1.58%	1.99%
		Wage and salary disbursements ($million)	$73.1	$410.4	$432.0	$537.2
		Wage and salary jobs (000)	10.4	17.6	17.4	19.3
		Wage and salary per worker (dollars)	$7,045	$23,303	$24,825	$27,869
	St. Charles Parish	Personal income ($million)	$88.9	$1,166.9	$1,215.5	$1,349.1
		Population (000 persons)	29.0	48.2	48.5	50.0
		Per capita personal income (dollars)	$3,063	$24,211	$25,050	$27,005
		Income maintenance benefits ($million)	$1.0	$15.3	$15.9	$22.1
		Income maintenance percent of personal income	1.15%	1.31%	1.30%	1.64%
		Wage and salary disbursements ($million)	$69.7	$817.4	$858.7	$1,047.1
		Wage and salary jobs (000)	8.9	20.7	20.9	24.0
		Wage and salary per worker (dollars)	$7,820	$39,522	$41,106	$43,573

Source: Regional Economic Information System, U.S. Bureau of Economic Analysis. Regional Economic Models, Inc.

Table 17
Economic Characteristics of Other Areas

			1969	2000	2001	2004
Louisiana		Personal income ($million)	$10,453.4	$103,150.7	$110,256.2	$123,020.6
		Population (000 persons)	3,619.0	4,469.5	4,465.3	4,506.7
		Per capita personal income (dollars)	$2,888	$23,079	$24,692	$27,297
		Income maintenance benefits ($million)	$186.4	$2,203.5	$2,294.6	$3,101.0
		Income maintenance percent of personal income	1.78%	2.14%	2.08%	2.52%
		Wage and salary disbursements ($million)	$7,042.2	$55,571.8	$58,061.2	$63,897.6
		Wage and salary jobs (000)	1,256.2	2,033.1	2,033.8	2,036.9
		Wage and salary per worker (dollars)	$5,606	$27,333	$28,548	$31,370
MS, AL & TX	3 States	Personal income ($million)	$51,808.6	$758,783.0	$792,802.1	$887,040.0
		Population (000 persons)	16,705.0	28,250.4	28,658.6	29,897.7
		Per capita personal income (dollars)	$3,101	$26,859	$27,664	$29,669
		Income maintenance benefits ($million)	$452.7	$10,318.0	$10,676.5	$15,215.6
		Income maintenance percent of personal income	0.87%	1.36%	1.35%	1.72%
		Wage and salary disbursements ($million)	$34,328.0	$429,964.2	$444,949.1	$480,646.6
		Wage and salary jobs (000)	6,172.4	13,214.6	13,259.3	13,255.1
		Wage and salary per worker (dollars)	$5,562	$32,537	$33,558	$36,261
	Mississippi	Personal income ($million)	$5,303.2	$59,836.9	$62,738.9	$71,122.1
		Population (000 persons)	2,220.0	2,848.8	2,857.6	2,900.8
		Per capita personal income (dollars)	$2,389	$21,005	$21,955	$24,518
		Income maintenance benefits ($million)	$83.3	$1,452.9	$1,535.0	$1,982.4
		Income maintenance percent of personal income	1.57%	2.43%	2.45%	2.79%
		Wage and salary disbursements ($million)	$3,376.7	$30,748.3	$31,081.2	$34,287.9
		Wage and salary jobs (000)	749.3	1,243.7	1,223.0	1,217.0
		Wage and salary per worker (dollars)	$4,506	$24,724	$25,414	$28,174
	Alabama	Personal income ($million)	$9,383.8	$105,806.7	$110,420.9	$125,330.0
		Population (000 persons)	3,440.0	4,452.3	4,467.5	4,525.4
		Per capita personal income (dollars)	$2,728	$23,764	$24,717	$27,695
		Income maintenance benefits ($million)	$126.9	$1,849.6	$1,930.4	$2,583.9
		Income maintenance percent of personal income	1.35%	1.75%	1.75%	2.06%
		Wage and salary disbursements ($million)	$6,347.8	$57,643.5	$59,088.0	$66,049.2
		Wage and salary jobs (000)	1,215.5	2,025.9	2,007.4	2,018.6
		Wage and salary per worker (dollars)	$5,223	$28,453	$29,436	$32,721
	Texas	Personal income ($million)	$37,121.7	$593,139.4	$619,642.2	$690,588.0
		Population (000 persons)	11,045.0	20,949.4	21,333.6	22,471.5
		Per capita personal income (dollars)	$3,361	$28,313	$29,045	$30,732
		Income maintenance benefits ($million)	$242.6	$7,015.6	$7,211.1	$10,649.4
		Income maintenance percent of personal income	0.65%	1.18%	1.16%	1.54%
		Wage and salary disbursements ($million)	$24,603.5	$341,572.5	$354,780.0	$380,309.5
		Wage and salary jobs (000)	4,207.6	9,945.0	10,028.9	10,019.6
		Wage and salary per worker (dollars)	$5,847	$34,346	$35,376	$37,957
All US States		Personal income ($million)	$772,235.0	$8,422,074.0	$8,716,992.0	$9,705,504.0
		Population (000 persons)	201,298.0	282,193.5	285,107.9	293,656.8
		Per capita personal income (dollars)	$3,836	$29,845	$30,574	$33,050
		Income maintenance benefits ($million)	$7,275.0	$106,616.0	$109,403.0	$141,490.0
		Income maintenance percent of personal income	0.94%	1.27%	1.26%	1.46%
		Wage and salary disbursements ($million)	$512,242.0	$4,825,906.0	$4,939,944.0	$5,383,900.0
		Wage and salary jobs (000)	78,726.0	139,002.0	138,831.0	138,769.0
		Wage and salary per worker (dollars)	$6,507	$34,718	$35,582	$38,798

Source: Regional Economic Information System, U.S. Bureau of Economic Analysis. Regional Economic Models, Inc.

Employment: Employment increased in the New Orleans Region from 430,000 in 1969 to almost 580,000 in 2000 (Table 16). However, Louisiana, the three-state area of Mississippi, Alabama, and Texas, and the nation experienced substantially greater growth in employment than the New Orleans Region (comparing Tables 16 and 17).

7.2.2.2.2. New Orleans Region Economy, 2001 to 2004

Population: Population in the five-parish New Orleans Region has declined slightly since 2000—1.08 million in 2000, 1.07 million in 2001 and 1.06 million in 2004 (Table 16). The populations in all five of the parishes in the New Orleans Region appear to be gradually falling or are remaining almost constant.

Personal Income: Personal income in the New Orleans Region has continued to increase after 2000: from $30.1 billion in 2001 to $32.8 billion in 2004. Each of the five parishes in the New Orleans Region also experienced similar increases in personal income (Table 16). Income maintenance benefits in 2004 reached 2.57 percent, well above the national average of 1.46 percent (comparison of Tables 16 and 17).

Per Capita Personal Income: Again, growth in PCPI for the New Orleans Region between 2001 and 2004 reflected the growth in personal income (i.e., population remained almost constant during the period): $28,085 in 2001 and $30,960 in 2004 (Table 16).

Employment: Employment in all areas examined has either declined slightly or remained fairly constant since 2000 (comparing Tables 17 and 18).

Table 18
Employment Declines from August to September 2005, by Sub-Sector

Percentage Declines in Employment between August 2005 and September 2005

NAICS	Industry	New Orleans Region	Rest of NO BEA	Rest of Louisiana
		percentage decline */		
111	Crop production	6.3		
112	Animal production		1.0	1.4
113	Forestry and logging	40.0	1.4	
114	Fishing, hunting and trapping	69.2	22.7	16.1
115	Support activities for agriculture and forestry	7.7	10.9	
211	Oil and gas extraction	1.1	4.5	1.2
212	Mining (except oil and gas)	6.5	2.9	
213	Support activities for mining	8.9		
221	Utilities	0.6		0.1
236	Construction of buildings	19.5	3.6	
237	Heavy and civil engineering construction	6.4	1.8	
238	Specialty trade contractors	38.9	2.6	
311	Food manufacturing	32.1	3.6	
312	Beverage and tobacco product manufacturing		1.0	
313	Textile mills			3.9
314	Textile product mills	71.3	9.0	
315	Apparel manufacturing	12.8	16.7	3.5
316	Leather and allied product manufacturing			2.6
321	Wood product manufacturing		1.9	
322	Paper manufacturing	2.5	1.3	0.7
323	Printing and related support activities	38.0	4.0	0.4
324	Petroleum and coal products manufacturing	1.3	0.7	1.0
325	Chemical manufacturing	6.0	0.6	
326	Plastics and rubber products manufacturing	10.4	12.5	
327	Nonmetallic mineral product manufacturing	22.2	5.2	0.3
331	Primary metal manufacturing	7.2		2.2
332	Fabricated metal product manufacturing	33.9	2.7	
333	Machinery manufacturing	2.0	2.3	0.5
334	Computer and electronic product manufacturing	20.5	1.5	3.4
335	Electrical equipment, appliance, and component manufacturing	33.2	18.8	
336	Transportation equipment manufacturing	32.1		2.0
337	Furniture and related product manufacturing	44.8	2.7	
339	Miscellaneous manufacturing	45.6	26.5	2.4
423	Merchant wholesalers, durable goods	19.5	3.4	0.3
424	Merchant wholesalers, nondurable goods	19.2	4.1	0.2
425	Wholesale electronic markets and agents and brokers	9.9	2.6	1.5
441	Motor vehicle and parts dealers	28.5	7.1	
442	Furniture and home furnishings stores	38.6	14.8	1.1
443	Electronics and appliance stores	27.1	4.8	
444	Building material and garden equipment and supplies dealers	45.4	6.3	0.5
445	Food and beverage stores	65.5	5.6	
446	Health and personal care stores	18.1	0.7	
447	Gasoline stations	70.3	8.4	
448	Clothing and clothing accessories stores	35.3	9.1	3.9
451	Sporting goods, hobby, book, and music stores	27.7	6.6	2.0
452	General merchandise stores	13.8	2.1	
453	Miscellaneous store retailers	53.7	17.4	1.5
454	Nonstore retailers	35.6	7.8	
481	Air transportation	3.4		
482	Rail transportation			
483	Water transportation	7.9	8.5	
484	Truck transportation	27.0	4.4	
485	Transit & ground passenger transportation	30.3	13.5	

* BLUE cells depict declines between 10 and 25 percent; YELLOW cells depict declines of greater than 25 percent

Table 18 (Concluded)

NAICS	Industry	New Orleans Region	Rest of NO BEA	Rest of Louisiana
		percentage decline */		
486	Pipeline transportation	0.6		0.1
487	Scenic & sightseeing transportation		20.0	13.3
488	Support activities for transportation	24.3	1.6	
491	Postal service			
492	Couriers & messengers	7.9	2.6	0.6
493	Warehousing & storage	17.1	6.2	
511	Publishing industries (except internet)	7.4	5.4	0.1
512	Motion picture & sound recording industries	28.5	29.4	5.2
515	Broadcasting (except internet)	6.3	3.2	
516	Internet publishing and broadcasting	42.2		
517	Telecommunications	11.1	2.6	
518	Internet service providers, web search portals, and data processing services	3.8		3.1
519	Other information services	0.9	0.3	0.8
521	Monetary authorities - central bank			
522	Credit intermediation & related activities	12.2	2.7	
523	Securities intermediation & related activities	12.8	5.3	
524	Insurance carriers & related activities	12.0	3.9	
525	Funds, trusts, & other financial vehicles (part)	36.2	4.1	
531	Real estate	28.0	9.4	0.6
532	Rental & leasing services	27.3	3.7	0.4
533	Lessors of intangible assets, except copyrighted works	19.4		2.1
541	Professional, scientific, & technical services	23.1	8.1	
551	Management of companies & enterprises	11.7	2.9	1.2
561	Administrative & support services	36.2	3.4	
562	Waste management & remediation services			
611	Educational services	1.1		
621	Ambulatory health care services	37.9	9.3	
622	Hospitals	4.1	0.6	
623	Nursing & residential care facilities	49.4	7.9	
624	Social assistance	47.9	8.3	
711	Performing arts, spectator sports, & related industries	24.1	6.3	
712	Museums, historical sites, & similar institutions	16.3	10.1	9.4
713	Amusement, gambling, & recreation industries	23.8	12.7	3.3
721	Accommodation	21.3	2.4	
722	Foodservices & drinking places	49.9	13.7	
811	Repair & maintenance	42.0	9.0	
812	Personal & laundry services	49.2	15.6	1.0
813	Religious/grantmaking/civic/professional & similar organizations	13.6	15.8	
814	Private households	55.0	6.1	0.1
921	Executive, legislative, and other general government support	1.7	2.1	1.5
922	Justice, public order, and safety activities	1.7	0.2	
923	Administration of human resource programs	0.9		
924	Administration of environmental quality programs		11.2	4.4
925	Administration of housing programs, urban planning, and community development	4.6	2.9	
926	Administration of economic programs	2.1	0.5	
928	National security and international affairs			0.6
999	Unclassified	6.7	9.9	
1000	Total non-farm	24.0	4.5	

* BLUE cells depict declines between 10 and 25 percent; YELLOW cells depict declines of greater than 25 percent

7.2.2.2.3. Immediate Economic Impact of Hurricane Katrina

Recently released data from the U.S. Bureau of Labor Statistics for the third quarter of 2005 permit a tentative estimate of the toll that Hurricane Katrina has had on the New Orleans economy, at least in terms of the non-farm employment. Figure 8 shows monthly estimates of total non-farm employment in the New Orleans Region, the remaining portion of the New Orleans Bureau of Economic Analysis (BEA) Economic Area and the rest of Louisiana for the period January 2001 through September 2005. Except for the last month of data, employment in these three areas remained fairly constant. Then between August and September 2005 total non-farm employment plummeted from 512,000 to 388,000—a loss of 124,000 or nearly one-fourth of the jobs in one month (24.2 percent). The remainder of the New Orleans BEA area experienced a milder decrease in employment (4.5 percent). The rest of Louisiana even experienced a 1.8-percent increase in jobs.

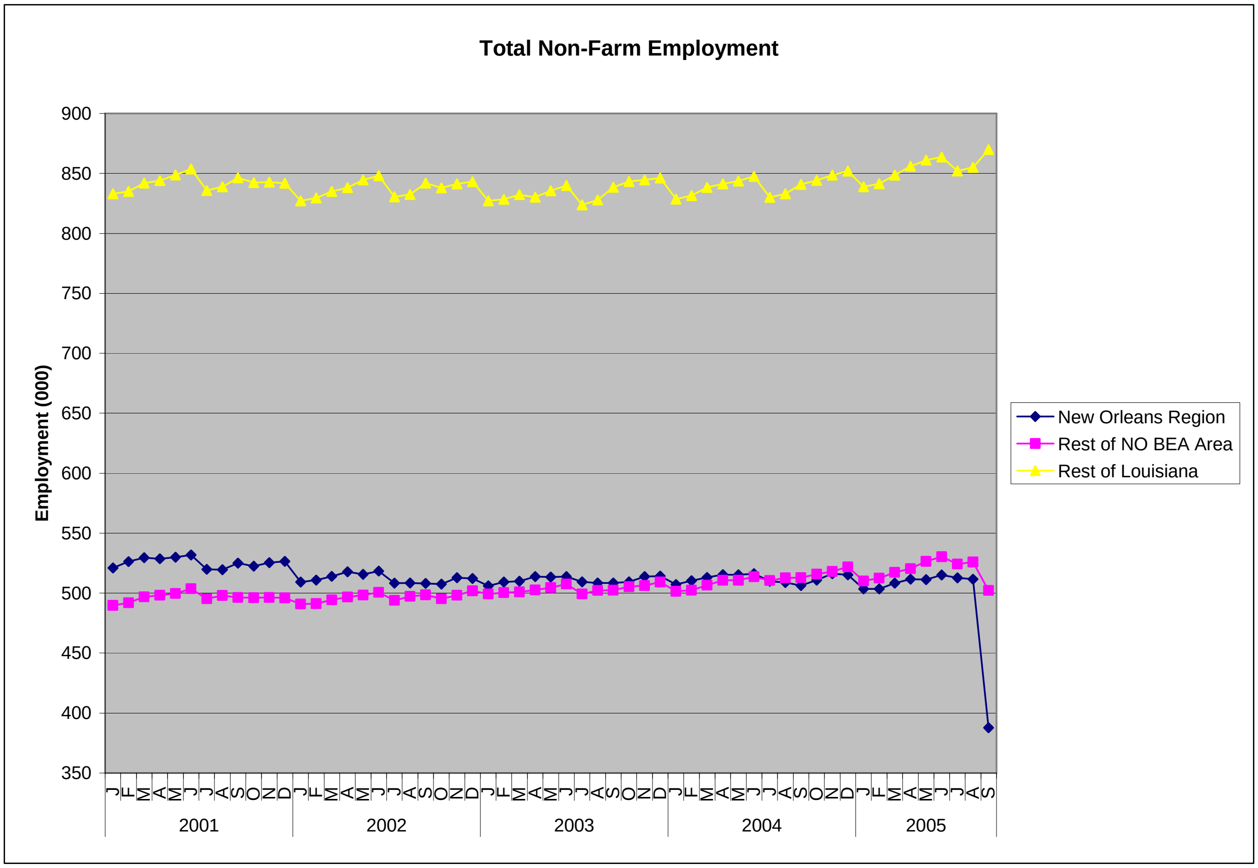


Figure 8. Total Non-Farm Monthly Employment, 2001 to 2005 (Source: Bureau of Labor Statistics, Quarterly Census of Employment and Wages).

At a more industrially detailed level, the employment losses are even more dramatic in some cases. Table 18 lists the August to September 2005 percentage losses in employment for each of the three-digit NAICS industries located in the New Orleans Region, the remaining portion of the New Orleans BEA area, and the rest of Louisiana. Those job losses that are 10 percent or more are highlighted in yellow for ease of reference. In the New Orleans Region 59 percent of the three-digit NAICS code industries have employment losses that are greater than 10 percent.

Figure 9 shows seasonally adjusted annual rate of growth in real gross domestic product for the U.S. beginning with the third quarter of 2005. Cumulative effects of the 2005 hurricane season and high energy prices are among other factors beyond Katrina that may have contributed to slow fourth quarter growth in US-GDP. First quarter 2006 GDP growth rebounded and is currently at its highest number since the index reached 7.2 percent in the third quarter of 2003.

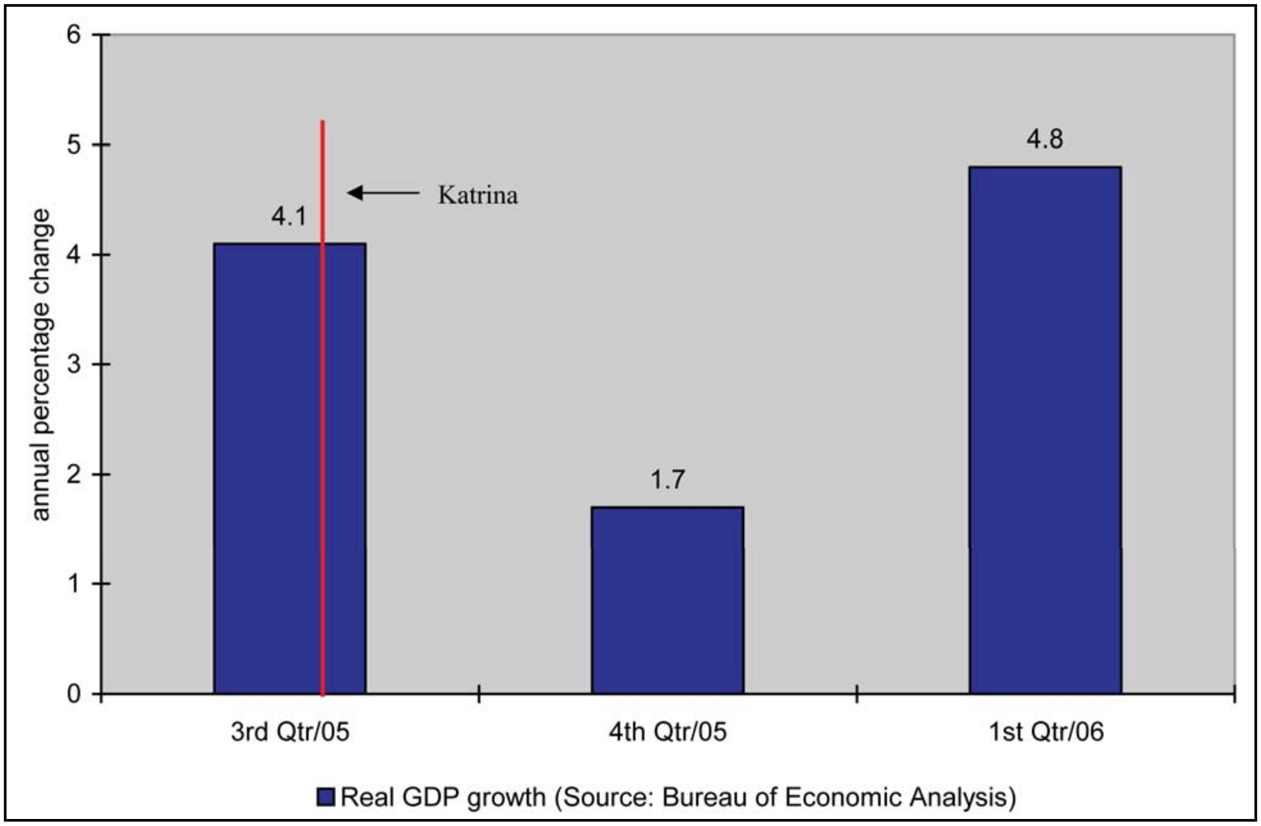


Figure 9. Real U.S. gross domestic product: Percentage change from previous period.

7.2.2.3. Regional Economic Forecast

Prominent among the socioeconomic consequences of the Katrina related flooding in metro New Orleans are that more than $17 billion of residential damage and roughly $3 billion in non-residential damage was sustained (Table 7) and as of Spring 2006 more than 400,000 fewer people reside in the area (Table 46). Using a regional economic forecasting model compiled for IPET by Regional Economic Models, Inc. (REMI), this section introduces these three impacts into a pre-Katrina forecast and reports how they change the REMI economic forecasts for population, employment, value of residential capital, and value of non-residential capital in metro New Orleans. In addition, the same comparison is reported for gross regional product for metro New Orleans, the rest of Louisiana, the combined states of Alabama, Mississippi, and Texas, and for the remainder of the U.S.

Amidst all the uncertainty and evolving facts surrounding the storms impact on metro New Orleans, we know that billions of dollars worth of property was damaged or destroyed and that many thousands of households remain displaced from their primary residence. Socioeconomic models are generally not built to anticipate social or economic behaviors under these circumstances. Rather, models typically are calibrated from observed behaviors under normal circumstances by gauging changes in social and economic decisions around the margin. For example, when relative prices of goods, services, or factors of production change, buyers often redirect their expenditures to viable and more favorably priced alternative products. With discrete jumps in personal wealth, such as through a new tax credit or sudden drop in asset prices, socioeconomic behaviors are observed. As household life-stages, neighborhood quality of life indicators, or economic opportunities evolve, locational decisions of households are observed. Each of these categories of observed socioeconomic decisions can be used to estimate behavioral parameters, and they are often estimated for different types of households or business activities. The fundamental issue that social scientists must often address is that observed behaviors around the margin, such as those described here, may have little relevance when applying these behaviors to large and unprecedented changes in socioeconomic conditions.

The model compiled for IPET by REMI is not immune from these limitations but there are a number of reasons why the architecture of this model can provide useful insights. For example, factors affecting both household cohort and firm behaviors are built into the model simulations. The ability to control future forecasts of key economic drivers that influence market outcomes gives the modeler considerable leverage in assessing the bounds of uncertain outcomes. Finally, the model characterizes the entire economic system rather than select elements of that system. So, for example, the sudden and large scale destruction of personal and business property and mass displacement of households within the study area translates into varying but generally lesser burdens placed on both nearby and far away regions that absorb the displaced households and redirected market demands. These can be specified and traced across geography and over time.

7.2.2.3.1. Approach

The approach for this analysis involves the translation of select results from our study of direct economic plus social consequence analysis into propagating market effects by use of a multiregional economic and demographic model of the U.S. economy, heretofore called the model. The model was compiled for IPET by REMI using 2003 baseline economic data and official government forecasts from the Labor and Commerce Departments as well as from the University of Michigan. Regional definitions are depicted in Figure 10 and sector level detail is defined in Table 19. Major economic and demographic data sources are listed in Table 20.

REMI, Policy Insight (version 8.0) is a proprietary model that is commercially available and used by private industry, academic, and government institutions. The dynamic forecasting features of REMI and the model's wide use make it a useful point of reference for depicting how Katrina-related flooding of metro New Orleans changes the economic forecast of the New Orleans, regional, and national economy. Complete documentation of the model is available on their web site (www.remi.com). Important features of the model for the purposes used in this report are described below.

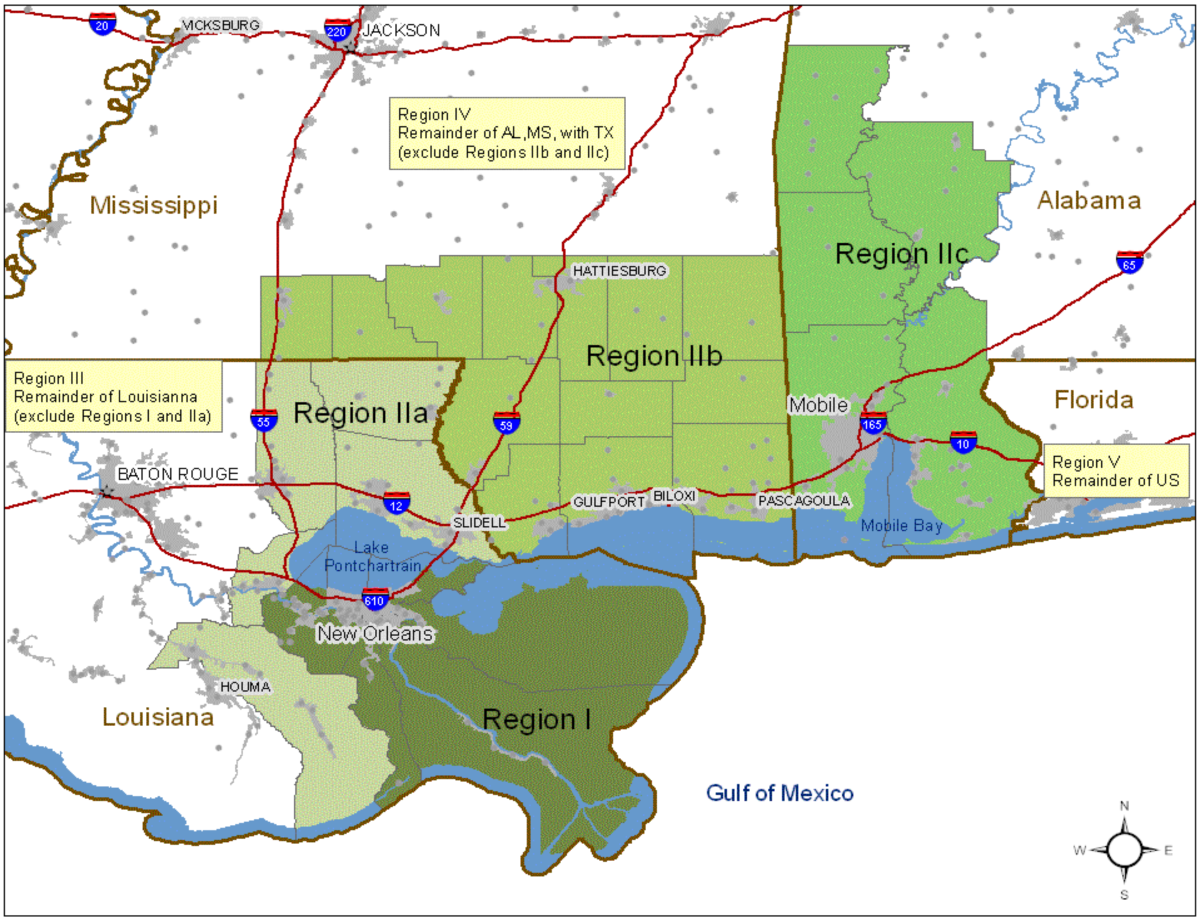


Figure 10. Map of model regions.

Table 19
Model Industries, Associated NAICS Codes, and Industry Descriptions

Model Industry	NAICS	Description
1	113, 114	Forestry and Logging; Fishing, Hunting and Trapping
2	115	Support Activities for Agriculture and Forestry
3	211	Oil and Gas Extraction
4	212	Mining (except Oil and Gas)
5	213	Support Activities for Mining
6	221	Utilities
7	23	Construction
8	321	Wood Product Manufacturing
9	327	Nonmetallic Mineral Product Manufacturing
10	331	Primary Metal Manufacturing
11	332	Fabricated Metal Product Manufacturing
12	333	Machinery Manufacturing
13	334	Computer and Electronic Product Manufacturing
14	335	Electrical Equipment, Appliance, and Component Manufacturing
15	3361-3363	Motor Vehicle Manufacturing
16	3364-3369	Transportation Equipment Manufacturing, Excl. Motor Vehicles
17	337	Furniture and Related Product Manufacturing
18	339	Miscellaneous Manufacturing

(Continued)

Table 19 (Concluded)		
Model Industry	**NAICS**	**Description**
19	311	Food Manufacturing
20	312	Beverage and Tobacco Product Manufacturing
21	313	Textile Mills
22	314	Textile Product Mills
23	315	Apparel Manufacturing
24	316	Leather and Allied Product Manufacturing
25	322	Paper Manufacturing
26	323	Printing and Related Support Activities
27	324	Petroleum and Coal Products Manufacturing
28	325	Chemical Manufacturing
29	326	Plastics and Rubber Products Manufacturing
30	42	Wholesale Trade
31	44	Retail Trade
32	481	Air Transportation
33	482	Rail Transportation
34	483	Water Transportation
35	484, 492	Truck Transportation; Couriers and Messengers
36	485	Transit and Ground Passenger Transportation
37	486	Pipeline Transportation
38	487, 488	Scenic and Sightseeing Transportation; Support Activities
39	493	Warehousing and Storage
40	511	Publishing Industries (except Internet)
41	512	Motion Picture and Sound Recording Industries
42	516, 518, 519	Internet Services and data processing; Other Information
43	515	Broadcasting (except Internet); Telecommunications
44	521, 522, 525	Monetary Authorities-Central Bank; Credit Intermediation and Related Activities; Funds, Trust, Other Finance Vehicles
45	523	Securities, Commodity Contracts, and Other Financial Investments and Related Activities
46	524	Insurance Carriers and Related Activities
47	531	Real Estate
48	532, 533	Rental and Leasing Services; Lessors of Nonfinancial Intangible Assets
49	54	Professional, Scientific, and Technical Services
50	55	Management of Companies and Enterprises
51	561	Administrative and Support Services
52	562	Waste Management and Remediation Services
53	61	Educational Services
54	621	Ambulatory Health Care Services
55	622	Hospitals
56	623	Nursing and Residential Care Facilities
57	624	Social Assistance
58	711	Performing Arts, Spectator Sports, and Related Industries
59	712	Museums, Historical Sites, and Similar Institutions
60	713	Amusement, Gambling, and Recreation Industries
61	721	Accommodation
62	722	Food Services and Drinking Places
63	811	Repair and Maintenance
64	812	Personal and Laundry Services
65	813	Religious, Grantmaking, Civic, Professional, and Similar Organizations
66	814	Private Households
67		State and local government
68		Federal, Civilian
69		Military
70	111	Farm (Crop and Animal Production)

Table 20
Major Economic and Demographic Data Sources

Series	Geography	Source	Timeframe
Major Economic Data Sources for Version 8.0 of REMI, Policy Insight			
Employment, Wages, Personal Income, Industry Compensation	County	**Bureau of Economic Analysis (BEA)**, County Business Patterns (CBP); Regional Economic Information System (REIS) **Bureau of Labor Statistics (BLS)**, Quarterly Census of Employment and Wages (QCEW)	2001 to 2003
	State	**BEA**, State Personal Income (SPI); CBP **BLS**, QCEW	2001 to 2003
	National	**BEA**, SPI; CBP **BLS**, Employment Projections (EP); QCEW	2001 to 2003 and 2012
Commuter Flows	County-to-County	**Bureau of Census (Census),** Census of Population and Housing, 2000 (C2K) **BEA**, SPI	2000 2003
Industry-to-Industry Purchases, Consumption, Investment, International Trade	National	**BLS**, Annual Input-Output Series (BLS-IO) **BEA,** National Income and Product Accounts of the U.S. (NIPA) **U. of Michigan (UMI)**, Research Seminar in Quantitative Economics (RSQE)	2001-02, 2012 2001-2003 2004-2007
Occupations by Industry	National	**BLS**, Occupational Employment Statistics (OES)	2002, 2012
Major Demographic Data Sources for Version 8.0 of REMI, Policy Insight			
Fatality Rates **Survival Rates** **Net International Migrants** **Labor Participation** **Active Military** **Military Dependants** **Prisoners**	Nation	**Census** **Census** **Census** **BLS** **Dept. of Defense (DoD)** **DoD** **Bureau of Justice Statistics (BJS)**	1999-2100 1999-2100 1999-2100 1990-2050 1990-2003 1990-2003 1990-2003
Birth Rates	State	**Center for Disease Control (CDC)**	1990-2002
Total Population **Population by age, sex, race, etc.** **Labor Force** **Prisoners by sex, race** **Total active military**	County	**BEA** **Census** **BLS** **Census** **DoD**	1990-2003 1990-2003 1990-2003 2000 1994-2003

7.2.2.3.2. Forecast Scenarios

For the study region (region I), population and economic forecasts reflecting pre-Katrina market conditions and expectations (REMI forecasts) are used as the control forecast for the analysis. Next, two what-if scenarios are simulated as follows:

1) Flat population forecast – In 2005, $17,628 million dollars worth of residential dwellings, content, and autos are damaged or destroyed (section 7.2.1) and by year's end the population of the five-parish study area is at 632,731 (section 7.4.3). This scenario places population at 632,700 through 2010 on the pessimistic assumption that all remaining displaced will not return. This scenario provides a post-Katrina baseline forecast by assuming there are changed perceptions of non-market factors (e.g., higher perceived risk, diminished community infrastructure, etc.) that have kept displaced and potential new residents away from the region and that this perception will persist.

2) Economic recovery forecast – In 2005, $17,628 million dollars worth of residential dwellings, content, and autos are damaged or destroyed and by year-end the population of the five-parish study area is at 632,730. This scenario assumes that non-market factors (e.g., higher perceived risk, diminished community infrastructure, etc.) explain the 2005 year end population of 632,700, but that the existing recovery process and a subsequent uneventful hurricane season remove these perceptions by year-end 2006 and through 2010.

The mechanism in REMI for representing household perceptions of non-market factors such as risk and community infrastructure is referred to as the non-pecuniary (amenity) aspects policy variable. This variable describes the non-market quality of life component within the migration equation. The quality improvement/decline may come from changes in morbidity/mortality, visibility, crime, environmental factors, quality of public services, and so forth. For simulation purposes, the change may be quantified in terms of a real compensation change equivalent for economic migrants. An amenity decrease perceived as a real compensation cost makes the region less attractive, so fewer numbers of economic migrants enter the region annually (see model documentation at www.remi.com).

The purpose of these control experiments is to anticipate the time path of the study region's economic recovery and, hence, the time path of future loss exposures contribution to future risk. It is not possible at this stage to speak authoritatively on critical issues like changes in perceived personal risk of future flooding, on the extent of government's role in assuming and addressing this risk, on the nature of future gulf region storms, etc. While these issues will greatly influence socioeconomic forecasts of the study region, it is, nonetheless, useful to examine these two transparent assumptions regarding their outcomes. These grim facts will remain the part of more informed analysis and will almost certainly still drive the forecast results.

7.2.2.3.3. Approach to Developing Policy Variables

In the study region, both population and local employment have diminished since the storm. March, 2006 estimates of population are at 632,700 and under both forecast scenarios discussed above, this is assumed to be the year-end 2005 population. This information is used to calibrate our two post-Katrina scenarios. Figure 11 depicts the procedure.

In Figure 11, the larger upper panel describes the population, migration and labor participation process in region I. The far left sub-panel depicts the 2004 pre-Katrina regional population which is slightly over 1 million people. The arrow carries population over to the following period where the storm and flooding created long term displacement of evacuees and hence a smaller regional population assumed to be 632,700 by year-end 2005. Passage of time, progress on recovery and repairs plus a desire by many to return characterize the post-Katrina (far-right) upper sub-panel. In the flat population forecast scenario, it is assumed that such progress is more perceived than real such that net in-migration, births, and deaths exactly offset such that population stays constant. In the economic forecast scenario, the non-pecuniary amenities factor returns to its pre-Katrina value and population recovery in the region is motivated by the remaining three categories of economic migration incentives. These are improving employment opportunities, better commodity access, and wage incentives necessitated by a scarcity of labor.

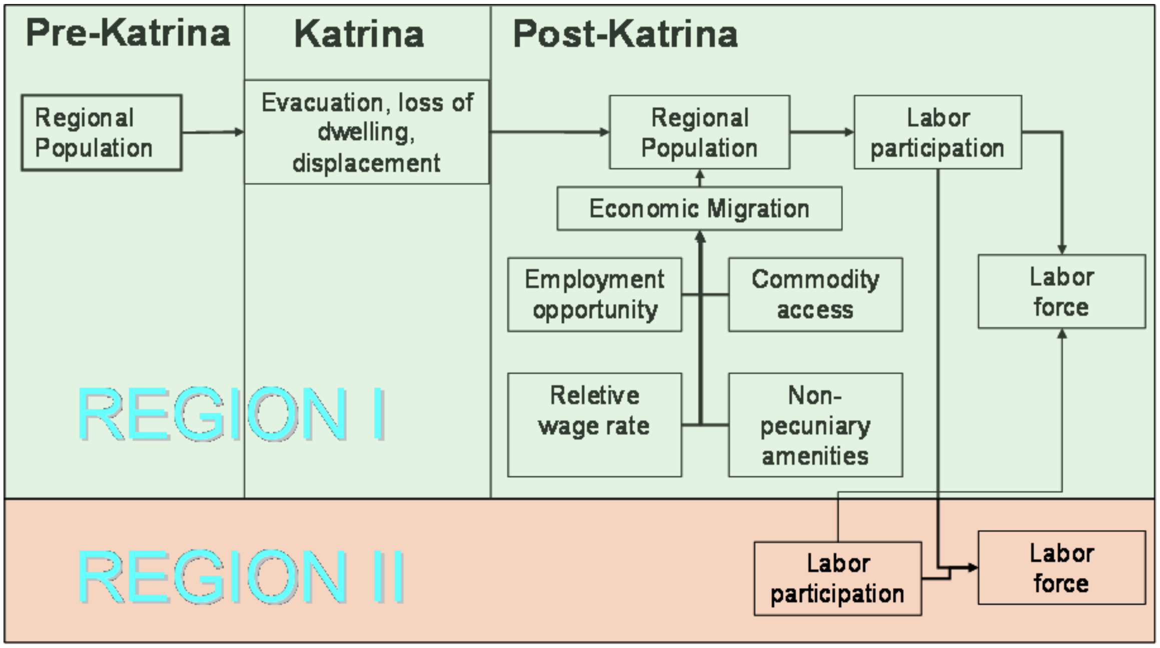


Figure 11. Tracing time-path of regional population recovery.

Implicit but not depicted is the fact that these four attractions also exist in other regions, region I is competing with those regions to attract both displaced and new households to the region--in effect, to recapture its comparative advantage. From this post-Katrina growing regional population is drawn labor participants, and the local economy has an advantage in bringing local participants into its local work force. But it may also become an increasing reality that a premium wage will be offered to attract a labor force from outside regions willing to commute and work in the region. This is depicted by the lower quadrant of the figure labeled region II, where we abstract from the seven regions of the model.

Another perspective of this same process is the business recovery. Figure 12 depicts this parallel to population recovery and partitions the timeframe into two periods—pre- (upper panel) and post- (lower panel) Katrina. The upper panel depicts primary production factors (far left) as the existing regional workforce, the production capital in place, and available energy inputs. These primary factors are combined with purchased inputs that are outputs from other industries and assemble them according to a region specific production recipe. With all production activity categorized into 70 sector outputs (Table 19), each region may have up to 70 unique such recipes that produce this region's version of the 70 categories of national output. The lower panel of Figure 5 depicts the disruption in this process caused by the storm. A reduction of potential local labor has already been discussed. The damage to structures, equipment, and infrastructure, as quantified in the section on direct losses, also diminishes production capital. Since each industry is limited by the existing production technology available to it, its combination of primary production factors will change in response to relative costs of these primary factors but consistent with existing technology. Since all industry in the region faces the same kind of labor and capital supply issues, the purchased inputs for production will be delivered at higher prices and, in many instances, in more limited quantities. The result is local production with changed recipes, lower capacities, and higher production costs. This translates into lower regional output at higher prices.

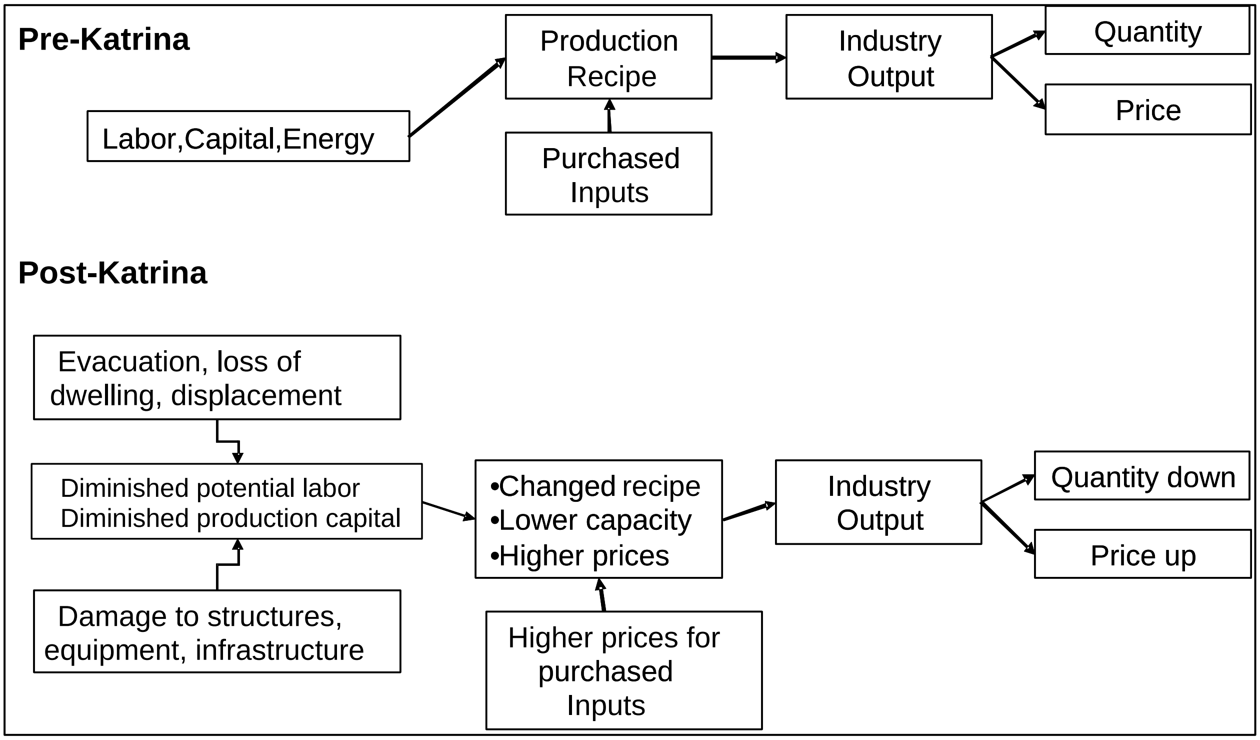


Figure 12. Impact of a labor and capital supply on regional industry output.

Regional output is sold for many different types of use and often to many different regions. One such use is final sales to households, usually facilitated via wholesalers, freight services, and retailers. In Figure 13, each oval depicts an economic region and shows a causal relationship between earnings, demand, and supply. Suppose the far left oval is our study region. We would expect post-Katrina local earnings (from local industry sales) to have diminished and this would reduce the contribution to disposable incomes. It is likely that local earnings are the primary source for local disposable income (top of far-left oval) although an increasing share of these local earnings may go to commuter households in adjacent regions. The study region's disposable income translates into local demand and for many (or most) categories of output, such as local government services, local demand typically draws extensively from local output (bottom of far-left oval). As depicted in Figure 5, this output is likely to be diminished so both local and external region demands (including exports) will initially redirect their purchases to sources outside their home region. Over time, as the regional population recovers, new investment flows in to recapture the pre-Katrina comparative advantage, and local disposable incomes should increase.

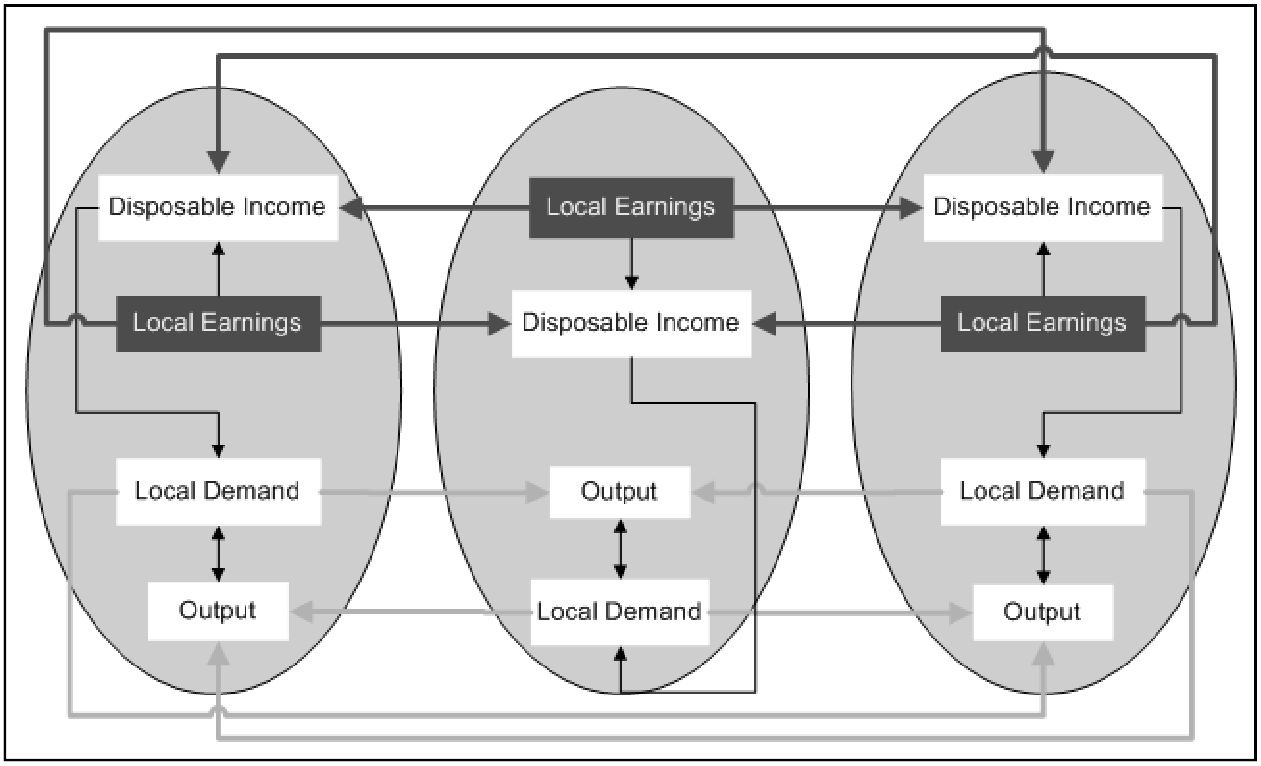


Figure 13. Interregional trade in final market goods and services. Source: Model documentation for REMI, Policy Insight, version 6.0 (www.remi.com).

7.2.2.3.4. Input Data

Only six input elements describe the scenarios considered, and these only apply to region 1, metro New Orleans. These are (1) percentage change in value of regional residential capital, (2) percentage change in the value of regional non-residential capital, (3) change in the economic migration of all cohorts (all people under age 65) to the region, (4) change in the retirement migration of all cohorts (all people over age 65) to the region, (5) change in the international migration of all cohorts (all ages) to the region, and (vi) change in the non-pecuniary amenity, expressed as a percentage of total household compensation, associated with residing in the region. Since the REMI forecast is our control, no values are entered and the economic and population forecasts are as provided by REMI. For the two forecast scenarios values are required for each input element for 2005. For the flat population scenario, values for the amenity element are required for each forecast year. Table 21 reports the input data for each scenario.

Residential Capital. Estimates of residential capital losses including autos in the five-parish study area totaled $17.65 billion from a total exposure value of $69.53 billion. This represents a 25.4-percent loss to exposure value ratio. These values are expressed in nominal 2005 dollars and the model is solved using constant 2000 dollar values; however, share of exposure ratios is the same in nominal or constant dollar denominations. This loss applies to both scenarios.

Table 21 Region I Model Inputs for Economic and Demographic Policy Variables by Scenario							
Variable	**Scenario**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
Value of residential capital as **percent** of region control	flat population	-25.4					
	economic recovery	-25.4					
Value of non-residential capital as **percent** of regional control	flat population	-12.0					
	economic recovery	-12.0					
Change in economic migration cohorts as **percent** of regional control	flat population	-40.3					
	economic recovery	-40.3					
Change in retirement migration cohorts as **percent** of regional control	flat population	-40.3					
	economic recovery	-40.3					
Change in international migration cohorts as **percent** of regional control	flat population	-40.3					
	economic recovery	-40.3					
Change in non-market regional amenity as **percent** of migrant compensation in the regional control	flat population		-32.6	-31.5	-30.1	-28.8	-27.5
	economic recovery						

Non-Residential Capital. Estimates of non-residential capital losses in the five-parish study area totaled $2.93 billion from a total exposure value of $24.46 billion. This represents a 12.0-percent loss to exposure value ratio. These values are expressed in nominal 2005 dollars and the model is solved using constant 2000 dollar values; however, share of exposure ratios is the same in nominal or constant dollar denominations. This loss applies to both scenarios.

Migration. Estimates of March 2006 population in the five-parish study area totaled 632,731—down from a 2004 estimate of 1,037,862. This represents a 39-percent decline in population. Without specific demographic information to assign all destinations of out-migrants or demographic profiles of these out-migrants, cohorts were assigned by probability based on 2004 population shares while destinations were assigned by historical and economic factors, as described in REMI documentation.

Non-Market Amenity. For the flat population scenario only, population in the five parish study area is assumed to remain constant throughout the forecast period at 632,700. By assumption, the flat population forecast is attributed to a diminished regional amenity associated with heightened risk and diminished community infrastructure perceptions, which are both non-market factors of household locational decisions. The values chosen were obtained by an iterative discovery process in which levels were assigned, forecasts were obtained, and then assigned levels were adjusted until the desired population forecasts are obtained for each forecast year. While procedurally this process describes a simulation input, the results were in effect reverse engineered and their values are discussed in the Results section.

7.2.2.3.5. Forecast Results

Forecast results on population, employment, value of capital stock (residential and non-residential) are reported in Table 22 for the "No Katrina" regional control and for the two scenarios described in section 7.2.2.3.2. A summary of findings includes:

- Regional control forecasts (assumes Katrina did not occur) for metro New Orleans indicate:

- Population in 2010 stays stable at the 2005 level of roughly 1.06 million
  - Residential real capital stock value increases 26 percent from 2005 to 2010
  - Non-residential real capital stock grows 10 percent in value from 2005 to 2010
  - Employment increases from 678,000 to 712,000 between 2005-2010
- Flat population scenario forecast for metro New Orleans indicates:
  - Population remains flat by assumption at 2006 end of year levels
  - Residential real capital stock values reach pre-Katrina levels by 2010
  - Non-residential real capital stock values reach pre-Katrina levels by 2009
  - Employment reaches 619,000 by 2010—which is still below pre-Katrina levels
- Economic recovery scenario forecast for metro New Orleans indicates:
  - Population by 2010 reaches 776,000, or roughly 73 percent of pre-Katrina level
  - Residential real capital stock value surpasses pre-Katrina levels by 2010
  - Non-residential real capital stock value surpasses pre-Katrina levels by 2009
  - Employment reaches 637,000—which is still below pre-Katrina levels

Table 22
Region I Economic and Demographic Forecast Results for Regional Control and Post-Katrina Scenarios

Variable	Scenario	2005	2006	2007	2008	2009	2010
Value of residential capital (million fixed 2005$)	regional control	69,521	73,108	76,560	80,090	83,696	87,386
	flat population	51,874	55,152	58,591	62,224	65,944	69,688
	economic recovery	51,874	55,201	58,751	62,556	66,509	70,550
Value of non-residential (million fixed 2005$)	regional control	24,460	24,969	25,496	26,006	26,495	26,965
	flat population	21,528	22,299	23,208	24,143	25,055	25,917
	economic recovery	21,528	22,293	23,171	24,047	24,875	25,635
Population (thousand)	regional control	1,058	1,057	1,056	1,055	1,055	1,056
	flat population	633	633	633	633	633	633
	economic recovery	633	667	699	728	754	776
Total Employment (thousand)	regional control	678	687	695	701	706	712
	flat population	591	610	617	620	620	619
	economic recovery	591	613	623	629	633	637

Source: Value of residential (including autos) and non-residential capital based on REMI simulations described in section 7.2.2.3.5 and adjusted up to constant 2005 dollars using the ratio of IPET 2005 estimated residential and non-residential exposure values to the same measures in the REMI control forecast model. Population and employment estimates are from REMI simulations described in section 7.2.2.3.5.

Forecast results for annual real gross region product are reported for the study region and three other U.S. regions. These include the remainder of Louisiana (model regions IIa and III), the combined States of Alabama, Mississippi, and Texas (model regions IIb, IIc, and IV), and remainder of the U.S. (model region V). These regions are depicted in Figure 14. Results are reported in Table 23.

Figure 14. Regional groupings for reported gross regional product forecast.

A summary of findings includes:

- Regional control forecasts for gross domestic product (million fixed 2000$) indicates:
  - Metro New Orleans GDP increase 20 percent to $47.4 billion from 2005 to 2010
  - Remainder of Louisiana real GDP grows 18.8 percent to $105 billion by 2010
  - Combined Alabama, Mississippi, Texas real GDP grows 25.4 percent to $1,306.5 billion by 2010
  - Remainder of U.S. real GDP grows 26.4 percent to $13,115 billion by 2010
- Flat population scenario forecasts for gross domestic product (million fixed 2000$) indicates:
  - Metro New Orleans GDP grows 19.7 percent, still $5.5 billion. below control forecast
  - Remainder of Louisiana real GDP unaffected relative to control forecast
  - Combined Alabama, Mississippi, Texas real GDP unaffected relative to control forecast
  - Remainder of U.S. real GDP growth nearly offsets metro New Orleans losses by 2010

Table 23
Gross Regional Product Forecast Results for Regional Control and Post-Katrina Scenarios: Metro New Orleans, Louisiana, Gulf Region, and Remaining United States

Region	Scenario	2005	2006	2007	2008	2009	2010
Metro New Orleans (billion fixed 2000$)	regional control	39.9	41.6	43.1	44.6	46.0	47.4
	flat population	35.0	37.2	38.6	39.8	40.9	41.9
	economic recovery	35.0	37.4	39.0	40.5	41.7	43.0
Other Louisiana (billion fixed 2000$)	regional control	88.4	92.4	95.6	98.9	101.9	105.0
	flat population	88.1	92.2	95.4	98.6	101.7	104.8
	economic recovery	88.1	92.2	95.4	98.6	101.7	104.8
Alabama, Mississippi, Texas (billion fixed 2000$)	regional control	1,041.5	1,096.5	1,146.4	1,199.3	1,251.8	1,306.5
	flat population	1,041.3	1,096.3	1,146.3	1,199.3	1,251.8	1,306.5
	economic recovery	1,041.3	1,096.3	1,146.2	1,199.1	1,251.7	1,306.3
Remainder of United States (billion fixed 2000$)	regional control	10,373.5	10,933.9	11,450.3	12,008.3	12,553.1	13,115.4
	flat population	10,376.0	10,936.6	11,453.9	12,012.7	12,558.2	13,121.1
	economic recovery	10,376.0	10,936.1	11,452.9	12,011.2	12,556.2	13,118.6

Source: Baseline and scenario forecasts based on REMI regional control and simulations described in section 7.2.2.3.5. Model forecasts derived from a 2003 base year model. Model national control forecast for 2005 U.S. GDP (billion chained 2000$) is $11.04 trillion. Actual 2005 U.S. GDP (billion chained 2000$) published by BEA (28 April 2006) was $11.13 trillion.

- Economic recovery scenario forecasts for gross domestic product (million fixed 2000$) indicates:
  - Metro New Orleans GDP grows 22.9 percent, still $4.4 billion below control forecast
  - Remainder of Louisiana real GDP unaffected relative to control forecast
  - Combined Alabama, Mississippi, Texas real GDP unaffected relative to control forecast
  - Remainder of U.S. real GDP growth slightly less than in flat population scenario

7.3. Human Health and Safety Consequences

This section presents more detail on the objectives, approach, and results of the human health and safety consequences assessment. The discussion is divided into two main parts. Section 7.3.1 describes the assessment of actual and potential future human health effects resulting from Hurricane Katrina. Section 7.3.2 describes loss of life modeling that was used to estimate fatality risks associated with various hypothetical Katrina flooding regimes as well as post-Katrina flood risks as of June 2006.

7.3.1. Human Health Effects of Hurricane Katrina

This section provides a review of literature that describes the actual and potential health and mental health effects of Hurricane Katrina on the city of New Orleans and surrounding areas. The search strategies used for the literature review are outlined in Appendix 2, and the results of the review are presented below.

7.3.1.1. Objectives and Limitations

Literature reviews are always undertaken with one or more specific purposes in mind, and in the context of one or more challenges. The basic purpose of the reviews that are described in this report was to describe:

A wide range of specific exposures associated with Hurricane Katrina for people in New Orleans, including those who evacuated, those who remained in New Orleans through the storm, first responders, and those who came following the storm as part of the recovery efforts.

The health and mental health effects of the storm that have already been documented.

Other health and mental health effects that can be expected, in either the near or longer term, based on empirical studies of previous, similar disasters (e.g., other severe hurricanes, major floods).

One of the important challenges for the review described in this document is that only seven months had passed since the event, a very short timeframe for empirical articles to begin appearing in the scientific (i.e., peer-reviewed) literature. The impact of this timeframe on the search was to create an emphasis on the grey literature for the first and second components (as denoted above) of the review. For these components of the review, we searched newspapers, magazines, websites, and related information sources to compile a rich, though largely anecdotal, description of what happened in the storm, and how the storm and its aftermath affected the health and mental health of the people of New Orleans from 29 August 2005 until the present (through April 2006).

A second important challenge to documenting the details of the storm and its aftermath is the monumental infrastructure damage (e.g., destruction of buildings, extended power outages, lack of drinking water) and displacement of the population that it created. Because the population remains so widely scattered – both those who evacuated prior to the storm and the much smaller group who were relocated afterward – the logistics of studying systematically the epidemiology of exposures and associated illnesses or disorders are unusually challenging. Although it remains a nearly daily topic for national news, the fact that much of New Orleans is in ruins and that only a small fraction of the pre-hurricane population has returned complicate population-based empirical documentation of the storm and its impact.

The relocation of so many New Orleans residents, even for relatively short periods (e.g., weeks rather than months), represents a substantial barrier to the development of a comprehensive understanding of the storm and its impact on people for the short and the longer terms. Comprehensive understanding of the exposures and health- and mental health-related outcomes of survivors requires structured assessment, which requires contact with victims, which requires knowing where they are. By December 2005, 33 states reported having received Hurricane Katrina evacuees, creating substantial challenges for sampling and assessing the victims.

The relocation also creates other health and mental health challenges. For people who had chronic health conditions that require regular medication and/or periodic professional monitoring (e.g., diabetes, cardiovascular disease, major depression, schizophrenia), relocation means quickly finding new providers who can fulfill the needed functions. For those who are also economically challenged (e.g., Medicaid recipients), the administrative challenges of moving to a different state can seem overwhelming.

Finally, because of the event's population-wide impact, another challenge is to document exposures and outcomes for both adults and children. Studies of recent disasters (e.g., the Oklahoma City bombing, the terrorist attacks of September 11, various prior hurricanes) have confirmed the findings of previous research which indicate that the reactions of children to disasters are different from those of adults, and may be more likely to have long-term implications. Therefore, it is important that information about children be included.

In summary, the purpose of the literature review is to provide as rich a description as possible of the exposures and health/mental health outcomes of Hurricane Katrina, and a forecast of additional health/mental health consequences that may not yet have come to the surface. Given that months, not years, have passed since Hurricane Katrina came ashore, much of the information for the rich description of what has already happened must rely on news reports and related sources, not systematic studies reported in peer-reviewed journals. As a result, much of that description is anecdotal. The description of additional, longer-term consequences that may not yet be apparent can, however, rely on extrapolation from empirical studies of outcomes from prior similar events. Therefore, our description of what happened from 29 August 2005 until today comes predominantly from the grey literature, and our forecast of other outcomes of potential concern comes primarily from the peer-reviewed literature, based on prior disasters with similar characteristics.

7.3.1.2. Health and Safety Exposures and Outcomes

7.3.1.2.1. Specific Health-Related Exposures and Outcomes

This report addresses the health outcomes among New Orleans residents and the emergency and relief workers who went to New Orleans immediately following Hurricane Katrina. The denominator cannot be determined exactly. The United States Census estimated that 462,269 people lived in New Orleans in 2004 (U.S. Census 2006a). This report addresses health effects of the evacuation process for people who left before Hurricane Katrina landed, as well as an estimated 100,000 who had not left and remained in the city (Manjoo 2005). Perhaps 10,000 remained a week later, some marooned and some refusing to leave (Thomas and Padgett 2005).

Additionally, thousands of relief workers, paid and volunteer, could have been affected, including 1,580 Corps workers (Cloud 2005), as many as 40,000 active-duty military and National Guard (Manjoo 2005), 148 CDC public health workers such as epidemiologists (CDC 2005h), approximately 500 SAMHSA mental health and substance abuse counselors (SAMHSA 2006), some 800 firefighters from New York and Illinois (Longman 2005), 303 New York police officers (Baker 2005), a sheriff and 33 deputies from Michigan (Lipton et al. 2005), and 38 Public Health Service physicians and nurses (Altman and Chang 2005). Another 40 FEMA medical teams were also expected (Abelson and Feuer 2005). Finally, some tourists were stranded in New Orleans, including at least three physicians, a physician's assistant, and a pharmacist, all of whom got actively involved in emergency health care (Henderson 2005a). (Volunteer physicians from outside Louisiana were not legally allowed to provide treatment until an executive order suspended medical licensing requirements on 2 September (Manjoo 2005). We found no reports of the volunteers being prosecuted.)

Following Hurricane Katrina, CDC immediately engaged in surveillance to determine the extent and cause of morbidity and mortality among people in the affected geographical regions. The result was a thorough assessment of infectious disease, injuries, morbidity, and mortality either immediately caused by or associated with Hurricane Katrina. However, the surveillance was limited to those geographic regions that were most immediately affected: Louisiana, Mississippi, Alabama, and Texas.

The summary of health effects below relies on reports from people who were in New Orleans during or immediately after the hurricane, typically as emergency workers, reporters, or residents hoping to return. There were reports of violence and injury during the hurricane that were based on hearsay and later proven to be untrue; there were also estimates of mortality that far exceeded the ultimate result. Therefore, we made every effort not to rely on hearsay evidence or projections in developing this summary. (See Appendix 2 for a thorough description of the literature review.)

7.3.1.2.1.1. Mortality and its Causes

Determining the number and cause of deaths due to Hurricane Katrina is quite challenging. At the time of this writing, many people remain missing; and, for those whose bodies have been found, no standardized, universally accepted method exists for determining whether deaths are caused by a natural disaster. Each state determines the cause of any death that occurred within its borders, and states use different criteria. Therefore, evacuee suicides were deemed "associated with" Hurricane Katrina in Texas, while none of 20 evacuee deaths in Atlanta were deemed "directly or indirectly related" (Possley and McCormick 2005). Similarly, Florida counts a death due to a pre-existing condition in an evacuee as "indirect," but Louisiana officials are "hesitant to count" similar deaths (Dewan 2005a). Finally, many bodies were not autopsied quickly, making accurate assessments more difficult, and the quality of the autopsies was weak (Fairbank 2005; Dewan 2005b, 2005c).

The CDC defines a directly related death as "a death caused by the physical forces of a hurricane" and an indirectly related death as "one caused by unsafe or unhealthy conditions that existed during the evacuation phase, occurrence of the hurricane, or post-hurricane/cleanup phase." A third category – "possibly related" – was used if "1) the death occurred in the hurricane-affected area during August 23-October 23, 2005; 2) the cause or manner of death was undetermined or pending; and 3) reviewers agreed that a possible relation between the death and the hurricane might exist" (CDC 2006d).

As of 2 August 2006, the Louisiana Department of Health and Hospitals (LDHH) reported that a total of 1,464 Louisiana residents died as a direct or indirect result of Hurricane Katrina, as shown in Table 24. These include 1,118 fatalities that occurred within Louisiana, and 346 Louisiana evacuees who died in other states but were nevertheless classified by the State of Louisiana as storm-related fatalities. Another 135 Louisiana residents remained missing as of 2 August 2006. The mortality report by LDHH cited above did not include enough information to determine how many of the reported storm-related deaths within Louisiana were associated with residents of the five parishes that roughly comprise the greater New Orleans metropolitan area. But judging from earlier mortality reports issued by LDHH that did include such data (see below), residents of these five parishes likely comprise the vast majority of 1,118 deaths reported to have occurred within Louisiana.

Table 24
Storm-related Deaths of Louisiana Residents Identified by the State of Louisiana as of 2 August 2006

Reporting Source	Number of Deaths
St. Gabriel and Carville Morgues	875
Orleans Parish Coroner	20
Other Parish Coroners	223
All Louisiana Reporting Sources	1,118
Reported by Other States (Evacuees who died outside of LA)	346
All Louisiana and Other State Sources	1,464

Source: Department of Health and Hospitals, State of Louisiana. "Reports of Missing and Deceased Aug. 2, 2006." http://www.dhh.louisiana.gov/offices/Page.asp?ID=192&Detail=5248&Print=1.

The morality report by LDHH dated August 2, 2006 also includes summary statistics on the gender, race, and age profiles for 853 of the 875 storm-related victims identified at the St. Gabriel and Carville Morgues. That data, which is reproduced in Table 25, indicate that in terms of race and gender, African-Americans and males accounted for slightly more than half of these fatalities. The data also show that these fatalities were heavily skewed toward the elderly, with people aged 76 and over accounting for 45 percent of storm-related deaths.

Table 25 Characteristics for 853 of the 875 Storm-Related Victims from Louisiana Identified and Released by St. Gabriel and Carville Morgues as of 2 August 2006		
Characteristic	**Number of Deaths**	**Share of Total (%)**
Mortality by Gender		
Male	432	53
Female	421	47
Mortality by Race		
African-American	451	53
Asian/Pacific Islander	6	< 6
Caucasian	334	39
Hispanic	18	2
Native American	4	< 1
Other	5	< 1
Unknown	35	5
Mortality by Age		
5 or less	1	< 1
6 – 10	1	< 1
11 – 15	5	< 1
16 – 20	5	< 1
21 – 30	13	< 2
31 – 40	26	3
41 – 50	75	8
51 – 60	119	14
61 – 75	196	23
76 and over	388	45
Unknown	24	3
Source: Department of Health and Hospitals, State of Louisiana. “Reports of Missing and Deceased Aug. 2, 2006.” http://www.dhh.louisiana.gov/offices/Page.asp?ID=192&Detail=5248&Print=1.		

While the LDHH 2 August 2006 mortality report provided the latest available data on Katrina-related deaths within Louisiana at the time of this writing, that data set does not provide as a rich a characterization of the people that died as provided by earlier LDHH mortality reports. For example, an LDHH mortality report data 23 February 2006 provided data that allows the cross-matching of race, gender and age categories for the recorded fatalities. Moreover, that earlier mortality report indicates the Parish residence for each recorded fatality. Data from the 23 February 2006 mortality report are reproduced and discussed below.

As of 23 February 2006, 910 bodies had been examined at the St. Gabriel morgue, and the results of the examinations had been made available for 750 victims. The identity and cause of death of the remaining victims had not yet been released as of that date, however. Of the 750 released cases, the Louisiana coroner determined that Hurricane Katrina explicitly caused 727 fatalities. As demonstrated in Table 26, the deaths were overwhelmingly among New Orleans metro area residents, with only 2 percent of deaths among residents of other areas in Louisiana, visitors from out of state, or people of unknown residence. Mortality was evenly distributed by sex. However, only 46.5 percent of New Orleans metro area residents prior to the hurricane were male, so males are somewhat over represented among the identified dead. The Louisiana Department of Health and Hospitals coroner determined that about two dozen deaths were not “storm related,” instead occurring by “violence or suspicious means” (Bourque et al. 2006b).

Table 26 **Mortality by Sex for the 727 Storm-related Deaths Identified and Released by St. Gabriel Morgue as of 23 February 2006**						
	New Orleans Metro[a]		Other Louisiana		Total	
Female	355	49.7%	8	61.5%	363	49.9%
Male	359	50.3%	5	38.5%	364	50.1%
Total	714	100.0%	13	100.0%	727	100.0%

[a] The five parishes making up metropolitan New Orleans include Jefferson, Orleans, Plaquemines, St. Bernard, and St. Charles.
Source: Department of Health and Hospitals, State of Louisiana. 2006. "Vital Statistics of All Bodies at St. Gabriel Morgue 2/23/2006." http://www.dhh.louisiana.gov/offices/publications/pubs-192/Deceased%20Victims_2-23-2006_information.pdf. Accessed 3 April 2006.

Table 27 demonstrates that just over half the released fatalities as of 23 February 2006 were among African-Americans, both in the New Orleans metro area and in the rest of Louisiana. This is somewhat surprising, given that the New Orleans metro area was 68 percent African-American prior to the hurricane (Kaiser Family Foundation 2005b).

Table 27 **Mortality by Race for the 727 Storm-related Deaths Identified and Released by St. Gabriel Morgue as of 23 February 2006**						
	New Orleans Metro[a]		Other Louisiana		Total	
African-American	381	53.4%	7	53.8%	388	53.4%
Asian/Pacific Islander	5	0.7%	0	0.0%	5	0.0%
White	308	43.1%	6	46.2%	314	43.2%
Hispanic[b]	17	2.4%	0	0.0%	17	2.3%
Native American	2	0.3%	0	0.0%	2	0.0%
Other	1	0.1%	0	0.0%	1	0.0%
Total	714	100.0%	13	100.0%	727	100.0%

[a] The five parishes making up metropolitan New Orleans include Jefferson, Orleans, Plaquemines, St. Bernard, and St. Charles.
[b] The data presented Hispanic as a race, not an ethnicity regardless of and separate from race.
Source: Department of Health and Hospitals, State of Louisiana. 2006. "Vital Statistics of All Bodies at St. Gabriel Morgue 2/23/2006." http://www.dhh.louisiana.gov/offices/publications/pubs-192/Deceased%20Victims_2-23-2006_information.pdf. Accessed 3 April 2006.

The age distribution of the released fatalities was distinctly skewed towards older people, as seen in Table 28. There were very few children identified as killed: four girls and a boy in Orleans Parish, and an infant in St. Tammany Parish. The number of fatalities among 50-59-year olds and 60-69-year olds was distinctly higher among males (14.8 percent of male deaths and 18.7 percent respectively) than among females (11.0 percent and 10.7 percent, respectively). In the oldest age group, those 80 and above, the proportion of fatalities among females was much higher than among males (46.0 percent versus 28.3 percent). This could be due in part to a larger number of older women than of older men. Table 29 illustrates the relationships between the sex, race, and age of the identified dead.

Lack of access to care. Before Hurricane Katrina, many hospitals and other health care providers evacuated some patients. However, many patients were too ill, disabled, or dependent on immobile technology to be evacuated. Some people looked for shelters that could accommodate the ill, such as a woman on oxygen, or a severely demented elderly woman, but could not find any (Dewan and Roberts 2005, Shute 2005a, Salopek and Horan 2005).

Table 28 **Mortality by Age for the 727 Storm-related Deaths Identified and Released by St. Gabriel Morgue as of 23 February 2006**						
	New Orleans Metro[a]		**Other Louisiana**		**Total**	
Female						
Infant-49	28	7.9%	3	37.5%	31	8.5%
50-59	40	11.3%	0	0.0%	40	11.0%
60-69	38	10.7%	1	12.5%	39	10.7%
70-79	84	23.7%	2	25.0%	86	23.7%
80+	165	46.5%	2	25.0%	167	46.0%
Subtotal	355	100.0%	8	100.0%	363	100.0%
Male						
Infant-49	61	17.0%	3	60.0%	64	17.6%
50-59	53	14.8%	1	20.0%	54	14.8%
60-69	67	18.7%	1	20.0%	68	18.7%
70-79	75	20.9%	0	0.0%	75	20.6%
80+	103	28.7%	0	0.0%	103	28.3%
Subtotal	359	100.0%	5	100.0%	359	100.0%
Total						
Infant-49	89	12.5%	6	46.2%	95	13.1%
50-59	93	13.0%	1	7.7%	94	12.9%
60-69	105	14.7%	2	15.4%	107	14.7%
70-79	159	22.3%	2	15.4%	161	22.1%
80+	268	37.5%	2	15.4%	270	37.1%
Total	714	100.0%	13	100.0%	727	100.0%

[a] The five parishes making up metropolitan New Orleans include Jefferson, Orleans, Plaquemines, St. Bernard and St. Charles.
Source: Department of Health and Hospitals, State of Louisiana. 2006. "Vital Statistics of All Bodies at St. Gabriel Morgue 2/23/2006." http://www.dhh.louisiana.gov/offices/publications/pubs-192/Deceased%20Victims_2-23-2006_information.pdf. Accessed 3 April 2006.

The hospitals were required to have supplies to last for up to three days; they were not required to evacuate, but were expected to survive (Rohde et al. 2005). As hospitals were flooding and backup generators failed or ran out of fuel, medical staff strained hard to care for patients. All electric-powered life-support systems were affected: suction machines, bedside monitors, intravenous fluid pumps, and dialysis machines. Without power, staff resorted to manually squeezing ventilator bags for both adults – including some who had been evacuated *to* the hospital from a flooded nursing home – and premature infants. Nurses held the infants, who typically have very sensitive immune systems, in their arms to keep them warm in lieu of their incubators (Shute 2005a, Williams 2005, Manjoo 2005, Rohde et al. 2005, deBoisblanc 2005).

To avoid spreading infection when toilets at Charity Hospital failed, people used 5-gallon buckets lined with infectious waste bags as toilets. Bleach was poured over the waste and the bags were thrown out the window (Berggren 2005, Rohde et al. 2005). The Memorial Medical Center in New Orleans flooded, drowning 45 people and trapping almost 2,000 (Manjoo 2005, Graham 2005). Only three hospitals remained fully functional throughout the hurricane: East and West Jefferson Medical Centers and the Ochsner Clinic Foundation (Kaiser Family Foundation 2006a, Winslow 2005).

Table 29 Mortality by Race and Age, Within Sex for the 727 Storm-related Deaths Identified and Released by St. Gabriel Morgue												
	≤49		50-59		60-69		70-79		80+		Total	
Female												
African-American	22	71.0%	20	50.0%	24	61.5%	37	43.0%	58	34.9%	162	44.6%
White	9	29.0%	17	42.5%	14	35.9%	44	51.2%	101	60.8%	185	51.0%
Other	0	0.0%	3	7.5%	1	2.6%	5	5.8%	7	4.2%	16	4.4%
Male												
African-American	48	75.0%	40	74.1%	41	60.3%	46	61.3%	51	49.5%	226	62.1%
White	13	20.3%	14	25.9%	26	38.2%	27	36.0%	49	47.6%	129	35.4%
Other	3	4.7%	0	0.0%	1	1.5%	2	2.7%	3	2.9%	9	2.5%
Total												
African-American	70	73.7%	60	63.8%	65	60.8%	83	51.6%	109	40.5%	388	53.4%
White	22	23.2%	31	33.0%	40	37.4%	71	44.1%	150	55.8%	314	43.2%
Other	3	3.2%	3	3.2%	2	1.9%	7	4.4%	10	3.7%	25	3.4%

Source: Department of Health and Hospitals, State of Louisiana. 2006. “Vital Statistics of All Bodies at St. Gabriel Morgue 2/23/2006.” http://www.dhh.louisiana.gov/offices/publications/pubs-192/Deceased%20Victims_2-23-2006_information.pdf. Accessed 3 April 2006.

The hospitals ran out of food, water, and ice, putting patients at risk of starvation, dehydration, and heat stroke (Shute 2005a, Shute 2005b). Patients became so weak that when 110 were evacuated on Friday, 2 September 2005, along with some 500 staff and their families, three did not survive the evacuation (Manjoo 2005). Even the lack of coffee proved problematic, as many staff at Charity Hospital reported having “severe caffeine-withdrawal headaches” (Berggren 2005).

The Louisiana Department of Health and Hospitals had set up seven “special-needs shelters” in the city. They were quickly overwhelmed as 6,000 people, many evacuees from failing hospitals, requested care (Shute 2005a).

Because the hospitals were inoperable or inaccessible, an impromptu trauma center was set up at the Louis Armstrong International Airport. Rescued patients were delivered by helicopter, while others were delivered by truck. Supplies were extremely limited; one physician described “having no beds, no oxygen, no nothing except some nitro, aspirin, and all the good intentions in the world.” In this situation, there was sometimes nothing they could do for severely ill patients except “providing morphine and a blanket to septic and critical patients and allowing them to die”[1] (Fischman 2005).

The Superdome and Convention Center, which held as many as 45,000 people, also had minimal supplies and extremely unsanitary and crowded conditions. Some 34 people died there, due to various causes, at least two to dehydration (Manjoo 2005, Salopek and Horan 2005).

Some people did not reach the evacuation centers. Some died from lack of medication such as insulin, or from dehydration (Dewan and Roberts 2005).

Common Ground, a loose coalition of nurses and medical assistants that typically provides medical care to protesters at anti-war demonstrations, arrived within days, followed by physi-

[1] While there were anecdotal reports of euthanasia during the week after Hurricane Katrina, we found no documented reports.

cians, nurses, and grief counselors. They set up a free clinic that served more than 100 people a day in Algiers and "dozens more" at mobile clinics situated near the most intense cleanup efforts (Shorrock 2006). On Friday, 2 September 2005, Governor Blanco issued an executive order suspending the licensing requirement for medical personnel. If they could prove they were licensed in their home states, they could provide care in Louisiana during the declared public health emergency. Prior to that, volunteer physicians and the Red Cross (as well as firefighters, morticians, and a convoy of boats offering to help rescue those stranded in the floodwater) had been turned away (Blumenthal 2005, Manjoo 2005).

Other health care providers apparently did not make such efforts. Seventy percent of the area nursing homes did not implement the standard evacuation procedures that they were required to have. (It is not clear whether they were required to follow Mayor Nagin's mandatory evacuation order.) Multiple facilities had contracted with the same bus service for evacuation services (and many drivers were not available), so thorough evacuation was impossible (Janega 2005, Rohde et al. 2005, Lipton et al. 2005). (Municipal transit and city school buses were ruined by the flood instead of being pressed into earlier service(Winslow 2005).) Many nursing home residents were evacuated to local hotels. At one, when broken windows left rooms unusable, over a thousand people – guests and patients – stayed in an exhibit hall with no power, air conditioning, or water, much less regular care or functioning medical equipment (Frohlich 2005). Thirteen nursing homes and six hospitals were investigated regarding possible euthanasia (Roman and Baum 2005). The operators of one nursing home, which did not attempt to evacuate patients, and which turned down an offer of buses from local officials, have been charged with 34 counts of negligent homicide (Manjoo 2005, Rohde et al. 2005).

Drowning. Once the levees broke, the floodwaters overwhelmed adjacent neighborhoods with great speed. Louisiana State University's Geographic Information Center reports that the flood reached depths of as much as 19 feet, with a vast expanse of the city under 7 feet (Kent 2005). The majority of deaths in Orleans Parish were caused by drowning and pre-existing medical conditions, while deaths in St. Bernard Parish were primarily attributed to drowning in the storm surge (Bourque et al. 2006a).

Some people lost hold of family members in the flood, or grabbed for them and drowned. Other people simply could not swim and were overwhelmed. Reports of the speed of the water rising – some roofs were reached within 9 minutes; a hospital reception area was under 5 feet of water within 15 minutes; farther from the levees the water might rise a foot every ten minutes – suggest that some people could not get into their attics or other safe spaces quickly enough. Some attics filled with water, requiring residents to quickly break holes in their roofs; one woman had a heart attack trying. One man, not having time to help his partly paralyzed and bedridden wife, stayed with her until she drowned then joined his daughter in the attic (Baum 2005c, Dewan 2006a, Dewan and Roberts 2005, Rohde et al. 2005).

Infection. Five deaths were caused by wound-associated Vibrio, defined by the CDC as "an illness that likely resulted from infection of a wound or abrasion acquired before or during immersion in floodwaters." The deceased had lived in Louisiana and Mississippi; of the three case reports provided, two were from New Orleans (CDC 2005i). Routine infections, such as a mastoid infection of the ear, became fatal in the absence of medical care in the days after the hurricane (Dewan and Roberts 2005).

Suicide. There were some reports of suicide during the first days of the disaster, including two police officers and one man who threw himself from the Superdome (Baum 2006, Manjoo 2005).

Access to mental health care prior to the storm was limited; only 28 percent of adults and 3.5 percent of children identified as having a mental illness in Louisiana received care. After the storm, the primary mental health crisis center, 96-bed Charity Hospital, was forced to close. With no local source of care for those who remained behind, and evacuees not necessarily knowing where to access local care, calls to a Louisiana suicide prevention hotline immediately almost tripled and to the National Suicide Prevention Hotline more than doubled. Six months later, calls to the city hotline remained at double pre-hurricane rates, despite the population being about one-third the size (Reuters 2006, Associated Press 2006, Kalb and Murr 2005).

In the months after the hurricane, suicides increased. While the numbers may seem low – seven in four months – they represent a rate two to three times New Orleans' 2004 rate[1] (Nossiter 2005).

Homicide. Despite early reports of mayhem at the Superdome and Convention Center, only one homicide occurred, at the latter (Salopek and Horan 2005). The risk of homicide was also great in the flooded areas, where people desperately foraged for food and water and protected their property. "Of all the white people I met that week [following the hurricane]," wrote one reporter, "only two were unarmed"(Baum 2006).

Some experts say that the hurricane would be the catalyst, but not the pure cause, of most suicides. Some suicides were preceded by homicides, perhaps born of despair. At least two cases were found in the grey literature in which a father shot his child and the child's mother; only one child survived (Associated Press 2006).

New Orleans had been known for an extremely high homicide rate, which was ten times the national rate before Hurricane Katrina (Baum 2006). There is some evidence that evacuees are increasing the homicide rate in their new locations. For example, in Houston, 33 of 189 homicides (17 percent) involved Hurricane Katrina evacuees, although they increased the population by only about 7 percent (U.S. Census 2006b, Campo-Flores 2006). In addition to the increase in homicide itself, additional patrolling and detective work is expensive: $6.5 million in Houston for 6 months, for example. These outlays leave less money available for regular public safety measures, and this in turn could affect the public's health (Campo-Flores 2006).

[1] Calculation of the rate depends on an estimate of the current population, which is not precise.

Accident. Carbon monoxide poisoning frequently resulted from running gasoline-powered generators to replace lost electric power. If generators are placed too close to the home, particularly near air conditioning vents that draw air into the home, the carbon monoxide can reach toxic levels. Other sources of carbon monoxide include gas stoves. Since carbon monoxide has no color or odor, in the absence of a detector it can be fatal without the victim being aware of it. Of the 14 documented cases of carbon monoxide poisoning among New Orleans residents – the CDC recognizes that the surveillance probably reflects underreporting – five resulted in death (CDC 2006g). In nearby states where many evacuees fled, there were ten deaths in Texas and Alabama, combined (Tucker et al. 2006), and two in Florida (CDC 2006d).

All accidents are, in theory, preventable. Therefore, public health professionals usually use the term "unintended injury" instead. However, many of the major injuries that resulted in death among people who remained in New Orleans during Hurricane Katrina were no longer realistically preventable. Some were crushed under rubble, swept into trees, or trapped in attics or, wheelchair-bound, first floors, where they likely died of drowning or dehydration (Glanton 2005).

Some people died while attempting to evacuate. For example, one woman fell while being lifted into a rescue helicopter, possibly because her weight was too much for the cable. There were numerous reports of shooting during the days immediately following the hurricane. Police report being fired on, and returning fire. Of seven investigated shootings in which an officer hit someone, four were fatal. In a separate incident, police shot and killed "at least five residents" who had fired on government contractors. An officer was shot, non-fatally, in the head (Barringer and Longman 2005, Manjoo 2005, Baum 2006).

7.3.1.2.1.2. Currently Evident Morbidity

Injury. Injury and soft tissue infections are expected to immediately follow a natural disaster (CDC 2005g). During 8 September to 15 October 2005, a total of 6,597 injuries were reported. The CDC reported the injuries in sets. The first wave of surveillance covered four New Orleans area parishes (Jefferson, Orleans, Plaquemines, and St. Bernard) over 8-25 September (Ferdinand 2005). The second wave added two parishes (St. Charles and St. Tammany) and lasted longer, 25 September-15 October (CDC 2006c). The results are summarized in Table 30.

In the days following the hurricane, New Orleans was rife with the potential for injury. The force of helicopter rotors "blew out the windows on at least two Corps SUVs parked in a bad spot," sent "loose roofing tiles knifing through the air and raising a rotor wash that nearly swamped" a boat of rescuers , and made "a frightening maelstrom of loosened pieces of wood (Baum 2005c, Baum 2006, Cloud 2005).

There were numerous stories of people escaping the rising water in their homes by moving into attics or onto roofs. Even this straightforward maneuver was not without risk. For the very heavy or the very old, climbing a ladder and getting through a hatch present challenges. For the more able-bodied, swinging axes and hammers or breaking attic windows while desperate is dangerous (Baum 2005c, Treaster and DeSantis 2005, Harris 2005a).

Table 30
Selected Injuries Among New Orleans Residents and Relief Workers, 8 September-15 October 2005

Injury/exposure	Relief Workers		Residents		Unknown		Total		
	Sept.8-Sept.25	Sept.25-Oct.15	Sept.8-Sept.25	Sept.25-Oct.15	Sept.8-Sept.25	Sept.25-Oct.15	Sept.8-Sept.25	Sept.25-Oct.15	Total
Injury									
Fall	46	64	196	449	222	479	464	992	1,456
Bite/Sting	67	52	92	114	152	173	311	339	650
Motor-vehicle crash	16	20	65	161	64	235	145	416	561
Intentional injury	4	11	20	32	18	46	42	89	131
Other unintentional injury	117	334	237	934	362	1,143	716	2,411	3,127
Undetermined etiology	72	44	99	96	128	158	299	298	597
Toxic Exposure/Poisoning									
Carbon monoxide poisoning	5	1	3	1	6	3	14	5	19
Other toxic exposure	11	7	4	11	12	11	27	29	56
Total	338	533	716	1,798	964	2,248	2,018	4,579	6,597

Source: Injury and illness surveillance in hospitals and acute-care facilities after Hurricanes Katrina And Rita--New Orleans area, Louisiana, September 25-October 15, 2005. *MMWR Morb. Mortal. Wkly. Rep.* 55(2):35-8

Illness. The types of illness that resulted, either directly or indirectly, from Hurricane Katrina fall into the following, somewhat overlapping, categories:

- infectious disease
- gastrointestinal
- dermatologic
- respiratory
- exacerbation of underlying illness due to disruption in care
- underlying illnesses that are diagnosed during medical care provided at emergency care centers or evacuation centers
- site-specific illness

Many of these illnesses are directly or indirectly caused by environmental exposures. The exposures, etiology, and potential outcomes are specifically addressed in a separate section.

Summary of major illnesses. During 8 September to 15 October 2005, a total of 13,166 illnesses were reported. The CDC reported the illnesses to the public in sets. The first wave of surveillance covered four New Orleans area parishes (Jefferson, Orleans, Plaquemines, and St. Bernard) over 8-25 September (Ferdinand 2005). The second wave added two parishes (St. Charles and St. Tammany) and lasted longer, 25 September—15 October (CDC 2006c). The results are summarized in Table 31.

Although infectious disease outbreaks rarely follow natural disasters in developed countries, when they do occur, the most common are skin, diarrheal, and respiratory infections. In addition, airborne, waterborne, and foodborne diseases are expected to occur up to a month following the disaster (CDC 2005g).

Table 31
Selected Illnesses Among New Orleans Residents and Relief Workers, 8 September-15 October 2005

Selected Illness	Relief Workers		Residents		Unknown		Total		
	Sept.8-Sept.25	Sept.25-Oct.15	Sept.8-Sept.25	Sept.25-Oct.15	Sept.8-Sept.25	Sept.25-Oct.15	Sept.8-Sept.25	Sept.25-Oct.15	Total
Infectious-disease-related									
Skin or sound infection	101	62	192	361	347	459	640	882	1,522
Acute respiratory infection	119	179	158	538	228	587	505	1,304	1,809
Diarrhea	11	18	52	92	83	123	146	233	379
Other infectious disease	36	28	109	219	143	223	288	470	758
Noninfectious-disease-related									
Rash	67	59	87	170	146	290	300	519	819
Heat-related	34	28	80	86	93	118	207	232	439
Nondiarrhea gastrointestinal	23	24	77	200	108	253	208	477	685
Renal[a]	8	11	44	49	35	104	87	164	251
Other classifiable illness[b]	22	76	52	758	88	1,030	162	1,864	2,026
Other illnesses	107	217	649	1,166	870	1,469	1,626	2,852	4,478
Total	528	702	1,500	3,639	2,141	4,656	4,169	8,997	13,166

[a] Includes kidney stones and renal failure (i.e., chronic and acute).
[b] Includes diabetes, cardiovascular conditions, obstetric/gynecologic conditions, and dental problems.
Source: Injury and illness surveillance in hospitals and acute-care facilities after Hurricanes Katrina And Rita--New Orleans area, Louisiana, September 25-October 15, 2005. *MMWR Morb. Mortal. Wkly. Rep.* 55(2):35-8

The CDC engaged in numerous surveillance efforts, with the cooperation of local, federal, and voluntary organizations. The results are very well documented cases of numerous diseases. However, the incidence rates are extremely difficult to estimate, as demonstrated by the surveillance implemented on 8 September 2005 in 489 evacuation centers (EC) in Louisiana. Each EC served from 10 to approximately 7,000 people. On the one hand, the majority of large clusters of some illnesses, such as influenza-like illness and rash, were attributed to over reporting. Given that an EC was defined as “any facility that housed displaced persons overnight,” many would be staffed by people with little, if any, medical experience. On the other hand, there could have been significant underreporting. The system was encouraged, not mandatory. No training was provided. EC staff/volunteers experienced rapid turnover, and many staff did not have a health care background. Some ECs did not provide any medical care onsite, and the ECs themselves were not static, but changed location and number (CDC 2006h).

A Dallas evacuation shelter reported an outbreak of methicillin-resistant *Staphyloccoccus aureus* (MRSA), which can cause skin infections of “a particularly deadly form of pneumonia” (Beil 2006). In some areas with large populations of evacuees, the rate of sexually transmitted diseases is increasing. Health officials in Houston hypothesize it could be “an outgrowth of high rates in New Orleans” (Campo-Flores 2006).

Gastrointestinal. Very careful surveillance of the 24,000 evacuees sheltered at Reliant Park in Houston, most from Louisiana, demonstrated that fully 18 percent (1,169) of people reported symptoms of gastrointestinal illness on 2 September 2005. The proportion peaked on 5 September, and as many as 21 percent of adults and 40 percent of children had acute gastroenteritis on any given day through 12 September 2005. In the United States, acute gastroenteritis, which the CDC defines as “diarrhea and/or vomiting,” is most commonly caused by noroviruses. Outbreaks can result from exposure to contaminated food or water supplemented by secondary, person-to-person contact and fomite transmission. (Fomites are inanimate objects that can transmit infectious agents from one person to another.) Preliminary testing confirmed the presence of norovirus by reverse transcription-polymerase chain reaction testing in half the selected specimens; no other enteropathogen was identified. Given the large number of relief, medical, police, and other personnel who came in contact with many infected people, the CDC suspects "substantial" secondary spread. The spread was limited by isolating some of the ill and implementing extensive disease control measures: education; ensuring soap and water were available in medical, food preparation, and personal hygiene areas; and disinfection (CDC 2005f).

Of the approximately 1,000 cases of diarrheal disease and vomiting among evacuees in Mississippi and Texas by 30 September, causes included sporadic nontyphoidal *Salmonella,* nontoxigenic *V.cholerae O1,* in addition to norovirus, as described above (CDC 2005g).

Dermatologic. Eighteen cases of wound-associated *Vibrio*, defined by the CDC as "an illness that likely resulted from infection of a wound or abrasion acquired before or during immersion in floodwaters," as well as four cases of non-wound associated *Vibrio* infections, were found among former residents of New Orleans (CDC 2005i).

The CDC performed surveillance on over 200,000 evacuees at 750 evacuation centers in 18 states, and rescue workers. It is not known how many of these people were in New Orleans on 28-29 August. In addition to the *Vibrio* infections noted above, an outbreak of methicillin-resistant *Staphylococcus aureus* (MRSA) affected 30 adult and pediatric evacuees in Dallas (CDC 2005g).

Among rescue workers, the CDC identified the following:

Tinea corporis, a skin lesion with infectious etiology.

Three non-infectious rashes: "1) prickly heat (malaria crystalline, rubra, and pustulosa); 2) two clusters of nonpruritic erythermatous papular, nonfollicular lesions … presumed to have been caused by arthropod (likely mite) bites; and 3) circumferential lesions, appearing as bands of macerated skin at the waist, attributed to excessive chafing" (CDC 2006h).

People who waited on a roof for days developed rash on their arms and legs from contact with the hot tar roof (Baum 2005c). Two evacuees to Colorado sought emergency care for "rash illness" such as rash with fever (CDC 2006b).

Respiratory Disease. Tuberculosis is a particularly infectious disease of the lungs that can be controlled by early detection and treatment of new cases. Interruptions in treatment are important, not only for the health of the patient, but because they can encourage multiple-drug resistant forms of the disease. One hundred-thirty people were being treated for tuberculosis in New Orleans before Hurricane Katrina landed. Fourteen were incarcerated. Most[1] were transported (with continued treatment) to other facilities before the hurricane landed. After the hurricane, a nationwide initiative was immediately implemented to locate the other 116 patients

[1] The CDC reported that all tuberculosis patients were evacuated prior to the hurricane, but a teaching physician of infectious disease at Charity Hospital reports four patients with active tuberculosis being cared for during the hurricane (Berggren 2005).

and ensure continuity of care. By 13 October 2005, all were located and had resumed treatment if it was indicated (CDC 2006i).

Two evacuees to Colorado sought emergency care for possible tuberculosis (CDC 2006b). The diagnosis was apparently not confirmed (CDC 2006i).

One 2-month-old infant was diagnosed with pertussis after being evacuated from a rooftop in New Orleans. Two other cases of respiratory disease, one streptococcal pharyngitis and one respiratory syncytial virus, were reported by 23 September 2005 (CDC 2005g).

There was widespread reporting of "Katrina cough," a constellation of symptoms thought to be related to dust and mold. A small case control study (n = 201) by the Louisiana Department of Health and Hospitals in early 2006 found that a history of respiratory conditions such as asthma, chronic obstructive pulmonary disorder, or tobacco smoking was a stronger predictor of requiring emergency medical care than exposure to dust or mold (Golden and Ratard 2006). The study did not investigate the effect on requiring non-emergency care.

Morbidity due to disruption in care during the hurricane. As noted above, in Mortality-Lack of access to care, the entire health care system in New Orleans was in tatters. Due to the overwhelming volume of medical need, and sudden lack of basic necessities for nutrition, hygiene, or medical care, healthy people became ill and ill people got sicker or died (Shute 2005a, Shorrock 2006, Shute 2005b). Medical staff in hospitals were overtaxed. One physician noted that the nurses immediately applied a disciplined schedule of 12-hour shifts, rotating staff, while physicians worked around the clock, potentially "compound[ing] the danger with our incoherence" (Berggren 2005). Additionally, a large number of professional staff who normally would be available to identify people in need and provide emergency care were gone or incapacitated: 150-250 police deserted, and over 500 firefighters were displaced (although the latter had a lower desertion rate) (Baum 2006, Longman 2005, Barry and Longman 2005, Hancock 2005).

Morbidity due to disruption in care or medication after the hurricane. As noted under subhead Respiratory Disease above, 116 non-incarcerated people were being treated for tuberculosis in New Orleans before Hurricane Katrina landed. (An additional 14 were incarcerated (CDC 2006i).) Four were in Charity Hospital, which lost power, requiring them to don N95 masks (Berggren 2005). To ensure continuity of care – and to control the spread of tuberculosis and help prevent development of multiple-drug- resistant strains – a "national network of TB control programs" implemented a variety of measures to identify patients (CDC 2006h). By 13 October 2005, all were located and had resumed treatment if indicated. Continuity of care was ensured, in part, by free shipments of replacement medications by a pharmaceutical provider, and by health departments in 14 states assuming responsibility for tuberculosis case management while patients were in their jurisdiction (CDC 2006i). Tuberculosis care, however, was the exception.

Hurricane Katrina, quite simply, sent all components of health care to the winds: health care facilities closed; health care providers dispersed throughout the country; people with serious or chronic medical conditions fled without, or with inadequate, medical supplies; and medical records and proof of insurance, even of identity, were lost. Adding to this confusion, evacuees encountered the fact that each state determines its Medicaid and AIDS Drug Assistance Programs (ADAP) eligibility and coverage, and many of the states receiving large numbers of evacuees had already strained health care systems. Finally, in some cases people did not know their medical history or pharmaceutical needs.

Care for specific medical needs was also disrupted. All the major HIV/AIDS care providers were significantly damaged and closed for "several weeks" (Wockner 2006). MCLNO, in partnership with LSU School of Medicine, ran the HIV Outpatient Program (HOP). The HOP Clinic was the "primary provider of HIV/AIDS care" in New Orleans, with 3,300 patients in 2005 (Kaiser Family Foundation 2006a). As of 13 April 2006, the HOP Clinic, at a temporary location, had seen only 850 patients. Community-based NO/AIDS Task Force resumed services in mid-March, having lost a third of its staff (Wockner 2006).

Diabetes requires daily care; supplies of insulin and other medication, which requires a supply of clean syringes; glucose monitoring; and careful attention to comorbidities. (Handling of the waste, particularly syringes, also presents health risks.) Vigilance regarding nutritional intake protects diabetics against hypoglycemia and hyperglycemia. The latter would put the diabetic at risk of conditions such as skin infections, a particular concern for those exposed to floodwaters. Many evacuees experienced periods of no or inadequate food during the week after the hurricane. As a result, "[w]hile statistics for the prevalence of these problems are currently unavailable, [there are] anecdotes about the high frequency and severity of both [hypo- and hyperglycemia], which may have resulted in some deaths" (Cefalu et al. 2006).

Many diabetics' dialysis treatment was interrupted, a particularly dangerous situation as diabetes can lead to heart disease, blindness, kidney damage, and lower-limb amputation due to circulatory problems. Some nursing home patients were evacuated to a local hotel, then transferred days later to a local hospital dialysis center. Anecdotal reports describe people rowing, wading, and being wheeled to treatment facilities as their serum potassium levels peaked. As of mid-October, as many as half the New Orleans dialysis patients were not located and their treatment status was unknown. Other conditions, such as seizure disorder and cardiac disease, also require constant care (Greenough and Kirsch 2005, Spake 2005, Frohlich 2005, Cohen 2005).

Some people were scheduled for surgery, which had to be postponed. For some, the loss of medical records forced them to repeat costly, time-consuming testing before being able to get surgery elsewhere (Glanton 2006, Murphy 2006).

While pregnancy is not a critical condition, the extreme stress related to evacuation could have contributed to premature birth (Montero 2006).

Health care facilities closed.

Most hospitals in New Orleans were crippled or destroyed. The two large state hospitals in New Orleans were destroyed, and were shut down after Hurricane Katrina (Kalb and Murr 2005). The Medical Center of Louisiana at New Orleans (MCLNO), which included Charity and University Hospitals, was central to providing care to the most needy: 51 percent of Charity's patients were uninsured and another 32 percent were covered by Medicaid.(Kaiser Family Foundation 2006c) This was possible in part because these hospitals trained health care professionals, including residents of two medical schools, Louisiana State University and Tulane (Thomas 2005). The schools were also devastated, affecting the flow of trainees. As of 22 April 2006, the LSU Schools of Medicine, Allied Health and Nursing were being renovated or environmentally remediated (Kaiser Family Foundation 2006a).

Only two of the eight hospitals in New Orleans were open in the months following the hurricane. In mid-November, they had to serve a day-time population of as many as 150,000 people (Thomas 2005). Of 15 adult acute-care facilities, only 7 remained open, with a third the number of beds (1,750 compared with 5,063) (Barringer 2006). The closure of Charity Hospital also affected access to emergency care, as it was the Level I Trauma Center for the entire Gulf Coast region. The closest other Level I facilities are in Shreveport, LA, Birmingham, AL, and Houston, TX, all over 300 miles away (Kaiser Family Foundation 2006a, Thomas 2005).

Health care providers dispersed throughout the country.

Health care providers were also dispersed throughout the country, including 6,000 physicians from Louisiana and Mississippi, "the largest displacement of doctors in U.S. history" (Adams 2005, 2005). The entire Louisiana State University School of Medicine department of family medicine, which served 10,000 to 15,000 patients, was displaced (Lubell 2005). By mid-November, only 15 percent of physicians had returned to the city, and "nurses are in short supply" (Thomas 2005). By April, health care providers remained so rare that Orleans Parish was declared a Health Professionals Shortage Area, with fewer than one primary care physician per 3,200 residents and less than one psychiatrist for every 21,000 residents (Louisiana Department of Health and Hospitals 2006). In contrast, New Orleans had a very high rate of approximately 9.6 physicians per 3,200 residents in 2001 (more typically presented as 300/100,000) (Kaiser Family Foundation 2006d). Some physicians could not be located to confirm prescriptions.

People with serious or chronic medical conditions fled without, or with inadequate, medical supplies.

Immediately following the hurricane, many people at the New Orleans Convention Center, where as many as 15,000 gathered, had run out of medication within days. They included the elderly, some wheelchair-bound, and children, including two with known seizure disorders and a third with a severe asthma attack (Henderson 2005b). The situation was similar at the Superdome, where people reported not having medication for conditions such as cancer, asthma, and seizure disorder (Associated Press 2005b, Treaster 2005).

CDC surveillance of Mississippi residents immediately following Hurricane Katrina found that medication refills were in high demand, constituting approximately one-third of frequently requested illness-related services at hospital emergency departments and federal Disaster Medical Assistance Team operation sites. The proportion dropped to about 18 percent in the second week (CDC 2006g). In another Mississippi county, surveillance in mid-September showed that, of the 41 percent of homes that were inhabited, 29 percent had a household member with a prescription that would need to be refilled within three days (CDC 2006f). Among former New Orleans residents evacuated to Colorado, the majority of visits to an outpatient medical clinic between 7 and 21 September and 13 percent of emergency room visits between 1 and 23 September were for medication refills (CDC 2006b).

Others missed medication because treatments that required a viable health care infrastructure – such as HIV experimental treatment or chemotherapy infusions – were not available (Kalb and Murr 2005). Others simply expected a shorter evacuation period and took an inadequate supply of medication, or ran out during evacuation (Wockner 2006).

Mental health patients who run out of medication risk causing themselves physical harm. They, and older patients, are likely to get confused by not being able to get care at their usual facility. Some refuse care, make themselves vulnerable by, for example, sleeping outside in nothing but a "half-open housecoat," or otherwise descend into psychosis (Lutz 2006).

By October 15, a website containing medical histories and pharmaceutical requirements was on-line, enabling physicians and pharmacists to access information on some people. While this was an important step, the source data covered many states affected by the storm. Additionally, even one million patient records would not include many evacuees (Schneider 2005).

Supply shortages abounded.

The evacuation centers were hard-pressed to provide the necessary medications and medical supplies. In Houston, after a federally deployed Disaster Medical Assistance Team did not deliver supplies as anticipated, a physician "ended up raiding his own hospital's pharmacy to try to get through the night." Private suppliers filled the void. In this case, 20 CVS corporation pharmacists with a "complete mobile operation" arrived to disseminate medications (Spake 2005). The Wal-Mart Corporation and Sam's Club also provided supplies such as food, water, and ice (Shute 2005a).

Medical records and proof of insurance, even of identity, were lost.

Many New Orleans residents evacuated without proof of identity, or lost it during the confusion of the storm and evacuation. Louisiana drivers' licenses were computerized, so people who could provide basic personal information and looked reasonably like the saved image could receive a new license (Sullivan 2005a). However, many people – particularly the young and the poor – did not have licenses in the first place, leaving them without proof of identity and thus exposing them to many health risks. Many shelters required identification, although some relaxed their rules (Sullivan 2005a), and housing is fundamental to health. Similarly, in some cases, proof of identity ensured continuity of coverage. For example, if evacuees claimed that they were on tuberculosis medication, the TB program in that state could confirm this through a special "Katrina TB help desk" in Atlanta. The help desk would facilitate the interjurisdictional transfer form allowing public health authorities in the index state to provide treatment (CDC 2006i).

The 12,849 people (Kaiser Family Foundation 2005a) with HIV/AIDS in Louisiana were also in a disease-specific registry, but have been far harder to locate. Two months after the hurricane, only half had been located (Kalb and Murr 2005). Those who lived in New Orleans may be harder to locate; by late April, the state had "up-to-date information on 2,170 of the 7,432 people with HIV [29 percent] who lived in metro New Orleans before the storm" (Wockner 2006). Anecdotal reports indicate that HIV/AIDS patients did not seek care, have been refused shelter after disclosing, or have not sought new sources of medication because they have not disclosed their status to people whose homes they evacuated to (Kalb and Murr 2005, Wockner 2006). Since they may be financially eligible for state-subsidized medication, not disclosing could have serious health ramifications.

People with diseases and conditions that do not have targeted funding streams need health insurance. Before Hurricane Katrina, 134,249 New Orleans residents were covered by Medicaid and, assuming that the Louisiana rate of being uninsured applied to New Orleans, approximately 93,000 additional residents were uninsured (Kaiser Family Foundation 2005b). Almost one-third of the workers in the state lived in New Orleans; many lost their jobs, and subsequently their insurance coverage, when many businesses were forced to close (SAMHSA 2005a).

Within six weeks after the hurricane, approximately 8,400 Louisiana households had sought Medicaid coverage. Of the 6,700 completed applications, well over half (58 percent) were not approved. Due to the unique circumstances, after 16 September eligibility workers gave unapproved households a “pending” status, not “screened out,” to facilitate subsequent approval when criteria were met (Ross 2005).

Evacuees who went, or were taken, to other states faced similar hurdles. A survey of evacuees in Houston[1] revealed that “half” the respondents had no health insurance, although 41 percent had a chronic condition such as heart disease, hypertension, asthma, diabetes, or cancer (Kalb and Murr 2005). While they could apply for Medicaid, each state determines eligibility criteria, coverage, and benefits. Many evacuees did not meet local eligibility criteria, or had certain uncovered conditions (Ross 2005). Some families found that children who had been covered by SCHIP in Louisiana did not meet the host state age requirements (Kaiser Family Foundation 2006d).

As a result of all these factors, many people went without care. A Spring, 2006, study of evacuees showed that 14 percent of children had gone without prescribed medication during the three months prior to the study (Dewan 2006c). A second study, of people who remained in FEMA housing in the 11-20 February period, revealed that many children had been hospitalized or repeatedly visited the emergency room for asthma care, as their caregivers could not get medication. Nearly half who had had a pediatrician before Hurricane Katrina no longer had one.

Some did not know their medical needs or medical history.

Many patients do not know the names of medications they are on, or where in a course of treatment – such as radiation – they are. “They would tell the physician, ‘I take a blue pill’,” health care providers report (Kalb and Murr 2005). Children’s vaccination histories were also lost, which compounded with multiple moves made it difficult for many to remain on their schedule (Splete 2005).

New and expectant mothers were particularly affected.

Many women about to give birth, or who had just given birth, had to evacuate. One arguably lucky woman was airlifted with her 2 ½-pound premature son to Baton Rouge, wearing just her

---

[1] This survey was reported in Newsweek; the sampling methodology and sample size were not provided.

hospital robe (Mercy Corps 2006). Other mothers watched their premature, incubated infants flown out to undetermined sites (Barringer and McNeil 2005). Over the months following the exodus, the Houston Fire Department reports numerous calls for rides for sick children or women going into labor (Shamlian 2006). In Arkansas, a physician who operates the only abortion clinic offered to perform free abortions on hurricane evacuees, if they chose, because late-term abortions carry more risk for the mother (Associated Press 2005a).

Withdrawal. Some people, suddenly without a supply of drugs or alcohol, went into withdrawal (Boo 2005, Baum 2006). Hospital pharmacies were threatened by armed assailants (Graham 2005). There were stories of people wading through deep water, holding large amounts of alcohol and little else (Baum 2006).

Previously Undiagnosed Morbidity. Some evacuees were diagnosed with illnesses for which treatment would be critical to their health. Four cases of tuberculosis were identified among evacuees, widely dispersed in California, Connecticut, Pennsylvania, and Texas (CDC 2006i). Others were suspected in Colorado (CDC 2006b).

Site-specific Morbidity. Many Hurricane Katrina evacuees were sent to geographical regions with characteristics vastly different from those of New Orleans. Approximately 6,000 evacuees were distributed throughout Colorado in September 2005, and as many as 9,000 were there in December. The most common medical needs were related to altitude sickness, as demonstrated by two measures. A survey of 106 households evacuated to Colorado between 4 and 9 September shows that the “most common acute medical conditions among households reporting one or more conditions were related to altitude sickness (e.g., dehydration, lightheadedness, or problems breathing).” A review of the 124 emergency room visits by evacuees between 1 and 23 September also demonstrates prevalent symptoms related to altitude sickness: 20 percent of visits were for pain or headache and 15 percent for an “other” reason, including dizziness (CDC 2006b).

7.3.1.2.1.3 Potential Future Morbidity or Mortality

New Orleans

Health care in New Orleans remains seriously unavailable. By late March, there were only 456 staffed hospital beds, one-fifth the number prior to the hurricane (Kaiser Family Foundation 2006b). The Tulane University School of Medicine, whose residents supplied a large proportion of care to the uninsured, is operating in Houston through at least the 2005-2006 academic year.

Need for psychiatric services is expected to increase as a result of the “psychological stress and trauma caused by the destruction of homes, the loss of jobs, the separation of families, and the death and devastation surrounding those in the areas hit by Hurricane Katrina” (Kaiser Family Foundation 2006c). In December, some psychiatrists in New Orleans reported that clients who had been stable before the hurricane were “preoccupied with death and suicide” (Nossiter 2005). One survey indicated that 39 percent of Louisiana residents reported feeling angry, and 53 percent depressed, following the hurricane season (Kalb and Murr 2005).

But availability of services decreased. In mid-February, only ten psychiatric beds in local hospitals were staffed. As a result, mental health patients are referred to emergency rooms (creating even more pressure on them) (Reuters 2006, Barringer 2006). For patients who are referred to care, just three city psychiatric clinics are open, raising concerns about potential suicides. Funding care is a challenge, as FEMA money may be used for referral, but not treatment, and private care providers are eligible for Medicaid reimbursement only if they served Medicaid patients before the hurricane (Reuters 2006, U.S. DHHS 2006).

HIV prevention efforts were interrupted by the hurricane, to the great concern of U.S. Surgeon General Richard Carmona, M.D. (Kaiser Family Foundation 2006c). Five of the Louisiana Office of Public Health community-based HIV prevention contractors went out of business because they lost facilities and staff (Wockner 2006).

Nationwide

Health insurance coverage

As discussed in morbidity due to disruption in care above, the mass interstate migration had a significant impact on Medicaid and on systems for providing care to the uninsured in many states. The Centers for Medicare and Medicaid Services (CMS) implemented emergency mechanisms to provide states with some flexibility and financial support to provide coverage to evacuees. However, these mechanisms are short-term.

CMS approved 17 waivers (from 15 states, the District of Columbia, and Puerto Rico). These waivers provided temporary Medicaid or the State Children's Health Insurance Program (SCHIP) to eligible evacuees – parents, pregnant women, children, disabled people, Medicare beneficiaries, and people in need of long-term care who meet income criteria. States cannot extend Medicaid or SCHIP to adults without dependent children or to "certain groups of immigrants, regardless of income." Sixteen of the 17 states that requested this waiver can provide coverage through June 2006. (Ohio's waiver only allowed temporary coverage through 31 December 2005.) (Kaiser Family Foundation 2005a).

To ensure service to the uninsured, eight waivers allow states[1] to reimburse providers "that incur uncompensated care costs of furnishing services to uninsured evacuees (including adults without dependent children) and to pay for services not covered under the states' Medicaid or SCHIP programs that are provided to evacuees (Kaiser Family Foundation 2005a). Some of these states had extremely high numbers of uninsured residents before Hurricane Katrina. Texas ranked first with 28 percent of the population uninsured; 20 percent of Arkansas' had no coverage (Kaiser Family Foundation 2006c). The uncompensated care pool coverage will end on 30 June 2006 (Kaiser Family Foundation 2006d).

An additional significant change to the United States health insurance system is that, as of 1 January 2006, Medicaid drug coverage was terminated for low-income elderly and disabled Medicare beneficiaries who had been dually eligible. There were only four months between Hurricane Katrina and the scheduled implementation of the Medicare Part D prescription drug program. While a large proportion of the dually enrolled will have been automatically enrolled in Medicare Part D, there will inevitably be a great deal of confusion regarding coverage. Addi-

[1] Alabama, Arkansas, Georgia, Louisiana, Mississippi, South Carolina, Tennessee, and Texas.

tionally, others were terminated from Medicaid but not eligible for Medicare Part D (Kaiser Family Foundation 2006c).

People with HIV/AIDS can be eligible for medication through the AIDS Drug Assistance Programs (ADAP). However, each state also determines financial eligibility and covered medications. Patients may not qualify in new states, or may have to change drug regimens (Wockner 2006). Louisiana residents who go to Texas, for example, will face more-restricted coverage. Additionally, the federal AIDS initiative was not renewed, forcing some people from federal into state systems after 1 October 2005.

Among those who evacuated to states where they were eligible for insurance (and food stamps), some who returned to New Orleans found they were not eligible in Louisiana, despite their changed circumstances (Dewan 2006c).

The dispersion of hundreds of thousands of people across the country will have effects on many areas other than New Orleans. Cities and states that welcomed evacuees on an emergency basis are facing the reality that many evacuees may not want to – or cannot – return to New Orleans. Medical professionals believe that the "city's sickest residents were among the first to leave New Orleans after Hurricane Katrina and should be the last to return" (Barringer 2006). These people will need medical care in their host locations.

Health care needs

A survey of 1,335 New Orleans households that had evacuated to San Antonio, TX, demonstrates significant medical needs among some evacuees. Fully 42 percent (563) of households reported having a family member with chronic illness and 28 percent (367) had a family member with physical or mental disability. These rates are extremely high, so it should be noted that the survey was administered to the 3,700 evacuees who remained by 14 September 2005, out of 12,700 who were there on 3 September. That is, the more healthy households may have been able to move out of the evacuation centers more rapidly than households with greater medical needs or less physical mobility. Of the remaining households, "approximately half" plan to settle in San Antonio. Of these, half the heads of household had held unskilled jobs, and one-third were "unemployed, retired, or on disability assistance before evacuation" (CDC 2006e).

A similar review of approximately 6,000 evacuees in Colorado during 7-21 September 2005, demonstrated that 10.5 percent had a chronic disease – including hypertension (28 percent), asthma or chronic lung disease (21 percent), cardiovascular disease (18 percent), and diabetes (14 percent) – and 49 percent planned to remain in Colorado (CDC 2006b).

People who left the evacuation centers first, finding housing and possibly jobs, are healthier than people who continued to rely on evacuation systems. Those who remained in FEMA-funded hotel rooms as long as December 2005, tended to be elderly, disabled, mentally ill, or felons who were "routinely rejected" for other housing. Some, having been homeless before the hurricane, are not eligible for FEMA rental assistance, so have few options (Wilgoren 2005).

A March 2006 study of people currently in FEMA housing supports this theory: "nearly half" of adults said they have at least one chronic condition such as diabetes. The children among these evacuees show increased rates of asthma, anxiety, and behavioral problems: 34 percent report these conditions compared with 25 percent before the hurricane (Dewan 2006c).

The influx of evacuees without health insurance has increased the demand for emergency medical services in many areas, such as Houston (Shamlian 2006). Some experts predict that those who were homeless in New Orleans will become homeless in their new locations (Wilgoren 2005), increasing pressure on local emergency services.

Stress from living conditions

Missing children

Compounding these stressors were the 4,710 Louisiana children who were missing in the aftermath of the storm. These children were mostly from New Orleans, "where heavy flooding and frantic rescues separated families." (This number includes some children displaced by Hurricane Rita.) Even premature infants evacuated in incubators were separated from parents (Barringer and McNeil 2005) All the children were ultimately identified, the last after 6 ½ months (Plaisance 2006). While reunited with at least one guardian, many were missing at least one other family member as of early March (Dewan 2006b).

In addition to separating families, Hurricane Katrina separated as many as 3,400 children from their "Big Brothers" and "Big Sisters," adult volunteers who provide the children with a stable role model. Still other children were transferred from the New Orleans juvenile detention facility to Baton Rouge (Kelly and Boyle 2005).

Housing and food instability

Between Hurricane Katrina and April 2006, families had moved an average of 3.5 times, often between evacuation centers (Dewan 2006c, Cowan 2006, Dewan and Roberts 2005). While many people who received temporary housing from FEMA were able to return to their homes or find longer-term housing, many remained on FEMA housing. For these people, the threat of losing housing subsidies could be quite stressful. Approximately 5,000 evacuees had either not received an extension or had not contacted FEMA before the 14 February deadline. More than 20,000 had received extensions, but likely face tighter housing markets than people who found housing quickly (Easton 2006).

Nearly 400,000 hurricane evacuees remained unemployed (including those affected by Hurricane Rita) on 6 March 2006. The benefit period was extended, so Hurricane Katrina evacuees can collect disaster unemployment assistance through 4 June 2006 (Kaiser Family Foundation 2006c). Employment may be difficult for the approximately 40 percent of the population that returned to New Orleans (Dewan et al. 2006, Rivlin 2006) as well as those who entered other job markets. Although there is significant cleanup work, a far smaller proportion of sustainable jobs than people have returned. Many local businesses have lost their base: "What's a neighborhood pharmacy without a pharmacy?" asked one former owner (Rivlin 2006, Seelye 2006).

Food shortages are an unexpected consequence of Hurricane Katrina relief efforts, as food pantries and shelters around the country found themselves in competition for donated food

(Salzman 2005). Many evacuees will find themselves needing the assistance of these pantries and shelters. Six months after the hurricane, 10 percent of evacuees surveyed said they were homeless or still needed a permanent place to live, and “a majority of whites and blacks reported that they had depleted their savings since the storm.” Since the poorest evacuees were not reached by this survey, the true number of needy will be higher (Dewan et al. 2006). Food shortages will affect new as well as the regular users. Some people who were homeless in New Orleans have already appeared in official counts of the homeless elsewhere (Horner 2006). In order to avoid a flood of new homeless when FEMA aid is cut off, Houston sent housing inspectors to determine whether evacuees could be returned to their New Orleans homes (Nichols 2006a).

Overcrowded conditions

According to a CDC Survey of households in Jefferson and Orleans Parishes between 17 and 22 October 2005, approximately a quarter of households “included a person not present in the household before Katrina struck,” implying substantial migration within New Orleans as well as from New Orleans (CDC 2006a). It also implies that crowding may have increased in habitable buildings. In fact, six months after the hurricane, a survey of people who were in a Web database of evacuees – which by definition does not include the poorest people – demonstrated that one-fifth were living in someone else’s home (Dewan et al. 2006). The sudden influx of evacuees to small towns as well as large cities has certainly caused local overcrowding. There are numerous stories of people housing large numbers of family, friends, and even pets (Steinhauer 2005, Shamlian 2006, Nichols 2006b, Griffin et al. 2005, McKinney 2005). The additional residents also caused shortages of everyday supplies, as demonstrated in Baton Rouge, which added 100,000 evacuees to its 225,000 residents (Campo-Flores 2006, Egan et al. 2005). The Wal-Mart was forced to close for a few hours each night to restock. “It has been like Christmas every day,” said a spokeswoman. Lines at stores are longer, and with increased traffic came a doubling in traffic accidents (Steinhauer 2005).

Resentment

During the evacuation, resentment built among evacuees and hosts. People in host cities and towns began to lose their patience with the crowding, high level of need among evacuees, and perceived increasing crime (Steinhauer 2005, Shamlian 2006, Nichols 2006b, Montero 2006). Evacuees, meanwhile, learned that twists of choice – about whether and when to leave New Orleans – and fate led them to their current state, and different states offered vastly different levels of support and services. In addition to varying medical coverage, described in Section 3.2.2 (subhead “Morbidity due to disruption in care or medication after the hurricane”) above, states had vastly different degrees of preparation, coordination, and of course ratio of evacuees to residents. In South Carolina, a volunteer group provided evacuees in FEMA-funded hotels with meals prepared by a local restaurant chain. Free public transportation – which was rerouted to accommodate evacuees – provides access to a local thrift shop and church groups collected furniture for future homes. Finally, the state Emergency Management Department provided the volunteer group with a three-month contract to support its efforts in finding housing and convincing evacuees to move (Wilgoren 2005, Bartels 2005, Working 2005). In contrast, evacuees who landed “miles from the edge of nowhere in the middle of eastern Oklahoma” where cell phones were out of range were treated – with apparently good intentions – like "summer campers," with scheduled meals and strict rules (Wilkerson 2005).

A final source of stress comes from the feeling among many refugees that they have been "left behind." As discussed in the *American Journal of Public Health*:

"Katrina highlighted a population already left behind by government, civic, and corporate leadership…. [D]istrust of the government by racial and ethnic minority groups is a critical concern in the context of terrorism, when adherence to government directives may be essential to protect the health of Americans" (Quinn 2006).

7.3.1.2.2. Environmental Health Exposures and Outcomes. Infectious and vector borne diseases are the primary causes of environmental health impacts due to hurricanes. Flooding exposes people to microbial contaminants that result in skin, diarrhea, and respiratory infections in survivors (CDC 2005c, CDC 2006a, Dewan and Goodnough 2005).

The second significant risk is vector-borne disease, as stagnant waters provide breeding habitat for mosquitoes, which tend to transmit diseases such as malaria, cholera, and West Nile virus (Bourque et al. 2006c, Dewan and Goodnough 2005).

However, in developed countries, infectious and vector-borne disease outbreaks following natural disasters are rare. Instead, the potential threat occurs from the failure of the essential infrastructure that provides safe drinking water, wastewater removal, and power (electric and natural gas), combined with crowded and unsanitary living conditions in shelters, along with stagnant water. The existence of all these conditions after the extensive and prolonged flooding of Hurricane Katrina increased the risk of infectious and vector-borne disease outbreaks (Bourque et al. 2006c, Dewan and Goodnough 2005, Peres and Janega 2005).

After acute exposures to floodwaters was no longer an issue it became apparent that mold-growth in the thousands of flooded structures had the potential to be both an acute and long-term environmental health problem (CDC Joint Task Force 2005, CDC 2005e, Bennett 2006).

Public health professions were concerned about risk of exposure to chemicals and toxins in the floodwaters. The EPA identified 54 Superfund sites in the area affected by Hurricane Katrina, including sites with pesticides and dioxins (Manuel 2006). Immersed vehicles could leak gasoline; demolished residences and businesses could have cleaning fluids, caustic drain cleaners, solvents, and other materials draining into the floodwaters. Skin exposure could potentially lead to burns, infections, and rashes. Finally, after New Orleans was dewatered, heavy metals, pesticides and petroleum products would settle into sediment. These contaminants present a potential long-term health risk (CDC Joint Task Force 2005).

7.3.1.2.2.1. Exposure to Floodwaters. Immediately after the hurricane, two groups tested the floodwaters to provide a snapshot of the chemical and biological characteristics of the water immediately following the flood caused by Hurricane Katrina.

The EPA and Louisiana Department of Environmental Quality (LDEQ) analyzed the floodwaters for "more than 100 hazardous pollutants such as volatile and semi volatile organic compounds, metals, pesticides, herbicides, and polychlorinated biphenyls. … They also tested for biological agents such as *Escherichia colo*" (Manuel 2006).

Pardue and colleagues also measured volatile and semivolatile organic compounds as well as microbial agents. Samples were collected in the main area of New Orleans, the East Bank, where human contact with floodwaters occurred during rescue operations, as well as from the 17th Street drainage canal. Samples were collected on 3 and 7 September 2005 (Pardue et al. 2005).

A few months later, the Natural Resources Defense Council (NRDC) tested sediment from the floodwaters for arsenic and other carcinogenics (Manuel 2006). The results of these three sets of tests are presented below.

Microbial contamination of floodwaters and infectious disease. The EPA/LDEQ reported "greatly elevated" levels of E. coli. (Manuel 2006, Kent 2005). Therefore, on 6 September 2005, the director of the Centers for Disease Control and Prevention announced the high levels of sewage-level bacteria in the floodwater and warned against contact with it (Manjoo 2005).

Perdue et al. confirmed elevated fecal coliform bacteria (Mid-City average of 1.4×10^5 MPN/100 mL), which was similar to levels historically observed in storm water runoff in the region, but still much higher than the water quality standard for primary contact (200 MPN/100 mL). Fecal coliform is a general indicator of the presence of human pathogens. Another team of researchers found high concentrations (5.6×10^6 MPN/100 mL) of *Aeromonas* spp. in water samples near the Superdome and Charity Hospital. EPA also conducted floodwater testing and reported that samples revealed elevated bacteria levels associated with untreated sewage (Dewan and Goodnough 2005, EPA 2005b).

It is likely that rescue workers, emergency response personnel, and stranded populations had at least dermatological exposure to human pathogens and, therefore, increased risk of illness. For example, a study of beachgoers in Los Angeles reported a higher incidence of gastrointestinal illness and upper respiratory infections among individuals swimming in marine water impacted by storm-water runoff than among non-exposed populations (Haile 1999, Dewan and Goodnough 2005).

CDC received reports of clusters of diarrheal disease among persons in evacuation centers in Louisiana, Mississippi, Tennessee, and Texas. Gastrointestinal illness was widespread in some areas, with as many as many as 21 percent of adults and 40 percent of children at one large evacuation center having acute gastroenteritis on any given day between 2 and 12 September 2005. About half the illnesses were demonstrated to be caused by norovirus. While the CDC suspects substantial secondary person-to-person transmission occurred in crowded evacuation shelters, many of the index cases may have been infected by contaminated food or water. For example, lack of electricity leads to food spoilage and potential for poisoning (CDC 2005d). In addition to the food left in homes and over 300,000 now-useless refrigerators, large amounts of food in the delivery chain were deserted – for example, 40 tons of packaged chicken and more than six million dead poultry and livestock (Dewan and Goodnough 2005, Manuel 2006).

On 30 September 2005, the CDC reported there were no confirmed cases of *Shigella* dysentery, typhoid fever, or infection by toxigenic V. cholerae O1, which in developing countries causes cholera, a severe diarrheal illness. In the United States, cholera is usually due to the consumption of contaminated shellfish, not contaminated water (CDC 2006g, Dewan and Goodnough 2005).

Two cases of toxigenic *Vibrio cholerae* O1 infection were identified in a Louisiana couple; the cases were attributed to consumption of undercooked or contaminated seafood apparently due to disruptions caused by Hurricane Rita, not Hurricane Katrina (CDC 2005i, Dewan and Goodnough 2005).

Among hurricane evacuees from the New Orleans area, a cluster of infections with methicillin-resistant *staphylococcus aureus* (MRSA) was reported in approximately 30 pediatric and adult patients at an evacuee facility in Dallas, TX. In addition, 24 cases of Vibrio-related wound infections were reported, with six deaths (CDC 2006d, Dewan and Goodnough 2005). CDC also received reports of tinea corporis and folliculitis, skin lesions with infectious etiology.

Heavy metal contamination of floodwaters. Preliminary results of the EPA/LDEQ study, particularly regarding elevated lead levels in the floodwaters, were widely reported. Community members became concerned about exposure to lead, which can result in severe neurological damage. In addition, seven major oil spills[1] were reported and the media were aware that hazardous chemicals could be leaking into floodwaters from thousands of sources, including cars, homes, and businesses (Loftis 2006, Loftis 2005, Chan and Revkin 2005, Dewan and Goodnough 2005).

Pardue et al. also found that lead, arsenic, and, in some instances, chromium approached and sometimes exceeded drinking water standards. Lakeview surface samples for lead had a mean of 3.2 μg/L, SD=1.4, less than EPA action level of 15 μg/L. In contrast, Mid-City surface samples for lead had a mean of 28, SD=31, which exceeds the action level. However, the Mid-City mean is being driven by a single test result of 111 μg/L, while the remaining 8 of 9 samples had lead levels of 26 μg/L or less (Pardue et al. 2005).

The NRDC study found extremely elevated arsenic levels in the sediment, as much as 30 times EPA safety limits. Louisiana environmental officials stress that the state has naturally elevated arsenic levels, so the flooding is not necessarily to blame (Manuel 2006).

The primary source of lead exposure for most children under normal circumstances is ingestion of deteriorating lead-based paint, lead-contaminated dust, or lead-contaminated soil. EPA estimates that 10 to 20 percent of human exposure to lead may come from lead in drinking water. Infants who consume mostly mixed formula can receive 40 to 60 percent of their exposure to lead from drinking water. Dermal absorption of inorganic lead compounds is generally considered to be much less than absorption by inhalation or oral routes of exposure; however, few studies have provided quantitative estimates of dermal absorption of inorganic lead in humans, and the quantitative significance of the dermal absorption pathway as a contributor to lead body burden in humans remains an uncertainty. The Agency for Toxic Substances and Diseases

[1] These spills, combined with at least 4 medium and 134 minor spills, totaled 8 million gallons of oil (Manuel 2006, Kent 2005).

Registry has not established a minimal risk level for lead, nor has EPA developed a reference concentration. EPA has decided it would be inappropriate to develop a reference dose for lead because some of the health effects associated with exposure to lead occur at blood lead levels so low as to be essentially without a threshold (ATSDR 2005, Dewan and Goodnough 2005).

Pardue et al. (2005) conclude that what distinguished Hurricane Katrina floodwater was its large volume and the extent of human exposure to toxic pollutants, rather than the elevated concentrations of the pollutants themselves. The extent of exposure was due in large part to the topography of New Orleans, which caused the standing water to remain, instead of draining away as it did in other urban areas (Pardue et al. 2005). The absence of highly concentrated toxic pollutants was explained by dilution from the large volume of water, the absence of chemical plants or refineries in the area sampled, low supplies of gasoline due to the evacuation, and chemically stable (buffered) water that resisted drops in pH, which could otherwise have leached more metals.

It is possible that, had the flooding been less extensive and provided less dilution of microbial and chemical contaminants, the resulting concentrations could have been substantially higher, resulting in additional/more-severe illness and injury.

Vector-borne disease. Mosquitoes presented the most significant potential risk of vector borne disease. The disease risk is quite low in the developed world, and previous experience has shown that, as after Hurricane Andrew in 1992, increased numbers of mosquitoes does not necessarily lead to an increase in disease (Bourque et al. 2006c, Dewan and Goodnough 2005). However, the enormous stagnant floodwaters left in the wake of Hurricane Katrina provided extensive breeding grounds for mosquitoes and raised concerns regarding West Nile virus (WNV) and viral encephalitis (Erickson 2005, Peres and Janega 2005).

Most people (about 4 out of 5) who are infected with West Nile virus will not develop any type of illness (an asymptomatic infection). It is estimated that about 20 percent of people who become infected with WNV will develop West Nile fever. Symptoms include fever, headache, tiredness, and body aches, occasionally with a skin rash (on the trunk of the body) and swollen lymph glands. While the illness can be as short as a few days, even healthy people have reported being sick for several weeks. The symptoms of severe disease (also called neuroinvasive disease, such as West Nile encephalitis or meningitis or West Nile poliomyelitis) include headache, high fever, neck stiffness, stupor, disorientation, coma, tremors, convulsions, muscle weakness, and paralysis. It is estimated that approximately 1 in 150 persons infected with the West Nile virus will develop a more severe form of disease. Serious illness can occur in people of any age, but the people at highest risk are those over age 50 and some immunocompromised persons (for example, transplant patients) (Dewan and Goodnough 2005, CDC 2004).

One mosquito-district in Louisiana reported that the number of trapped mosquitoes had increased 800 percent over pre-hurricane levels (Erickson 2005). However, other researchers observed minimal activity at sampling sites in New Orleans (Presley et al. 2006). In either case, people appeared to be at additional risk because they were spending extended time outdoors (e.g., relief and remediation operations), and even when they were inside, broken windows and screens did not keep mosquitoes from entering (Cowan 2006, Sullivan 2005b).

A key factor in disease transmission appeared to be missing. The key vertebrate hosts, birds, which are required to transmit and maintain the viral reservoir, were almost non-existent in these areas, perhaps driven from the area or killed by Hurricane Katrina (Sullivan 2005b, Erickson 2005). In addition, four traps operating overnight captured 47 mosquitoes, comprising 34 Aedes spp., 6 Culex spp., and 7 unidentifiable specimens; all the mosquitoes tested negative for the presence of West Nile virus and SLE (Presley et al. 2006). In the end, very little mosquito-borne illness was reported (CDC 2005g, Dewan and Goodnough 2005, Bourque et al. 2006c, Wilson 2006).

7.3.1.2.2.2. Mold

Mold is a type of fungus, an organism that reproduces by creating spores that travel through the air. Spores typically range from 2 to 10 micrometers, and can settle in the upper and lower respiratory tracts. While the process of inhaling and absorbing fungal-spores is poorly understood, it is clear that cleaning mold carries particular risks, as it can aerosolize the mold, dispersing respirable spores. Molds produce characteristic volatile organic compounds that can indicate exposure (CDC 2005e).

While mold has no established exposure limits, the key findings of a recent report from The Institute of Medicine (IOM) are:

Mold presents a risk of opportunistic fungal infection in immunocompromised persons.

There is sufficient evidence of an association between damp indoor spaces and upper respiratory symptoms, such as nasal congestion and throat irritation, and lower respiratory symptoms, such as cough, wheeze, and exacerbation of asthma (Institute of Medicine 2004).

There are no established health-based indoor exposure limits for the compounds resulting from mold, such as airborne endotoxins. However, measured indoor endotoxin levels in five homes were comparable to those of certain industrial settings in which declines in pulmonary function have been demonstrated. The CDC determined that “the findings of this assessment indicated that mold growth inside homes was likely at or above a level sometimes reported to be associated with certain health effects (e.g., cough; airway hyper-reactivity; influenza-like symptoms; ear, nose, and throat irritation; decreased lung function; and skin rash)” (Ratard et al. 2006).

Large sections of New Orleans were flooded for weeks, resulting in extensive mold growth in buildings. The CDC assessed the extent of mold growth in a sample (N = 112) of households in the area (Orleans, Jefferson, Plaquemines, and St. Bernard Parishes), and collected indoor (N = 20) and outdoor (N = 11) air samples. Air samples were analyzed for culturable fungi-b-D-glucan (a cell-wall component of many fungi) and endotoxin (a cell-wall component of gram negative bacteria). In addition, a questionnaire was administered to remediation workers and residents (not necessarily those of the 112 inspected homes) regarding demographics, home occupancy, and remediation activities (N = 235 or 70.1 percent participation rate) (Ratard et al. 2006).

Almost half the homes had “visible mold growth” and 17 percent had heavy mold coverage, defined as “>50 percent coverage on [the] interior wall of most-affected room.” Indoor and outdoor air sampling indicated that *Aspergillus* spp. and *Penicillium* spp. were the predominant populations (Ratard et al. 2006). Geometric mean glucan levels were 1.6 μg/m^3 inside homes and 0.9 μg/m^3 outside. Geometric mean endotoxin levels were 23.3 EU/m^3 (endotoxin units per cubic meter) inside and 10.5 EU/ m^3 outside. The authors reported that differences between inside and outside mold concentrations were not statistically significant, but no information is provided on the statistics for this small sample size (Ratard et al. 2006).

Hospitals in the area have reported seeing an increased number of patients with allergy and cold symptoms, and doctors have suggested that allergy to the mold and dust circulating in New Orleans is making residents susceptible to respiratory illness (Wilson 2006). A nagging cough going around town has been nicknamed “Katrina cough”; this is believed to be caused by high levels of dust in the air—particles from construction debris and dried mud, coupled with high spore counts from fungi, and mites that feed on fungal spores (Bennett 2006). This a particular concern for workers removing debris (Wilson 2006).

The CDC survey results could underestimate the potential effect of mold, as only homes that were occupied were included in the study; more-damaged or longer-flooded homes could have even greater coverage of mold (Ratard et al. 2006). Furthermore, the interviews with residents and remediation workers during 18-23 October indicated low levels of correct use or even appropriate respirators (31 percent of residents, and 35 percent of workers who had already cleaned up mold), in spite of high levels of belief that mold can make people sick (92 percent of residents and 95 percent of workers) (Ratard et al. 2006). In addition, many of the evacuees were from sensitive subpopulations such as the elderly, infirm, and immune- compromised, all of whom may be more sensitive to mold exposures. (Dewan 2006c)

Overall, limited data indicate that indoor and outdoor environmental conditions in post-Hurricane Katrina New Orleans almost certainly led to exposure to airborne mold, and may have people put at risk for the health effects identified by the IOM report. In addition, lax or inappropriate use of personal protective equipment may have undermined efforts to reduce these exposures. Mold is likely to be an ongoing problem. An estimated 30 million cubic yards maybe need to be removed from New Orleans and managed. The material will likely contain mold and hazardous materials (e.g., asbestos and lead paint) and will require appropriate safety precautions by remediation workers (CDC 2005a).

7.3.1.2.2.3. Heavy metals in sediments and seafood

Hurricane Katrina has the potential to cause environmental health risk over the long term. Two major potential concerns have been identified, in light of New Orleans’ particular architecture and geography—it consists of wetlands and is below sea level—and in light of experience with hurricanes in general, and the extent of flooding after the hurricane. They are:

- Exposure to elevated concentrations of heavy metals in soil and sediment deposited by receding floodwaters.

- Consumption of seafood that may have significant mercury and heavy metal accumulation from these sediments.

As described above, the primary sources of lead exposure for most children are deteriorating lead-based paint, lead-contaminated dust, and lead-contaminated soil. Children are more vulnerable to lead poisoning than adults. A child who swallows large amounts of lead may develop blood anemia, severe stomachache, muscle weakness, and brain damage. If a child swallows smaller amounts of lead, much less severe effects on blood and brain function may occur. But even at much lower levels of exposure, lead can affect a child's mental and physical growth (ATSDR 2005).

To assess immediate and long-term public health implications, a research team collected soil and sediment samples during 16-18 September 2005 in the City of New Orleans and in Orleans and St. Charles Parishes. The authors found that concentrations of aldrin, arsenic, lead, and seven semivolatile organic compounds in sediments/soils exceeded one or more USEPA thresholds for human health soil screening levels (Presley et al. 2006). The authors comment that while the lead concentrations in post-Hurricane Katrina samples are not the highest reported for urban New Orleans, they still might pose a significant health risk, particularly to children returning to highly contaminated areas. Given that a number of compounds exceeded screening values, the authors concluded that planning and execution of cleanup and rebuilding operations must include steps to protect construction workers, waste handlers, and residents. Schoolyards and athletic fields are of particular concern (Lubell 2005).

A large oil spill from the Murphy Oil Refinery also raised questions about health risk to people returning to residences in or near the spill zone. Storm surge from Hurricane Katrina lifted and dislodged a 250,000-barrel aboveground storage tank at the Meraux Murphy Oil Refinery. At the time the tank reportedly contained 65,000 barrels of mixed crude oil, and approximately 25,110 barrels (1,050,000 gallons) was released. Visual inspection indicated the oil release impacted approximately 1,800 homes and an undetermined number of other structures in a 1-square-mile area, as well as several adjacent canals (Dewan and Goodnough 2005, Zarus and Fowler 2005).

A few weeks later, after floodwaters had receded from St. Bernard Parish, soil samples in a church yard, school yard, and other areas revealed high levels of arsenic, cadmium, chromium, and various benzene compounds, according to activists. This raised concerns about contamination from, for example, young children putting their dirty hands into their mouths.

The Agency for Toxic Substances and Diseases Registry subsequently reviewed the results of sediment/soil sampling conducted at more than 800 properties. The conclusions of that analysis were that concentrations of oil-related chemicals in sediment and soil samples from most properties were below ATSDR comparison values and LDEQ RECAP standards for petroleum products. Short-term or long-term exposures to such sediments do not pose a public health hazard. The report also concluded that concentrations of petroleum products in sediment and soil samples from some properties exceeded LDEQ RECAP standards and that these properties should be remediated prior to re-occupancy (Zarus and Fowler 2005).

In December 2005, EPA reported on results of environmental sampling of air, soil, water, and seafood in New Orleans independent of site-specific activities at industrial locations such as the Murphy oil spill (Zarus and Fowler 2005). Some of EPA's summary findings were:

Ambient air quality samples appear to be typical for this region of the state, and pollutants are below any levels of health concern. The VOC samples and TAGA data showed some elevated reading of pollutants immediately after the storm. However, subsequent sampling has shown that the levels of pollutants have returned to pre-hurricane levels. A review of PM 2.5 (fine particulate) data shows concentrations below levels of concern. All concentrations of the toxic air pollutants are below the EPA one-year screening levels and below the Louisiana ambient air standards.

In general, the sediments located in areas flooded by the hurricanes in Orleans, St. Bernard, and Plaquemines Parishes are not expected to cause adverse health effects, provided people use common sense and good personal hygiene and safety practices. The levels of fecal coliform bacteria and TPH in the sediments were initially elevated, but they are expected to decrease naturally over time.

As expected in an old, densely populated urban area, a variety of chemicals were detected in the sediments. In general, other VOCs, SVOCs, pesticides, and metals were at levels that would not be expected to result in adverse health effects. However, in areas where sediment samples contained contaminant levels exceeding LDEQ and EPA criteria, further investigation is underway to adequately characterize the nature and extent of contamination.

As sediments dry out, the fecal coliform bacteria cannot be expected to survive, and the hazard represented by the bacteria will decrease. The elevated levels of TPH are likely attributable to urban background TPH levels associated with surface runoff from roadways in combination with releases of petroleum products from vehicles submerged under floodwaters. In some localized areas, elevated TPH levels may be attributable to known releases of petroleum products.

While the detected levels of contaminants may not pose an unacceptable health risk for most people, some individuals may be bothered by dust raised by disturbances of the sediment. It is therefore recommended that efforts be made to minimize contact and take measures to minimize dust (reestablish lawn, rinse off sidewalks and driveways, etc).

Exposure to the majority of residual sediment contaminants is expected to decrease over time due to growth of vegetation and the degradation and dispersion of these chemicals from natural processes in the environment.

As of 9 December 2005, the data show no reason for concern about consuming seafood from the Gulf region due to the hurricanes. The samples were analyzed for chemical and micro-biological contaminants that the hurricanes could have introduced. The extensive seafood tissue sampling occurred in an area from the estuaries of New Orleans to Gulf Shores, AL. The sampled areas included Lake Pontchartrain, Mississippi Sound, and Mobile Bay, as well as the offshore areas of the northern Gulf of Mexico. While many oyster harvest areas have been tested and reopened, others remain closed until routine sampling by existing state-regulated Molluscan Shellfish Programs determines that oyster harvesting can resume. Current data from analyses of fish and other shellfish from these areas show no reason for concern.

EPA has continued to conduct analyses since the release of the data sampling results in December 2005. More recent resampling and evaluation in February 2006 led to the following conclusions (EPA 2006).

The results from the composite samples collected in February 2006 support the conclusions of the 6 December 2005 summary assessment that the sediments in most of the areas flooded by the hurricanes are not expected to cause adverse health impacts. The concentrations of arsenic detected in samples collected in Fall 2005 were not found to be representative of the average concentration of arsenic in the areas around the original sample locations. Similarly, the concentrations of benzo(a)pyrene at most of the Fall 2005 sample locations were not found to be representative of the benzo(a)pyrene concentrations in the areas around the original locations.

Elevated concentrations of lead were detected in composite samples collected during February 2006 at several locations in older residential areas of New Orleans. However, the elevated levels of lead found in the February 2006 samples are consistent with pre-hurricane conditions. Studies conducted in New Orleans prior to Hurricane Katrina showed both elevated levels of lead and a similar distribution of lead in the soil.

7.3.1.2.2.4. Other potential environmental causes of morbidity and mortality

Other potential environmental causes of morbidity and mortality that have not been clearly established in the literature to be caused by Hurricane Katrina are:

Smoke from fires and debris. Natural disasters such as hurricanes and floods can leave a lot of debris, some of which may be burned during cleanup. Smoke from these outdoor fires is unhealthy to breathe and may cause cough, shortness of breath or tightness in the chest, and stinging of the eyes, nose, or throat (CDC 2005b).

Natural gas leaks. These are a potential source of poisoning and fires (CDC 2005a).

Accidents. Post-hurricane clean-up has been associated with numerous accidents involving chainsaws, electrocution, and fires (Bourque et al. 2006c, Dewan and Goodnough 2005).

Animal and insect hazards. An increased prevalence of dog and insect bites has been reported in prior hurricanes, and was observed to some degree in Hurricane Katrina relief workers (Bourque et al. 2006c). Wild animals – especially snakes and rodents fleeing rising floodwaters – may come into closer contact with humans.

Industrial fires/chemical emergencies. These were a potential risk given the number of oil refineries in the gulf coast area. EPA’s environmental surveillance aircraft were used to assess spills and chemical releases. On 3 September, the aircraft surveyed the smoke plume of a large fire in the New Orleans warehouse district. The survey did not reveal any contaminants of undue concern in the smoke (EPA 2005a).

Residential/commercial fires. Fires did not appear to be a significant problem, but the lack of running water for fire suppression suggests that they had that potential.

7.3.1.3. Mental Health Exposures and Outcomes

In this section, we summarize what is known to date about traumatic exposures resulting from Hurricane Katrina and mental health outcomes associated with those exposures. As used by mental health practitioners, the term trauma describes "a wide range of intensely stressful experiences that involve exposure to levels of danger and fear that exceed normal capacity to cope" (Fairbank et al. 2001). The brain's response to cues that suggest imminent loss of control is believed to be responsible for the structural and functional changes (in the hypothalamic-pituitary-adrenal [HPA] axis and in multiple neurotransmitter systems) that produce the symptoms of posttraumatic stress disorder (PTSD) in a subset of those who have been exposed (Bremner et al. 1999).

The basic epidemiology of exposure to a wide variety of potentially traumatic events (PTEs) – including such diverse events as natural disasters (e.g., hurricanes, floods, earthquakes, fires), serious accidents (e.g., industrial, auto), physical or sexual assault, combat--has been well documented in recent decades. Findings from this body of research suggest that, even in the U.S., the majority of people will be exposed to at least one PTE in their lifetime, and many to more than one (Kessler et al. 1994). Further, across a wide range of PTEs, most of those exposed do not have any clinically significant mental health sequelae, and the likelihood of such sequelae is closely related to the details of an individual's specific exposure (Green 1993). Additionally, "human made" events (i.e., purposeful, or intentional, violence) have been shown to be more malignant in this regard than natural disasters (Norris et al. 2001b). Also, although most people exposed to a PTE experience some distress – e.g., feelings such as fear, anger, uncertainty, and sorrow – the clinically significant reactions that occur typically include PTSD and its frequent comorbidities: depression and substance use disorders.

7.3.1.3.1. Mental Health Outcomes: Posttraumatic Stress Disorder and Other Clinically Significant Consequences of Disaster Exposure. The Posttraumatic Stress Disorder syndrome describes the most common human response following exposure to life-threatening experiences. Posttraumatic Stress Disorder is a specific psychiatric disorder whose official definition in the U.S. is provided by the American Psychiatric Association's *Diagnostic and Statistical Manual of Mental Disorders* (DSM-IV) (Norris et al. 2001a). The current definition of PTSD comprises five major criteria that include both exposure to a PTE and the presence of a specific constellation of symptoms that was not present before the exposure. Specifically, the formal definition requires:

- Exposure to an event that involves high potential of serious harm or death, combined with peritraumatic experience of specific emotional responses, including intense fear, helplessness, or horror.
- Involuntary reexperiencing of the PTE, via distressing dreams about it, distressing intrusive recollections of it while awake, or flashbacks (perceived reliving) of it.
- Active avoidance of reminders of the PTE, and emotional numbing (attempts not to feel anything).
- Symptoms of hyperarousal, such as sleep disturbance and exaggerated startle response.

- The symptoms must have been present for at least one month and have caused significant distress or impaired functioning.

Several excellent summaries of the current knowledge about the epidemiology, etiology, and treatment of PTSD are available (Schnurr and Friedman 2001, Fairbank et al. 2001, Yehuda 2002). Community epidemiologic studies indicate that about 8 percent of the U.S. population has had Posttraumatic Stress Disorder at some time in their life, and more than 10 percent of men and 6 percent of women report having been exposed to four or more PTEs in their lifetime (Kessler et al. 1994). Fortunately, there are a number of treatments available today whose efficacy for Posttraumatic Stress Disorder has been demonstrated empirically. These include a variety of psychotherapeutic approaches, and two pharmacologic agents (sertraline [Zoloft] and paroxetine [Paxil]) have recently been approved by FDA for the treatment of Posttraumatic Stress Disorder. Additionally, two sets of practice guidelines for clinicians have recently been published (Foa et al. 2000, Foa et al. 1999).

A second clinically significant mental health outcome associated with exposure to Potentially Traumatic Events is depression. Major depressive disorder is a specific psychiatric disorder characterized by a constellation of affective (dysphoric mood, anhedonia), cognitive (trouble concentrating, indecisiveness), somatic (fatigue, disturbed appetite, and sleep), and behavioral (irritability, feelings of guilt or worthlessness) symptoms, with associated functional impairment.

Community epidemiologic studies indicate that the lifetime prevalence of major depressive disorder (MDD) is 16.2 percent and the 12-month prevalence 6.6 percent (Kessler et al. 2003). Additionally, it is estimated that depression costs U.S. employers $44 billion per year in lost productive time, which represents $31 billion more than the lost productive time of their non-depressed coworkers (Steward et al. 2003). Further, epidemiologic and clinical studies document that depression is typically a chronic condition. Among individuals who have an initial major depressive episode, 80 percent will have at least one more episode in their lifetime, with 25 percent having six or more episodes total (Angst 1995, Judd et al. 1996). The average number of major depressive episodes experienced over their lifetime among people with MDD is about four (Angst 1995). The comorbidity of depression and PTSD is thought to result in part from the many losses that people exposed to large-scale disasters typically experience (e.g., death of loved ones, loss of home and/or job, loss of social support).

The third primary outcome associated with exposure to disasters and other trauma is substance use disorders, particularly alcohol abuse. Community epidemiologic studies indicate that more than half of men and more than one-quarter of women who have had PTSD have lifetime histories of drug or alcohol abuse, or both (Kessler et al. 1994). One hypothesized mechanism for the relationship between PTSD and substance use is the self-medication hypothesis, i.e., that people with PTSD use alcohol and drugs to reduce the impact of their intrusive symptoms (i.e., their recurrent, distressing thoughts and dreams about the traumatic event).

7.3.1.3.2. Evidence Concerning Prevalence of Specific Mental Health-Related Exposures. The literature that describes the details of specific exposures from Hurricane Katrina – i.e., what was your exposure to specific aspects of the storm? – is currently very limited. In broad strokes, however, the answer to this question is obvious. Those who remained in New Orleans and the surrounding area were exposed to very high winds, torrential rains, and an unusually high storm surge. In addition to the usual problems of blowing debris, trees falling on houses, and power lines downed and arcing, the confluence of these three factors also caused breaches in protective levees that produced widespread, rapid-onset flooding. Given these storm characteristics, it is clear that those who remained in New Orleans had a very high likelihood of exposure to levels of danger and fear consistent with the current use of the term trauma. In addition, given the death toll attributed to the storm and the large number of people who were classified as missing, many New Orleans residents were exposed to the death or missing status of one or more family members or close friends who died or were missing following the storm.

Although the grey literature provides many anecdotes about storm-related experiences, there is little systematic information available that describes exposure to psychological trauma. We were able to identify only three reports of systematically collected information that was even marginally relevant in either the scientific or grey literature. One of these was a telephone survey conducted by the Gallup Organization for CNN, USA Today, and the American Red Cross. The survey was conducted between 30 September and 9 October 2005, and consisted of telephone interviews with a "random sample from all individuals who contacted the Red Cross since Hurricane Katrina" (n = 1,510). The fact that the sample includes both people who evacuated and those who did not is an important strength of this survey, but the fact that it contains people from the whole geographic region affected by the storm is a weakness with respect to the objectives of this review.

To enhance its information value for this review, we obtained a public use file of the survey responses from the Roper Center for Public Opinion Research, an archive for public opinion research located at the University of Connecticut. Because the survey is an opinion poll, the psychometric properties of its items are unknown, and because the focus is primarily on survivors' reactions to the storm, the assessment of exposures is less precise than we would have liked.

Given those caveats, some findings are informative with respect to exposure. Just over half of survey respondents reported having feared for their lives during the storm. In addition, about 7 percent reported being injured or hurt during the storm, and 8 percent reported having been a victim of a crime during or immediately after the storm. Also, half reported being separated from family members for at least one day, more than 70 percent reported being worried about elderly family members, and about 20 percent reported losing a pet. Further, about one-quarter of respondents reported having spent at least one night in a shelter during or after the storm.

A second source was a telephone survey conducted by and reported in the *New York Times* during the period 16 February through 3 March 2006 (Boo 2005). Although this survey focused largely on what had happened to evacuees *since* the storm, it also documented some exposure details. The sample was selected at random from a list of more than 160,000 Hurricane Katrina evacuees (and therefore includes evacuees from all affected areas, not just New Orleans). Responses from the 337 participants indicated that African-American evacuees were more likely than whites to report that: their former homes had been destroyed; a close friend or relative had died in the storm; and that they had been separated from family members by the storm. These kinds of exposures have been found to be associated with higher levels of PTSD and depressive symptomatology in empirical studies of other large-scale disasters.

Additionally, two-thirds of respondents in the *Times* survey reported that their former residence had been rendered unlivable by the storm. About 40 percent indicated an intention to return to their former residences, with those aged 40 and over most likely to be planning to return, and those aged 20 to 39 most likely to indicate that they did not plan to return (most out of fear of another hurricane/flood disaster).

The third source of more systematic exposure information comes from reports by survey teams sent by CDC to Jefferson Parish and Orleans Parish, which were among the first areas to reopen after the storm, during the week of 17-22 October 2005 (CDC 2006a). The purpose of the survey was to find out about conditions in those areas. The sample was housing-unit based, and was drawn in 45 randomly generated Census blocks in the two parishes. Among respondents in New Orleans Parish, which comprises the city of New Orleans, 46 percent described their homes as having "very much damage," and 52 percent rated their homes as being "not safe." In addition, 60 percent indicated that at least one person in the household had a pre-existing chronic illness, and 41 percent reported a new illness since the hurricane. More than two-thirds of Orleans Parish residents reported no electricity, no gas, no telephone service and no garbage removal, and more that half reported no running water and no working toilet. One-third reported problems obtaining medical care.

Beyond the severity of the storm and flooding, however, extrapolation from studies of prior disasters suggests that two aspects of Hurricane Katrina will influence the mental health and other psychosocial outcomes over the long term. The first is the monumental infrastructure damage inflicted over a very large area. This suggests that many people have very substantial property and other losses, and these losses have been shown repeatedly to be correlates of poorer psychosocial outcomes. Hobfoll has conceptualized these kinds of losses in a comprehensive theory of the role of diverse resources (e.g., financial, emotional, social, intellectual) in determining psychosocial adjustment (Hobfoll and Lilly 1993).

The second factor that can be expected to influence the mental health of Hurricane Katrina survivors over the long term is the massive relocation of the affected population, and the wide spread of that relocation. Both of these aspects predict poorer psychosocial outcomes for the evacuees, particularly the children.

Additionally, it is important to note that the infrastructure damage and massive relocation of Hurricane Katrina victims are major barriers to the development of an empirical database about the psychosocial impact of Hurricane Katrina. As an example, in the 12 months following the September 11 terrorist attacks, findings from four major community epidemiologic studies of their mental health impact were published in top-tier journals (Silver et al. 2002, Schuster et al. 2001, Galea et al. 2002, Schlenger et al. 2002). Among the most important reasons why this was possible was the relatively limited and circumscribed impact – in terms of the residents of New York and Washington, DC – which the attacks had. All four studies were based on interviews conducted via telephone or the internet. Given the widespread infrastructure damage and relocation of Hurricane Katrina survivors, rapid-response empirical research was feasible after September 11 in ways that it was not in response to Hurricane Katrina.

7.3.1.3.3. Evidence Concerning Mental Health Outcomes

Posttraumatic Stress Disorder (PTSD). As with exposure, we found very little scientific literature that provided empirical findings about the psychosocial impact of Hurricane Katrina. The only systematic, empirical study we found was an *MMWR* report that described screening results from the area probability sample study conducted by CDC in Orleans and Jefferson Parishes (CDC 2006a). Participants in the study were screened for mental health service needs with the Short Post-Traumatic Stress Disorder Rating Interview (SPRINT), a brief screener with documented relationship to mental health service utilization in clinical and community samples. Based on the SPRINT screen, 35 percent of respondents had screening scores suggesting high need for mental health services, and another 50 percent had scores suggesting possible need. These are very high proportions, suggesting a substantial need for mental health treatment and case management.

Some preliminary findings from studies of Hurricane Katrina's psychological impact have begun to be reported in the news media, however. Most have focused on the impact of the storm and its destruction on children. For example, one report described a 3-year-old who screams and cries as her grandmother fills the bathtub (Callimachi 2006). The child was at home with her family when the storm surge destroyed the house, and she was swept out of the house underwater. Although she was fortunate to have been saved by an alert neighbor, her fear of water is clear. The report went on to note that of the first 1,000 children evaluated at the LSU Health Sciences Center following the storm, 27 percent displayed symptoms of PTSD. Additionally, it noted that a study conducted by Columbia University's Mailman School of Public Health found that children who lived through Hurricane Katrina were more than twice as likely as a comparison group of urban children assessed in 2003 to develop conduct problems, depression, and anxiety.

Although not providing new empirical information about the mental health consequences of Hurricane Katrina, Borque and her colleagues(Green et al. 1990) reviewed the hurricane literature and used the findings to forecast Hurricane Katrina impacts. Interestingly, they conceptualize Hurricane Katrina as not just a natural disaster, but a natural disaster confounded with human-initiated technological disasters, referring to the slow governmental response to the storm and the wide dispersion of evacuees. They note that the poverty levels among evacuees, the disruption of support systems that evacuation has exacerbated, and the multiple resource losses that many evacuees experienced suggest that Hurricane Katrina will have a strong and long-lasting effect on many evacuees.

The existing literature includes studies of prior hurricanes and floods that are informative. The best studied flood is the Buffalo Creek dam collapse in 1972 (Gleser et al. 1981, Bourque et al. 2006d). An extended period of heavy rain in a strip mining area of West Virginia resulted in the collapse of a mining company-created dam in Buffalo Creek, which unleashed a 15 to 20-foot wall of water through a narrow valley with no advance warning to residents downstream from the dam. In the course of the next hour, more than 132 million gallons of water rushed through 17 miles of Buffalo Creek hollow and emptied into the Guyandotte River. In its wake, the flood left behind 125 deaths, more than 1,100 injuries, and more than 4,000 people homeless due to 546 houses demolished and 943 damaged. Gleser and her colleagues assessed the mental health status of survivors two years after the flood and found two thirds of the adults and one third of the children to be moderately or severely impaired (Gleser et al. 1981). The PTSD syndrome was not yet recognized at the time of the study, but a retrospective estimate of the probable PTSD rate two years post flood was 44 percent for adults and 32 percent for children, and a follow-up assessment more than a decade later found a 25 percent PTSD prevalence for adults (Bourque et al. 2006d). This carefully conducted longitudinal study provides strong evidence of the lasting effects that floods can produce.

From the broader perspective, Norris and her colleagues reviewed two decades (1981-2001) of published literature on disasters and mental health outcomes (Norris et al. 2002b, Norris et al. 2002a). They reviewed about 250 articles, chapters, and books, which included 160 distinct samples of disaster victims with more than 60,000 research participants. The identified literature included 15 studies of floods and 25 studies of hurricanes (most of which focused on either Hurricane Hugo or Hurricane Andrew).

Based on the review, they found that natural disasters as a class were less traumatogenic than disasters involving mass violence (Norris et al. 2002a). Longitudinal studies of the aftermath of disasters typically document a decrease over time in PTSD and related symptomatology in the post-exposure period, and symptom levels in the early post-exposure period are typically good predictors of later symptomatology (Norris et al. 2002a). Intensity of exposure to the disaster is typically the strongest correlate of post-exposure symptomatology, but multiple studies document that the following factors are also consistently associated with post-disaster mental health outcomes:

- gender (females more symptomatic following exposure)
- age (younger people more symptomatic)
- prior trauma exposure (more symptomatic)
- pre-exposure psychiatric disorder (more symptomatic)
- socioeconomic status (lower more symptomatic)
- social support in the post-exposure period (lower more symptomatic)
- resource losses (those with more losses more symptomatic) (Norris et al. 2002a)

In thinking about the implications of the review findings, Norris et al. concluded that early intervention is necessary following disasters, “especially when the disaster is associated with extreme and widespread damage to property, ongoing financial problems for the stricken community, violence that resulted from human intent, and a high prevalence of trauma in the form of injuries, threat to life, and loss of life” (p. 260). Most of these characteristics pertain to Hurricane Katrina. In addition, Norris et al. noted that “family context is central to understanding and meeting those needs,” and that “Altogether, the research demands that we think ecologically and design and test societal- and community-level interventions for the population at large and conserve scarce clinical resources for those most in need” (Norris et al. 2002b, p. 260).

Among the most important lessons of the past two decades of epidemiologic research on the psychological aftermath of large-scale PTEs is that although very high proportions of the exposed population may experience distress of various kinds (e.g., fear, anger, uncertainty, sorrow) at the time of and/or in the wake of the exposure, most of this distress proves to be both self-limiting and not clinically significant. For a subset of the exposed, however, the distress will be clinically significant, and will typically take the form of PTSD. Even among this subset, though, epidemiologic evidence suggests that for many, their clinically significant reaction will also prove to be self-limiting. The net result is that although typically the vast majority of those exposed to large-scale PTEs are distressed in some way by the exposure, the subset that ultimately develops a long-term, clinically significant reaction is likely to be a relatively small proportion of all of those who were exposed.

Because of the large numbers of people exposed inherent in large-scale Potentially Traumatic Events, however, even a small proportion of clinical cases among those exposed can mean an epidemic. As a specific example, Schlenger et al. (2002) estimated that 11.2 percent of adults in the New York metropolitan area were probable cases of PTSD in the second month after the September 11 attacks. Even if only 10 percent of those cases prove ultimately to be chronic, because there are more than 10 million adults living in the New York metropolitan area, that would mean more than 100,000 adults with chronic, clinically significant reactions following the terrorist attacks in the New York metropolitan area alone. This is clearly an important public health problem.

The existing literature also documents a decline in the prevalence of disaster-specific PTSD over time. One of the most striking demonstrations of this is found in a series of studies conducted in New York by Galea and his colleagues following the September 11 terrorist attacks (Galea et al. 2002). In a series of three cross-sectional, community epidemiologic studies conducted in New York at 2, 4, and 6 months after the attacks, the prevalence of attack-related PTSD reduced from about 8 percent to about 1 percent. This pattern of relatively rapid resolution of PTSD following single-event disasters have been shown from multiple types of disasters (e.g., terrorist attacks, earthquakes, hurricanes).

Nevertheless, it is clear from the literature that not enough is currently known about the details of the course of PTSD. The available empirical information clearly suggests that for many who develop Posttraumatic Stress Disorder symptomatology in the weeks and months following exposure to a disaster, the condition will prove to be self-limiting – i.e., the symptoms will resolve within 3 to 6 months without clinical intervention. For these people, “returning to normal” in the aftermath of trauma is a reasonable and attainable goal. What remains unclear, however, is what proportion of disaster-related Posttraumatic Stress Disorder cases will prove to be chronic, what are the appropriate interventions for them, and how can we identify them early?

Additionally, although severity and characteristics of the specific Potentially Traumatic Events exposure has repeatedly been shown to be the strongest predictor of post-exposure Posttraumatic Stress Disorder prevalence, a number of other risk factors for the development of Posttraumatic Stress Disorder have also been identified. The best established of these include that: women are more likely to develop Posttraumatic Stress Disorder than men; minority group members (e.g., African-Americans, Hispanics) more likely than majority group members; those with history of prior Potentially Traumatic Events exposure more likely than those without; and those younger at time of exposure more likely than those older. Given the substantial minority population of New Orleans and the relatively high level of poverty, these characteristics suggest a relatively high prevalence of Posttraumatic Stress Disorder from Hurricane Katrina.

Furthermore, recent research has focused on the association of disaster-caused relocation (e.g., evacuation) with post-disaster mental health outcomes. Riad and Noris (1996) found that relocation was related to psychosocial outcomes, including psychological symptom levels. They further found interactions with ecological stress (i.e., poor living conditions), such that those who relocated to poor living conditions had worse outcomes than either those who did not relocate and lived under comparable conditions, or those who relocated but lived under better conditions. These findings add to the concern over the Hurricane Katrina evacuees.

Depression. As was true for Posttraumatic Stress Disorder, we could find no empirical findings about depression directly associated with Hurricane Katrina. The disaster literature, however, documents clearly the frequent comorbidity of these conditions with PTSD (Keane and Wolf 1990). The substantial death toll from the storm, the lingering number of persons unaccounted for, the many separations of family members (caused by the storm, the evacuation, or both), the major relocation of population, and the screening results from the CDC study (CDC 2006a) all point to a likely high prevalence of both depressive and substance use disorders in the wake of Hurricane Katrina.

Substance Abuse. Similarly, we could find no studies documenting substance use in the aftermath of Hurricane Katrina, and somewhat surprisingly no mention of substance use in the grey literature. Nevertheless, substance abuse has been shown to be a robust correlate of PTSD in studies of a wide variety of traumatic exposures. What remains unclear, however, is whether exposure to PTEs has a direct effect on substance use, independent of the psychological distress it causes, or whether increased substance use post-exposure reflects victims' attempts to medicate their psychological distress.

Interruptions in Mental Health Service Delivery. Among the many problems resulting from Hurricane Katrina, one of the most serious is the decimation of the health and mental health service systems. Because Posttraumatic Stress Disorder, major depression and the substance use disorders can all be chronic, episodic disorders, the lack of mental health care is an important problem.

Federal agencies, however, worked in partnership with state governments to address some of the mental health service needs of Hurricane Katrina survivors. SAMHSA immediately made responding to the devastation caused by Hurricane Katrina its top priority, working in partnership with FEMA and the affected state governments. In September 2005, SAMHSA announced that:

In collaboration with State, local and Federal partners, our missions are to: 1) "ensure that mental health assessment and crisis counseling are readily available to residents and evacuees of areas impacted by Hurricane Katrina and establish a longer term plan to assure Post Traumatic Stress Disorders (PTSD) are addressed with this population, and 2) ensure that people impacted by Hurricane Katrina who have serious mental illness and/or addictive disorders and children with serious emotional disturbances continue to receive ongoing treatment for their chronic disorder (SAMHSA 2005b).

In that same month, SAMHSA began to put these aims into practice. It awarded $600,000 in SAMHSA Emergency Response Grants (SERG) to provide clinical services and pharmaceuticals to those affected by Hurricane Katrina. The state of Louisiana received one-third of this grant money to provide counseling services to disaster workers and first responders (SAMHSA 2005c).

In addition to this grant, the Department of Health and Human Services (HHS) provided SAMHSA with a $6 million contract to assist in identifying, credentialing, and deploying mental health professionals. SAMHSA identified 194 chaplains, mental health workers, psychologists, and social workers eligible to provide services in the disaster-stricken areas. One hundred of these mental health professionals were deployed to the state of Louisiana.(SAMHSA 2005c)

SAMHSA also worked with the National Suicide Prevention Line to extend its services to people impacted by Hurricane Katrina. From the onset of the hurricane to 26 September 2005, the 110 certified crisis centers involved in the hotline received an average of 173 calls daily; 35 percent more daily calls were received after the onset of the hurricane (SAMHSA 2005b).

SAMHSA and the Federal Emergency Management Agency (FEMA) also partnered to administer the FEMA Crisis Counseling Assistance and Training Program (CCP). These grants are being used to benefit evacuees through outreach, counseling, and public education service. The state of Louisiana in particular was awarded $1 million to provide assistance to hurricane victims after federal workers leave the area (SAMHSA 2005b).

In addition to these efforts, the SAMHSA Emergency Response Center (SERC) was launched in September to assist state officials, support staff deployed in the field, and to be a liaison to other federal and voluntary agencies involved in the public health response to the disaster. SERC deployed teams of people to support state and local efforts, including the provision of: substance abuse/methadone treatment expertise to Louisiana; mental health clinical services to police officers and fire fighters and their families housed on the two Carnival cruise ships in New Orleans; and stress management services to first responders in Mississippi. By the end of September 2005, SAMHSA successfully deployed 63 people (including 12 SAMHSA staff and 7 NIH staff) to the state of Louisiana (SAMHSA 2005b).

By mid-September 2005, SAMHSA estimated that the agency had served 23,500 individuals affected by Hurricane Katrina (SAMHSA 2005a). Subsequently, SAMHSA reported that by February, 2006 it had:

Coordinated the mobilization of more than 500 people to work in the field on mental health and substance abuse issues.

Provided more than 17,000 counseling sessions (91 percent with individuals).

Of these individuals, 26 percent presented problems requiring a referral to local mental health resources for ongoing treatment, and 5 percent required a referral for ongoing substance abuse treatment. These are new cases to an already burdened system.

Despite these important contributions, the fact remains that the health and mental health service systems in New Orleans have been decimated by the combination of: (a) massive facility damage or destruction (e.g., hospitals, practitioner offices), and (b) the departure of the majority of virtually all kinds of clinical service providers, from primary care physicians to optometrists to pharmacists to psychotherapists. Therefore, other mental health issues have resulted from the destruction caused by Hurricane Katrina, beyond the trauma created and people's responses to it.

The publicly funded mental health system in the U.S. is focused on the traditional concept of "serious mental illness," comprising people with chronic disorders, including schizophrenia, bipolar disorder (formerly called manic depressive illness), and borderline personality disorder. These disorders require long-term medication use (antipsychotics, antimanics, and anti-depressants), periodic personal contact with mental health professionals, and assertive case management. People with these disorders who either stayed in New Orleans to ride out the storm or who quickly returned face difficult challenges in adhering to their established treatment regimens, given the current lack of mental health providers, facilities, and pharmacies. The inability to obtain needed medication alone is a very serious problem, but in combination with the current life stressors (home uninhabitable, relatives or friends dead or missing, no job) and lack of clinical resources it becomes a public health disaster.

Those who evacuated and have not returned face possibly greater challenges in establishing new therapeutic alliances in their new residences. Although the population prevalence of serious mental illness is relatively low (about 3 to 5 percent, depending on the specific definition), given the pre-hurricane size of the New Orleans population, this is another important public health problem. Obviously, many important needs must be addressed to reestablish New Orleans as a viable community, but it is clear that establishing fully functioning health and mental health service systems in New Orleans is one of the multiple foundations on which recovery of the city will be built.

Additionally, however, studies of recent disasters have made it clear that the reactions of children to mass disaster differ from those of adults. Studies of both the bombing of the Murrah Federal Building in Oklahoma City (Pfefferbaum et al. 1999, 2000, 2001) and the September 11 terrorist attacks (Hoven et al. 2006) have provided empirical documentation of serious impact of these events on children and adolescents, even those who were not directly affected. Given the large number of children directly affected by Hurricane Katrina, and the life disruptions created by evacuation, it is reasonable to anticipate the possibility of long-term consequences of Katrina for both directly and indirectly affected children and adolescents.

7.3.1.4. Pre-Literature: Studies Currently in the Field or Recently Completed

In addition to searching the scientific and grey literatures, we attempted to identify studies currently underway or soon to be underway that may produce findings of relevance to this report. We contacted relevant funding sources and key researchers in the field to identify current and/or planned studies about Katrina and its health and mental health impacts.

In what follows, we describe major studies that we identified that are relevant to the health and mental health effects of Hurricane Katrina. We organize the studies by the organization(s) conducting the work.

7.3.1.4.1. Harvard University. With funding primarily from NIMH, Dr. Ronald C. Kessler of the Department of Health Care Policy, Harvard Medical School, is conducting a longitudinal study of the impact of Katrina. The study sample of about 2,000 people was selected via a mixture of area probability and list sampling methods. About half the sample lived in New Orleans when the storm hit and the other half lived in the other areas hit (Alabama, Louisiana, Mississippi). Dr. Kessler calls the study sample the "Hurricane Katrina Community Advisory Group," and they are interviewed every three months for a period of two years. The study aims to document the experiences of a broad cross section of people affected by Katrina – their experiences during the storm, their emotional reactions, and problems that they may have faced in the aftermath. Although no findings have been released yet, the plan is that information will begin to be released when the first scientific article of findings has been accepted for publication, which may be as early as June 2006.

7.3.1.4.2. Columbia University. A group at Columbia University's National Center for Disaster Preparedness (Mailman School of Public Health), led by Drs. David Abramson and Richard Garfield, along with The Children's Health Fund, is studying the health and psychosocial status of people who were exposed to Hurricane Katrina. The researchers conducted interviews with a probability sample of 665 households of people who had evacuated New Orleans and were living in trailers or hotels in Louisiana during February 2006. Preliminary findings indicate that nearly half of parents report new emotional or behavioral problems in their child(ren) since the storm, and that more than half of mothers assessed had mental health screening results consistent with probable clinical diagnosis. Additionally, about 25 percent of the school-aged children were not enrolled in school or had missed 10 or more days of school in the past month.

In addition, another group at the Mailman School, led by Dr. Neil Boothby and working with Save the Children, has conducted psychological evaluations with about 1,400 children in school-based psychosocial programs in New Orleans. This group intends to conduct more than 50,000 evaluations between January and June 2006. An early finding from the screenings is a relatively high prevalence of pre-Katrina exposure to other trauma, mostly violence.

7.3.1.4.3. Johns Hopkins University. A group of experienced investigators from the Bloomberg School of Public Health has recently completed a set of five coordinated studies referred to collectively as the Johns Hopkins Public Health and Safety Consequence Analysis and Projection, funded by FEMA. Dr. Tom Burke, Professor of Health Policy and Management and co-director of the Risk Sciences and Public Policy Institute, served as principal investigator for the effort, and each of the five studies was led by an expert in its topic area (pathogens and disease, Dr. Kellogg Schwab; environmental toxins, Dr. Mary Fox; psychological impact on resident populations, Dr. Donald Steinwachs; physical injuries, Dr. Adnan Hyder; and Continuity of care, Dr. Gerald Anderson). The reports of the studies have recently been submitted to FEMA, where they are under review.

7.3.1.4.4. RAND Corporation. In collaboration with seven local universities, The RAND Corporation, a private, not-for-profit research firm headquartered in Santa Monica, CA, has created the RAND Gulf States Policy Institute. The Institute's mission is to facilitate recovery from the devastation of Hurricanes Katrina and Rita by "providing evidence-based policy guidance to facilitate and speed regional recovery and growth, re-establish services and result in a wise investment in infrastructure." Funded in part by RAND donor contributions and unrestricted funds, RAND and its partner universities implemented quickly a set of studies aimed at important policy issues for recovery. These studies address diverse issues, including: dealing with uninsured losses; safety planning for healthcare structures; recruitment/retention of high-quality healthcare workforce; options for education in New Orleans; the housing crunch in Mississippi; Katrina's effect on the health of first responders and residents; mental health needs of students; the effect of hurricane-related displacement on schools and students; and documenting lessons learned from the public health response.

Several of the studies currently in the field are relevant to this review. The study of mental health needs of students is focused on developing an infrastructure in the New Orleans school system to address the needs of flood-affected students. The study of hurricane-related displacement will document where displaced students went and for how long, and will compare achievement and psychosocial outcomes of displaced versus not displaced students over time. The study of lessons learned, funded by DHHS's Office of Public Health Emergency Preparedness, is focusing on documenting and assessing specific aspects of the public health response, including: communications, disease surveillance and investigation, laboratory capacity, provision of essential medical services to affected people, and planning and policy development.

7.3.2. Loss of Life Modeling

7.3.2.1. Objective

The objective of the analysis was to estimate loss of life associated with hurricane-related flood events that may affect the greater New Orleans area. Potential loss-of-life estimates are limited to the 27 drainage subbasins making up the New Orleans hurricane protection system. We evaluated loss of life from flooding corresponding to two demographic and structural base conditions. First, we estimate the loss of life associated with all flood levels given the population and housing stock that existed prior to Hurricane Katrina. These results will be helpful in IPET's forensic study of the impact of Hurricane Katrina, and in understanding how the effects might have been different had the flood protection system performed differently. Second, we estimate the loss of life associated with all flood levels given the population and housing stock that are expected to exist in June 2006. These results will help inform decisions regarding the residual risk that exists today and how these risks can be reduced in the future.

7.3.2.2. Limitations of the Analysis

Certain limitations and analytical issues constrained the loss-of-life estimation technique available at the time of the study. The analysis was dependent on the best available information at the time the input data elements were identified or developed. Future analysis of the estimated fatalities associated with hurricane-related flooding in the greater New Orleans area may be better informed by results and outputs from other IPET tasks, continued compilation of information from local data sources, and publication of other relevant reports. Key limitations of the analysis are summarized below:

Evacuation—Estimates of the total population evacuated prior to Hurricane Katrina making landfall for the greater New Orleans area range between 70 and 90 percent. Little or no information is available to determine what the spatial distribution of the population at risk (PAR) during Hurricane Katrina was on a parish or neighborhood-level. Presumably, individuals with access to a vehicle evacuate well in advance of hurricane landfall if they have received adequate warning and communication prior to the storm event. More evidence is needed to characterize the PAR, based on demographic profiling and survey information.

Rescue—Full information from various sources is not readily available to account for the total number of individuals rescued in the days and weeks following Hurricane Katrina in late August and early September 2005. U.S. Coast Guard, Louisiana National Guard, Fish and Wildlife Service, and other state and local emergency responders rescued thousands of stranded individuals from rooftops, multi-story buildings, highway overpasses, and localized points where survivors congregated (e.g., the Superdome and the New Orleans Civic Center). Furthermore, the demographic profile of those that were rescued is unclear (gender, race, approximate age, and place of residence). This information will be useful if it becomes available to more accurately calibrate the loss-of-life model to account for fatalities associated with prolonged exposure or dehydration, as opposed to fatalities associated with submergence due to flood inundation or levee/pump station failure.

Fatalities— Detailed Hurricane Katrina fatality information is currently not available to improve the calibration of the loss-of-life modeling. The spatial and demographic distribution of fatalities associated with Hurricane Katrina cannot be estimated without a linkage to the cause of death, location of body and/or place of residence, age, race, gender, or other non-personal information for victims of Hurricane Katrina. Data from parish coroners' offices in the greater New Orleans area have not been released to the USACE, and the information from the St. Gabriel Morgue is incomplete. Better loss-of-life information for Hurricane Katrina would make it possible to calibrate the model more accurately.

Flooding Dynamics—The analysis does not capture the temporal and spatial flood dynamics. Flow and velocity of storm surges, flood duration, and the flood dynamics across drainage subbasins were not considered. Other components of the IPET study are characterizing some aspects of flooding dynamics and interactions between and across drainage subbasins in the greater New Orleans area; however, these results, and outputs that could inform the loss-of-life modeling, are not yet available. Therefore, the loss-of-life model treats each drainage subbasin independently, and only the maximum flood elevation (high-water mark) is considered. The flooding dynamics and interactions could influence the loss-of-life estimates greatly, and these estimates may become less uncertain as more information from the IPET study is made available.

Levee Breaches/Inundation Rates—The analysis does not address the localized impacts of levee breaches and the rate of inundation. For the Hurricane Katrina model scenario, the total area of the impacted zones around levee breaches is relatively low. The rate of water flow associated with the levee breaches is not considered. As a result, it is unclear to what extent additional fatalities due to drowning can be attributed directly to submergence versus collapse.

Population at Risk (PAR) Demographics—Pre-Hurricane Katrina population estimates (August 2005) were derived from the 2000 Census, and the post-Hurricane Katrina repopulation estimates (June 2006) were estimated based on school re-enrollment data (further described in Section 3). The spatial distribution of the PAR based on race, income, and gender were not considered.

It is anticipated that these limitations and analytical gaps can efficiently be addressed in future studies through enhancements to the current modeling approach, by sufficiently minimizing the uncertainty associated with probabilities of evacuation, rescue, and fatalities. Additionally, greater analytical rigor to characterize the hydrograph during flood events should inform the loss-of-life estimates, through better understanding of the time and spatial interrelationships of the hurricane protection system versus physical impacts of hurricane events.

7.3.2.3. Modeling Approach

Our modeling approach is a two-step process. We use the LIFESim model to estimate how the population in the flooded areas will be distributed vertically in relation to the depth of the flood. We then import these vertical distribution estimates into a Monte Carlo Uncertainty Model to estimate the expected loss of life.

7.3.2.3.1. LIFESim Simulation Modeling System. LIFESim is a spatially distributed dynamic simulation modeling system for estimating potential loss of life associated with flood events. It is structured as a modular modeling system built around a database. LIFESim was developed to overcome the limitations of the purely empirical life-loss estimation approaches used previously. It includes the important processes that affect loss of life, while also depending on readily available inputs—including GIS information on topography and road layout, as well as population and buildings databases—combined with a reasonable level of effort to customize and implement the analysis. Development of LIFESim was sponsored by the U.S. Army Corps of Engineers, the Australian National Committee on Large Dams, and the U.S. Bureau of Reclamation. For this analysis, LIFESim was adapted to estimate flood-related mortality associated with hurricanes impacting the greater New Orleans area. Figure 15 illustrates the processes of the LIFESim simulation modeling system.

The four modules that make up the LIFESim simulation modeling system are:

Inundation Module—interfaces with an existing inundation model to provide a set of grids representing water depth and flow velocities over the entire study area and throughout the duration of the flood event.

Loss-of-Shelter Module—simulates the exposure of people in buildings during each flood event as a result of structural damage, building submergence, and toppling of partially damaged buildings. Loss-of-shelter and flood zone categories are assigned to each building level in various types of buildings throughout the inundation area.

Warning and Evacuation Module—simulates population redistribution following issue of a warning. Redistribution includes lateral evacuation along evacuation routes from each Census block, and vertical relocation within the inundation area to accessible shelters. Times when vehicles and pedestrians are expected to become unstable, such as by flotation of vehicles and toppling of pedestrians are estimated along evacuation routes. After those events, mobilization ceases, and people in vehicles or on foot along evacuation routes are assigned to a chance flood zone.

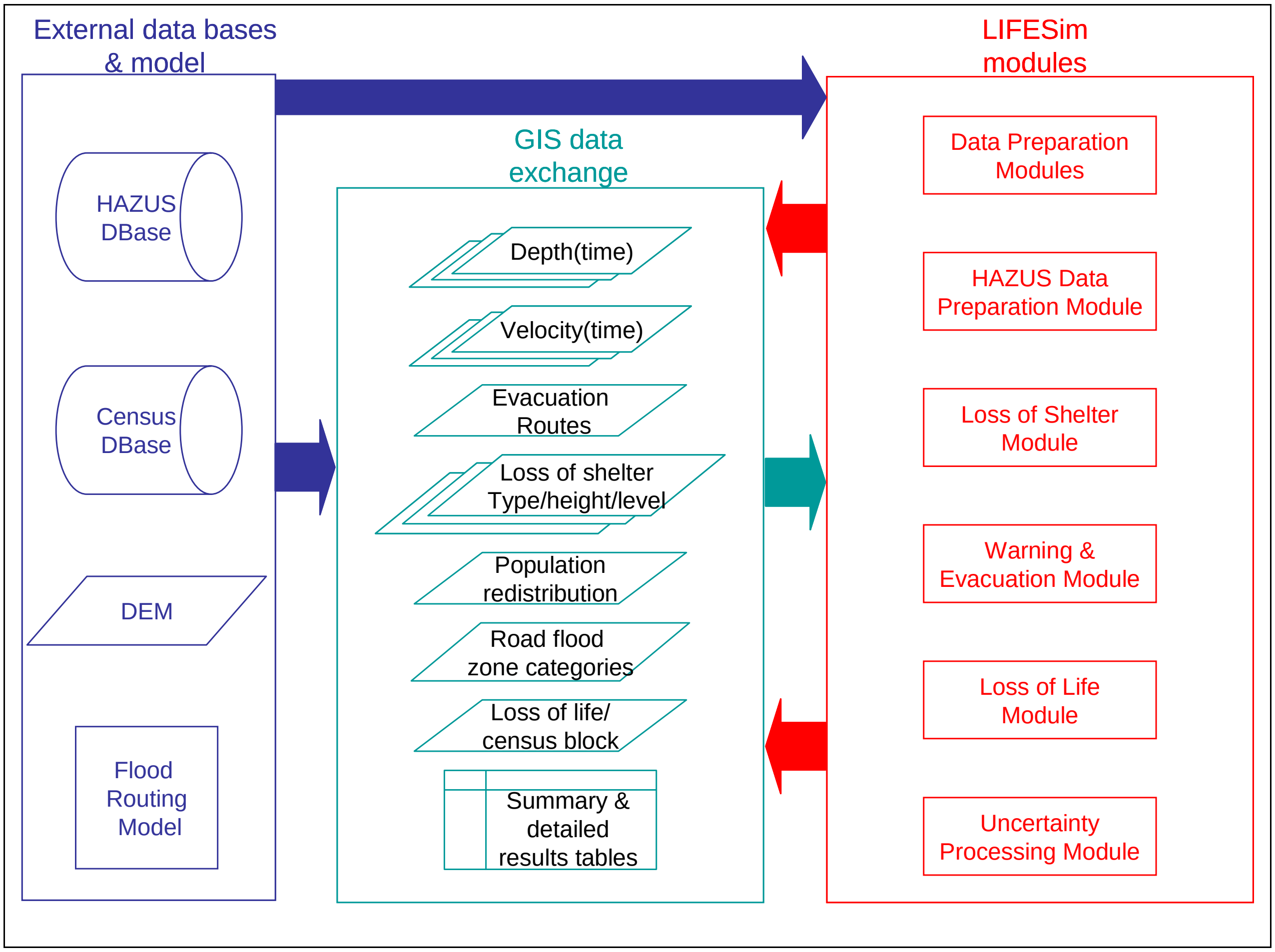


Figure 15. Simplified schematic diagram of the LIFESim Modeling System (Source: *Adapted from Aboelata (2005*).

Loss-of-Life Module—based on the assigned flood zone categories, life-loss estimates are made using life-loss probability distributions.

The analysis only used the two most relevant modules, the *Loss-of-Shelter Module* and the *Loss-of-Life Module*. The study did not use the *Inundation Module* because inundation rates and water flow velocity estimates were not available at the time of the study. The omission of this module from the study is less significant in hurricane protection system failure flooding scenarios than it is in dam breach flooding scenarios. The *Warning and Evacuation Module* was not used because there was insufficient information to calibrate it. These aspects were accounted for in the Monte Carlo model.

LIFESim has been applied to a set of event-exposure scenarios. Events include various dam or levee failure modes and breach locations, no-failure flooding, and varying flood severities. Exposure cases include different seasons, day/night, and weekend/weekday.

The difference in nature between a dam break and a hurricane-related flooding necessitated some additional assumptions for the model as well as elimination of some LIFESim functions.

The following list describes the adjustments made to the LIFESim model to simulate Hurricane Katrina and future hurricane events.

Dam break events are usually sudden, with short warning time. This implies the strong effect of the dynamics of evacuation. In the case of Hurricane Katrina or another hurricane scenario, sufficient warning was given long before hurricane landfall (estimated to be as long as 50 hours in advance), such that the evacuation dynamics have no effect. The warning and evacuation module in LIFESim was, therefore, marginalized.

Loss-of-shelter in LIFESim depends mainly on two factors—building damage and submergence. Based on site investigations, the major cause of life-loss appears to be submergence of buildings. Building damage criteria depend on combinations of water depth and flow velocity. During Hurricane Katrina, most areas not adjacent to levee breaks experienced flow velocities that were too low to play a role in building damage. Therefore, in this study loss of shelter is calculated based on only the submergence consideration, which is water depth relative to floor elevation at each habitable building level and an additional loft or roof level.

Vertical distribution of people inside a building is also a factor related to available evacuation time. The LIFESim model, for the purposes of hurricane-related flood events, assumes that all people exist in the highest habitable level of the building. In addition, it was further assumed that all people under the age of 65 years can climb to a higher level such as an attic or roof.

The original LIFESim model assumed a fixed value for the average first floor level. Data were available for the greater New Orleans area on the average first floor level per Census block. The LIFESim model was modified to accommodate variable first floor level elevation for added accuracy.

The original definitions of flood lethality zones used in LIFESim are chance, being in an open flood or flowing water, compromised, such as being in a partially damaged building, and safe, such as being in an undamaged building above the maximum water level. The threshold event maximum water depths associated with each flood zone were estimated through a calibration process under the assumption that all buildings that stay intact with no damage. Figure 16 shows these calibrated water depths for loss-of-shelter definitions used in this study for the three associated flood zones—safe, compromised, and chance. The three flood lethality zones were further modified to account for the disproportional impacts to populations over the age of 65 years old. The model assumes those over the age of 65 years old are unable to evacuate vertically above the highest habitable floor. For populations under 65 years old, the three flood lethality zones begin immediately above the first floor—i.e., the attic or roof.

Another flood zone category was added to account for the number of people within the flooded area who can evacuate without any need for rescue. The people in the walk-away flood zone are those in areas where water depth does not exceed 2 feet above ground surface.

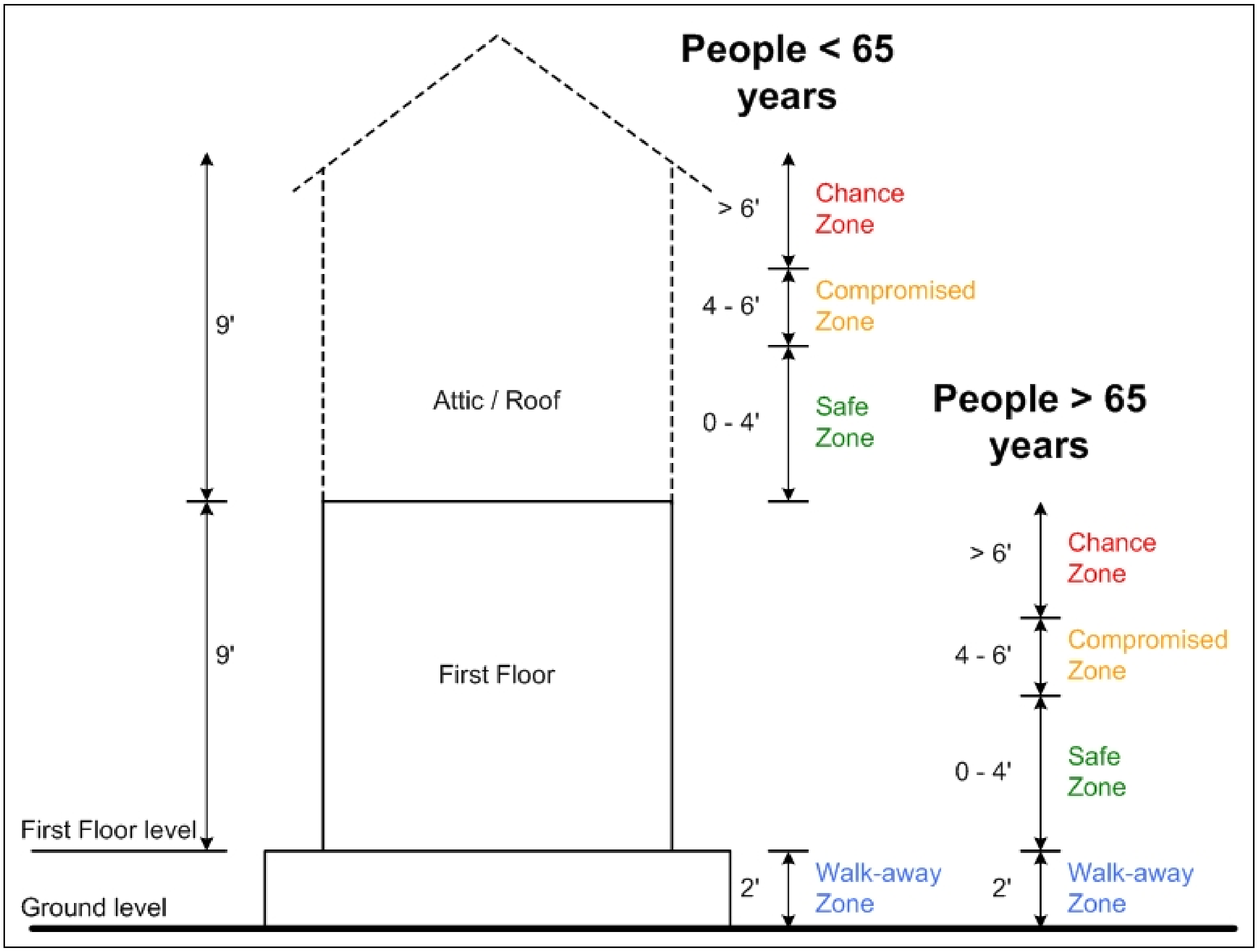


Figure 16. Modified building submergence criteria.

For each maximum flood elevation (e), LIFESim estimated the following output statistics by drainage subbasin(s) across impacted flood zone categories:

1. Number of people in the *walk-away zone (*less than 2 feet inundation at ground level) ($WZ_{s,e}$).
2. Number of people in the *safe zone* (less than 4 feet inundation on highest habitable level) ($SZ_{s,e}$).
3. Number of people in the *compromised zone* (between 4 feet and less than 6 feet inundation on highest habitable level) ($CZ_{s,e}$).
4. Number of people in the *chance zone* (greater than or equal to 6 feet inundation on highest habitable level) ($HZ_{s,e}$).

7.3.2.3.2. Loss-of-Life Uncertainty Modeling. The LIFESim PAR by flood zone data ($WZ_{s,e}$, $SZ_{s,e}$, $CZ_{s,e}$, $HZ_{s,e}$) was imported into a Monte Carlo Uncertainty Model. The Uncertainty Model accounted for uncertainty by running 50,000 Monte Carlo simulations (i). For each iteration, the Uncertainty Model addressed the following steps:

1. Picked a random value for each of the uncertain parameters based on defined probability distributions (the actual distributions are provided in Section 4):

- Evacuation Rate (ER)
- Rescue Efficiency in Safe Zone (RSE)
- Rescue Efficiency in Compromised or Chance Zone (RCE)
- Fatality Rate in Safe Zone (FS)
- Fatality Rate in Compromised Zone (FC)
- Fatality Rate in Chance Zone (FH)

2. Adjusted the number of estimated people in each flood zone by drainage subbasin given the evacuation rate (ER_i):

$$WZ_{s,e,i} = WZ_{s,e} * (1- ER_i) \text{ \{Walk-away Zone\}}$$

$$SZ_{s,e,i} = SZ_{s,e} * (1- ER_i) \text{ \{Safe Zone\}}$$

$$CZ_{s,e,i} = CZ_{s,e} * (1- ER_i) \text{ \{Compromised Zone\}}$$

$$HZ_{s,e,i} = HZ_{s,e} * (1- ER_i) \text{ \{Chance Zone\}}$$

3. Calculated the number of immediate fatalities (IF) due to inundation:

$$IF_{s,e,i} = SZ_{s,e,i} * FS_i + CZ_{s,e,i} * FC_i + HZ_{s,e,i} * FH_i$$

4. Calculated the number of stranded persons in each zone (SPS, SPC, SPH):

$$SPS_{s,e,i} = SZ_{s,e,i} * (1- FS_i)$$

$$SPC_{s,e,i} = CZ_{s,e,i} * (1- FC_i)$$

$$SPH_{s,e,i} = HZ_{s,e,i} * (1- FH_i)$$

5. Calculated the fatalities among stranded persons (DF):

$$DF_{s,e,i} = SPS_{s,e,i} * (1- RSE_i) + SPC_{s,e,i} * (1- RCE_i) + SPH_{s,e,i} * (1- RCE_i)$$

6. And finally, calculated the total fatalities (F):

$$F_{s,e,i} = IF_{s,e,i} + DF_{s,e,i}$$

After completion of the 50,000 iterations, the results were summarized for each drainage subbasin and elevation by estimating the mean and percentiles of the distribution (1, 5, 10, 25, 50, 75, 90, 95, and 99 percent) of $F_{s,e}$.

7.3.2.4. Data Requirements

Data requirements for the LIFESim simulation modeling system include GIS data layers and non-spatial information. These data sets are described below in Table 30. All of the information was compiled into a database and accessed through a customized LIFESim model interface for the New Orleans situation. The analysis considered the loss-of-life impacts from hurricanes across the five-parish study area by evaluating flood elevation at 2-foot increments within each of 27 affected drainage subbasins.

7.3.2.4.1. Data Sources and Processing. The data types and sources used in the LIFESim model are described in Table 32. In general, these data were collected, synthesized, and compiled into a database consistent with other IPET teams and USACE sources. All GIS data layers were based on the Universal Transverse Mercator (UTM) coordinate system, and projected according to the North American Datum of 1983 (NAD 1983) in all instances except for elevation data, which were projected in accordance with the North American Vertical Datum of 1988 (NAV88).[1] The greater New Orleans area is within UTM Zone 15N. All GIS data layers were collected, corrected, cleaned, or geoprocessed into ESRI shapefile format for use within the ArcGIS ArcView 9.1 software. GIS base map data not pertinent to the LIFESim modeling requirements are not listed in Table 32. These data layers were collected from USACE sources for the purpose of generating map outputs for this report.

[1] The North American Datum of 1983 (NAD83) is the horizontal control datum for North America and the North American Vertical Datum of 1988 (NAV88) is the vertical control datum of North America. These projection systems are compatible and widely used in conjunction with each other, particularly for studies in coastal areas.

Table 32 LIFESim Model Data Requirements		
Data Element	**Source**	**Description**
GIS/Spatial Information		
LIDAR Data	NASA, USACE-New Orleans District	The light detection and ranging (LIDAR) data were geoprocessed by the USACE-New Orleans District into one mosaic covering the study area. The LIDAR data were converted from LA-State Plane (NAD83) to UTM 15N (NAD83) and resampled to estimate average elevation in each 30-meter grid cell covering the study area.
Census Blocks	HAZUS database (FEMA)	2000 Census block boundaries
Flood Depth / Extent	USACE	High-water mark points demarcating the maximum flood extent in the affected greater New Orleans area. The maximum flood depth at the lowest elevation within the drainage subbasin was calculated based on the high water marks and flood extent.
Drainage Subbasins	USACE	27 drainage subbasins comprising the New Orleans flood protection system.
Non-Spatial Information		
August 2005 Population (pre-Hurricane Katrina)	U.S. Census Bureau, HAZUS database (FEMA), Woods and Poole (2001)	2000 census block data (U.S. Census Bureau) available through the HAZUS database (FEMA) were projected to 2005 using parish-level population growth rates (Woods and Poole) specific to each of the age categories considered in the analysis (< 16 years old, 16-65 years old, and > 65 years old). August 2005 population estimates were spatially joined to the census block boundary ESRI shapefile using the STIFID field.
June 2006 Population (post-Hurricane Katrina)	U.S. Census Bureau, HAZUS database (FEMA), Woods and Poole (2001), McCarthy et al. (2006)	The 2005 population estimates (see description above) were adjusted based on repopulation rates based on flood depth / housing damage categories (McCarthy et al.). June 2006 population estimates were spatially joined to the Census block boundary ESRI shapefile using the STIFID field.
2005 Building/Infrastructure Data	HAZUS database (FEMA)	Average ground level and first-floor level (typically 2 feet above ground) were calculated for each census block based on the HAZUS data. First floor level varied depending on whether buildings were constructed on a concrete slab or slightly raised several feet above ground level.
2006 Building/Infrastructure Data	HAZUS database (FEMA)	Average ground level and first-floor level (typically 2 feet above ground) were calculated for each census block based on habitable buildings (no damage or partially damaged) from the inventory of buildings in the HAZUS database.

7.3.2.4.2. Pre-Hurricane Katrina Population at Risk (PAR) Estimate (August 2005).

The 2000 census block population data were projected to 2005 to estimate the pre-Hurricane Katrina population in the greater New Orleans area. This was done based on the following steps:

1. Extracted 2000 census block data by age groups (<16 yr, 16-65 yr, and >65 yr) from the HAZUS-MH database.

2. Extracted Woods and Poole (2001) population (by age category) multipliers for each of the five parishes in the greater New Orleans study area for 2005.

3. Averaged Woods and Poole age groups into three categories to match 2000 census block age categories in HAZUS-MH.

   a. <16 years (HAZUS-MH) = Weighted average by year: <1, 1-4, 5-9, and 10-14, 15-19 (Woods and Poole) *b.* 16-65 years (HAZUS-MH) = Weighted average by year (Woods and Poole): 15-19, 20-24, 25-29, 30-34, 35-39, 40-44, 45-49, 50-54, 55-59, 60-64, 65-69

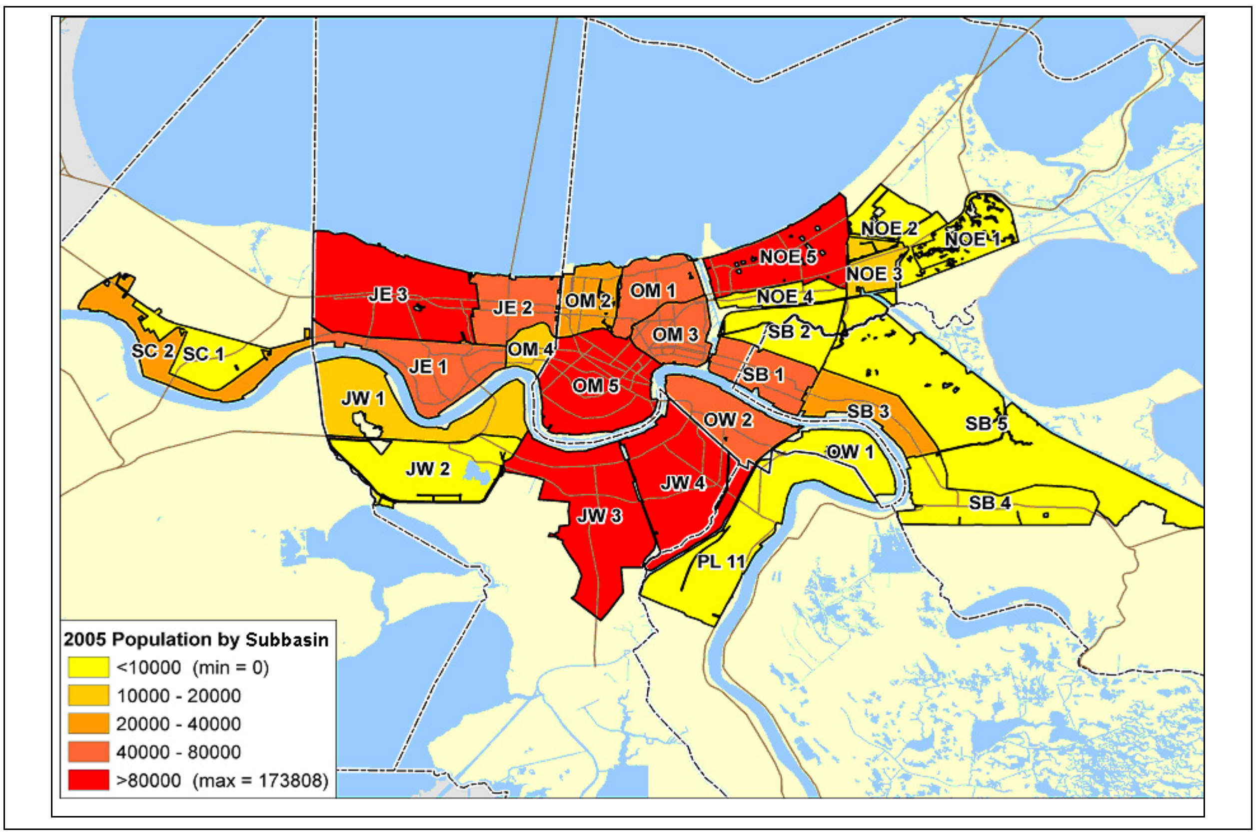
c. >65 years (HAZUS-MH) = Weighted average by year (Woods and Poole): 65-69, 70-74, 75-79, 80-84, 85 Up

4. Multiplied 2000 census block population data by the Woods and Poole multiplier by parish and age group. (See Table 33) August 2005 estimated population densities by drainage subbasin are illustrated in Figure 17.

Table 33
2005 Population Multipliers by Parish

Parish	< 16 Years Old	16 – 65 Years Old	> 65 Years Old
Jefferson	0.9925	1.062	1.144
Orleans	0.9293	1.003	0.9793
Plaquemines	0.9298	1.034	1.147
St. Bernard	0.9586	1.023	1.132
St. Charles	0.9980	1.076	1.136

Source: Woods and Poole (2001).



JE = Jefferson East, JW = Jefferson West, OM= Orleans Metro, PL= Plaquemines, NOE = New Orleans East, SB = St. Bernard, and SC = St. Charles.

Figure 17. August 2005 estimated population density within the greater New Orleans area.

7.3.2.4.3. Post-Hurricane Katrina Population at Risk (PAR) Estimates (June 2006). June 2006 population at risk (PAR) estimates used in the analysis were based on a comparison of two methods used for calculating post-Hurricane Katrina repopulation dynamics in the greater New Orleans area. The Greater New Orleans Community Data Center (GNOCDC) estimates population from school enrollments by month and parish (GNOCDC 2006), while McCarthy et al. (2006) consider flood level from Hurricane Katrina for their estimates of repopulation. More specifically, McCarthy et al. derived repopulation rates into four categories of flood level by a consensus process with qualitative evidence and assumptions (Table 34). Comparing the two methods, the McCarthy et al. method was preferred in this analysis, primarily because the data were calculated by census block as the unit of analysis (higher spatial resolution) versus the parish-level approach used in the GNOCDC method.

Table 34
Hurricane Katrina Flood Level Classification and 2006 New Orleans Repopulation Rates

Flood-Depth / Housing-Damage Category	Mean Depth of Floodwater	Housing Damage	Repopulation Rate March 2006[1] , %
1	No flooding	None	100
2	< 2 feet	Minor	35
3	2 – 4 feet	Serious	15
4	> 4 feet	Severe	5

[1] March 2006 is used as a proxy for June 2006.
Source: McCarthy et al. (2006).

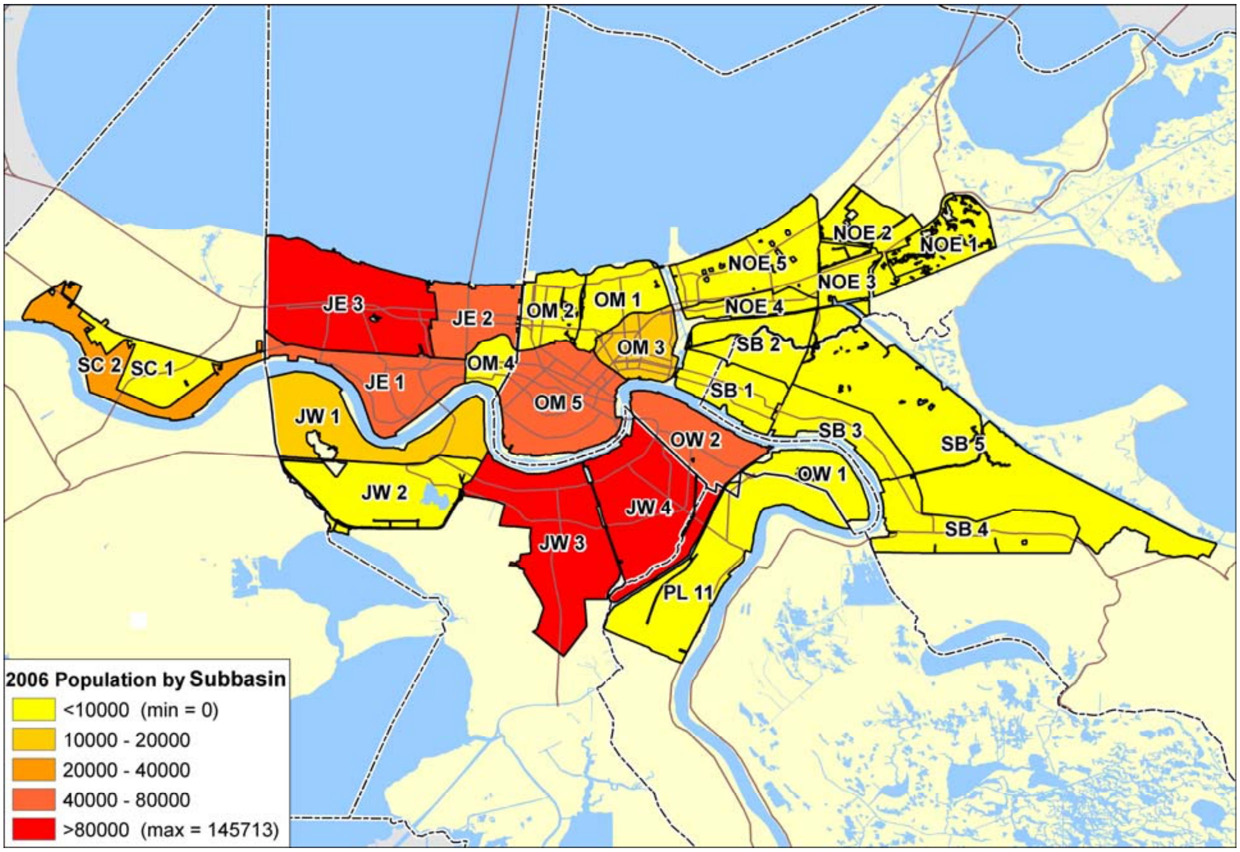
The analysis summarized the mean flood depth data by census block. In following the McCarthy et al. method, the Census blocks are repopulated according to the following four categories: no flooding, less than two feet, two to four feet, and greater than four feet. Next the 2005 census block population projections were multiplied by repopulation rate (according to the flood level category). Table 35 illustrates the results of the June 2006 population projection for the five parishes comprising the greater New Orleans area. Figure 18 maps the projected population density for the census blocks in the greater New Orleans area for June 2006.

Table 35
Projected June 2006 Total Population by Hurricane Katrina Mean-Flood Extent

Flood by Mean	2000	2005	Repopulation Rate, %	2006
No flooding	609,355	636,361	100	636,361
< 2 feet	80,124	80,093	35	28,026
2 – 4 feet	93,653	92,732	15	13,904
> 4 feet	298,692	295,920	5	14,747
Total	**1,081,824**	**1,105,106**		**693,038**

Source: McCarthy et al. (2006)

7.3.2.4.4. Population Change in Greater New Orleans. The post-Hurricane Katrina (June 2006) total population for the area is anticipated to be approximately 64 percent of the pre-Hurricane Katrina (August 2005) total population. Table 36 illustrates the estimated change in population across the five-parish greater New Orleans study area since 2000.



JE = Jefferson East, JW = Jefferson West, OM= Orleans Metro, PL= Plaquemines, NOE = New Orleans East, SB = St. Bernard, and SC = St. Charles.

Figure 18. June 2006 estimated population density within the greater New Orleans area.

Table 36
Population Dynamics Pre- and Post-Hurricane Katrina in Greater New Orleans Area

Parish	2000	August 2005	June 2006
Jefferson	455,407	481,322	472,084
Orleans	484,431	476,705	141,511
Plaquemines	26,738	27,206	20,053
St. Bernard	67,194	68,912	8,429
St. Charles	48,054	50,961	50,961
Total	**1,081,824**	**1,105,106**	**693,038**

7.3.2.5. Analysis

The analysis was conducted in three stages. Section 7.3.2.5.1 describes how the LIFESim model was calibrated in the first stage using the Hurricane Katrina event as a single known hurricane flooding event. Section 7.3.2.5.2 discusses how the LIFESim model was then used to develop elevation versus fatality relationships for pre- and post-Hurricane Katrina conditions.

7.3.2.5.1. Model Calibration. One of the necessary steps, and challenges, associated with simulation modeling is the need to calibrate the model to one or more known outcomes to ensure that the model's results are reasonable. As mentioned above, there are seven unknown parameters that must be jointly calibrated in order for the results of our simulation to be meaningful. These are:

- Evacuation rate
- Fatality rate in safe zone
- Fatality rate in compromised zone
- Fatality rate in chance zone
- Rescue rate in safe zone
- Rescue rate in compromised zone
- Rescue rate in chance zone

Our approach to calibrating the model was to assume reasonable values for each of these uncertain parameters using all information available to us. This was an iterative process and there is no correct answer. Many reasonable combinations of these parameters can be found. This fact is addressed in how we use the LIFESim model to estimate fatalities under the pre-Katrina and post-Katrina scenarios. We continue to treat each of these parameters as uncertain and develop our estimates for the full range of reasonable values for each of these parameters. In a sense, this calibration exercise assured us that our best estimate of the value of each of the uncertain parameters was reasonable. When we use the model to actually predict life-loss, rather than use point estimates of these uncertain parameters, we use uncertainty distributions where these best estimates will become the mean of each distribution.

In the remainder of this section we will demonstrate how we calculated the loss of life for the Katrina event and then compared our estimate to the actual number of fatalities to determine if our best estimates led to reasonable results.

At the time this analysis was conducted, the latest data on Katrina-related deaths in Louisiana as of 2 August 2006 reported by the Louisiana Department of Health and Hospitals (reproduced in Table 24 in Section 7.3.1.2.1.1 of this report) were not yet available. Consequently, the model calibration relied on mortality data published by the Louisiana Department of Health and Hospitals State (2006) on bodies processed at the St. Gabriel Morgue as of 23 February 2006, and data on the number of people missing and presumed dead as of that date. The St. Gabriel Morgue data provide the name, age, and parish of residence for each deceased person. Because this is the only information available, we assume throughout this analysis that people died in the parish of their residence. These statistics are presented in Table 37. Of the 887 corpses identified by the Department, 160 did not have their parish of residence listed. We apportioned these 160 fatalities based on the known proportions of fatalities across all geographical categories (i.e., the parishes and out of state). We consider these to be "recorded fatalities." Recorded fatalities are the low-end of the potential Katrina-related fatalities. To estimate the high-end of the number of fatalities, or "potential fatalities" we used an estimate provided by the Louisiana Department of Health and Hospitals (*LA Times* 2006) that up to 400 persons who are currently missing are

Table 37: Recorded and Potential Fatalities Associated with Hurricane Katrina

Parish	St. Gabriel Morgue February 23, 2006	Not ready/missing Apportioned	Recorded Fatalities	400 Likely Fatalities Apportioned	Potential Fatalities
East Baton Rouge	2	0	2	1	4
Jefferson	28	6	34	15	50
Orleans	554	122	676	305	981
Out of State	3	1	4	2	5
Plaquemines	3	1	4	2	5
St. Bernard	129	28	157	71	228
St. John the Baptist	1	0	1	1	2
St. Tammany	3	1	4	2	5
Unknown	3	1	4	2	5
Washington	1	0	1	1	2
Ready to be released	74				
Unknown	86				
TOTAL	887	160	887	400	1,287

Source: St. Gabriel Morgue not ready/missing adapted from LA DHH, http://www.dhh.louisiana.gov/offices/publications/pubs-192/Deceased Victims_2-23-2006_information.pdf

actually deceased. We apportioned these according to the proportion of recorded fatalities across the geographical categories.[1]

LIFESim was used to simulate the loss of life based on the maximum flood elevation during Katrina. For each drainage subbasin, LIFESim output the following statistics:

- Number of people in the walk-away zone
- Number of people in the safe zone
- Number of people in the compromised zone
- Number of people in the chance zone

As mentioned above, actual fatality data are available only at the parish level; therefore we aggregated the LIFESim drainage basin level results to the parish level. These results are presented in Table 38.[2] It is important to remember that the results in Table 38, as well as the results in Tables 39 and 40 assume that nobody evacuated the area prior to the flooding.

Table 38
LIFESim Model Results Assuming 0% Evacuation

	Walk-Away Zone	Safe Zone	Compromised Zone	Chance Zone	Total
Jefferson Parish	19,410	5,380	2	5	24,797
Orleans Parish	94,566	308,219	3,439	2,974	409,198
St. Bernard Parish	7,299	54,625	1,883	1,613	65,421
TOTAL	121,275	368,225	5,324	4,592	499,416

[1] Note that the number of recorded 1,118 deaths within Louisiana as of 2 August 2006 (as reported in Table 24 in Section 7.3.1.2.1.1) falls within the range of potential fatalities (887- 1,287) reported in Table 35 and used to calibrate the loss of life model.
[2] We only used three parishes to calibrate the model, since only four or five fatalities are reported to have occurred in Plaquemines parish and the LIFESim model predicted that no people were in the safe, compromised, or chance zones in Plaquemines Parish. Likely, all of the Katrina-related fatalities occurred in parts of Plaquemines Parish that are outside the drainage basins included in this study.

Table 39 Immediate Fatalities Assuming 0% Evacuation					
	Walk-Away Zone	Safe Zone	Compromised Zone	Chance Zone	Total
Jefferson Parish	0	1	0	4	6
Orleans Parish	0	70	413	2,729	3,211
St. Bernard Parish	0	12	226	1,480	1,719
TOTAL	0	83	639	4,214	4,936

Table 40 Stranded Persons Assuming 0% Evacuation					
	Walk-Away Zone	Safe Zone	Compromised Zone	Chance Zone	Total
Jefferson Parish	0	5,379	2	0	5,381
Orleans Parish	0	308,150	3,026	245	311,421
St. Bernard Parish	0	54,613	1,654	133	56,403
TOTAL	0	368,142	4,685	379	373,205

The number of immediate fatalities, due to inundation, during the Katrina event is estimated by applying the fatality rate associated with each flood lethality zone by the number of people in each zone. Of the seven unknown parameters with which we are calibrating the model, the fatality rates are based on the soundest data. The mean fatality rates we use in this analysis come from a study of 66 flood events (McClelland, 2002). The mean fatality rates are 0.023 percent, 12 percent, and 91.75 percent in the safe, compromised, and chance zones. The number of estimated fatalities in each zone (absence any prior evacuation) is shown in Table 39.

As the name suggests, it is assumed that all persons in the walk-away zone can escape the flooding on their own and do not require rescue. People who survive the initial flood inundation in the other three flood zones are assumed to be stranded and must be rescued. The estimated number of stranded persons in each zone (absent any prior evacuation) is presented in Table 40

Of course, most people did evacuate from the flooded areas prior to the onset of the inundation. However, little information is available with regard to the exact number of people who evacuated. The evacuation rate is a major driver of the life-loss estimate. For the purposes of this calibration we assumed that 80 percent of the people evacuated. This figure has been seen in the popular press and seems to be a reasonable assumption. Given this, the number of immediate fatalities and stranded persons in each parish is shown in Tables 41 and 42.

Table 41 Immediate Fatalities Assuming 80% Evacuation Rate					
	Walk-Away Zone	Safe Zone	Compromised Zone	Chance Zone	Total
Jefferson Parish	0	0	0	1	1
Orleans Parish	0	14	83	546	642
St. Bernard Parish	0	2	45	296	344
TOTAL	0	17	128	843	987

Table 42 Stranded Persons Assuming 80% Evacuation Rate					
	Walk-Away Zone	**Safe Zone**	**Compromised Zone**	**Chance Zone**	**Total**
Jefferson Parish	0	1,076	0	0	1,076
Orleans Parish	0	61,630	605	49	62,284
St. Bernard Parish	0	10,923	331	27	11,281
TOTAL	0	73,628	937	76	74,641

The number of fatalities among stranded persons during the Katrina event is estimated by applying the rescue rate associated with each flood zone to the number of stranded people in each flood zone. We assume that the number of stranded people in the safe zone who die is very low. We assume that the vast majority of people can survive in up to 4 feet of water until help arrives. The rescue rate of the compromised zone and the chance zone are likely somewhat lower as very young and elderly people would have some difficulty surviving in 6 or more feet of water until rescued. We assume that the mean rescue rates are 99.9 percent in the safe zone and 97.5 percent in the compromised and chance zones. The number of estimated fatalities among stranded people in each zone is shown in Table 43.

Table 43 Fatalities Among Stranded Persons					
	Walk-Away Zone	**Safe Zone**	**Compromised Zone**	**Chance Zone**	**Total**
Jefferson Parish	0	1	0	0	1
Orleans Parish	0	62	15	1	78
St. Bernard Parish	0	11	8	1	20
TOTAL	0	74	23	2	99

In Table 44 we compare the estimated number of fatalities using our best estimates for each of the unknown parameters with the actual number of fatalities associated with Katrina in the three parishes. Overall, the results indicate that our best estimates represent a reasonable set of values for the unknown parameters. The total number of estimated fatalities, 1,086, is in the range of actual fatalities (867 to 1,259). Likewise, the number of fatalities estimated to occur in New Orleans, 720, is in the range of actual fatalities (676 to 981). The estimated numbers for Jefferson Parish and St. Bernard Parish do not fall within the range of the actual number of fatalities. However, even these estimates are reasonably close to the range of actual fatalities. For example, a 1 to 2 percent change in the evacuation rate could account for the error in our estimates. Given the range of the distributions that will be used to characterize each of the uncertain parameters for the simulated hurricanes (see below), these results provide a degree of confidence that the model will be useful for predicting life-loss under alternative hurricane flooding scenarios.

Table 44 Total Simulated Fatalities versus Actual Fatalities			
	Simulated Fatalities	**Actual Recorded Fatalities (as of February 23, 2006)**	**Potential Fatalities**
Jefferson Parish	2	34	50
Orleans Parish	720	676	981
St. Bernard Parish	364	157	228
TOTAL	1,086	867	1,259

7.3.2.5.2. Modeling Procedures. The model simulations under the pre-Katrina and post-Katrina scenarios were based on population at risk estimates for all drainage subbasins impacted in the five parishes comprising greater New Orleans. Housing units and inventories were also projected from the 2000 HAZUS-MH database for August 2005 (pre-Katrina), and modified based on flood extent from Hurricane Katrina to reflect the current status and forecast of habitable structures in the area, going into the 2006 hurricane season.

The LIFESim model was run at event-maximum flood inundation elevations in 2-foot increments for each drainage subbasin from the lowest elevation up to 36 feet above sea level. This level of analysis allowed for accuracy in calculating the effect of water depth on loss of shelter across four distinct flood zones.

LIFESim generated a set of 2-foot interval water surface grids, beginning at the lowest elevation point in each drainage subbasin, and filled the drainage subbasin with floodwater 2 vertical feet at a time through simulation.

Based on the results of the model calibration, the Uncertainty Model was run using the following distributions for the uncertain parameters:

- Evacuation Rate (ER) – triangular (65 percent, 80 percent, 95 percent)
- Rescue Efficiency in Safe Zone (RSE) – uniform (99.5 percent - 100 percent)
- Rescue Efficiency in Compromised or Chance Zone (RCE) – uniform (95 percent, 100 percent)
- Fatality Rate in Safe Zone (FS) – non-parametric distribution with mean of 0.023 percent (see Exhibit C)
- Fatality Rate in Compromised Zone (FC) – non-parametric distribution with mean of 12 percent (see Exhibit B)
- Fatality Rate in Chance Zone (FH) – non-parametric distribution with mean of 91.75 percent (see Exhibit A)

The following three graphs illustrate the non-parametric fatality rate distributions for the three zones:

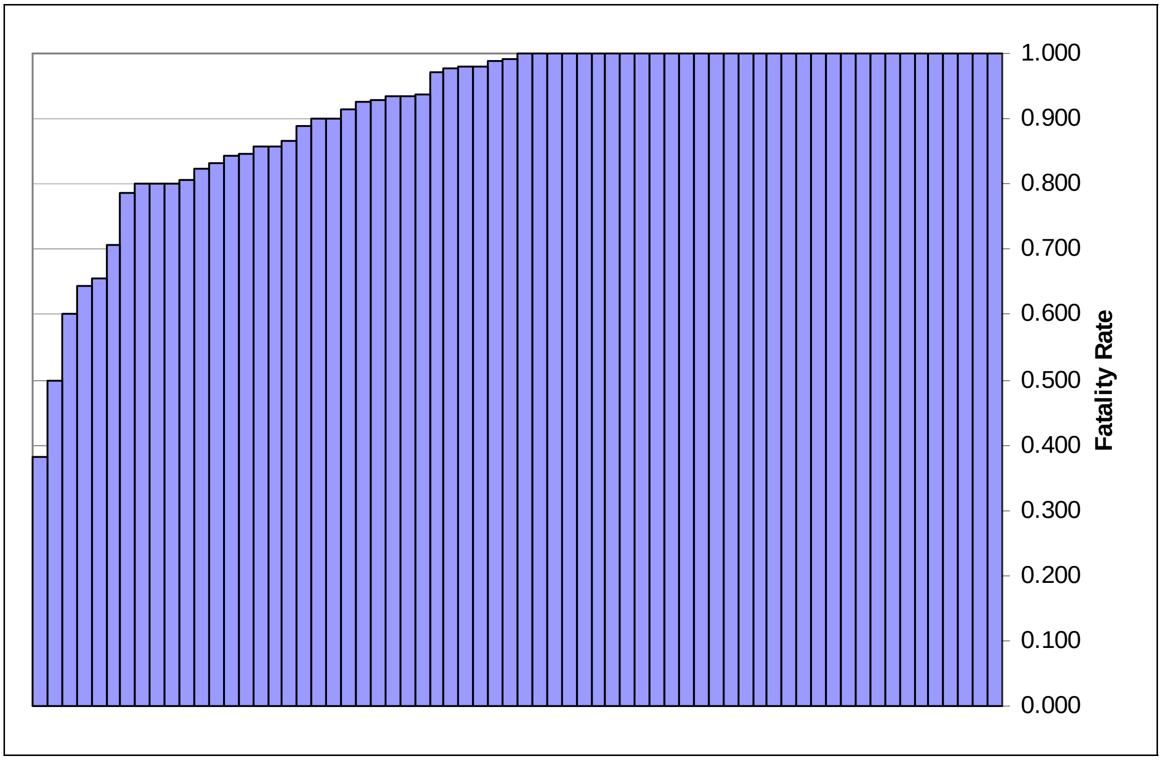


Exhibit A: Fatality rate for chance zone.

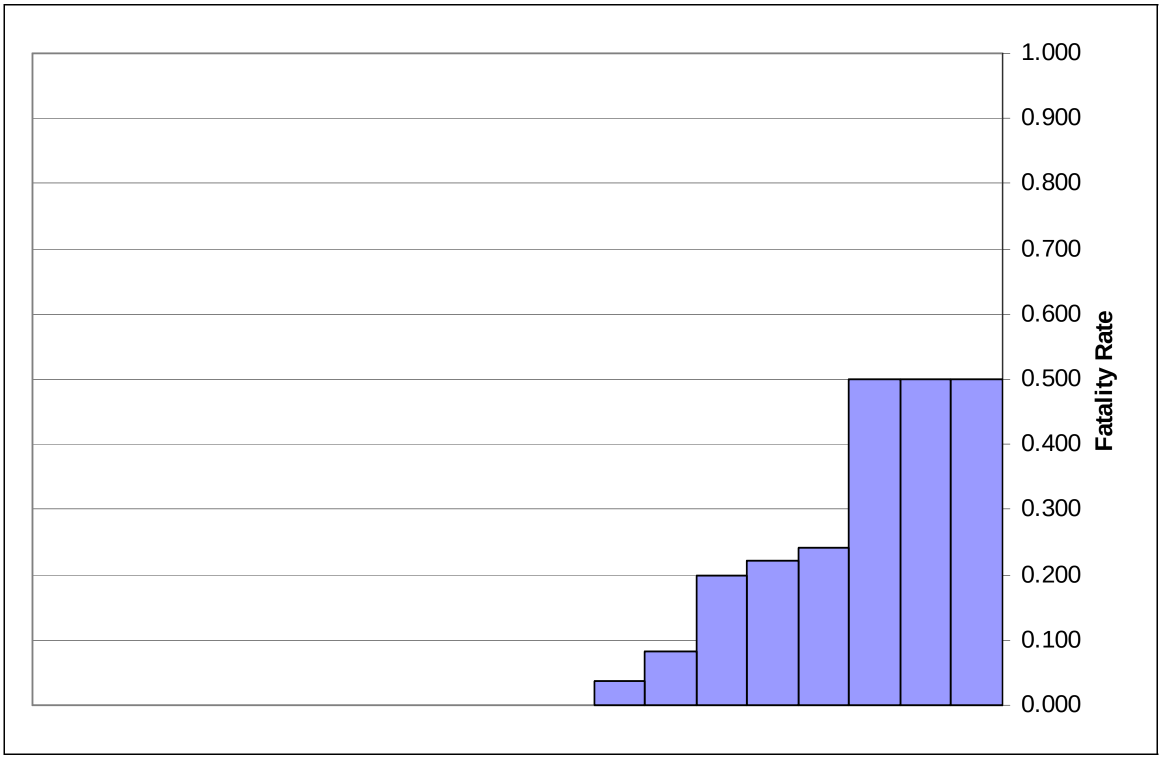


Exhibit B: Fatality rate for compromised zone.

Exhibit C: Fatality rate for safe zone.

The results of the life-loss modeling for the pre-Katrina and post-Katrina scenarios are provided in the next section.

7.3.2.6. Results

The results of the loss of life modeling are presented in Appendix 3. Stage-fatality results for each drainage subbasin corresponding to both pre- and post-Katrina demographic and structural conditions are provided in graphical and tabular formats. In each graph we provide the expected number of fatalities at each water elevation as well as the 90 percent confidence interval. The results presented in tabular form provide additional distributional information for the stage-fatality estimates.

The pre-Katrina stage-fatality estimates were used to contrast model estimates of fatalities associated with the Hurricane Katrina with actual system performance scenario with model estimates of fatalities corresponding to the various hypothetical Katrina scenarios. Table 45 shows estimated mean fatalities for the actual and various hypothetical Katrina scenarios.

Table 45 Comparison of Model Estimated Mean Fatalities from Katrina with Hypothetical Scenarios								
	Katrina Model		Hypothetical Katrina Scenario 1 (Resilient Levees)		Hypothetical Katrina Scenario 2 (Resilient Levees and Pumps)		Hypothetical Katrina Scenario 3 (Resilient Floodwalls)	
Basin Name	Water Surface Elevation ft NAVD99 (2004.65)	Model Estimates of Fatalities	Water Surface Elevation ft NAVD99 (2004.65)	Model Estimates of Fatalities	Water Surface Elevation ft NAVD99 (2004.65)	Model Estimates of Fatalities	Water Surface Elevation ft NAVD99 (2004.65)	Model Estimates of Fatalities
JE2	-4.10	34.70	-4.10	34.7	-7.00	0.0	-4.10	34.7
NOE1	3.00	0.01	2.60	0.0	2.60	0.0	3.00	0.0
NOE2	0.80	0.76	-1.60	0.6	-7.00	1.41	0.80	0.7
NOE3	0.60	7.25	0.0	0.0	-0.50	2.83	0.60	7.2
NOE4	7.50	0.37	7.10	0.3	7.00	0.28	7.50	0.4
NOE5	-0.70	44.56	-1.70	36.5	-2.50	31.3	-0.70	44.6
OM1	2.60	11.15	-0.90	6.6	-5.10	1.2	0.0	7.8
OM2	3.20	751.33	-2.50	393.6	-5.00	236.7	-2.70	381.0
OM3	3.80	83.98	3.10	63.1	2.90	57.1	3.80	84.0
OM4	2.30	11.64	0.10	8.8	-1.50	6.8	0.10	8.8
OM5	2.60	53.28	-0.80	22.8	-2.00	12.0	-0.40	26.4
SB1	10.50	121.64	4.20	48.0	3.90	44.4	10.50	121.6
SB3	10.90	0.00	3.70	0.0	3.70	0.0	10.90	0.0
SB4	11.20	0.00	6.60	0.0	6.40	0.0	11.20	0.0
Total		1,086.0		566.6		394.1		682.6
Note: The water surface elevation for JE2 is set to produce flood damages of zero assuming that the pumps could evacuate the rainwater.								

7.3.2.7. Recommendations for Future Mortality Risk Modeling

7.3.2.7.1. Addressing Limitations of the Analysis. Several limitations of the analysis were discussed earlier in Section 7.3.2.2. The scope and analytical rigor of the loss-of-life estimation technique used here reflect the utility of the data available prior to and during the study. With more reliable information, the accuracy and quality of the LIFESim results could improve greatly. Information from other IPET Team analyses necessary for IPET consequence assessments is rapidly becoming available. Data and quantified modeling results from other federal, state, and local sources could also be incorporated into LIFESim in the future to limit dependence on key assumptions, reduce the range of uncertainty, and rely more heavily on evidence-based parameters. Recommendations for revising and updating the LIFESim model results and implications are discussed below:

Evacuation—It is unclear what percentage of the total population will evacuate prior to the next significant hurricane that makes landfall in the greater New Orleans area. Further analysis should investigate potential correlations between income (access to vehicle), age, and health of the PAR with evacuation dynamics. The impact of the recently announced policy outlining the New Orleans hurricane evacuation plan could also influence evacuation and should be considered. The LIFESim model results should be made adjustable to user-defined evacuation rates.

Rescue—Lessons learned from Hurricane Katrina rescue operations will influence future efforts in areas affected by hurricane-related flooding. A more detailed examination of the demographics of those individuals rescued in the days following Hurricane Katrina's initial impacts should inform the assumptions used to incorporate the capacity and extent of rescue operations in LIFESim. Additionally, demographic profiling of those rescued from attics and rooftops after Hurricane Katrina made landfall should inform any adjustments to the age-adjusted flood lethality zones. Rescue information could also be useful to more accurately calibrate LIFESim to account for fatalities associated with prolonged exposure or dehydration, as opposed to fatalities associated with submergence due to flood inundation or levee/pump station failure.

Fatalities—Access to data from Parish Coroners' offices may become available that will shed light on the spatial distribution, demographics, and cause of death for confirmed fatalities associated with Hurricane Katrina. This information could influence the accuracy of the LIFESim model calibration. Future LIFESim model runs should benefit from detailed Hurricane Katrina fatality information by reducing the uncertainty accompanying the flood lethality zone assumptions.

Flooding Dynamics/Levee Breaches/Inundation Rates—We anticipate sufficient information will soon be available to utilize the LIFESim *Inundation Module* to more accurately quantify loss of life based on temporal and spatial inter-drainage subbasin flooding dynamics and inundation factors. Specifically, the results and outputs from other IPET Team analyses should be evaluated once the information becomes available to determine how LIFESim could be further adjusted to incorporate hydrograph data for representative hurricane modeling scenarios, flow and velocity of storm surges, flood duration, and inter-drainage subbasin flood extent. LIFESim has functionality available to incorporate floodwater velocity once these data are available.

Population at Risk (PAR) Demographics—Under a separate IPET Team 9 task, a team of surveyors recently compared observed repopulation patterns in the greater New Orleans area with repopulation estimates calculated by the Greater New Orleans Community Data Center (2006) and McCarthy et al. (2006). Once this information becomes available, the PAR used in LIFESim should be adjusted accordingly. More detailed analysis of the spatial dynamics of repopulated neighborhoods and the PAR following evacuation should be based on gender, race, access to vehicle, income, and household information in addition to age profiling already in use. Additionally the PAR should periodically be updated in LIFESim to reflect changes in evidence-based influential factors, such as data on school re-enrollment, building permits authorizations and location, and reestablishment of utilities and other public services.

7.3.2.7.2. LIFESim Model Automation and Enhancements. If warranted, LIFESim could be enhanced to enable USACE greater direct access and flexibility to assess various hurricane-related loss of life impacts. We recommend automating LIFESim to expedite simulations and efficiently accommodate additional runs if necessary by programming pre- and post-processors. The current version of LIFESim can run a group of simulations using a simple automation module. An improved system would improve the process of batch simulation and data storage and visualization. LIFESim could also be reprogrammed with a user-friendly graphical user interface.

We also recommend employing conditioned choropleth (CC) maps for LIFESim results to help the user detect interesting patterns and relationships to facilitate comparison and assessment. The CC maps could be comprised of a three-by-three matrix of maps containing three partitioning (or conditioning) sliders used to evaluate results based on estimated fatalities, flood elevation levels, and inundation rates. The sliders could partition the CC map regions into three ordered classes (low, middle, and high) based on the range of modeled results or inputs. CC maps use distinct colors to indicate each region's class membership. Moving the slider boundaries dynamically updates the colors of region polygons shown in the map matrix panels. The CC maps could complement the flood stage–fatality results for each drainage subbasin by addressing the inter-drainage subbasin flooding dynamics associated with modeled hurricane scenarios.

References

References for Health and Safety Consequences Assessment

1. Human Health Effects of Hurricane Katrina

New Orleans city, Louisiana. U.S. Census. 2006a.
Ref Type: Electronic Citation

Houston city, Texas. U.S. Census. 2006b.
Ref Type: Electronic Citation

Healthc. Financ. Manage., Nov. 2005.

Abelson R, Feuer A. 10,000 Patients and Staff Members Await Evacuation From Barely Functional Hospitals. The New York Times. 2005.
Ref Type: Newspaper

Adams D. 2005. Katrina Displaces 6,000 Doctors. *American Medical News* 48(39).

Altman L, Chang K. Disease and Coordination Vie as Major Challenges. The New York Times. 2005.
Ref Type: Newspaper

Angst J. 1995. The Epidemiology of Depressive Disorders. *European Neuropsychopharmacology* 5(Suppl):95-8

ATSDR. 2005. *Draft Toxilogical Profile for Lead*. Agency for Toxic Substances and Disease Registry.

Baker A. Remembering Help Received After Sept. 11, New York Sends Officers to Louisiana. The New York Times. 2005.
Ref Type: Newspaper

Barringer F. Patients Needing Care Overwhelm New Orleans's Hospital System. The New York Times . 2006.
Ref Type: Newspaper

Barringer F, Longman J. Owners Take Up Arms as Looters Press Their Advantage. The New York Times. 2005.
Ref Type: Newspaper

Barringer F, McNeil DG. Grim Triage of Ailing and Dying At a Makeshift Airport Hospital. The New York Times. 2005.
Ref Type: Newspaper

Barry D. Texas Way Station Offers a First Serving of Hope. The New York Times. 2005.
Ref Type: Newspaper

Barry D, Longman J. A Police Department Racked by Doubt and Accusations. The New York Times. 2005.
Ref Type: Newspaper

Bartels L. Welcome to Camp Katrina. Rocky Mountain News. 2005.
Ref Type: Newspaper

Beil L. 2 million in U.S. may carry staph. Dallas Morning News. 2006.
Ref Type: Newspaper

Bennett JW. 2006. The Molds of Katrina. *New York Academy of Sciences* January/February 2006:6-9.

Berggren R. 2005. Hurricane Katrina: Unexpected Necessities -- Inside Charity Hospital. *The New England Journal of Medicine* 353(15):1550-3.

Bourque LB, Siegel JM, Kano M, Wood MM. 2006a. Weathering the Storm: The Impact of Hurricanes on Physical and Mental Health. *The Annals of the American Academy* 604 (March 2006).

Bourque LB, Siegel JM, Kano M, Wood MM. 2006b. Weathering the Storm: The Impact of Hurricanes on Physical and Mental Health. *The Annals of the American Academy* 604 (March 2006).

Bourque LB, Siegel JM, Mano M, Wood MM. 2006d. Weathering the storm: the impact of hurricanes on physical and mental health. *Annals of the American Academy of Political and Social Science* 604:129-51.

Bourque LB, Siegel JM, Kano M, Wood MM. 2006c. Weathering the Storm: The Impact of Hurricanes on Physical and Mental Health. *The Annals of the American Academy* 604 (March 2006).

Bremner JD, Southwick SM, Charney DS. 1999. The neurobiology of posttraumatic stress disorder: an integration of animal and human research. In *Posttraumatic Stress Disorder: A Comprehensive Text*, ed. PA Saigh, JD Bremner,103-143. Needham Heights, MA: Allyn and Bacon.

Bruce JL. 2005. After the flood. *SportsTURF* 21(11).

Callimachi R. Katrina's Children Struggle With Fears. Washington Post. 2006.
Ref Type: Newspaper

Campo-Flores. 2006. "Katrina's Latest Damage." *Newsweek/MSNBC*.

CDC. 2004. *Symptoms of West Nile Virus*. Centers for Disease Control and Prevention.

CDC. 2005a. *Clean Up Safely After a Hurricane*.

CDC. 2005b. *Environmental Concerns After a Hurricane*.

CDC. 2005c. Infectious disease and dermatologic conditions in evacuees and rescue workers after Hurricane Katrina--multiple states, August-September, 2005. *MMWR Morb. Mortal. Wkly. Rep.* 54(38):961-4.

CDC. 2005d. *Keep Food and Water Safe after a Hurricane*.

CDC. 2005e. *Mold: Prevention Strategies and Possible Health Effects in the Aftermath of Hurricanes Katrina and Rita*.

CDC. 2005f. Norovirus outbreak among evacuees from Hurricane Katrina--Houston, Texas, September 2005. *MMWR Morb. Mortal. Wkly. Rep.* 54(40):1016-8.

CDC. 2005g. Surveillance for illness and injury after Hurricane Katrina--New Orleans, Louisiana, September 8-25, 2005. *MMWR Morb. Mortal. Wkly. Rep.* 54(40):1018-21.

CDC. 2005h. *Update on CDC's Response to Hurricane Katrina*.

CDC. 2005i. Vibrio illnesses after Hurricane Katrina--multiple states, August-September 2005. *MMWR Morb. Mortal. Wkly. Rep.* 54(37):928-31.

CDC. 2006a. Assessment of health-related needs after Hurricanes Katrina and Rita--Orleans and Jefferson Parishes, New Orleans area, Louisiana, October 17-22, 2005. *MMWR Morb. Mortal. Wkly. Rep.* 55(2):38-41.

CDC. 2006b. Illness surveillance and rapid needs assessment among Hurricane Katrina evacuees--Colorado, September 1-23, 2005. *MMWR Morb. Mortal. Wkly. Rep.* 55(9):244-7.

CDC. 2006c. Injury and illness surveillance in hospitals and acute-care facilities after Hurricanes Katrina And Rita--New Orleans area, Louisiana, September 25-October 15, 2005. *MMWR Morb. Mortal. Wkly. Rep.* 55(2):35-8.

CDC. 2006d. Mortality associated with Hurricane Katrina--Florida and Alabama, August-October 2005. *MMWR Morb. Mortal. Wkly. Rep.* 55(9):239-42.

CDC. 2006e. Rapid assessment of health needs and resettlement plans among Hurricane Katrina evacuees--San Antonio, Texas, September 2005. *MMWR Morb. Mortal. Wkly. Rep.* 55(9):242-4.

CDC. 2006f. Rapid community needs assessment after Hurricane Katrina--Hancock County, Mississippi, September 14-15, 2005. *MMWR Morb. Mortal. Wkly. Rep.* 55(9):234-6.

CDC. 2006g. Surveillance for illness and injury after Hurricane Katrina--three counties, Mississippi, September 5-October 11, 2005. *MMWR Morb. Mortal. Wkly. Rep.* 55(9):231-4.

CDC. 2006h. Surveillance in hurricane evacuation centers--Louisiana, September-October 2005. *MMWR Morb. Mortal. Wkly. Rep.* 55(2):32-5.

CDC. 2006i. Tuberculosis control activities after Hurricane Katrina--New Orleans, Louisiana, 2005. *MMWR Morb. Mortal. Wkly. Rep.* 55(12):332-5.

CDC Joint Task Force. 2005. *Environmental Health Needs and Habitability Assessment*.

Cefalu WT, Smith SR, Blonde L, Fonseca V. 2006. The Hurricane Katrina Aftermath and Its Impact on Diabetes Care. *Diabetes Care* 29:158-60.

Chan S, Revkin AC. Water Returned to Lake Pontchartrain Contains Toxic Material. The New York Times. 2005.
Ref Type: Newspaper

Cleveland Clinic. 2003. *Stress and Asthma*.

Cohen AJ. 2005. Hurricane Katrina: Lethal Levels. *The New England Journal of Medicine* 353(15):1549.

Cowan AL. Airlift of Evacuees to Northeast is Under Way. The New York Times. 2006.
Ref Type: Newspaper

Cox R. Alaskan led New Orleans pet-rescue efforts CALLAHAN. Anchorage Daily News. 2005.
Ref Type: Newspaper

Dao J, Treaster JB, Barringer F. New Orleans Is Awaiting Deliverance. The New York Times. 2005. Ref Type: Newspaper

deBoisblanc BP. 2005. Black Hawk, Please Come Down. *American Journal of Respiratory and Critical Care Medicine* 172:1239-40

Dewan S. Storm's Missing. The New York Times. 2006b.
Ref Type: Newspaper

Dewan S. Evacuee Study Finds Declining Health. The New York Times. 2006c.
Ref Type: Newspaper

Dewan S. Often, Tolls Don't Show True Picture. The New York Times. 2005a.
Ref Type: Newspaper

Dewan S. In Attics and Rubble, More Bodies and Questions. The New York Times. 2006a.
Ref Type: Newspaper

Dewan S. Bungled Records of Storm Deaths Renew Anguish. The New York Times. 2005b.
Ref Type: Newspaper

Dewan S. Weeks Later, Most Storm Victims Lie Unnamed. The New York Times. 2005c.
Ref Type: Newspaper

Dewan S, Connelly M, Lehren A. Evacuees' Lives Still Upended Seven Months After Hurricane. The New York Times. 2006. Ref Type: Newspaper

Dewan S, Goodnough A. Rotting Food, Dirty Water and Heat Add to Problems. The New York Times. 2005. Ref Type: Newspaper

Dewan S, Roberts J. Louisiana's Deadly Storm Took Strong as Well as the Helpless. The New York Times. 2005. Ref Type: Newspaper

Egan T, Balleza M, Panaloza DC. Uprooted and Scattered Far From the Familiar. The New York Times. 2005. Ref Type: Newspaper

EPA. 2005a. *Caution Urged Dealing with Debris and When Re-entering Hurricane-Damaged Homes and Buildings*. Environmental Protection Agency.

EPA. 2005b. *Environmental Assessment Summary for Areas of Jefferson, Orleans, St. Bernard, and Plaquemines Parishes Flooded as a Result of Hurricane Katrina.* Environmental Protection Agency.

EPA. 2006. *Summary Assessment of the Results of Sampling of Localized areas Identified For Focused Investigations Following Hurricane Katrina.* Environmental Protection Agency.

Erickson J. Mosquito Numbers Explode due to Hurricane Flooding. Rocky Mountain News. 2005. Ref Type: Newspaper

Fairbank JA, Ebert L, Caddell JM. 2001. Posttraumatic stress disorder. In *Comprehensive Handbook of Psychopathology (3rd Edition)*, ed. JE Adams, PB Sutker, New York: Kluwer Academic/Plenum Press.

Fairbank K. Counting, identifying the dead a low priority for officials. Dallas Morning News. 2005. Ref Type: Newspaper

Ferdinand KC. 2005. The Hurricane Katrina disaster: focus on the hypertensive patient. *J. Clin. Hypertens. (Greenwich.)* 7(11):679-80.

Foa EB, Davidson JRT, Frances A. 1999. The Expert Consensus Guidelines Series: Treatment of Posttraumatic Stress Disorder. *Journal of Clinical Psychiatry* 60(Suppl.16):1-76.

Foa EB, Keane TM, Friedman MJ. 2000. *Effective treatments for PTSD: Practice Guidelines from the International Society for Traumatic Stress Studies,* New York: Guilford Press.

Frohlich ED. 2005. Hurricane Katrina: Aftershocks. *The New England Journal of Medicine* 353(15):1545.

Galea S, Ahern J, Resnick H, Kilpatrick D, Bucuvalas M, Gold J. 2002. Psychological sequelae of the September 11 terrorist attacks in New York City. *The New England Journal of Medicine* 346:982-7.

Glanton D. Katrina survivor battles aneurysm. Chicago Tribune. 2006.
Ref Type: Newspaper

Glanton D. 'You can smell the death'. Chicago Tribune. 2005.
Ref Type: Newspaper

Gleser G, Green B, Winget C. 1981. *Prolonged psychological effects of disaster: a study of Buffalo Creek.,* New York: Academic Press.

Golden K, Ratard R. 2006. *Katrina Cough*.

Graham J. Hospitals struggle with multiple challenges. Chicago Tribune. 2005.
Ref Type: Newspaper

Green B, Grace M, Lindy J, Gleser G, Leonard A, Kramer T. 1990. Buffalo Creek survivors in the second decade: comparison with unexposed and nonlitigant groups. *Journal of Applied Social Psychology* 20:1033-50.

Green BL. 1993. Identifying survivors at risk: trauma and stressors across events. In *International Handbook of Traumatic Stress Syndromes*, ed. JP Wilson, B Raphael, New York: Plenum Press.

Greenough PG, Kirsch TD. 2005. Hurricane Katrina: Public Health Response -- Assessing Needs. *The New England Journal of Medicine* 353(15):1544-6.

Griffin L, Navarro M, Rich M. For Many, Relief Is Delivered by the Most Traditional of Rescue Groups. The New York Times. 2005. Ref Type: Newspaper

Gross J, Griffin L. Luck and Fate Seated Victims on a Doomed Bus. The New York Times. 2005. Ref Type: Newspaper

Haile RE. 1999. The health effects of swimming in ocean water contaminated by storm drain runoff. *Epidemiology* 10(4):355-63.

Hancock L. Exhausted firefighters fight to save New Orleans from blazes. Dallas Morning News. 2005. Ref Type: Newspaper

Harris G. Medical Team From Georgia, Trying to Provide Help, Hits Roadblocks Along the Way. The New York Times. 2005a. Ref Type: Newspaper

Harris G. Police in Suburbs Blocked Evacuees, Witnesses Report. The New York Times. 2005b. Ref Type: Newspaper

Henderson GS. 2005a. Hurricane Katrina: Finding Supplies. *The New England Journal of Medicine* 353(15):1542.

Henderson GS. 2005b. Hurricane Katrina: Triagine Tragedy. *The New England Journal of Medicine* 353(15):1551.

Herbert B. A Rush of Stories. The New York Times. 2005. Ref Type: Newspaper

Hitti M. Stress, Asthma Don't Mix Well in Kids. Thorax 59, 1046-1051. 2004. Ref Type: Electronic Citation

Hobfoll S, Lilly R. 1993. Resource conservation as a strategy for community psychology. *Journal of Community Psychology* 21:128-48.

Horner K. Homeless numbers fall 3.3%. Dallas Morning News. 2006. Ref Type: Newspaper

Hoven CW, Duarte CS, Lucas CP, Wu P, Mandell DJ, Goodwin RD. 2006. Psychopathology among New York City public school children 6 months after September 11. *Archives of General Psychiatry* 62:545-52.

Institute of Medicine. 2004. *Damp indoor spaces and health.* National Academies Press, Washington, DC.

Janega J. 'Wiped out' says it all for parish. Chicago Tribune. 2005. Ref Type: Newspaper

Johnson K. Urban Evacuees Find Themselves Among Rural Mountains. The New York Times. 2005. Ref Type: Newspaper

Judd LL, Paulus MP, Wells KB, Rapaport MH. 1996. Socioeconomic Burden of Subsyndromal Depressive Symptoms and Major Depression in a Sample of the General Population. *American Journal of Psychiatry* 153:1411-7.

Kaiser Family Foundation. 2005a. *Assessing the Number of People with HIV/AIDS in Areas Affected by Hurricane Katrina*. Kaiser Family Foundation.

Kaiser Family Foundation. 2006a. *A Pre-Katrina Look at the Health Care Delivery System for Low-Income People in New Orleans*. *Rep. 7442*, Kaiser Family Foundation.

Kaiser Family Foundation. 2006b. *Daily Health Policy Report*.

Kaiser Family Foundation. 2006c. *Addressing the Health Care Impact of Hurricane Katrina*. *Rep. 7387*, Kaiser Family Foundation.

Kaiser Family Foundation. 2006d. *A Comparison of the Seventeen Approved Katrina Waivers*. Kaiser Family Foundation.

Kaiser Family Foundation. 2005b. *Key Facts - States Most Affected by Hurricane Katrina*. Kaiser Family Foundation.

Keane TM, Wolf J. 1990. Comorbidity in posttraumatic stress disorder: an analysis of community and clinical studies. *Journal of Applied Social Psychology* 20:1776-88.

Kent J. 2005. *2005 Louisiana Hurricane Impact Atlas*.

Kessler RC, Berglund P, Demler O, Jim R, Koretz D et al. 2003. The Epidemiology of Major Depressive Disorder: Results From the National Comorbidity Survey Replication (NCS-R). *Journal of the American Medical Association* 289(23):3095-105.

Kessler RC, Sonnega A, Bromet E. 1994. Posttraumatic stress disorder in the National Comorbidity Survey. *Archives of General Psychiatry* 52:1048-60.

Louisiana Department of Health and Hospitals. Orleans Parish Declared as Health Professional Shortage Area. Louisiana Department of Health and Hospitals. 2006. Ref Type: Electronic Citation.

Lewis M. Wading toward home. The New York Times. 2005.
Ref Type: Newspaper

Lipton E, Drew C, Shane S, Rohde D. Breakdowns Marked Path From Hurricane to Anarchy. The New York Times. 2005. Ref Type: Newspaper

Loftis RL. Environmental damage from Katrina 'unprecedented', experts say. Dallas Morning News. 2005. Ref Type: Newspaper

Loftis RL. Environmental experts contemplate New Orleans' rebirth. Dallas Morning News. 2006. Ref Type: Newspaper

Longman J. Drying Out, New Orleans Fears a Blaze. The New York Times. 2005.
Ref Type: Newspaper

Lubell J. 2005. Storm-displaced physicians are trying to practice medicine. *Family Practice News* 35(21).

Manuel J. 2006. In Katrina's Wake. *Environmental Health Perspectives* 114(1).

McKinney D. Northern refuge. Anchorage Daily News. 2005.
Ref Type: Newspaper

Mercy Corps. 2006. *On the Road to Recovery*.

Minton E. Norton, G. 2006. Ref Type: Personal Communication.

Montero D. Longing for a taste of home. Rocky Mountain News. 2006.
Ref Type: Newspaper

Murphy J. 2006. O.D.s still struggle in Katrina's wake: with makeshift offices, many optometrists continue to provide much-needed care. *Review of Optometry* 143(2):2.

Nichols B. Houston team inspects New Orleans homes. Dallas Morning News. 2006a.
Ref Type: Newspaper

Nichols B. Houston wearying of Katrina evacuees. Dallas Morning News. 2006b.
Ref Type: Newspaper

Norris FH, Byrne CM, Diaz E, Kaniasty K. 2001a. *The Range, Magnitude, and Duration of effects of Natural and Human-Caused Disasters: A Review of the Empirical Literature*. National Center for PTSD.

Norris FH, Byrne CM, Diaz E, Kaniasty K. 2001b. *The Range, Magnitude, and Duration of effects of Natural and Human-Caused Disasters: A Review of the Empirical Literature*. National Center for PTSD.

Norris FH, Friedman MJ, Watson PJ, Burne CM, Diaz E, Kaniasty K. 2002a. 60,000 disaster victims speak: Part I. an empirical review of the empirical literature, 1981 – 2001. *Psychiatry* 63(3):207-39.

Norris FH, Friedman MJ, Watson PJ, Byrne CM, Diaz E, Kaniasty K. 2002b. 60,000 disaster victims speak: Part II. summary and implications of the disaster mental health research. *Psychiatry* 65(3):240-60.

Nossiter A. Hurricane Takes a Further Toll: Suicides Up in New Orleans. The New York Times. 2005. Ref Type: Newspaper

Pardue JH, Moe WM, McInnis D, Thibodeaux LJ, Valsaraj KT et al. 2005. Chemical and microbiological parameters in New Orleans floodwater following Hurricane Katrina. *Environ. Sci. Technol.* 39(22):8591-9.

Peres J, Janega J. Fear of epidemics ebbs. Chicago Tribune. 2005.
Ref Type: Newspaper

Pfefferbaum B, Nixon SJ, Krug RS, Tivis RD, Moore VL, Brown JM. 1999. Clinical needs assessment of middle and high school students following the 1995 Oklahoma City bombing. *American Journal of Psychiatry* 156:1069-74.

Pfefferbaum B, Nixon SJ, Tivis RD, Doughty DE, Pynoos RS, Gurwitch RH. 2001. Television exposure in children after a terrorist incident. *Psychiatry* 64(3):202-11.

Pfefferbaum B, Seale TW, McDonald NB, Brandt ENJr, Rainwater SM et al. 2000. Posttraumatic stress two years after the Oklahoma City Bombing in youths geographically distant from the explosion. *Psychiatry* 64:358-70.

Possley M, McCormick J. Officials struggle to determine Katrina-related deaths. Chicago Tribune. 2005. Ref Type: Newspaper

Presley SM, Rainwater TR, Austin GP, Platt SG, Zak JC et al. 2006. Assessment of pathogens and toxicants in New Orleans, LA, following Hurricane Katrina. *Environ. Sci. Technol.* 40(2):468-74.

Quinn SC. 2006. Hurricane Katrina: A Social and Public Health Disaster. *American Journal of Public Health* 96(2).

Quintero F, Prieto B. Evacuees pin hopes on future in Colorado. Rocky Mountain News. 2005. Ref Type: Newspaper

Ratard R, Brown CM, Ferdinands J, Callahan D. 2006. Health Concerns Associated with Mold in Water-Damaged Homes After Hurricanes Katrina and Rita -- New Orleans, Louisiana, October 2005. *MMWR Morb. Mortal. Wkly. Rep.* 55/No.2(March 10, 2006):41-4.

Riad JK, Norris FH. 1996. The influence of relocation on the environment, social, and psychological stress experienced by disaster victims. *Environment and Behavior* 28(2):163-82

Rivlin G. Some People Return, but Only One in 10 Businesses Has Reopened. The New York Times. 2006. Ref Type: Newspaper

Rohde D, McNeil DG, Abelson R, Dewan S. Vulnerable, and Doomed in the Storm. The New York Times. 2005. Ref Type: Newspaper

Roman L, Baum D. 2005. After Katrina, hospitals' fate is uncertain. *RN* 68(12).

Ross DC. 2005. *Many Katrina Survivors Seeking Medicaid in Louisiana Shelters Remain Without Coverage*.

Salopek P, Horan D. How places of refuge became hell. Chicago Tribune. 2005. Ref Type: Newspaper

Salzman A. Food Pantries Feel a Post-Hurricane Pinch. The New York Times. 2005. Ref Type: Newspaper

SAMHSA. 2005a. *SAMHSA Hurricane Katrina Update, Sept. 14-Sept.18.*

SAMHSA. 2005b. *SAMHSA Hurricane Katrina Update, Sept. 24-Sept.29.*

SAMHSA. 2005c. *SAMHSA Hurricane Katrina Update, Sept. 9-Sept.13*.

SAMHSA. 2006. *SAMHSA Post-Katrina/Rita/Wilma Activity Summary*.

Schlenger WE, Caddell L, Ebert BK, Jordan KM, Rourke D et al. 2002. Psychological Reactions to Terrorist Attacks: Findings from the National Study of Americans' Reactions to September 11. *Journal of the American Medical Association* 288:581-8.

Schneider ME. 2005. Web site provides Gulf Coast evacuee Rx data to doctors. *Family Practice News* 35(20).

Schnurr PP, Friedman MJ. 2001. An overview of research findings on the nature of posttraumatic stress disorder. *Psychotherapy in Practice* 3:11-25.

Schuster MA, Stein BD, Jaycox LH, Collins RL, Marshall GN, Elliott M. 2001. A national survey of stress reactions after the September 11, 2001, terrorist attacks. *The New England Journal of Medicine* 345:1507-12.

Seelye KQ. As Katrina Recedes, Newspapers Still Float. The New York Times. 2006.
Ref Type: Newspaper

Silver RC, Holman EA, McIntosh DN, Poulin M, Gil-Rivas V. 2002. Nationwide longitudinal study of psychological responses to September 11. *Journal of the American Medical Association* 288(10):1235-44.

Simmons A. More Katrina Fatalities Could Be Found. Los Angeles Times. 2006.
Ref Type: Newspaper

Steinhauer J. Storm and Crisis: Resettling. The New York Times. 2005.
Ref Type: Newspaper

Steward WF, Ricci JA, Chee E, Hahn SR, Morganstein D. 2003. Cost of Lost Productive Work Time Among US Workers With Depression. *Journal of the American Medical Association* 289(23):3135-44.

Sullivan MG. 2005b. Disrupted ecology may protect La. from West Nile. *Family Practice News* 35(19).

Treaster JB. At Stadium, A Haven Quickly Becomes an Ordeal. The New York Times. 2005.
Ref Type: Newspaper

Treaster JB, DeSantis J. With Some Now at Breaking Point, City's Officers Tell of Pain and Pressure. The New York Times. 2005.
Ref Type: Newspaper

Tucker M, Eichold B, Lofgren JP, Holmes I, Irvin D et al. 2006. Carbon Monoxide Poisonings After Two Major Hurricanes -- Alabama and Texas, August-October 2005. *MMWR Morb. Mortal. Wkly. Rep.* 55/No.9:236-9.

U.S. DHHS. U.S. Health and Human Services releases Katrina aid to 32 states to help with evacuee health cost. Science Letter, 1141. 2006.
Ref Type: Newspaper

Wilgoren J. Destitute Victims of Hurricane Remain Stuck in Hotels. The New York Times. 2005. Ref Type: Newspaper

Wilkerson I. In a Strange Land: From New Orleans to Sallisaw. The New York Times. 2005.
Ref Type: Newspaper

Wilson JF. 2006. Health and the Environment after Hurricane Katrina. *Annals of Internal Medicine* 144(2):153-6.

Winslow DL. 2005. Wind, Rain, Flooding, and Fear: Coordinating Military Public Health in the Aftermath of Hurricane Katrina. *Clinical Infectious Diseases* 41:1759-63.

Wockner R. New Orleans AIDS agencies struggle to resume services. Dallas Voice. 2006.
Ref Type: Newspaper

Working R. Evacuees spread across nation. Chicago Tribune. 2005.
Ref Type: Newspaper

Yehuda R. 2002. Posttraumatic stress disorder. *The New England Journal of Medicine* 346:108-14.

Zarus GM, Fowler DA. 2005. *Health Consultation: Murphy Oil Spill*. Agency for Toxic Substances and Disease Registry.

2. Loss of Life Modeling

Aboelata, M. 2005. "Conceptualization and Development of a Dam Break Life-Loss Estimation Model." Ph.D. dissertation, Utah State University, Logan, UT.

Department of Health and Hospitals, State of Louisiana. 2006. "Vital Statistics of All Bodies at St. Gabriel Morgue 2/23/2006." http://www.dhh.louisiana.gov/offices/publications/pubs-192/Deceased%20Victims_2-23-2006_information.pdf. Accessed 3 April 2006.

Federal Emergency Management Agency (FEMA). 2003. "HAZUS–MH flood technical manual." Department of Homeland Security, Emergency Preparedness and Response Directorate, FEMA, Mitigation Division, Washington, DC.

Gallup Organization. 2005. "Gallup/CNN/USA Today/Red Cross Poll #2005-45: Hurricane Katrina Survivors." Survey conducted among 1,510 adult survivors from across the Gulf South region. 30 September – 9 October 2005.

Greater New Orleans Community Data Center (GNOCDC). 2006. "Post-Disaster Population Estimates" Louisiana Department of Health and Hospitals Bureau of Primary Care and Rural Health (Oct 2005 - Feb 2006). Greater New Orleans Community Data Center. http://www.gnocdc.org/reports/PopEst_FEB06.xls. Accessed 13 April 2006.

McCarthy, K., Peterson, D., Sastry, N. and Pollard, M. 2006. "The Repopulation of New Orleans After Hurricane Katrina." RAND Corporation. Arlington, VA. http://www.rand.org/pubs/technical_reports/2006/RAND_TR369.pdf. Accessed 12 April 2006.

McClelland, D. M. 2002. "A team approach to improving dam-safety emergency action plans, flood maps, and emergency response plans using life-loss risk assessment." EAP 2002: International Workshop for Emergency Preparedness at Dams, sponsored by FERC and ASDSO.

Simmons, Ann. 2006. "More Katrina Fatalities Could Be Found." Article published in the *Los Angeles Times*. Reported on-line at http://www.latimes.com/news/nationworld/nation. 21 March 2006.

U.S. Army Corps of Engineers (USACE) Interagency Performance Evaluation Task Force (IPET) Data Repository. 2006. https://erdcpw.erdc.usace.army.mil/WEL/index.html. Accessed 11 April 2006.

U.S. Census Bureau. 2002. United States Census 2000. http://www.census.gov.

U.S. Geological Survey (USGS). 2005. Seamless Data Distribution Center. EROS Data Center, Sioux Falls, North Dakota. http://seamless.usgs.gov/index.asp.

Woods and Poole. 2001. Woods and Poole Data on CD-ROM. Woods and Poole Economics, Washington, DC.

7.4. Social and Cultural Consequences Assessment Digest

This section reports the objectives, approach, and results of the social and cultural consequences assessment.

7.4.1. Objectives

The objective was to characterize and compare social and cultural conditions before and after Hurricane Katrina to illustrate the consequences of that event, and to forecast the potential social and cultural consequences of a similar hurricane event once the flood protection system is repaired.

The breaching and overtopping of the levees caused a breakdown in New Orleans' social structure, a loss of cultural heritage, and dramatically altered the physical, economic, political, social, and psychological character of the area. These impacts are unprecedented in their social consequence and unparalleled in the modern era of the United States. They will remain part of the region's social, historic, and cultural consciousness for decades. In terms of the social consequences of the Katrina event specifically, the aftermath is best described as a catastrophe where the social organization of the community and region had been compromised by the mass exodus of the population, the structural damage, and the demands to respond and rebuild. The long term appreciation of the social, cultural, and historic consequences is beyond the scope of this analysis, which focuses on the short-term. Because of the magnitude and unique character of the event, the report only provides a general discussion of the long term social, cultural, and historic consequences. This report focuses on short term consequences.

The report does not include all the significant social consequences associated with the event. Given the unprecedented event, the report focuses on those consequences which can be addressed with reliable and consistent data. There are an unknown, but likely a sizable number, of factors that this report does not address. Though there is extensive research literature on social consequences of disasters, Katrina is unique, and will no doubt generate new insights from future research on what factors are involved in such events. Many agencies have been overwhelmed with responding to the event and could not devote resources to providing data regarding the event. Many of the consequences have yet to fully emerge and may take years to do so. As a result, the report only provides a limited view of nature of the social consequences of the event.

However, the objective of this subtask is to identify available indicators reflecting the overall social and cultural character of the impacted area and estimate potential futures conditions.

7.4.2. Approach

The general methodology was to identify changes in units of analysis (i.e., social units) over time using three discrete time periods:

- Pre-Katrina
- Immediate post-Katrina (Sept 2005 – May 2006)
- Long-term post-Katrina (after 1 June 2006) Because of the high level of uncertainty of the long-term consequences, the focus is more general than the shorter term time periods

For each time period, data were gathered and analyzed to provide a quantitative measure of observed changes and then a qualitative assessment of the changes was undertaken.

7.4.2.1. Units of Analysis

The primary units of analysis in this report are characterized by the social, cultural, and historic indicators and include both qualitative and quantitative measures. Because of the urban nature of Orleans Parish, the unit of analysis within that parish is the neighborhood in which people reside. The neighborhood is considered a meaningful social unit, representing the interactions, social processes and organizations of those living and conducting business within that area. Outside of Orleans Parish, but within the immediate area affected by the levee performance, the units of analysis are parishes and the larger communities within those parishes. This analysis also focused on social institutions. Social institutions are defined as ways of providing a basic societal need. Efforts to meet those needs are often situated in physical locations. To illustrate, religions vary in how they support parishioners through joyous events such as weddings or provide solace during events such as disasters and funerals. A given culture's ways of meeting key societal needs will take place in physical locations such as mosques, churches, and temples. As another illustration, urban areas routinely provide trauma centers and helicopter transport as a way of providing critical medical care often disrupted by disasters. Generally, key social institutions include the family, government/political structures, education, the economy, religion, and health care. The classification of units of analysis is not equal across all of our focal areas, so for our analysis, these are divided into two primary sub-groups: Social characteristics and historical/cultural resources as outlined in Table 47.

Table 47
Units of Analysis

Geography	Unit of Analysis	Spatial enumeration
	Social	
Within Orleans Parish	Population living within neighborhood	Sum of US census tracts (defined neighborhoods)
	Population living within planning districts	Sum of US census tracts (defined neighborhoods)
	Institutions (by type)	Location
Outside Orleans Parish	Parish	US census parish boundary
	Community	Incorporated place
	Institution (by type)	Parish
Region	Gulf Coast Impacted Area	Areas adjacent to New Orleans metropolitan area
Nation	Areas outside the immediate hurricane impacted area	Focus on areas with largest number of evacuees
	Historical and Cultural Resources	
Within and outside Orleans Parish	Geographic points/locales	Specific point locations (longitude and latitude)
	Neighborhoods	Self-identity, sense of place
	Community	Self-identity, sense of place

7.4.2.2. Study Area

The study area is defined by scale (local, regional, national) based on the impacts and consequences to populations and institutions. The impacts and consequences are more specific at the local scale and become more generalized at the regional and national levels. Local refers to the immediate hurricane impact area including all parishes within greater New Orleans (Jefferson, Orleans, Plaquemine, St. Bernard, St. Charles, and St. Tammany Parishes). Regional scale means those areas adjacent to the metropolitan area as well as the state of Louisiana. National includes the rest of the United States. Given the national and historic importance of this event, it is important to understand the larger context. Consistent and reliable data for regional and national consequences is largely unavailable at the time of the writing of the report. For that reason those consequences are discussed in less detail than those on the local level and in a mostly qualitative basis. However, this level of detail is not a reflection of the importance of the consequences on the region and the nation

7.4.2.3. Field Methodology

Though the overall study primarily used secondary data sources, some field-based data collection was required to fully comprehend and understand of the residents' attempts to reoccupy the flooded metropolitan area. The fieldwork was designed to estimate the current extent of repopulation and probable reoccupation in selected neighborhoods in New Orleans. A sample of the U.S. Census Bureau geographically defined block groups were developed to capture the socio-economic diversity of the community, using stratified sampling techniques. In March 2006, field observers went to the sampled block groups and documented activities associated with repopulation. Study team members also conducted unstructured interviews with key persons in the community who had long-term knowledge of the community. This information provided insights into both repopulation of flooded areas and the other social and cultural conditions.

7.4.2.4. Data

7.4.2.4.1. Local. Table 48 exemplifies the variables, units of analysis, measures, data sources and time frame used in this analysis. Data sources included those for post-Katrina conditions which included estimates and qualitative assessments of future conditions. The timeframe is intended to capture the pre-Katrina conditions. Measures reflecting the variables are taken from a variety of secondary sources, most of which were not August 2005, the date of the hurricane. The table notes which year the data are available. This summary document examines only some of the variables listed in the table. More detailed discussion is provided in the detail Appendix D.

7.4.2.4.2. Regional and National Impacts. Regional and national consequences were discussed primarily in quantitative terms, with support of available information.

7.4.3. Results

The following is a summary of the analysis conducted using the variables described in Table 48. In the discussion below, key variables from the above list provide an indication of the findings. The results below are presented using three time frames. Data sources for pre-Katrina include data from the decennial US Census of Population and Housing and other sources that provide quantitative counts or estimates. Post-Katrina data have more uncertainty. There have been no post-Katrina observations for many of the variables listed in the table. In order to provide a general determination of what changes have occurred, this analysis used the disaster research literature, interviews with key persons in the community – local experts and expert opinion of those in the disaster research field, those on the study team – to provide a qualitative assessment of what those changes might be. A more detailed discussion is provided in the study documentation.

Table 48
Social, Cultural, and Historical Consequences/Impacts Matrix (Orleans, Jefferson, St. Bernard, and Plaquemines Parishes)

Variable	Unit of Analysis	Definition/ Measurement	Data Source	Time Frame (Actual Data Date)
Social				
1. Population/ Number of persons	Parish/Community/ (Neighborhood in Orleans Parish)	Population	US Census/Estimate	Pre-Katrina (2000-2004)
			Field Observations	Post- June 2006
			LA Recovery Authority/ RAND Corporation/Orleans	Post- Long-Term
2. Families	Parish/Community/ (Neighborhood in Orleans Parish)	Number of families	US Census	Pre-Katrina (2000-2004)
			Qualitative Assessment- (local experts/research literature/expert opinion)	Post- June 2006 Post- Long-Term
3. Gender ratio	Parish/Community/ (Neighborhood in Orleans Parish)	Number men/number of women	US Census	Pre-Katrina (2000-2004)
			Qualitative Assessment- (local experts/research literature/expert opinion)	Post- June 2006 Post- Long-Term
4. Women head family w/children	Parish/Community/ (Neighborhood in Orleans Parish)	% Female head family w/children	US Census	Pre-Katrina (2000/04)
			Qualitative Assessment (local experts/expert opinion)	Post- June 2006 Post- Long-Term
5. Children Under 5 years old	Parish/Community/ (Neighborhood in Orleans Parish)	% Under 5 years old	US Census	Pre-Katrina (2000-2004)
			Qualitative Assessment (Local experts/expert opinion)	Post- June 2006 Post- Long-Term
6. Adults over 65 years old	Parish/Community/ (Neighborhood in Orleans Parish)	% Over 5 years old	US Census	Pre-Katrina (2000/04)
			Qualitative Assessment (Local experts/expert opinion)	Post- June 2006 Post- Long-Term
7. Race	Parish/Community/ (Neighborhood in Orleans Parish)	% African American	US Census	Pre-Katrina (2000/2004)
			Qualitative Assessment (Local expert/expert opinion)	Post- June 2006 Post- Long-Term
8. Population with low income	Parish/Community/ (Neighborhood in Orleans Parish)	%Family income below $20K	US Census	Pre-Katrina (2000-2004)
			Qualitative Assessment- (local experts/expert opinion)	Post- June '06 Post- Long-Term

(Sheet 1 of 3)

Table 48 (Continued)				
Variable	**Unit of Analysis**	**Definition/ Measurement**	**Data Source**	**Time Frame (Actual Data Date)**
		Social (cont.)		
9. Population middle to upper income	Parish/Community/ (Neighborhood in Orleans Parish)	% Household income below $50K	US Census	Pre-Katrina (2000-2004)
			Qualitative Assessment- (local experts/research literature/expert opinion)	Post- June 2006 Post- Long-Term
10. Level of poverty	Parish/Community/ (Neighborhood in Orleans Parish)	% Below poverty	US Census	Pre-Katrina (2000/04)
			Qualitative Assessment (Expert opinion)	Post- June 2006 Post- Long-Term
11. Educational attainment	Parish/Community/ (Neighborhood in Orleans Parish)	%Persons over 25 education less than high school	US Census	Pre-Katrina (2000-2004)
			Qualitative Assessment- (Local experts)	Post- June 2006 Post- Long-Term
13. Population living alone	Parish/Community/ (Neighborhood in Orleans Parish)	% Persons in 1-person households	US Census	Pre-Katrina (2000-2004)
			Qualitative Assessment/ (Local experts/research literature/expert opinion)	Post- June 2006 Post- Long-Term
14. Housing stock	Parish/Community/ (Neighborhood in Orleans Parish)	Number of housing units	US Census	Pre-Katrina (2000/04)
			Qualitative Assessment (Local experts/research literature/expert opinion)	Post- June 2006 Post- Long-Term
15. Number of renters	Parish/Community/ (Neighborhood in Orleans Parish)	% Housing units renter occupied	US Census	Pre-Katrina (2000-2004)
			Qualitative Assessment (Local experts/research literature/expert opinion)	Post- June 2006 Post- Long-Term
16. Long-term residency	Parish/Community/ (Neighborhood in Orleans Parish)	% Lived in same house 1995	US Census	Pre-Katrina (2000-2004)
			Qualitative Assessment (Local experts/research literature/expert opinion)	Post- June 2006 Post- Long-Term
17. Households with no personal transportation	Parish/Community/ (Neighborhood in Orleans Parish)	% Households with no vehicle	US Census	Pre-Katrina (2000-2004)
			Qualitative Assessment	Post- June 2006 Post- Long-Term
18. Population change 1990-2000	Parish/Community/ (Neighborhood in Orleans Parish)	% Population change 1990-2000	US Census	Pre-Katrina (1990-2000)
19. Population change	Parish/Community/ (Neighborhood in Orleans Parish)	% Population change	US Census	Pre-Katrina (2000–2004)
			(Repopulation Observational data/ RAND Corporation/LRA	Post- June 2006 Post- Long-Term
20. Disabled persons	Parish/Community/ (Neighborhood in Orleans Parish)	% of persons/ households with disabilities	US Census	Pre-Katrina (2000-2004)
			Qualitative assessment –(local experts/research literature/expert opinion)	Post- June 2006 Post- Long-Term
21. Health care	Broad institutional level	Number before and after	LA Dept Health and Hospitals	Pre-Katrina (2005)
		(capacity), number in impact zone	LA Dept Health and Hospitals	Post- June 2006 Post- Long-Term
22. Education	Parish level/broad institutional	Number of students enrolled	LA Dept of Education	Pre-Katrina (2004)
			Qualitative assessment (Local experts)	Post- June 2006 Post- Long-Term
				(Sheet 2 of 3)

Table 48 (Continued)				
Variable	**Unit of Analysis**	**Definition/ Measurement**	**Data Source**	**Time Frame (Actual Data Date)**
		Social (cont.)		
23. Political/ Governance	Broad institutional	Qualitative descriptions (Local experts)	Qualitative assessment (Local experts)	Pre-Katrina (2005)
24. Public safety	Broad institutional level	Qualitative descriptions /(local experts)	DHH Qualitative assessment (local experts)	Pre-Katrina (2005) Post- June 2006 Post- Long-Term
25. Disaster preparedness warning/response	% Household w/o vehicle/ Broad Institutional	US Census/ qualitative descriptions	Qualitative assessment (Local experts/research literature/expert opinion)	Pre-Katrina (2005) Post- June 2006 Post- Long-Term
26. Socio-economic (employment)	Broad institutional level	Qualitative descriptions	Qualitative assessment (Local experts/expert opinion/research) literature)	Pre-Katrina (2005) Post- June 2006 Post- Long-Term
		Institutional/Cultural		
27. Community centers	Parishes, communities	Number of community centers in impact zone	Qualitative assessment (Local experts)	Pre-Katrina (2000/04) Post- June 2006 Post- Long-Term
28. Churches	Broad institutional level	Qualitative descriptors	Qualitative assessment (Local experts/ unpublished data bases)	Pre-Katrina (2000-2004) Post- June 2006 Post- Long-Term
29. Service organizations/ volunteer	Point	Qualitative descriptors	Qualitative assessment (Local experts)	Pre-Katrina (2000-2004) Post- June 2006 Post- Long-Term
30. Art and entertainment shows, museums, festivals	Point	Number of advertised events before/after	(Qualitative assessment) (Newspapers)	Pre-Katrina (2005) Post- June 2006 Post- Long-Term
31. Leisure and recreational facilities	Point	Parks, movie theatres, restaurants, libraries	Qualitative assessment (Media accounts) (Local experts)	Pre-Katrina (2005) Post- June 2006 Post- Long-Term
32. Landmarks	Point	Parish	Parish government (websites) (Local experts)	Pre-Katrina (2005) Post- June 2006 Post- Long-Term
		Historical		
33. Historical buildings	Point	Points, polygons	Parish government (Local parish websites) (Local experts/media accounts)	Pre-Katrina (2005) Post- June 2006 Post- Long-Term
34. Cemeteries	Point	Cemeteries in impact zone (historic)	Qualitative assessment (local parish websites) (Local experts)	Pre-Katrina (2005) Post- June 2006 Post- Long-Term
				(Sheet 3 of 3)

7.4.3.1. Local

7.4.3.1.1. Population. Table 49 shows the population of each of the parishes in the study area. Historically, the urban areas of the six parishes have experienced population decline. For example, Orleans Parish had a 1980 population of 557,927, over 100,000 persons more than the number of people in 2004. (U.S. Bureau of Census 2006). In conjunction with the hurricane event, the historic population dynamics are likely to be extenuated. Based on the observational data, the analysis indicates that the repopulation of the area is slow.

Table 49
Population Variables

Variable	Pre-Katrina US Census Count (American Community Survey 2004)	Post-Katrina	
		March-June 2006 LRA Estimates	Long Term Projected
Population	Jefferson 455,466 (449,288) Orleans 484,674 (444,515) Plaquemines 26,757 St. Bernard 67,229 St. Charles 48,072 (50,073) St. Tammany 191,268	Jefferson 368,435 (March 2006) Orleans 181,400 (LRA) Plaquemines 17,567 St. Bernard 14,015 St. Charles 51,314 St. Tammany 206,204	Jefferson Orleans 320,000-350,000 (RAND) Plaquemines St. Bernard St. Charles St. Tammany
Sources: U.S. Bureau of Census 2006; RAND Corporation 2006.			

New Orleans has 73 neighborhoods as identified by the City of New Orleans Planning Department. Only 8 neighborhoods did not flood, and 34 were completely inundated. Many neighborhoods remain uninhabitable because of damage to the residential structures. Repopulation of the neighborhoods will likely take more than a year because of the extent of the damage. There is a high degree of uncertainty that some neighborhoods will regain their pre-Katrina levels within the next five years, especially the poor neighborhoods with low levels of home ownership.

The pattern of long-term recovery and reconstruction in New Orleans will take decades. The disaster recovery process is not linear nor a set of systematic actions (Petterson 1999). Even under optimal conditions, recovery is a set of loosely connected activities, executed by a variety of public and private agencies. In a number of ways, New Orleans is a unique city. Hurricane Katrina and its aftermath is a unique and catastrophic event. The estimated time of reconstruction depends on a variety of conditions. For some segments of the community, the term recovery is not applicable at all. Given the magnitude of the event, the response and the multitude of social, political and economic conditions prior to and after the event, reconstruction of the physical structures in New Orleans could take up to 10 years. Some areas may not rebuild. In terms of social, cultural and historic consequences, the city will never be the community it was prior to the event.

Based on this study's observational analysis, some neighborhoods appear to stand at a turning point; they might either experience repopulation, or be abandoned completely. These neighborhoods, which lie between those with high occupancy rates (such as East Riverside or the Irish Channel) and those that remain devastated (such as the Lower 9th Ward), include Bayou St. John, Fairgrounds, Uptown and Lakeshore. Other neighborhoods that bear close scrutiny include the range of African-American neighborhoods, such as Tremé, Milan, Plum Orchard, and

Edgelake/Little Woods. The future of these neighborhoods may serve as an important indicator of the city's future.

7.4.3.1.2. Income/Poverty. Table 50 displays the percentage of persons living below the poverty line. Poverty has been a long-term condition for many areas of New Orleans, with 27.9 percent of the population living in poverty in 2000. This is much higher compared to the 12.4 percent national figure and the state of Louisiana's 19.4 percent. Floodwaters inundated eight of the ten poorest neighborhoods in New Orleans, along with a sizable portion of the metropolitan area. Floodwater disproportionately hit poor areas, with 21 percent of the households in damaged areas being below poverty level as compared to 15 percent of the population of area living in non-flooded areas. Income and race variables intersect as the two conditions do in many communities in the United States. Being African-American increases one's chance of being poor. In New Orleans, the median income for white households was $61,000 a year in 2000. Comparatively, the median of income for African-American households was $25,000. There are a number of dynamics that could be involved in future income and poverty levels. Influxes of low wage labor may result in a new set of unskilled working class groups staying in the city. Those experiencing property damage and storm related job loss may also confront financial burden and increase their chances to being or becoming poor.

Table 50
Income Variables

Variable	Pre-Katrina U.S. Census Count (American Community Survey 2004)	Post-Katrina	
		March-June 2006 Qualitative Assessment	Long Term Qualitative Assessment
Percent Below Poverty	Jefferson 13.7 Orleans 27.9 (23.3) Plaquemine 18.0 St. Bernard 13.1 St. Charles 11.4 St. Tammany 9.7	Moderate to high increase in percent below poverty	Moderate increate in percent below poverty

Source: U.S. Bureau of Census 2006.

7.4.3.1.3. Race. Table 51 displays the percentage of the population that considers themselves African American. Over two-thirds of the population of New Orleans is African American as compared to the population of Louisiana which is 32.5 percent African American and the entire U.S. population which is 12.3 percent African American.

Table 51
Race Variable

Variable	Pre-Katrina U.S. Census Count (American Community Survey 2004)	Post-Katrina	
		March-June 2006 Qualitative Assessment	Long Term Qualitative Assessment
% African American	Jefferson 22.7 Orleans 66.7 (68) Plaquemine 23.4 St. Bernard 7.6 St. Charles 20.0 St. Tammany 9.8	Uncertain, especially in Orleans Parish	Uncertain, especially in Orleans Parish; potential change to ethnic and racial composition due to out-migration of resident population and in-migration of rebuilding related population

Source: U.S. Bureau of Census, 2006.

Many of the neighborhoods of New Orleans that were flooded were predominately African American. Some of the neighborhood areas had served as residences for middle class African Americans. Though the population in New Orleans has decreased since 1980, the poverty rate had decreased over all in the metropolitan area, an indication there was an upwardly mobility of African Americans in the metropolitan area. Many of the predominately African American neighborhoods that were flooded provided an affordable residential place that fostered upward mobility for this segment of the population. With these places flooded, the areas where upward mobility occurs in the African American community no longer exist. Many of the evacuees who remain outside the city are African American. Observational data will provide indicators of which neighborhoods are being repopulated.

A review of the U.S. Bureau of Census data for neighborhoods in New Orleans shows that African Americans (56.36 percent) are about 23 percent more likely to have experienced heavy flooding (greater than 4 feet) than Whites (33.41 percent). This difference is statistically significant ($p < .0001$). Households with incomes less than $50,000 are about 2 percent (48.42 percent to 46.47 percent) more likely to have experienced flooding over 4 feet. Although this difference is statistically significant, it is substantively small. Although 40.83 percent of whites have household incomes of $50,000 or more, only 17.5 percent of African American households have this level of income. This difference of 23.33 percent is statistically significant ($p < .0001$). The analysis indicated there is little relationship between household income and level of flooding but a strong relationship between race and both level of flooding and household income.

There is a strong relationship between race and level of flooding taking into account household income level. Among households with less than $50,000 income, African Americans are about 20 percent more likely to have experienced heavy flooding. As noted the difference between levels of flooding between blacks and whites was 23 percent without considering income. However, for African American households with an income of $50,000 or more, this difference has increased to 34 percent. Almost 2 in 3 (66.21 percent) higher-income African American households experienced more than 4 feet of flooding. About 32 percent of white households experienced that level of flooding. Both of these differences are statistically significant ($p < .0001$).

Among white households, lower-income households are 2.44 percent (34.41 to 31.97 percent) more likely to have experienced heavy flooding than higher-income households were. Within the African American community, this pattern reverses: Higher-income African Americans households are almost 12 percent (66.21 to 54.27 percent) more likely to have experienced heavy flooding than lower-income households were.

We are seeing the effect of the differential impact of flooding in the observations conducted in New Orleans neighborhoods. Middle- and upper-middle-class African American areas that experienced heavy flooding have had few residents return to their homes. Middle- and upper-middle-class neighborhoods—such as Edgelake/Little Woods, Gentilly Terrace, and Plum Orchard--have 75 to 80 percent of their homes gutted and empty, or the houses simply stand empty and boarded-up. Almost 2 in 3 (66.21 percent) of higher-income African American households experienced flooding of greater than 4 feet. Although some hardy souls are struggling to recover in these empty and isolated neighborhoods, most have not come back in the 8 months since Katrina.

7.4.3.1.4. Age and Disabled Population. Table 52 displays the percentage of persons over 65 years old by parish. In 2000, 11.7 percent of the population of New Orleans was over the age 65. This compares to the state of Louisiana with 11.6 percent of population over 65 years old and the U.S. with 12.4 percent. In some neighborhoods impacted heavily by flooding, over 1 out of 4 persons were over the age of 65. The Census Bureau estimates that 23.2 percent of the Orleans Parish population over 65 years old is physically or mentally disabled. This compares to the state of Louisiana with 19.5 percent of population being disabled, and the U.S. with 16.6 percent.

Table 52
Age Variables

Variable	Pre-Katrina U.S. Census	Post-Katrina March-June 2006 Qualitative Assessment	Post-Katrina Long Term Qualitative Assessment
% Over 65 years old	Jefferson 11.9 Orleans 11. 37 Plaquemine 10.9 St. Bernard 13.8 St. Charles 9.0 St. Tammany 10.0	Decreased percentage of persons older than 65 years of age	Decreased percentage of persons older than 65 years of age
% Persons 5 and older with disability	Jefferson 21.0 Orleans 23.2 Plaquemine 19.1 St. Bernard 23.4 St. Charles 17.1 St. Tammany 17.6	Uncertain	Uncertain

Source: U.S. Bureau of Census 2006.

In comparison to population under 65 years old, those over 65 have more a difficult time responding to emergencies and evacuations, as well dealing with recovery. Some neighborhoods hit heavily by flooding had over a quarter of their population over the age of 65. Disabled populations are also vulnerable the events related to disasters. As might be expected, neighborhoods with higher percentage of older persons also have higher number of disabled persons. Media accounts (New Orleans Time Picayune 2006) and interviews with local informants cite many problems of evacuating the elderly and disabled. Mortality data of Katrina victims clearly indicates that being elderly increases the likelihood being killed by the event. Though no data are available, it is likely many of the elderly and disabled who were evacuated may not come back.

7.4.3.1.5. Educational Attainment. Table 53 displays the percentage of persons over the age of 25 who have not completed high school. Persons over 25 years old who do not have a high school education in Orleans Parish is 25.3 percent and in Plaquemine Parish is 31.3 percent. This compares to the state of Louisiana with 25.2 percent of population over 25 years old but no high school degree, and the United States with 19.6 percent.

Table 53 Educational Attainment Variables			
		Post-Katrina	
Variable	**Pre-Katrina U.S. Census Count**	**March-June 2006 Qualitative Assessment**	**Long Term Qualitative Assessment**
% Less than high school education	Jefferson 20.7 Orleans 25.3 Plaquemine 31.3 St. Bernard 26.9 St. Charles 20.0 St. Tammany 17.1	Uncertain; expected higher percentage not having high school education.	Uncertain; expected higher percentage not having high school education
Source: U.S. Bureau of Census 2006.			

Quality education and educational attainment has been an issue in the New Orleans area for decades. High school attainment is critical for employment purposes as well as understanding the social, political, and personal choices that individuals must make on a daily basis. High school attainment is also critical for being able to take advantage of employment, social, political, and personal opportunities, as well. As can be expected, neighborhoods in New Orleans with the highest level of poverty also have the highest level of persons who have not completed high school. Many of the public and private schools in New Orleans remain closed because of hurricane damage, adding to the pre-existing conditions associated with the lack of educational attainment in the population.

7.4.3.1.6. Housing. Table 54 displays the percentage of housing units that are occupied by renters. New Orleans has a considerably higher number of renters than Louisiana (32.1 percent renter occupied housing units) and the United States (33.8 percent).

Table 54 Housing Ownership Variables			
		Post-Katrina	
Variable	**Pre-Katrina U.S. Census Count**	**March-June 2006 Estimate**	**Long Term Projected**
% Housing renter occupied	Jefferson 36.1 Orleans 53.5 Plaquemine 21.1 St. Bernard 25.4 St. Charles 18.6 St. Tammany 19.5	Uncertain	Uncertain
Source: U.S. Bureau of Census 2006.			

Housing has been a long-standing issue in the New Orleans community, with high concentration of poor and African Americans in specific locations in the city. Much of that concentration is related to public housing. There were a number of flooded neighborhoods that had many public housing units. Public housing neighborhoods were predominately composed of African Americans. Housing units in neighborhoods such as Iberville, St. Bernard Area, and Florida Projects had over 90 percent being occupied by renters. All of these areas experienced extensive flood damage after the Hurricane and were evacuated. Rental housing units make up a majority of the New Orleans housing stock. The likelihood of rebuilding rental property is typically lower than the rebuilding owner occupied housing units. This is similar to what has been found in the research literature of long term recovery from of large scale disasters (Bolin and Stanford, 1998). A reflection of the availability of rental property is found in Brookings

Institution (2006) findings that average cost of residential rental property has increase by 39 percent since the hurricane event. Without affordable housing for returning families and workers, many former residents will not return. Overall, a high percentage of the flooded housing units were rental property which reduces the likelihood that residents were insured or have been offered alternate housing within the city.

Based on the observational data, occupancy levels fluctuate widely across blocks within neighborhoods, especially those that experienced significant flooding, the level of building repair proves surprisingly uneven. Some buildings have been gutted and appear to be under repair; others have been gutted with no apparent renovation; and others remain virtually untouched, eight months after Katrina. There appears to be no uniform timetable for rebuilding in any of the sampled neighborhoods. This lack of consistency contributes to the sense of isolation and feelings of vulnerability for residents. It also makes planning difficult for residents and for local officials.

7.4.3.1.7. Institutions. The analysis examined a wide variety of social institutions including those associated with religion, voluntary services, governance and justice, public services, public safety, economic relations, and others. Schools and hospitals are two social institutions of which quantitative data were readily available. Table 55 displays the public school enrollment. In comparing the pre- and post-Katrina figures, the table clearly indicates the impact on the hurricane on the schools in New Orleans.

Table 55
Public School Enrollment Variable

Variable	Pre-Katrina		Post-Katrina: March-June 2006 LDE (4/06)		Post-Katrina: Long Term Projected
Schools - Enrollment	Jefferson	51,666	Jefferson	42,777	Uncertain
	Orleans	65,349	Orleans	9,278	
	Plaquemine	5,034	Plaquemine	3,068	
	St. Bernard	8,872	St. Bernard	2,268	
	St. Charles	9,797	St. Charles	9,775	
	St. Tammany	36,169	St. Tammany	35,021	

Source: Louisiana Department of Education.

One of the key foundations of a community is its educational system. As noted, education has a historical problem in New Orleans areas. Issues ranged from deteriorated school buildings to low student achievement. According to the Bring New Orleans Back Committee (2006), 68 of the 127 New Orleans schools were deemed “academically unacceptable” while another 44 were below the state average. Though not reflected in the table, many parents have used private schools as an alternative to public education for their children. These private schools also were damaged by the hurricane. However, a large number of these private schools were parochial and institutionally linked to other schools that were undamaged. Many of those students were able to easily transfer to other schools. Given the pre-Katrina state of the educational system, the scattering of student and faculty and damage to schools made an undesirable condition worse. The rebuilding of the schools and the re-enrollment of students will be one of the key dynamics in the overall repopulation of the city.

New Orleans is also a center of higher education with a number of private and public universities and colleges. Most of these universities were forced to cancel fall classes and have limited enrollment in the spring. Dillard, UNO, and Xavier faced up to 50 percent decrease in enrollment from a year ago. Both Tulane and Loyola have between 10 and 20 percent fewer enrollments for Spring 2006 enrollment (Brookings 2006). Dillard, a historically black institution, is in danger of closing, with students currently housed in a local hotel. These universities have historically played a number of vital roles in the community and continued to do so during the hurricane response and recovery.

Table 56 displays the number of hospitals open before and after Hurricane Katrina. As with education, health care is a key institution in any community. Hurricane Katrina forced the closure of many of the hospitals in the area. New Orleans was a major medical clinical and research center, prior to Katrina. After the hurricane, New Orleans has less than a third of the hospitals functioning that were open pre-Katrina. With one large hospital totally destroyed by floodwaters and other major hospitals seriously damaged, the return of the level of health care provided in New Orleans before the hurricane may be years away.

Table 56
Hospital Variables

Variable	Pre-Katrina Louisiana Hospital Association	Post-Katrina: March-June 2006 Count	Post-Katrina: Long Term Projected
Hospitals Number	Jefferson 14 Orleans 22 Plaquemine - St. Bernard St. Charles 13 St. Tammany 12	Jefferson 13 Orleans 7 Plaquemine - St. Bernard (2 remained closed) St. Charles 12 St. Tammany 12	Uncertain in all parishes; one large community hospital in Orleans will not reopen.

Source: Louisiana Hospital Association 2006; Brookings 2006.

Hurricane Katrina impacted greatly social institutions key to the successful functioning of both small neighborhoods and the larger society. In addition, with a wide range of social institutions being impacted, the outcomes have been more severe though not enough to foster a complete standstill. Put another way, in other smaller disasters, perhaps a few social institutions may be impacted, but not severely enough to create a social standstill. However, with Hurricane Katrina impacting all the noted social institutions, a synergistic effect resulted that created a form of inertia.

7.4.3.1.8. Hurricane Preparedness, Warning, and Response. A community subject to hurricane events such as New Orleans develops both an official and unofficial means to prepare to respond to the threat. Preparedness includes activities such as writing and exercising plans for warning, transportation, and evacuation; its goal is to ready the population and response sectors for an event. Response occurs when warnings are issued and efforts to stem the loss of life begin: transportation, evacuation, search and rescue, medical assistance, and sheltering serve as common activities. There were a number of factors related to the community response to the threat of Hurricane Katrina. One of the most direct measures of being able to respond to evacuation is the availability of a vehicle to a household – the primary method of evacuation. Table 57 shows the percentage of households without a vehicle.

Table 57
Percent Households Without a Vehicle

Variable	Pre-Katrina 2000 Census	Post-Katrina March-June 2006	Post-Katrina Long Term Projected
% Households without a vehicle	Jefferson 9.3 Orleans 27. 3 Plaquemine 9.6 St. Bernard 10.3 St. Charles 6.4 St. Tammany 23.2	Uncertain	Uncertain
Source: U.S. Bureau of Census 2006.			

Evacuation is a protective action response that is ultimately designed to move populations out of harm's way in advance of hurricanes. There are many challenges in ordering and implementing evacuations along the nation's coastal regions. The entire process is complicated by the uncertainties in the timing, location, and strength of the hurricane. One of the most significant aspects of hurricane evacuation is clearance time—or the length of time it takes to clear the transportation network of vehicles prior to tropical force winds reaching the area. The clearance time is a function of the population size in the affected area, its mobility, and the road network and capacity. For New Orleans, the density of population, the lack of individual mobility of some residents, as indicated by the availability of vehicles, and the low elevations of many of the egress routes, meant that the time to effectively clear the area was on the order of days, not hours.

The City of New Orleans was in the mist of developing emergency preparedness plans immediately before Hurricane Katrina struck. In 2004 local, state and federal agencies participated in a "table top" exercise, Hurricane Pam. Before Katrina, many of the lessons learned had yet to be implemented. When Katrina approached, authorities at all level of governments issued warnings about the intensity of the hurricane and the likelihood that New Orleans was in it path came at least four days prior to landfall. Evacuation orders were issued more than 24 hours prior to landfall. However, a 2003 survey of the region conducted by Louisiana State University indicated that a sizeable population would not be able or willing to evacuate- the elderly, the poor, disenfranchised ethnic groups and those without access to automobiles -the vulnerable population. By some standards, the massive evacuation of New Orleans was successful. However, evacuation was obviously problematic for the vulnerable population, a reflection of the 2003 findings. Tens of thousands New Orleans residents were exposed to hurricane dangers and the flooding that followed. The number of the persons and lack of preparedness resulted in the failure of all levels of government to provide immediate assistance to those stranded in the city. Over a thousand people died waiting to be rescued.

Many residents refused to evacuate, despite official orders to do so. The reluctance on the part of evacuees to leave is based on a number of factors, among them are: perception that the risk is not that severe; assumption that the home is safe; unwillingness to leave pets behind; reluctance to use public shelters; the credibility of warning information; concerns about traffic; and past experience (Dow and Cutter 2001, 2002). The experience of Katrina and the perceptions of the effectiveness of preparedness, warning, and response will be part of the future of the city. Though there is not specific data, there is likely to be a high degree of uncertainty about preparedness and response to future threats. There is also likely to be a high degree of uncertainty about the ability to protect the city and adjacent areas from the physical forces of hurricane floodwaters, even with modification to the existing level of protection. The thousands of FEMA trailer residents in Louisiana are living in situations with a high degree of uncertainty about protection from future storms. This overall uncertainty will play a critical role in the repopulation of the area.

7.4.3.2. Historical and Cultural Resources

The greater New Orleans area is rich in historic and cultural resources, dating from pre-European era. Music, food, and art were not only part of the regional traditions but also a major contributor to the national character. Many of the flooded homes in Orleans and surrounding parishes were of historic significance. Many museums in New Orleans remain closed as of May 2006. For example, the Louisiana Museum of African American History in the Treme has major exhibits such as the “1811 Slave Revolt” and “The African European Root of the Underground Railroad” remaining closed. The many cemeteries, historic buildings, forts, churches and culturally significant places were flooded (New Orleans Museum.com 2006). Restaurants with a long tradition, not only tied to tourism but to places of cultural significance, were flooded. In addition, much of the labor associated with those restaurants evacuated. As of the writing of this report, an inventory of these losses has not been completed.

7.4.3.3. Regional

The social and cultural impacts of the hurricane event also include those associated with the mass in-migration of evacuees into communities immediately adjacent to the greater New Orleans metropolitan area. Communities in Alabama, Louisiana, and Mississippi have experienced the greatest impacts. Besides the flooding in New Orleans, the physical forces of Hurricane Karina caused property damage and disruption to the lives of those living in a gulf coast area.

Individuals, state and local governments, voluntary groups, and faith-based organizations all attempted to meet the needs of the populations living in areas adjacent to the New Orleans metropolitan area. For example, according to the Louisiana Hospital Association (2006), approximately 89 of the state’s 126 emergency room hospitals and 59 of the 84 non-critical service hospitals were impacted by Katrina. Yet injured and displaced patients from New Orleans were force to use the region’s hospitals to meet their health care needs. The performance of the levees and the aftermath indirectly impacted the region as evacuees sought out areas of safety. Cities such as Baton Rouge, Lafayette, Alexandria, Lake Charles, and Monroe in Louisiana and Jackson and Hattiesburg in Mississippi experienced a large influx of evacuees in a short period following the hurricane, causing some communities to nearly double in population. FEMA (2006) received over 700,000 applications for assistance in the region adjacent to the New Orleans metropolitan area as of March 2006.

Government and non-governmental agencies established evacuation centers and provided interim housing for many whose homes were damaged by flooding. The Louisiana Recovery Authority (LRA 2006) estimates that temporary relief services cost state and local governments $15 billion to $20 billion. At the same time, the LRA estimates that government revenue losses were $8 billion to $10 billion. Since much of the hurricane damage to residences and business in greater New Orleans has not yet been repaired, many of evacuees remain in temporary housing. The influx of population and length of stay has put heavy demands on local public services such as schools, hospitals, and public safety in other communities and states.

The impact on regional schools has been large. For example, the Louisiana State Department of Education (2006) reported that as of March 2006 there were 111,493 displaced students as a result of the hurricane, with 30,624 attending school in different parishes than prior to the event. School districts throughout the state have had to accommodate the needs of the new students, putting demands on an educational system already facing challenges prior to the event. Many of the local schools were closed because of the loss of power. However, after being reopened, the same schools face an influx of students whose New Orleans' schools were damaged by the hurricane.

The regional impacts of the mass evacuation of the greater New Orleans area will have a lasting effect, especially if large numbers of evacuees do not return to New Orleans. Their presence will alter the social and cultural character of their new residence. If the displaced of New Orleans residents follows other mass migrations, there will be long-term assimilation and acculturation, with both the host and the evacuee populations having a different social and cultural character than they did prior to the event.

7.4.3.4. National

Hurricane Katrina displaced over a million people making it the largest mass migration of people since the Civil War. By early October 2006, displaced individuals were located in every state of the nation, with thousands clustered in large southern cities such as Houston, Atlanta, and Memphis. Many others were scattered in large coastal cities or small rural communities. As of March 2006, the Federal Emergency Management Administration reported over 369 cities in the United States and it territorial procession-being host to evacuees, with 76 of the cities hosting over 1,000 evacuees each (FEMA 2006). It is not yet known how many people relocated because of the initial hurricane or because of the subsequent levee breaches.

The American Red Cross opened 1,095 shelters for evacuees with over 831 shelters in states outside of Louisiana (Brookings 2006). Other government, voluntary organizations, and private individuals provided shelter as well. The numbers of evacuee shelters will never be fully known. However, the magnitude of those seeking shelter outside the New Orleans area is reflected in the number of persons who applied for federal assistance because of the Hurricane.

A large number of persons who evacuated New Orleans remain far away from home. The overall impact of the displaced New Orleans residents on some communities throughout the United States may be similar to rapid population "booms" associated with rapid community growth. The impacts—as noted by anecdotal information from the Houston metropolitan area—include a sharp rise in demand for goods and services and the perceived disruptive consequences of rapid social change.

Recent trends in research on booms showed that rapid change has complex effects that are both adaptive and overburdening in nature (Finsterbusch and Freudenburg 2002, p. 413). Adaptive means that the incoming population adapts to the norms and culture of the local community at the same time that the local community adapts to the migrants. This fosters cross-fertilization of cultures and social organization. Overburdening means competition for limited resources, including public services and tax dollars. Accounts from the media (*New Orleans Time Picayune* 2006) indicated that evacuee host cities throughout the U.S. have experienced both.

Part of the national dialogue regarding the event will include the nation's role in rebuilding and protecting New Orleans from future hurricane events. Rebuilding and reconstruction will take considerable resources. It cannot happen without state and federal support. One to the lasting consequences of the nation will be devoting its resources to rebuild the region.

Even nine months after the event, the regional and national impacts are still occurring and it is premature to assess the full consequences of the New Orleans levee breeches and Hurricane Katrina. For example, there is little data on the consequences and costs of evacuation (a short-term situation) versus migration and relocation (the social and economic costs of setting up a new life in a new location). Protecting individual rights to privacy, agencies only have only provided generalized information on where impacted population went. Many of the measures of the social consequences in the over 1,000 cities receiving hurricane victims vary considerable and collected by a variety of state and local agencies. Though important, reporting the full range of regional and national consequences is not addressed in detail.

As with the local consequences, many of the manifestation of the consequences have yet to develop. For example, relocated families in stress could lead to increased divorce rates, domestic abuse, child abuse, and even substance abuse, all of which could occur in both the short term and longer term, requiring response from both a regional and national array of social and public agencies. Many of these issues emerge in relocated populations residing throughout the region and the United States. Those communities throughout the region and nation have had to accommodate the displaced population creating greater demand on public services such as public safety, health care, education, and social services. Many of the communities already had problems meeting demands prior to the hurricane event. There are undoubtedly many longitudinal studies that are currently underway to assess both the national and regional impacts of this disaster on the residents and communities in greater New Orleans. The report provides only a brief synopsis of some of the more important considerations.

7.4.4. Summary of Social and Cultural Consequences

The United States does not have recent experience with a sudden, mass migration of this magnitude. Studies of the responses to disasters have tended to focus on moving resources to the immediate area of the disaster rather than the migration of hundreds of thousands of people to new locations on a semi-permanent basis. In addition, the research literature does not provide clear insight of the social, historical consequences of this mass movement of people on the national character.

Perhaps the Mississippi River flood of 1927 provides the most recent insight into the effects of mass migration. That flood became part of the national folklore and displaced 700,000 people, many of whom were poor African Americans. Many eventually migrated to U.S. cities in the North. The treatment of flood victims varied by race and income and caused many people to question the existing social and political institutions. The migration also caused an exchange of culture between groups in the northern and southern parts of the United States. Though there are differences in the circumstances and the era in relation to Hurricane Katrina and the Mississippi Flood of 1927, both can be characterized as having a lasting effect on the political and cultural character of the nation, region, and the city.

The performance of the levees protecting New Orleans is obviously a key to its social, cultural, and historic conditions. The immediate physical damage made large portions of the city uninhabitable, with thousands of residential, commercial, and public structures destroyed. Basic infrastructure facilities, such as power, water, sewer, and natural gas lines were made inoperable and continued to be out of service for months after the event. Many victims not only lost their homes, but also their schools, health care, places of worship, places of trade, and jobs. The forced relocations disrupted family and friend networks. As a result, the event not only had an immediate impact on the well-being of the population of those living and working in the metropolitan area, but also resulted in basic changes in the social organization of all aspects of that population.

Local groups are struggling to rebuild their neighborhoods, but are doing so under great uncertainty about who will come back. As noted by Freudenburg and Gramling (1992) in their discussion of the social impacts from large natural resource based projects, the social processes of planning can have impacts itself. Groups within a community respond in a variety of ways to planned futures, even before physical construction begins. This results in a variety of consequences ranging from real estate speculation to various stakeholders maintaining lasting distrust of each other. As noted by the Brookings Institution, New Orleans has some of the most concentrated poverty neighborhoods in the nation. Given the racial and social stratification of the city, the planning of rebuilding will be a process that will shape future interactions of the various racial, ethnic, and economic groups that make up the community.

The issues of competency and legitimacy of governments to respond to the large-scale disasters as well as the allocation of resources for recovery will likely be part of the social and political future of the city. Repopulation, recovery, and investment will be contingent in the faith people put into their community's ability to provide a safe place to live.

With a number of people coming to the city to assist in rebuilding, the recovery process itself has changed the nature of the city. There has been anecdotal evidence of Spanish speaking workers becoming a source for the manual labor associated with recovery work. Less than 5 percent of the pre-Katrina population was of Hispanic origins. It is not clear how many of these workers will stay. However, the in-migration of Hispanic and out-migration of African Americans could have a lasting impact on the racial composition of the city.

The education system and health care institutions in New Orleans are critical elements of the city's future. A significant factor in the historic out-migration from the city can be attributed to the performance of the public school system. The flood resulted in the shutdown of schools and a relatively slow recovery, as indicated by school enrollment figures. The flood was a major blow to an already troubled system. New Orleans had some of the best hospitals in the region and, in some instances the nation. As an institution, hospitals had an essential role in the community as providing health care, public health education, and employment. The loss of many of the hospitals and the uncertainty of rebuilding will have long-term multi-dimensional social consequences.

No matter what level of flood protection proved in the future, disaster preparedness will be a factor in individual, business, and group decisions about moving back to the city. Though the concept may fade with time, the community of New Orleans has come to fully appreciate that no system of protection offers a risk-free condition. Protection of human populations from risks such as hurricanes is based on multiple systems, both physical structures and social organization. Each has its own probability of failure. The levee system and the protection it provides will be a critical part of the recovery of New Orleans. Equally important is the emergent social organization in the aftermath of the pre-Katrina levee system. The success of physically rebuilding of the city will be contingent on involvement of the region's diverse population, including evacuees. Planning and preparing for future hurricanes and potential storms exceeding whatever the level of protection is provided will determine whether another catastrophic event like Hurricane Katrina can be minimized. The success of that preparedness, too, is contingent upon involvement of all segments of the community.

References

Bolin, Robert, and Lois Stanford. 1998. *The Northridge Earthquake: Vulnerability and Disaster.* London, UK: Routledge.

Bring New Orleans Back Commission. Accessed January 2006 at http://bringneworleansback-education.org/docs/012606finalreport.pdf

Brookings Institution (Brookings Katrina Index). Accessed 15 May 2006 at: http://www.brookings.edu/metro/pubs/200512_katrinaindex.htm

Dow, K., and S.,L. Cutter, 2001. Public orders and personal opinions: Household strategies for hurricane risk assessment. *Environmental Hazards* 2(4):143-155.

_______.. 2002. Emerging hurricane evacuation issues: Hurricane Floyd and South Carolina. *Natural Hazards Review* 3(1):12-18.

Federal Emergency Management Administration. 2006. Accessed March 2006 at http://www.gnocdc.org/reports/Katrina-Rita_applicants_by_MSA_051206.pdf

Finsterbusch, Kurt, and William Freudenburg. 2002. Social impact assessment and technology assessment. In *Handbook of Environmental Sociology* ed. R. E. Dunlap and W. Michelson, 407-447. Westport, CT: Greenwood Press.

Freudenburg, William, and Robert Gramling. 1992. Opportunity-threat, development, and adaptation: Toward a comprehensive framework for social impact assessment. *Rural Sociology* 57: 216-234.

Louisiana Department of Education. Accessed 31 March 2006 at http://www.doe.state.la.us/lde/pair/1489.html#hurricane

Louisiana Hospital Association. Accessed 24 February 2006 at http://www.lhaonline.org

Louisiana Recovery Authority. Accessed 21 February 2006 at http://www.lra.louisiana.gov/assets/FINAL_QP2006_FEB%2006_revised.pdf

New Orleans Museums.com. Accessed 20 May 2006 at http://neworleansmuseums.com/multiculturalmuseums/afamhistory.html

New Orleans Times Picayune. Accessed 3 March 2006 at http://www.nola.com/newslogs/breakingtp/index.ssf?/mtlogs/nola_Times-Picayune/archives/2005_08.html#075278t

Petterson, Jeanine. 1999. A review of the literature and programs on local recovery from disasters. Natural Hazards Research Working Paper #102. Natural Hazards Research and Application Information Center, Institute of Behavioral Science, University of Colorado.

RAND Corporation. Accessed 16 March 2006 at http://www.rand.org/research_areas/education/

U.S. Bureau of Census. Accessed 30 January 2006 at http://www.census.gov

7.5. Environmental Consequences Assessment Digest

The environmental consequences assessment addressed the direct, intermediate, and long-term environmental consequences stemming from flooding of greater New Orleans during and after Hurricane Katrina. Environmental consequences are indicated by the altered condition of ecological resources. The ecological resources identified for this subtask are publicly owned wild species and supporting ecosystems of recognized environmental and economic significance.

7.5.1. Objectives

The environmental study addressed the direct, intermediate, and long-term environmental consequences stemming from flooding of greater New Orleans during and after Hurricane Katrina. This task was approached through the assessment and comparison of ecological resource conditions in the vicinity of New Orleans before and after Hurricane Katrina, and the extent to which city flooding and associated floodwater management contributed to the observed differences. We assumed that a reasonable assessment of the environmental consequences is reflected in the condition of the environment's ecological resources.

The ecological resources considered in this study are publicly owned wild species of recognized environmental and economic significance, and their supporting ecosystems. These include species that provide positive environmental and economic benefits as well as species that might threaten human comfort, property, and health and safety under certain conditions (pest species). Privately owned ecological resources were excluded—including soils, domestic plants and animals (including city trees), and cultured species—except as they might interact with floodwaters to impact wild resources (e.g., flooded contaminated soils). The fate of privately owned resources is addressed under economic consequences.

The objectives of the environmental study were to characterize and compare three environmental conditions to an extent allowed by available data and time constraints to assess the environmental consequences of Hurricane Katrina, and to qualitatively discuss the consequences of a fourth hypothesized condition resulting from a similar hurricane with flooding similar to actual Katrina conditions once the flood protection system is repaired on June 1, 2006. These environmental conditions include:

- The pre-Katrina condition existing inside and outside the flood protection system.
- The post-Katrina conditions
    - The observed flood and flood management condition inside and outside the flood protection system (actual condition)
    - Hypothesized condition inside and outside the flood protection system if the flood were limited to rainwater alone from Katrina and Rita, with no levee overtopping or breaching
    - Hypothesized June 2006 condition inside and outside the repaired flood protection system resulting from a repeat of the actual flood condition over an altered environment (discussed only).

The environmental study focused on ecological resources that provide environmental benefits, such as species of special concern because of their threatened conservation status and their supporting ecosystems. As defined here, environmental benefits exclude all economic and other social-cultural benefits, including health and safety benefits, which are addressed in consequences reported elsewhere in this volume. Most clearly left are the benefits to society that accrue from sustaining the security of the nation's biodiversity. These benefits are indicated non-monetarily in the status changes incurred in species listed for protection and recovery under state and federal laws and vulnerable to global extinction as indicated in the NatureServe Explorer database (NatureServe Explorer 2005). The study also considered closely related ecological resource conditions that affect regional and national economic benefits —such as commercial fisheries and fish and wildlife supporting recreation use—as well as pest species having other social effects related primarily to human health and comfort. Those resource conditions, once assessed here, were made available for studies of economic and health and safety consequences reported elsewhere in this volume.

The condition of supporting ecosystems was investigated to the extent that they contribute to both environmental and economic benefits by sustaining ecological resources. As defined here, ecosystems are complexes of physical habitat and interacting biotic community. The impacts on ecological resources, including species vulnerable to extinction, often can be only indirectly determined from changes in the supporting ecosystem communities and habitats. Losses and conversions of wetland ecosystems, for example, could indirectly impact a number of species listed under ESA protection.

7.5.2. Approach

7.5.2.1. Concept Model Development

A concept model of the potentially impacted ecosystems and ecological resources was developed and used to define the problem's ecological and geophysical dimensions, and the tactics used to achieve study objectives. Figure 19 is an illustration of the general concept. The fundamental need was to sort out the observed (or actual) environmental consequences of Hurricane Katrina, including extreme flooding within the flood protection system, from those that would have occurred if the flood protection system had prevented all flooding except for that associated with direct input of rainwater, which is routinely pumped out of the system (the hypothesized condition). Contributions of breaching and overtopping were not differentiated in the depiction of the actual or hypothesized condition in the concept model.

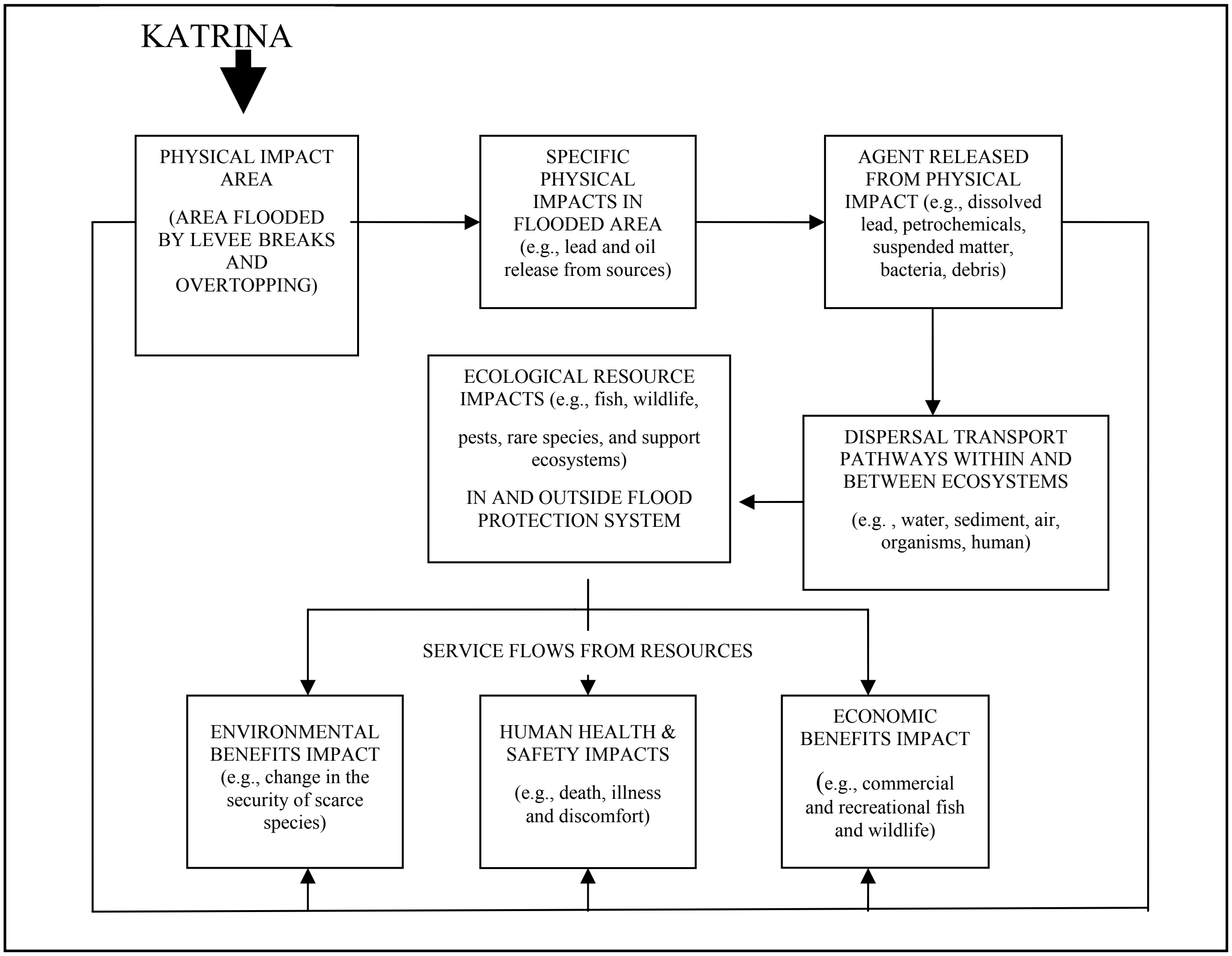


Figure 19. Conceptual model of the ecosystem area directly impacted by flooding within the flood protection systems and the area externally impacted outside the flood protection system by indirect impacts through pathways of impact transmission, such as water transport.

Determining the differences between the actual environmental conditions observed following Hurricane Katrina and the hypothesized conditions if no levee breaching or overtopping had occurred (rainwater flooding alone) required identification of the pathways of environmental impact between flooded areas and the ecological resources both inside and outside the flood protection system. Levee overtopping, levee breaching, and floodwater pumping were identified as potential impact pathways. Some rain-caused flooding normally occurs in greater New Orleans during storm events and is routinely pumped out as an integral part of the flood protection system. Similarly, the exceptional flooding that followed Hurricane Katrina was pumped out, only in larger than the usual rainwater volume, and with larger than usual total potential contamination load. The transport of contaminants in floodwater to other locations became a major concern when early results of floodwater sampling indicated that some biological (fecal) and chemical contaminants were present in the floodwaters. Saltwater contamination of freshwater wetlands within the flood protection system also became a concern upon learning of floodwater pumping into them and breaches in and overtopping of surrounding levees. The possible contaminants included a wide variety of toxic metals, petroleum and pesticide organics, and pathogens indicated by fecal bacteria and chemicals in concentrations that exceed health standards. Breaching and overtopping also allow redistribution of aquatic resources, including species that become pests when displaced from their natural habitats.

Possible ecosystem and ecological resource contamination was important to consider for several reasons. Habitat contamination can lead to plant and animal contamination through biological uptake and transfer through the food web. Contaminants can impact resource production directly through increased mortality and decreased birth and growth rates. Contamination can alter the capacity of ecosystems to support resource species indirectly by modifying habitat characteristics (e.g., oxygen levels, protective cover, roosting habitat), food supply, and the relative abundance of predators and parasites. Resource contamination above allowable limits can threaten human health and result in prohibitions of resource use for food supply, recreation, and other human services.

Aerial and overland connectivity were also considered, to the extent they were related to flooding and floodwater management. Except for debris disposal, little evidence of possible environmental impact pathways other than hydrologic pathways was discovered. The main exception was possible human transport and dispersal of pests in debris moved out of the flood protection system. The greatest concern was dispersal of the invasive and costly Formosa termite, which has not become established widely outside of New Orleans and Florida.

Although transitory physical impacts were expected just outside the flood protection system where water was pumped in large volume (e.g., sediment mobilization by turbulent flow), various chemical and biological contaminants were judged to be more likely to reach into more remote ecosystems with potentially more persistent impacts. The physical effects from Hurricane Katrina floodwater pumping on receiving ecosystems was expected to be local and not much different than for normal rainwater pumping because pumping rates were similar.

The potentially impacted ecosystems were separated into inner ecosystems within the flood protection system and the outer ecosystems outside the flood protection system (Figure 20). The inner ecosystems occurred throughout all or parts of Orleans, Jefferson, St. Bernard, St. Charles, and Plaquemines Parishes. Based on early estimates of floodwater volume and contamination level, and on outer-ecosystem estuary and ocean volumes, the outer boundary of identifiable contamination was estimated not to extend far into the Gulf of Mexico, and most probably would be limited to Lake Pontchartrain and parts of Lake Borgne.

The inner ecosystem included all subsystems in 13 drainage subbasins (Figure 20) enclosed within flood protection levees. Within the inner ecosystem, the study analysis concentrated on the direct effects of floodwater level and water quality on ecological resources and their supporting ecosystems and the possible effects of pest species invasion through breaches and overtopping. It also considered the possible movements within the flood protection system of pest species displaced from flooded areas, both natural and urban, into adjacent areas above flood level. Pest species include insect, reptile, rodent, and other species that potentially act as vectors of threat to the comfort, health, safety, and property of people within the area protected by system levees.

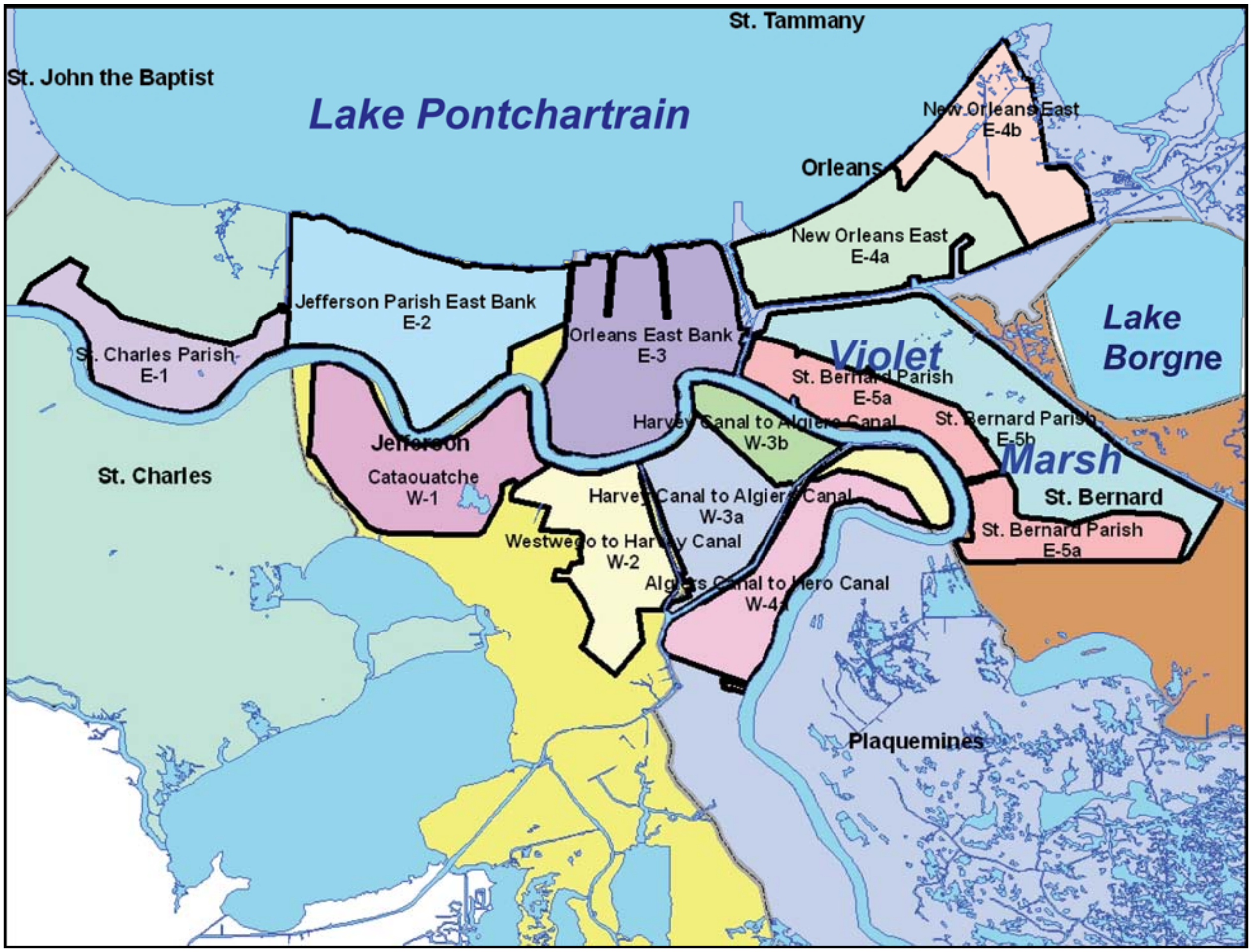


Figure 20. The hurricane flood protection system surrounding 13 subbasins, or polders, in greater New Orleans forms the boundary between the inner and outer ecosystems of the Mississippi River delta region.

Past rain-caused flooding, as well as flooding associated with Hurricane Katrina, was pumped out of the inner ecosystems into the outer ecosystems at numerous points around the city. Much of the water was pumped into Lake Pontchartrain across the northern levee boundary of the flood protection system. A number of pumps move water out of Chalmette and vicinity into a large wetland sump in a drainage subbasin to the north known as Violet Marsh (Figure 20). A few other pumps release water into the Intracoastal Waterway and the Inner Harbor Navigation Canal (IHNC) connecting Lake Pontchartrain and the Mississippi River. Because of their size, naturalness, and valued environmental resources, Lake Pontchartrain and Violet Marsh were especially important environmentally.

Ecosystems are hierarchically organized and both inner and outer ecosystems include a mix of smaller subsystems defined by differences in their biotic communities and associated habitats. Marine, brackish and freshwater aquatic ecosystems and wetlands, as well as uplands are found in both inner and outer ecosystems. Upland subsystems of the inner ecosystem are mostly privately owned properties in urban and suburban settings, which may include some wild ecological resources, such as freely ranging urban wildlife. Both inner and outer ecosystems include wetland ecosystems supporting a much wider range of wild species, including a few that are listed as threatened or endangered under the Endangered Species Act.

The inner ecosystem analysis included the possible impact of saltwater intrusion by water pumping, levee overtopping, and levee breaching on wetland vegetation and native plant and animal species that depend on waters of lower salinity. Most of the fresh water to brackish wetlands in the inner ecosystems occur in Violet Marsh and in Bayou Sauvage National Wildlife Refuge. The wildlife refuge occupies the eastern-most drainage subbasin of Orleans Parish (E-4B). No floodwater is pumped into that refuge, but some is pumped out when necessary into the Intracoastal Waterway. Violet Marsh occupies most of the E-5B drainage subbasin. Pumps along a non-federal levee separating the Chalmette area and the Ninth Ward from Violet Marsh were used to pump saline floodwaters out of the Chalmette area (St. Bernard Parish) and the Ninth Ward (in Orleans Parish) into Violet Marsh (St. Bernard Parish) following Hurricane Katrina.

Salt water also entered both wetland areas with the storm surge and through levee breaches along the Intracoastal Waterway and the Mississippi River Gulf Outlet. Changes in the fresh-water plant composition of Violet Marsh and Bayou Sauvage following exposure to salt water was not only of environmental concern, but could influence future performance of the city's flood protection system. Of particular interest in that regard were possible effects of salinity on the vertical development of the vegetation; i.e., the amount of forested wetland versus lower-lying herbaceous wetland (e.g., grasses, rushes, sedges) and open water.

Definition of the outer ecosystem boundary focused on the possible transport of chemical and biological contaminants to outer ecosystems from within the flood protection system and possible uptake in resource species including shrimp, oysters, fin-fishes, state and federal threatened and endangered species, and supporting habitats. The Lakes Pontchartrain-Borgne estuary was examined with the greatest intensity because of its close proximity to possible impact from flood protection system failure. The area demarked in Figure 21 approximates the boundary between the near-outer and far-outer ecosystems for which aquatic resource data were considered in the analysis.

7.5.2.2. Data Development and Analysis

Both existing and original data were analyzed. Ecological resource condition in the outer ecosystems was assessed primarily through assembly and analysis of data collected by various responsible federal and state agencies, universities, and other reputable organizations. A number of agencies and educational institutions collect data in the area. In addition, original data were collected at Violet Marsh and vicinity, and analyzed by personnel at the Environmental Laboratory of the Engineer Research and Development Center (ERDC) operated by USACE at Vicksburg, MS.

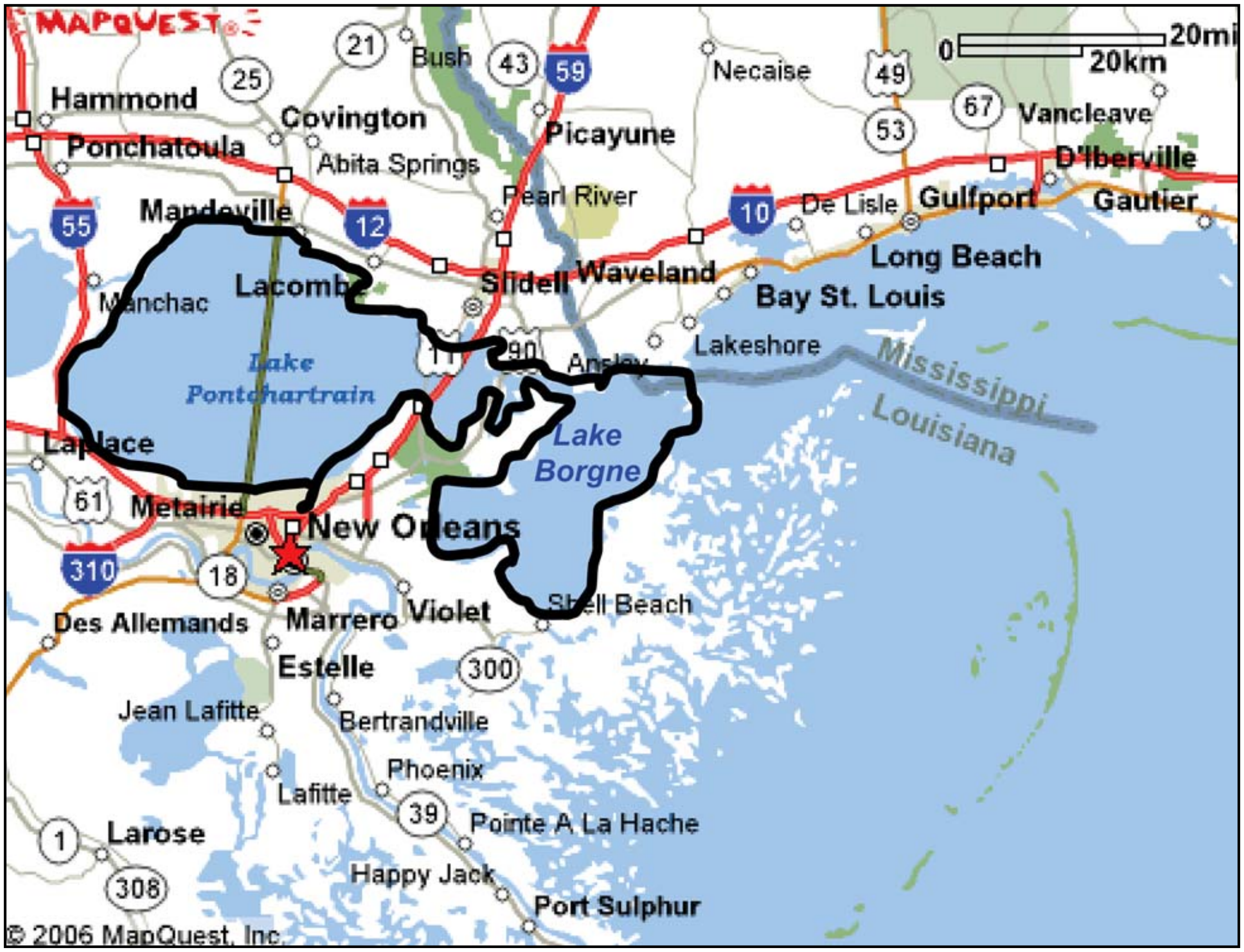


Figure 21. The Lakes Pontchartrain-Borgne estuary (darkly outlined) and surrounding delta and gulf ecosystems comprising the outer ecosystems as defined for this study. The far-outer ecosystem includes coastal area, wetlands, barrier islands, and nearshore waters of the Gulf of Mexico in Louisiana and Mississippi.

7.5.2.2.1. Existing Data. Most existing data were collected under the auspices of other agencies and organizations including the National Oceanic and Atmospheric Administration (NOAA) and its National Marine Fishery Services (NMFS), more specifically, the United States Environmental Protection Agency (EPA), the Fish and Wildlife Service (FWS) and the United States Geological Survey (USGS), the Louisiana departments of Environmental Quality (LDEQ) and Wildlife and Fisheries (LDWF), Louisiana State University (LSU), and the University of New Orleans (UNO). Additional data were also reported in other academic publications. Much of the data are published on the Internet. The data have been collected for a variety of purposes and vary widely with respect to location, frequency and regularity of sampling. In most cases, standard EPA-sanctioned methods have been used, but there are some important differences, which are identified in the results and in referenced materials (specifics can be found in the data reports).

Closest attention was paid to data on ecological resource species and habitat contamination with selected biological indicators of pathogens, metals, synthetic organic compounds, and, for inner ecosystem wetlands, contamination with saline water. All data were reviewed, but arsenic, lead, benzo(a)pyrene, and DDE were selected specifically to compare to the results of contaminant fate model simulations and to original data obtained from Violet Marsh. Impacts of freshwater movement from inside the interior ecosystem on brackish and saltwater ecosystems outside the flood protection system were dismissed as insignificant because of relatively small volume and the euryhaline adaptations of estuarine communities.

All of the region considered in this study was exposed to the impacts of Hurricane Katrina. Post-Katrina effects from wind, contaminant transport from other areas, and other general storm damage contributed to observed environmental condition after the hurricane. Much of the post-Katrina data were gathered after Hurricane Rita and reflect the combined impacts of both storms. Quantitative assessment was emphasized when possible, but qualitative assessments were made in the absence of quantitative data.

In keeping with the boundaries of ecosystems defined in the concept model, the results are reported by ecological resource categories for 1) nearshore gulf and delta ecosystems most remote from impacts, 2) the exterior ecosystems most likely to be impacted outside the flood protection system, which occur in the Pontchartrain-Borgne estuary, and 3) the interior ecosystems within the flood protection system, which are primarily freshwater wetlands.

7.5.2.2.2. Original Data. Early review of existing data indicated a need to gather additional data specifically relevant to the study of inner-ecosystem wetland response to levee breaching and overtopping, and to subsequent floodwater management. These data were collected by ERDC personnel to fill in evident gaps in data collected by other organizations. Methodological details are provided in report Attachments B and C, and in Lin and Kleiss (2006) and Ray (2006) (Attachments F and G).

Data were collected at Violet Marsh on 14 and 15 December 2005 and on 14 and 15 February 2006. In December, surface salinity, temperature, oxygen, and water depth were measured along six transects in the marsh (Lin and Kleiss 2006, Attachment F). Salinity was compared to previous measurements made at the same locations in 1993-1994. In addition, three samples were collected with an Ekman Dredge at each of four floodwater pump sites to analyze the benthic infauna (Ray 2006a, Attachment G). Two of the pumps had not worked following Katrina and provided references for comparison of physical effects.

In February, sediments sampled and analyzed for chemical and microbiological contaminants were collected with a grab sampler for the chemical contaminants and a core sampler for the microbiological contaminants. (See Attachments B and C for details.) After considering the most probable sources of contamination in the Chalmette area, south of Violet Marsh, the flooded waste treatment plant off Florida Avenue (at Dubreuil Street) and the oil spill from the Murphy Oil Company on Paris Road were singled out as potential contaminant sources. Samples of sediment were collected as close as possible to these potential sources of contamination as well as from areas near the input and output sides of the four pumps. Samples were also taken along transects extending out from the pump outfalls into Violet Marsh. The grab samples were homogenized and analyzed for volatile and semivolatile organic compounds, polychlorinated biphenyls (PCBs as Aroclors), metals, pesticides, diesel range organics (DRO), oil range organics (ORO), and total organic carbon using EPA methods (see Appendix 5B for details).

For microbiological analysis, sediments were taken from the top and bottom of each core sample (11.6 inches deep) to estimate contaminant concentrations in recently deposited material and in pre-Katrina deposits. The sediment samples were analyzed for benzo(a)pyrene and for markers of infectious waste (e.g., from untreated sewage). Solvent extracts were analyzed for sterols to determine the ratio of coprostanol to cholesterol, which was used to estimate the distribution of untreated sewage in the wetlands (see Appendix 5C for details). Fecal coliform bacteria were measured in surface sediments only to compare to data collected elsewhere by other agencies. Fecal streptococci were also measured in surface sediments because they may be a better indicator of human pathogens in semi-tropical estuarine waters. The ability of these microorganisms to survive in sediments is uncertain, however.

7.5.2.2.3. Contaminants Fate/Transport Model Data. Wind and other storm-generated impacts were sorted from the impacts of inner ecosystem flooding and subsequent flood management with the aid of contaminant fate/transport models. The models were run for both hypothesized conditions and for actual conditions at Lake Pontchartrain and Violet Marsh. The hypothesized condition was defined by the volume of floodwater resulting solely from the estimated rainfall from Katrina (8 inches) and from Rita (2.25 inches) with no floodwater entering from outside the system by levee overtopping or breaching. Actual conditions were defined by the volume of water estimated to occur in the flooded inner ecosystems following Hurricane Katrina (see Appendix 5D for details). Contributions of breaching and overtopping were not differentiated in the depiction of the actual or hypothesized condition in the concept model.

Five contaminants were chosen to model for each condition: arsenic, lead, benzo(a)pyrene, DDE, and fecal coliform bacteria. These represent metal-, petroleum-, pesticide-, and sewage-derived contaminants. Because of hydrologic differences in the two ecosystems, different contaminant fate models were calibrated and used to estimate contaminant concentrations in water and sediments. Model outputs were compared with estimated concentrations of these contaminants in Lake Pontchartrain sediments collected before and after Hurricane Katrina and in Violet Marsh sediments collected after the hurricane.

For the more complex Lake Pontchartrain, the three-dimensional (3D) hydrodynamic model CH3D and the 3D water quality model CE-QUAL-ICM (ICM) were used to model contaminant concentrations over a period of 90 days, starting on 1 September 2005. Both the actual and hypothesized conditions include the period during which pumps were operating to remove flood and rainwater from the city following Hurricanes Katrina and Rita. The z-plane version of CH3D was used. The water quality model required mass/time loading for each of the effluent locations at pump outfall sites (see Appendix 5D for details).

The upper portion of Violet Marsh was selected for the model study since this area directly received pumped discharges and is well-defined geometrically. Given the relative simplicity of the water body and the rapid flushing rate, it was possible to use the RECOVERY model (Ruiz and Gerald 2001), which is much simpler than the Lake Pontchartrain model. RECOVERY is a time-varying model that treats the water column as a single, fully mixed cell of known area, depth, and flushing rate and represents the bottom sediments as a series of layers over the vertical dimension. Like the lake model, it produces time-varying concentrations for the water column and bottom sediments. The model assumes a constant flushing rate or flow through the system. A very short residence time of less than a day results for typical pumped discharges into upper Violet Marsh (see Appendix 5D for details).

Data gathered from a number of sources who examined the floodwater (reported here in the results) were used to calibrate the model for actual conditions. Median and 95-percent upper confidence limit concentrations were used to estimate the mass/time loaded. Modeled contaminant concentration was held constant over the duration of pumping. Hypothesized conditions were more problematic because of data scarcity for rainwater pumped out of the city in previous events. Based on a statement in Pardue et al. (2006), who stated that metal concentrations in the Katrina flooding were similar to rainwater concentrations, the same concentrations were used to calibrate the hypothesized condition. Fecal coliform bacteria concentrations (40,000 MPN/100 mL) measured in pumped storm water in 1998 (Jin et al. 2004) were similar to Katrina concentrations. Therefore, the concentrations used to calibrate the hypothesized condition in rainwater were the same as the actual floodwater condition. However, the volume of water associated with the sum of the Katrina and Rita rainwater flooding (10.25 inches) was used, which was much less than the Katrina flood volume. Thus the total mass of materials pumped into receiving areas was much greater for the Katrina flood.

7.5.3. Results: Actual and Hypothetical Katrina Scenarios

The results are organized according to ecological and regional breadth of consequences, from greatest to most limited extent. Results are reported first for ecosystem support resources (primarily habitat condition), followed by broad categories of fishery and wildlife resources, and ending with the most narrowly defined special status and potential pest species. Within each ecological resource category, the broadest regional effects are reported first, intermediate effects proximal to the flood protection are reported next, and local consequences within the flood protection system are reported last.

7.5.3.1. Ecosystem Support

Delta and Nearshore Gulf Region

Pre-Katrina. The coastal region defined by the Mississippi River delta surrounding New Orleans is flat, low and wet; characterized by tidal freshwater, brackish, and saltwater wetlands; shallow estuaries; barrier islands; and homogenous nearshore habitats of the Gulf of Mexico. Before modern development, much of the natural history of the delta region was controlled by sediment transport, deposition and erosion dynamics, and a humid, semi-tropical climate punctuated by severe storms. Katrina and Rita were the most recent of many such events. The mix and pattern of delta habitats affected by Hurricane Katrina has changed dramatically over the past several thousand years (Gosselink et al. 1998). Changes caused by Hurricane Katrina are consistent with this past pattern, but profoundly affected by human development, as were previous storms in the last century.

The delta has continuously changed form as sediments were deposited and eroded away, and as river distributaries changed location. New deltaic lobes were deposited as river distributaries migrated, creating new wetlands as older deltaic deposits subsided and were eroded away by the sea. The most recent deltaic expansion around the mouth of the Mississippi River is now being artificially maintained by river control structures. Without them, the Mississippi River would soon divert to the west through the Atchafalaya River distributary where a new deltaic lobe would form as areas to the east subsided and eroded away in natural cycle.

All of the natural maritime ecosystems are decreasing in area because of subsidence and development in the delta. Development over the past century disrupted the natural equilibrium established between wetland destruction and creation and caused a net loss of vegetated wetlands to sediment subsidence and erosion, and to open-water inundation (Gosselink et al. 1998). Barrier islands have thinned and partly disappeared beneath the sea as they moved closer to shore with each major storm event. Between 1880 and 1980 total barrier island area decreased by 41 percent (57.8 km^2). Estimated loss rates of wetland from 1930 to 1990 have averaged about 75 km^2 per year. Over 16,000 km^2 of the entire coastal Louisiana habitat was wetland in the late 1990s, about two thirds of which was herbaceous marsh (Table 58). The rest is forested wetland. Of the remaining coastal habitat, over 7,500 km^2 is upland and about 10,500 km^2 is open water.

Table 58
Geographical areas in major types and subcategories of coastal Louisiana ecosystems in1989-1990 as described by Gosselink et al. (1998).

Ecosystem Type	**Area (km^2)**	**% of Total Area**	**% of Area In Type**
Marsh	10,192	29.4	100.0
Fresh	3,829		37.5
Intermediate	1,495		14.7
Brackish	3,209		31.5
Saline	1,659		16.3
Forested Wetland	5,935	17.1	100.0
Bald cypress forest	2,541		42.8
Bottomland/scrub-shrub	3,393		57.2
Upland	7,656	22.1	100.0
Forest/scrub-shrub	2,022		26.5
Developed	1,649		21.5
Pasture/agriculture	3,943		51.5
Barren	41		0.5
Water bodies	10,491	30.3	
Submerged aquatics	306	<0.1	
Shore-flat	87	<0.1	
Other	2	<0.1	
Total	**34,669**	**100.0**	

Adapted from Gosselink et al (1998).

If the average rate of loss continues, nearly 3,000 km^2 of vegetated wetland and barrier island habitat are threatened over the next 40 years—nearly one-fifth of the wetland and barrier island habitat in coastal Louisiana based on data provided in Gosselink et al. (1998). About 10 percent of this threatened area is managed for the public in twelve national wildlife refuges, several state wildlife management areas, and Jean Lafitte National Park.

The human activities that have upset the equilibrium between sediment deposition and erosion include, in particular, the river control structures that prevent freshwater overflow and sediment transport into nearby coastal areas during spring river flooding. Fresh water and sediment are dumped instead into the deep waters of the Gulf of Mexico (Gosselink et al. 1998). Oil industry and other industrial canal development have also contributed significantly to vegetated wetland loss. Additional loss is linked to extraction-caused subsidence. Early in the 20th century, areas of coastal wetland that were pumped dry for agriculture subsided as soils oxidized and were inundated with open-water habitat. Watershed changes in the Mississippi River Basin have also contributed, but the net effect is less clear as agriculture, reservoirs, and other human impacts have contributed both positively and negatively to sediment transport. The pattern of wetland loss has not been uniform. About one-third of the loss is high-salinity marsh at the coastal fringe and two-thirds is low-salinity, interior marsh, which may be more vulnerable to saltwater intrusion effects on the freshwater vegetation.

Because of urbanization, agriculture, and industrial activity and oil and gas development, the region's waters, soils, and sediments are locally contaminated with metals, pesticides, petroleum derivatives, and nutrients. The LDEQ, USGS, LDWF, and NMFS sample water quality and fisheries to assure they meet standards for recreational use and food consumption. Historically, resource contamination, especially with microbiological contaminants, is most likely to be encountered following major rain events in resources near outfalls and river mouths draining developed drainage basins (see Attachments A and E). Nearly 75 percent of the upland area in the region has undergone some form of urban and agricultural development (Table 5-1).

Concentrations of contaminants in soils and waters vary widely, however, and in general follow patterns of urban and industrial concentration. Suburban to rural levels of contaminants studied by Mielke (1994) and Mielke et al. (2001 and 2004) indicate that areas farther from the most dense urban development are similar to mean concentrations in soils of the United States and are typically well within screening standards set by LDEQ and others (see Appendix 5A and Plumlee et al. 2006).

Post-Katrina. Early estimates of wetland habitat loss in southeastern Louisiana following Hurricanes Katrina and Rita were about 295 km^2 (118 square miles) (USGS 2006), or nearly four times the past average annual loss of 75 km^2 (nearly 30 square miles) since the 1930s. Some of this immediate loss may recover during future growing seasons, as was observed following past storms, especially Hurricane Andrew. Among the most vulnerable habitats during Katrina was freshwater floating-mat wetland, which was broken up and redistributed as "marshballs." These chunks of rooted vegetation, which are mostly maidencane (*Panicum hemitomon*), have some capacity to reestablish in place and to newly establish where no wetland previously existed.

Immediately following Hurricane Katrina, NOAA, EPA, USGS, and Dauphin Island Marine Lab (DIML) launched a joint sampling effort to assess potential contamination levels present in inshore and offshore water, and sediment in association with fish and shellfish tissues reported above. Results from these analyses indicated that bacterial contamination (*E. coli, Enterococcus*, or *Vibrio cholera* and other *V. spp*.) in water and sediments from Mississippi Sound and offshore areas did not exceed EPA standards for recreational waters (Peterson et al. 2005a, 2005b). Sediment quality standards for microbes do not exist.

Post-Katrina sediment data obtained from EPA STORET files were collected in the delta region in Plaquemines Parish, southeast of New Orleans, in an area that is mostly rural except for a main highway with towns and industry along it (Tables 59 and 60). The samples were collected near the road and development (Appendix 5A). In general, the concentrations were lower than LDEQ screening standards, with a few exceptionally high concentrations near roads consistent with urban development patterns reported for New Orleans by Mielke (1994) and by others elsewhere. This was most evident for the petroleum derivative, benzo(a)pyrene.

Table 59
Post-Katrina Contaminant Concentrations in Water Samples Collected from Plaquemines Parish (reported in EPA STORET), the LDEQ Standard, and the Percentage of Samples That Exceed the Standards

Compound	Samples	Average (mg/L)	Maximum (mg/L)	LDEQ Standard (mg/L)	> LDEQ Standard (%)
Arsenic	87	0.001	0.047	0.01	2
Lead	64	0.00001	0.008	0.015	0
BaP[1]	53	0	0	0.0002	0
DDE	56	0	0	0.0002	0

[1] Benzo(a)pyrene.

Table 60
Post-Katrina Contaminant Concentrations in Sediment Samples Collected From Plaquemines Parish (reported in EPA STORET), the LDEQ Standard, and the Percentage of Samples That Exceed the Standards

Compound	Samples	Average (mg/kg)	Maximum (mg/kg)	LDEQ Standard (mg/kg)	> LDEQ Standard (%)
Arsenic	29	4.9	14.5	12	3
Lead	29	22	60	400	0
BaP[1]	29	0.42	12.2	0.33	3
DDE	29	0.01	0.26	1.7	0

[1] Benzo(a)pyrene.

Pontchartrain-Borgne Estuary

Pre-Katrina. Lakes Pontchartrain and Borgne filled basins formed during lobe development of the Mississippi River delta several thousand years ago. They form a large and complex estuary that receives, in addition to rainwater, fresh water from tributaries entering mostly along northwestern and northern shores. The Pearl River typically contributes more than half of the tributary fresh water to Lake Borgne just west of Rigolets Pass, one of two natural passes between the two lakes (Chef Menteur Pass is smaller and to the south). During river flooding, Mississippi River water spills into Lake Pontchartrain through an overflow channel west of New Orleans (Bonnet Carré Spillway opened in 1937).

Lake Pontchartrain was probably less saline before development in the region. Saline water now enters Lake Pontchartrain primarily through the Inner Harbor Navigation Canal (IHNC) from the Mississippi River Gulf Outlet (MRGO) and the Intracoastal Waterway (ICWW). The salinity is typically greatest in the southeastern quadrant of the lake along the New Orleans shoreline. Most flow out of Pontchartrain is via the two passes into Lake Borgne where saline water from the gulf mixes with fresher water from the Pearl River and other estuary tributaries. As tidal elevation changes, water movement increases to highest velocities in and near Rigolets

Pass. The salinity of the tidal flow between Pontchartrain and Borgne is greatly influenced by fresh water from the Pearl River.

Because of agricultural drainage mostly from the north, urban drainage mostly from the south, and gas and oil development, Lake Pontchartrain habitats have been exposed for many years to significant runoff contamination with nutrients, metals, petroleum derivatives, and suspended sediment (Penland et al. 2002). Most of the 10 watersheds contributing water to the lake have serious water quality problems. The largest single source of pollutants is urban runoff from New Orleans. Untreated or partially treated wastewater from numerous smaller communities also continues to be released into tributaries and lake margins. Many individual septic systems also leak into tributaries and directly into Lake Pontchartrain.

A long history of wetland dredging and filling, accompanied by continuous subsidence and increased salinity, has resulted in a wetland loss of at least 50 percent since 1900 (Stone 1980). Submersed aquatic vegetation has declined. Suspected causes are shore armoring and increased nutrient concentrations, which cause plankton growth and turbidity. The composition of the remaining vegetation varies, apparently in response to salinity fluctuation. Past release of formation brine, a byproduct of gas and oil extraction, has contributed salinity to Lake Pontchartrain. The brine is contaminated with metals and radioactive compounds. There is presently a moratorium on further oil and gas development in Lake Pontchartrain.

High salinity intrusion via the IHNC, coupled with freshwater input from the Pearl River and other north-shore tributaries, creates a great enough difference in water density to cause temporary stratification of fresh water over saline water. This can remain in effect long enough for severe oxygen depletion to occur over the bottom of southeastern Lake Pontchartrain, which stresses or kills sedentary bottom species, including native clams and oysters. The hypoxia is accentuated by the decomposition of plankton made more productive by high nutrient concentrations in the fresher surface water. The impacts from stratification have been greatest in the southeastern quadrant of the lake. Exceptional nutrient addition is associated with spill-over of Mississippi River floodwater through a spillway that enters the southeastern part of the lake.

For many years before the practice was stopped in 1990, shell was dredged in large quantity from Lake Pontchartrain. The dredging increased water turbidity, which has decreased significantly since dredging stopped. Dredging mixed contaminated surface sediments with much older and cleaner sub-surface sediments, resulting in lower exposure of bottom communities to contaminants. Dredging, however, negatively impacted lake bottom communities, especially the native clams, which have become more abundant in recent years. Because clams filter the water for particulate foods, they help clarify it and reduce concentrations of fecal coliform bacteria and associated pathogens (they are not harvested for food).

Despite sources of contamination, the average concentrations of metals in Lake Pontchartrain sediments in general remained below concentrations established in state standards for health and habitat protection (Table 61). The concentrations of most metals measured in the suspended solids of the Mississippi River are higher than lake sediment concentrations, making the river a contamination source for surface sediments when it spills into the lake. Some recent increases in iron and copper concentrations have occurred in surface sediments, perhaps associated with episodic contributions of Mississippi River floodwater.

Table 61
Pre-Katrina Mean Concentrations of Metals in Lake Pontchartrain Sediments and in Total Suspended Solids of the Mississippi River, and Standards Set by the Louisiana Department of Environmental Quality (from Penland et al. 2002)

Metal	Lake Pontchartrain Sediment Mean	Mississippi River TSS Mean	LDEQ screening standard
Ag (µg/g)	0.148		3.7
Al (%)	5.05	8.00	NA
As (µg/g)	7.02		7.0
Ba (µg/g)	482.1		NA
Cd (µg/g)	0.211	1.3	9.6
Co (µg/g)	9.41	21	NA
Cr (µg/g)	26.3	80	370
Cu (µg/g)	17.5	45	270
Fe (%)	2.43	4.61	NA
Hg (µg/g)	0.42		0.71
Mn (µg/g)	526.2	1300	NA
Ni (µg/g)	18.2	55	51.8
Pb (µg/g)	17.5	46	218
Sb (µg/g)	0.62		
Se (µg/g)	0.34		
Sn (µg/g)	1.53		
V (µg/g)	78.3		
Zn (µg/g)	73.3	193	

Concentrations of bacterial indicators of domestic sewage pollution, once substantially higher, have decreased in general along the south shore of the lake, probably in response to waste treatment improvements in New Orleans. Monitoring for various pollutants and rainfall events by the University of New Orleans since 1998 indicates that storm water runoff pumped from New Orleans has episodically elevated concentrations of fecal coliform, nitrogen, phosphorus, and suspended solids along the south shore (USGS 2002). This is normally observed in rainfall water pumping out of New Orleans (Jin et al. 2004). Fecal coliform data were also collected at multiple sites in Lake Pontchartrain by the Lake Pontchartrain Basin Foundation (2006). These are summarized in Appendix 5C.

Post-Katrina—*Empirical Data.* Both the Mississippi Department of Marine Resources (MDMR) and the LDWF report significant physical damage to oyster beds due to scouring, sedimentation, and debris deposition (MDMR 2005, and personal communication from Marti Bourgeois (LDWF)). However, data quantifying pre- and post-Katrina oyster-bed conditions have yet to be discovered.

As reported in the EPA STORET database, water was sampled about 2 weeks into the flood dewatering of New Orleans at three pump-houses adjacent to the estuary and just east of the New Orleans Lakefront Airport (see Appendix 5A). In 34 sample results, arsenic barely exceeded the LDEQ criterion of 0.01 mg/L in one sample. The highest lead sample—0.007 mg/L—is half of the LDEQ standard. Most samples were below detection levels. Neither benzo(a)pyrene nor DDE were found in any of the samples taken from the pump-house sites. Fecal coliform data were also collected at multiple sites in Lake Pontchartrain by the Lake Pontchartrain Basin Foundation (2006) after Hurricanes Katrina and Rita and most results were lower than LDEQ water quality standards. No sample results were reported for most of September, however, during the time when pumped water concentrations were likely to be high. These data are provided in Appendix 5C.

The USGS has just completed post-Katrina analyses for Lake Pontchartrain sediment contamination, which have yet to be published. A preview indicates that metal contaminants differ little from pre-Katrina concentrations reported in Table 58 and contaminant candidates, in general, are below the LDEQ screening standards.

Post-Katrina—*Model Results*. Modeled concentrations of indicator contaminants complemented empirical data. Results indicated that, for both hypothesized and actual conditions, modeled floodwater pumping raised arsenic, lead, benzo(a)pyrene, and DDE concentrations in lake water, and the maximum gains in concentrations were similar. Because of the much greater volume of floodwater pumped, the elevated concentrations of modeled contaminants following Katrina extend farther into the lake than the maximum modeled concentrations for the rainwater pumping alone. Figure 22 illustrates a common pattern for the maximum gain in water concentration using arsenic median levels of 0.02 mg/L for the actual hurricane conditions and for a 90-day pumping duration. Figures for all five contaminants can be seen in Appendix 5D. All model outputs followed generally similar patterns of dilution.

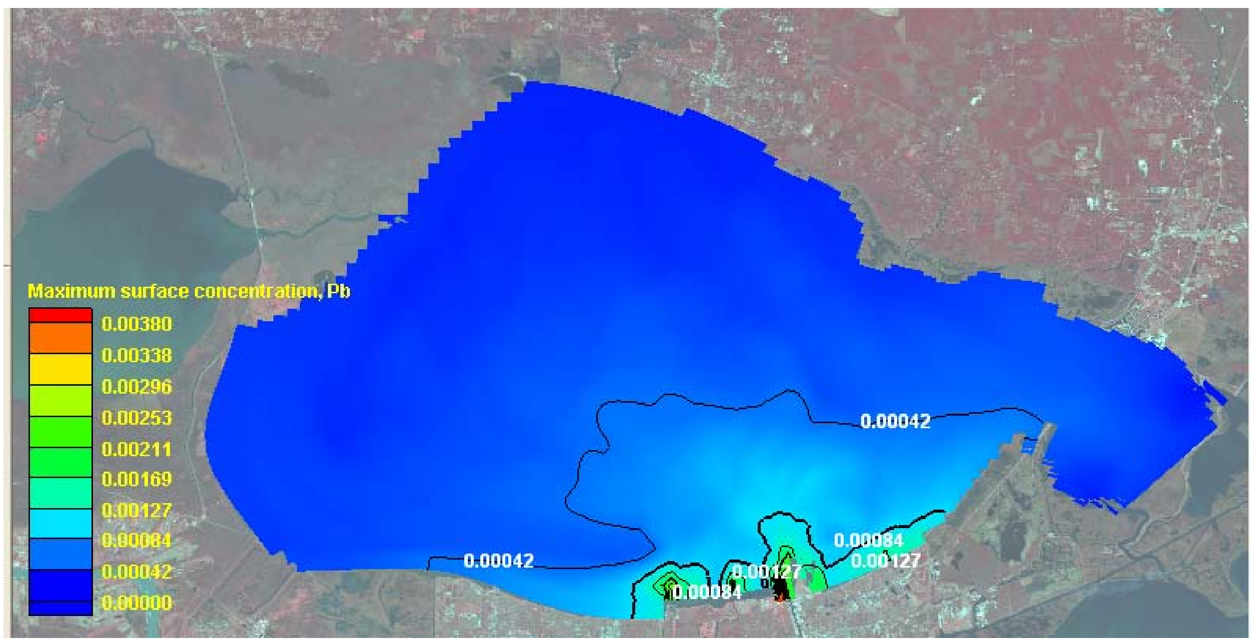


Figure 22. Maximum arsenic concentrations (mg/L) in the surface water layer of Lake Pontchartrain estimated using a contaminant fate model for the actual flood condition.

The modeled distribution of increased sediment contamination also was closely associated with the southeastern shore of the lake and decreased to much lower concentrations along the north and west shores. This distribution reflects the modeled sedimentation of contaminants with solids from the water column. In general, because of the higher volume pumped and the net deposition to sediments, the total added load to the sediment following Hurricane Katrina was estimated to be an order of magnitude greater than would occur from dewatering rainwater from Katrina and Rita alone. The model results for Lake Pontchartrain confirm the empirical results, which revealed no measurable gain in metal contamination of sediments following Hurricane Katrina. Comparing the model simulation results in Table 62 to pre-Katrina sediment results in Table 61 indicates a maximum gain of 0.9 percent for the Actual 95 simulation of arsenic concentration (Table 63). For lead it would be about 2.2 percent. Given the mixing in the shallow waters, these small increments of additional contamination would not be identifiable as actual gains in the sediment concentrations near the outfall points along the south shore. Farther from shore, concentrations fall toward infinitesimally small increments above background sediment concentration.

Table 62
Computed Maximum Increments Gained in Water (µg/L) and Sediment (mg/kg) Concentrations (total) of Arsenic (As), Benzo(a)pyrene (BaP), DDE, Lead (Pb), and Fecal Coliform Bacteria (FCB) for Lake Pontchartrain Water and Sediment (sed). Actual (floodwater conditions as they occurred) and hypothesized (rainwater flooding alone) conditions are compared (see Appendix 5D for details)

Condition	As water	As sed	BaP water	BaP sed	DDE water	DDE sed	Pb water	Pb sed	FCB water*
Actual	13	0.048	3.7	0.173	0.036	0.0024	3.7	0.053	1,055
Actual95	16	0.066	3.7	0.173	0.209	0.0171	25.4	0.384	42,214
Base	14	0.0052	3.7	0.014	0.037	0.000172	3.7	0.0062	1,413
Base95	14	0.0054	3.7	0.014	0.053	0.000598	32.1	0.051	44,780

*Units for fecal coliform bacteria are cfu/100 mL or MPN/100 mL.
Note: Actual and Base are median loading concentrations, and Actual95 and Base95 are 95 percent upper confidence limit loading concentrations.

Table 63
Model-estimated Maximum Contaminant Concentration Added to Sediment Contaminant Concentrations in Lake Pontchartrain and the Estimated Maximum Percentage Gain in Contaminant Concentration that Resulted. Median gains are lower

Contaminant	Model Maximum at 95% UCL load (ppm)	Mean	
		ppm	%
Arsenic	0.066	7.02	0.91
Lead	0.384	17.5	2.18

The maximum gain in water concentrations for arsenic and benzo(a)pyrene were less than the LDEQ criteria for both hypothesized and actual conditions and for the loading concentrations. Water concentrations for lead temporarily exceeded the LDEQ criterion for median concentration in floodwater and for both hypothesized and actual conditions. The DDE maximum concentration exceeded the LDEQ criterion for both conditions at the upper confidence limit, but not the median concentration. In both hypothesized and actual conditions, water concentrations of contaminants above standards were temporary and added very little to concentrations in sediments, which, on average, met sediment standards criteria established by LDEQ.

The maximum fecal coliform bacteria concentration estimated by the model temporarily exceeded criteria for both conditions and for median concentrations in the floodwater. Temporary elevation of concentrations to levels above standards is a normal occurrence observed in rainfall water pumped out of New Orleans (Jin et al. 2004). The modeled concentrations soon fall below LDEQ criteria with distance from the south shore. Modeled concentrations were diluted at least ten-fold before water reached Lake Borgne. Reports of fecal contamination along the north shore of Lake Pontchartrain indicate the many different sources of fecal coliform bacteria existed in the lake's watershed.

Inner Ecosystems

Pre-Katrina. A significant fraction of the inner ecosystem is occupied by fresh to brackish wetlands and open water. Over half of the area within the flood protection system of St. Bernard Parish is wetland (Violet Marsh) that is entirely surrounded by levees (Figure 20). These comparatively wild areas within the flood protection system are not entirely natural, however. Construction of the flood protection system and other levees isolated them from tidal influence. Before levee construction, the salinity and other estuarine attributes of the wetlands in these areas probably varied more than now. Another source of variation for Violet Marsh has been its use as a rainwater sump as part of the functioning hurricane protection system. In the early 1990s fresh water was siphoned into Violet Marsh to reduce salinities that were suspected to have increased as a consequence of constructing the Mississippi River Gulf Outlet. The only pre-Katrina data on salinity in Violet Marsh indicated that it ranged from about 3 to 10 ppt salinity in 1993-94 (Lin and Kleiss 2006). The siphon had little effect, so it was discontinued. Bayou Sauvage only recently became a National Wildlife Refuge in the 1990s. While smaller than Violet marsh, Bayou Sauvage is the largest urban refuge in the United States. It includes about 90 km^2 (nearly 36 square miles) of fresh to brackish wetlands and water.

Much of the soil in the urbanized inner ecosystems is contaminated with metals, petroleum derivatives, and other pollutants. While there was no useful information stored in the EPA database, STORET, on chemical contamination for any of the inner ecosystems before Hurricane Katrina (Appendix 5A), other data are informative. The most useful information is reported in journal articles by Mielke and others (Mielke 1994; Mielke et al. 2001, 2004). They sampled street side, house side and open space for lead concentrations primarily, and other contaminants secondarily, throughout metropolitan New Orleans in areas of various urban densities ranging from inner city to suburban.

Their investigations indicate patterns of contamination along gradients of urban density and intensity of automotive and other activity. In street-side soil samples in the inner city, lead concentrations ranged from 600 to 1,200 ppm, which is substantially greater than LDEQ screening standards. Lead concentrations were typically less than 75 ppm in suburban soils, which is well below standards. Concentrations in open-space soil samples were all below standards and ranged from an average of 222 ppm in the inner city to 28 ppm in the suburbs. The suburban environments approached the mean U.S. soil concentrations (19 ppm) referred to by Plumlee et al. (2006). Mielke (1994) believed the distributions of lead concentrations in the New Orleans area reflected the production and use of lead-based paints and leaded gasoline. While Mielke did not sample outside the New Orleans metropolitan area, the trends in his results suggest that average lead concentrations in rural areas remote from the city were similar to U.S. soil averages and well below LDEQ standards.

Mielke et al. (2004) found generally similar patterns for other metals and polycyclic aromatic hydrocarbons. They reported concentrations of benzo(a)pyrene from 0.091 to 6.859 mg/kg in New Orleans soils. Sediment concentrations for spillways and bayous ranged from non-detection to 4.044 mg/kg. Lead concentrations in city soils ranged from 32 to 4298 mg/kg, whereas bayou sediment concentrations ranged from 4 to 1,587 mg/kg (Mielke et al. 2001). The contaminants tended to be most concentrated near busy streets and older buildings in the inner city, and were low in open areas, especially in suburban neighborhoods. Consistent with local subbasin conditions, some urban bayou sediments were substantially more contaminated with lead than the average concentration (47 ppm) reported for Lake Pontchartrain (Penland et al. 2002). These patterns support conclusions that urban runoff is the major source of pollutants in Lake Pontchartrain.

Data on contaminant concentrations in rainwater pumped out of the inner ecosystems into Lake Pontchartrain and other receiving waters is scarce and anecdotal. Pardue et al. (2005) indicated that "…Katrina floodwater is similar to normal storm water runoff, but with elevated [lead] and [volatile organic compound] concentrations." More specific data were not referenced, however.

No pre-Katrina contaminant data were discovered for Violet Marsh, but results of examining the bottom of sediment cores for sewage contamination were used to evaluate pre-Katrina sediment contamination (see Appendix 5C for details). The results of fecal caprostanol sterol analysis showed that the waste treatment plant in the Chalmette area was historically a major source of fecal contamination in Violet Marsh. Of the 18 samples taken from the bottom of sediment cores, 15 were contaminated above the most lenient screening standard. Concentrations of benzo(a)pyrene varied widely between non-detectable and 11.8 μg/g (dry weight). Half of the 18 samples and a mean of 2.8 μg/g exceed the EPA sediment quality criterion (0.062 μg/g dry weight). Six samples and the mean exceeded the LDEQ screening standard of 0.33 μg/g.

Post-Katrina—*Empirical Data*. The storm surge associated with Hurricane Katrina destroyed much of the levee structure on the northeast side of Violet Marsh, which separated it from the Mississippi River Gulf Outlet. The storm surge moved into and over Violet Marsh, to at least some extent replacing relatively fresh water with more saline water. It breached the non-federal levee along the south side of Violet Marsh in several locations. The storm surge also breached levees between Bayou Sauvage NWR and the Intracoastal Waterway. Information about the condition of the refuge ecosystems has been limited (FWS 2005a). Similar to Violet Marsh, the storm surge overtopped levees and increased the salinity of freshwater wetlands. An extended dry period following the two hurricanes may have prolonged exposure to salt water because rainwater is the primary source of fresh water to the inner ecosystem wetlands.

Soon after flooding first occurred, samples were collected from floodwaters in Orleans Parish by Pardue et al. (2005*)* and by Presley et al. (2006), including data on Benzo[a]pyrene, arsenic, lead and other contaminants. Assuming concentrations were similar and there was no dilution effect, the larger volume of Katrina floodwater far exceeded that of past rainfall-caused flooding, and would have caused a much larger total load of contaminants to be pumped into Lake Pontchartrain.

Dissolved metal concentrations in sediments underlying the floodwaters were also sampled and ranged from 17 to 54 µg/L (Pardue et al. 2005) and 6 to 24 mg/liter (Presley et al. 2006) for arsenic and 1 to 72 µg/L (Pardue et al. 2005) and 340 to 640 mg/kg (Presley et al. 2006) for lead. The range in lead concentrations was lower than those reported for soils in the New Orleans area by Mielke et al. (2001). The benzo(a)pyrene concentrations reported by Presley et al. (2006) ranged from 0.01 to 1.26 mg/kg, in close agreement to concentrations estimated for soils before Katrina struck. Some of the samples collected exceeded the LDEQ screening standards, which are 12 ppm for arsenic, 400 ppm for lead, and 0.33 ppm for benzo(a)pyrene.

Appendix 5A reports data from EPA's STORET Katrina Central Warehouse (EPA 2006a), which presents another large set of data for floodwaters and sediments sampled as floodwaters receded. Table 64 summarizes STORET floodwater data collected as water levels fell. Floodwater concentrations for arsenic, lead, benzo(a)pyrene, and DDE in the EPA database ranged between 1 and 5 µg/L, 1 and100 µg/L, non-detect and 2 µg/L, and non-detect and 1 µg/L, respectively. Most individual sample values were less than the LDEQ screening standards. Small fractions of the samples (less than 14 percent) had one or more of the four elements in concentrations that exceeded the LDEQ standard. Average concentrations were well below the standard.

Table 64
Post-Katrina Contaminant Concentrations (dissolved) in Water Samples Collected from Orleans Parish (reported in EPA STORET), the LDEQ Standard, and the Percentage of Samples That Exceed the Standards

Compound	Samples	Average (mg/L)	Maximum (mg/L)	LDEQ Standard (mg/L)	> LDEQ Standard (%)
Arsenic	458	0.005	0.357	0.01	13
Lead	357	0.012	1.34	0.015	11
BaP[1]	258	0.000002	0.0004	0.0002	0.4
DDE	261	0.0000009	0.00007	0.0002	0

[1] Benzo(a)pyrene.

Average soil/sediment concentrations in the five parishes of greater New Orleans ranged from 5 to 12 mg/kg for arsenic and from 20 to 117 mg/kg for lead. Highest mean concentrations were in Orleans Parish (Table 65), although the maximum found in any sample sometimes occurred in another parish. These results are in general agreement with the data collected immediately after the flooding by Pardue and Presley, but substantially lower for soil concentrations of lead collected in inner city areas by Mielke (1994), Mielke et al. (2001), and Mielke et al. (2004). Up to 36 percent of the samples had concentrations of one or more of the four contaminants above the screening standards set by LDEQ. Benzo(a)pyrene (BaP) ranged between 0.01 and 0.5 mg/kg, similar to pre-Katrina soil samples (Mielke 2001), except for one extreme outlier (6.5 mg/kg), and DDE ranged between 0.007 and 0.013 mg/kg. Except for benzo(a)-pyrene, the mean sediment concentrations were below standards set by LDEQ.

Table 65
Post-Katrina Sediment Contaminant Concentrations in Samples Collected from Orleans Parish, the LDEQ Standard (reported in EPA STORET), and the Percentage of Samples That Exceed the Standards

Compound	# Samples	Average (mg/kg)	Maximum (mg/kg)	LDEQ Standard (mg/kg)	> LDEQ Standard (%)
Arsenic	273	11.8	78	12	36
Lead	265	117	1160	400	7
BaP[1]	277	0.50	35.5	0.33	23
DDE	280	0.01	0.44	1.7	0

[1] Benzo(a)pyrene.

In Orleans Parish, 15 other metals occurred in all sediment samples reported in STORET (EPA 2006a) and four more occurred in at least 90 percent of the samples, including cadmium and mercury, which are especially toxic. Similar to the lead and mercury, the concentrations varied greatly among samples. Only one sample of mercury exceeded the LDEQ standard, but 17 percent of the samples had higher than standard concentrations of cadmium. In water, 4 percent of the samples had zinc levels that exceeded standards. All other metals were within the standards.

Because it was several months after the storm, water samples were not collected at Violet Marsh by the ERDC research team. Measurements in December 2005 revealed a 75 percent higher average salinity (12.4 ppt compared to 7.4 ppt) in the wetland than previous measurements at nearby locations in 1993-1994, which had to be interpreted from a bar graph, however (Lin and Kleiss 2006). Of the sediment samples collected for this study in Violet Marsh in December 2005 and March 2006 (see Attachments A and B), arsenic ranged from 3 to 13 mg/kg and lead concentrations ranged from 27 to 181 mg/kg. The DDE concentrations ranged from 0.003 to 0.015 mg/kg.

Sediments revealed by dewatering of the flooded areas of greater New Orleans were also the focus of study by the USGS (Plumlee et al. 2006) using samples collected by the EPA and the LDEQ. Plumlee et al. (2006) characterized a subset from sediment samples collected on 15-16 September in 11 localities around downtown New Orleans, and two locations from the Chalmette area south of Violet Marsh. Their results tended to be higher than the EPA analysis because of a different sample digestion process. The USGS found comparatively high concentrations of metals (lead, zinc, mercury, copper, arsenic, and cadmium) in downtown New Orleans and relatively low concentrations in the Chalmette area. Similar to lead data collected by Mielke, many of the New Orleans samples for lead were above 500 ppm and substantially above the LDEQ screening standards for health and safety. Based on information previously collected and published by Mielke (1994), Mielke et al. (2001), and Mielke et al. (2004), Plumlee et al. (2006) tentatively concluded that, at least in part, the high concentrations of metals were derived from contaminated soils existing before the flood.

This tentative conclusion is consistent with the much lower concentrations of metals existing in Lake Pontchartrain sediment (see above) before lake water flooded the inner ecosystems of Orleans Parish. If the sediment had come entirely from the lake, lead and other metal concentrations would have been lower than concentrations in soil samples before and after Katrina.

Analysis by Mielke et al. (2004) also indicated that some soils in New Orleans were high in polycyclic aromatic hydrocarbons, such as benzo(a)pyrene. Chalmette samples, in comparison, were lower and consistent with sediments from other parts of the Mississippi River delta.

With respect to pathogen contamination, post-Katrina data sets include many fecal coliform bacteria estimates for water and sediment, but very limited information on other pathogens (such as *Aeromonas*). In 139 water and 569 sediment samples collected by EPA and LDEQ (and stored in STORET) in Orleans and St. Bernard Parishes in September and November 2005, fecal coliform bacteria could not be detected or were not quantifiable in 19 water samples and 406 sediment samples. The detection limits were not reported, but appear to be about 1,000 cfu/ 100 mL for sediments (see Appendix 5C for details).

Fecal coliform measurements in the floodwater of New Orleans routinely exceeded water quality standards set by LDEQ (see Appendix 5C for details). These data raised concerns with respect to a potential public health hazard and environmental impact resulting from the failure of the levees and were responsible in part for applying a contaminant transport and fate model to assess impacts outside the flood protection system. Of the 10,047 New Orleans patient visits during and immediately following flooding, the most common were for gastrointestinal, acute respiratory, and skin infections.

Both Violet Marsh and Bayou Sauvage National Wildlife Refuge were inundated with saline water associated with the Hurricane Katrina storm surge and widespread levee failure. Data reported in Plumlee et al. (2006) identified the source of sediments in Chalmette as from wetlands to the northeast, which would include parts of Violet Marsh. This is consistent with evidence that the storm surge overwhelmed and destroyed major reaches of levee along the Mississippi River Gulf Outlet, swept across Violet Marsh, broke through levees between Violet Marsh and the Chalmette area of St. Bernard Parish, and inundated it. That levee had to be repaired before floodwater could be pumped out of the subbasin and into the Violet Marsh sump. Water also entered St. Bernard Parish by way of overtopping and failure of the levee bordering the Ninth Ward on the west.

In Violet Marsh, concentrations of arsenic, lead, benzo(a)pyrene, and DDD (a breakdown product of DDT) measured by ERDC personnel were compared with sediment concentrations reported for the city of New Orleans (see Appendix 5B for details). Except for samples that had been collected near the waste treatment plant for the Chalmette area, the concentrations of all of these indicator contaminants were lower than city estimates (Appendix 5B). In addition, there were no differences between areas in the marsh around the two pumps that operated and the two pumps that did not operate. These results indicate that contaminated sediment was not pumped into the marsh from the Chalmette area in quantities that could be detected above background levels.

The STORET data for St. Bernard Parish all came from the urbanized subbasin south of Violet Marsh (Tables 66 and 67). They also indicated that mean contaminant concentrations tended to be lower than in the inner city area of New Orleans (Orleans Parish samples in Tables 64 and 65), but varied a bit more. Somewhat higher maximum concentrations of lead and DDE were found in St. Bernard Parish (see Appendix 5A for details).

Table 66 **Post-Katrina Water Contaminant Concentrations (dissolved) in Samples Collected from St. Bernard Parish (reported in EPA STORET), the LDEQ Standard, and the Percentage of Samples That Exceed the Standards**					
Compound	**Samples**	**Average (mg/L)**	**Maximum (mg/L)**	**LDEQ Standard (mg/L)**	**> LDEQ Standard (%)**
Arsenic	57	0.003	0.059	0.01	12
Lead	40	0.001	0.022	0.015	8
BaP[1]	31	0	0	0.0002	0
DDE	31	0	0	0.0002	0
[1] Benzo(a)pyrene.					

Table 67 **Post-Katrina Sediment Contaminant Concentrations in Samples Collected from St. Bernard Parish (reported in EPA STORET), the LDEQ Standard, and the Percentage of Samples That Exceed the Standards**					
Compound	**Samples**	**Average (mg/kg)**	**Maximum (mg/kg)**	**LDEQ Standard (mg/kg)**	**> LDEQ Standard (%)**
Arsenic	304	5.7	22.8	12	3
Lead	304	42	1370	400	1
BaP[1]	847	0.01	0.41	0.33	0.1
DDE	308	0.01	0.76	1.7	0
[1] Benzo(a)pyrene.					

Fecal contamination showed a different result, however. Whereas in one section of Violet Marsh, all surface sediment samples were below detection limits for all bacterial indicators measured (total coliform, fecal coliform, fecal streptococci), at other sites in the marsh the levels of bacterial indicators showed a continuing possible influence of potentially infectious sewage contamination from Chalmette. Surface sediment samples were slightly more contaminated with fecal caprostanol sterol than bottom samples, and all 18 samples exceeded the selected health and safety criterion indicating that floodwater pumping was an important factor in further contamination of Violet Marsh with potentially infectious sewage waste (see Appendix 5C for details).

Post-Katrina—*Model Results (Violet Marsh)*. The contaminant model for Violet Marsh indicated that the wetland water quality was dominated by water pumped from the Chalmette subbasin to the south; i.e., water column concentrations were nearly equal to the pumped water concentration (such as 90 percent of the pumped effluent for arsenic as shown in Appendix 5D, Figure 20). This result is consistent with the relative volumes of floodwater and Violet Marsh water. Violet Marsh is relatively shallow; it rarely exceeds a depth of 1 meter. The model also indicates that the sediment concentrations were affected by the loading of contaminants by floodwater pumping, but much less so than the water column concentrations (see Appendix 5D for details).

The expected increase in sediment concentrations resulting from the actual floodwater pumping were about 10 times greater than for the hypothesized rainwater flooding, but only exceeded screening criteria for the two organic chemicals. The computed maximum increase in concentrations for arsenic, benzo(a)pyrene, and DDE were all below the LDEQ water quality criteria. However, lead concentrations exceeded the LDEQ criteria for both hypothesized and actual conditions and for median and upper confidence limit concentrations in the pumped water. The maximum fecal coliform bacterial concentration exceeded the criterion for hypothesized and actual conditions at the upper confidence limit for pumped water concentration, but is below the criterion for the median concentration. The maximum sediment concentrations for arsenic and lead were less than LDEQ screening criteria for all conditions and floodwater concentrations. The benzo(a)pyrene and DDE concentrations in sediments were less than screening criteria for the hypothesized condition but exceeded screening criteria for both loading concentrations under actual conditions.

For those contaminants addressed in common by model and empirical analysis, the estimated loading from the floodwater pumping into Violet Marsh, using the high extreme estimate (95 percent upper confidence limit) for concentration in the floodwater, was low compared to the contaminant load already present in Violet Marsh (Table 68).

Table 68
Model-estimated Maximum Contaminant Concentration Added to Sediment Contaminant Concentrations in Violet Marsh and the Estimated Maximum Percentage Gain in Contaminant Concentration That Resulted

	Model Maximum at 95% UCL Load (ppm)	Outer Marsh		Pump Station	
		ppm	%	Ppm	%
Arsenic	0.18	4.2	4.29	8.7	2.07
Lead	0.22	14.6	1.51	84.7	0.26
Benzo(a)pyrene	0.28	ND	--	79	0.35

While the model assumed complete mixing and constant deposition across the upper marsh, it was clear from empirical results that floodwater pumping before Katrina had significantly raised concentrations at all pump outfall sites examined, whether or not they had worked following Hurricane Katrina. These results indicate that the extent to which flood management may have added to existing contamination of habitat sediments was at most a few percent and more probably averaged less than 1 percent.

7.5.3.2. Fisheries (Fish and Invertebrates)

Delta and Nearshore Gulf Region

Pre-Katrina. The delta and nearshore region are rich in estuarine and marine fisheries resources (Gosselink et al. 1998), which are monitored by local and federal agencies for trends in relative abundance and for consumption safety. Significant fractions of the nation's oyster and shrimp fisheries exist here. Marine fin-fish harvest is also significant, but more modest economically. The relative abundances of fish and invertebrate species monitored in trawls generally follow the salinity gradient from freshwater wetlands to outer wetlands and open waters that approach oceanic salinity (Gosselink et al. 1998, Penland et al. 2002).

Fish assemblages in the low-salinity interiors of the estuaries are dominated by freshwater species that tolerate limited salinity and commonly include blue catfish (*Ictalurus furcatus)*, channel catfish (*Ictalurus punctatus*), gizzard shad (*Dorosoma cepedianum*), and threadfin shad (*Dorosoma petenense*) during fall and winter when marine species are least abundant. All life stages of the euryhaline bay anchovies (*Anchoa mitchilli*), inland silverside (*Menidia beryllina*), code goby (*Gobiosoma robustum*), rainwater killifish (*Lucania parva*), sheepshead minnow (*Cyprinodon variegatus*), alligator gar (*Atractosteus spatula*), and eastern oyster (*Crassostrea virginica*) are common in a wide range of salinities, including locations where salinities are most variable. Adults and larvae of Gulf menhaden (*Brevoortia patronus*), Atlantic croaker (*Micropogonias undulatus*), spot (*Leiostomus xanthurus*), striped mullet (*Mugil cephalus*), southern flounder (*Paraichtys lethostigma*), sand seatrout (*Cynoscion arenarius*), spotted seatrout (*Cynoscion nebulosus*), black drum (*Pogonias cromis*), red drum (*Sciaenops ocellatus*), brown shrimp (*Penaeus aztecus*), white shrimp (*Penaeus setiferus*), and blue crab (*Callinectes sapidus*) are most abundant where salinity approaches ocean concentrations and juveniles must migrate to nursery areas in marshes of low salinity to survive. Less common are spanish mackerel (*Scomberomorus maculates*) and other more fully marine species that periodically contribute significantly to estuarine fisheries.

The freshwater fisheries are mostly recreational (a few species are caught commercially). The delta boasts excellent large-mouth bass (*Micropterus salmoides*) fishing. Other important freshwater recreational species include channel and blue catfish, black crappie (*Pomoxis nigromaculatus*), white crappie (*Pomoxis annularis*), warmouth (*Chaenobryttus gulosus*), bluegill (*Lepomis macrochirus*), and yellow bass (*Morone mississippiensis*).

The estuarine and marine fisheries are composed mostly of short-lived species that stand up to commercial fishing well. Except for the temporary hurricane effects in interior wetlands, most of the studied populations of regional fish and invertebrates have remained stable (Gosselink et al. 1998). This is based on data gathered primarily by government agencies. In their SEAMAP program, the Gulf States Marine Fisheries Commission (GFMFC) and NMFS have trawl-monitored inshore and offshore fish and invertebrate populations since 1972 (e.g., GSMFC 2006). Sample trawls have been made each summer and fall since 1987 throughout the Northern Gulf of Mexico. Data gathered by LDWF generally confirm the stability of marine and estuarine fisheries in the area. (See Table C2 in Appendix 5E for details.)

Based on past history, the freshwater fisheries and oysters are more likely to be severely impacted by hurricanes than other estuarine and marine species. Freshwater fish die from exposure to salt water and to hypoxia caused by decay of uprooted marsh vegetation and disturbed organic sediments. Storm-depressed fish populations rebounded following Hurricane Andrew and other hurricanes, once freshwater habitats reestablished normal salinities and oxygen concentrations. However, freshwater fish abundance is expected to decline permanently as more of the outer marsh disappears and allows more continuous intrusion of salt water into the interior wetlands. Oyster reef damage was estimated to be nearly 100 percent following Hurricane Katrina (LDWF 2005a).

Shrimp and crabs recover quickly after a hurricane because of high fecundity and increased food production resulting from increased nutrient loading in storm runoff. This rapid recovery quickly restores the food base for small fish, including the young of fish supporting important estuarine and nearshore marine fisheries. While recovery of regional abundances is typically rapid, the patterns of resource abundance often change because of habitat changes resulting from the storms.

Many of the estuarine fish and invertebrates comprising important commercial and recreational fisheries have life cycles that depend on interior wetlands for juvenile “nursery areas.” Without their protection, the juveniles are overexposed to predation. Optimum conditions occur when the marsh-water interface length is high, allowing for greatest penetration of young fish and invertebrates into the protective wetland interiors (Gosselink et al. 1998). In the early phases of marsh loss that have already occurred in the region, marsh-water interface length increased and provided more optimal nursery area. This may have helped maintain the stability of some fished populations.

If forecasts are correct, that trend is about to reverse, however (Gosselink et al. 1998). When about half of the marsh is lost through fragmentation, the interface length begins to decrease. This threshold is about to be reached in coastal Louisiana (Gosselink et al. 1998). Continued wetland loss is expected to result in a marine fishery decline in direct proportion to the decrease in interface length. Past construction of levee structures that completely enclosed interior estuary created freshwater wetlands and encouraged expansion of freshwater recreational fisheries, but prevented access of marine species to nursery habitat.

Data confirming past assessments of fish and invertebrates caught in trawls is available from the SEAMAP program of NOAA and the Gulf States Marine Fisheries Commission (GSMFC), the EMAP program of EPA, and the LDWF. Data downloaded from SEAMAP for 1998, 1999, and 2000 indicate that brown shrimp contributed most to the regional catch and Atlantic Croaker was the most caught fin fish (see Appendix 5E for details and GSMFC 2006). The EMAP program samples of EPA taken between 1991 and 1994 generally indicated similar species dominance (EPA 2006a). Data from LDWF are incorporated into the Coast 2050 report by the Louisiana Coastal Wetlands Conservation and Restoration Task Force and the Wetlands Conservation and Restoration Authority (1998) confirm that fished populations vary in the catch but, in general, the catches have been stable.

The tissues of fish, shrimp, and crabs from the gulf coast region were not found to be contaminated by *E. coli,* or other measured pathogen indicators, for samples taken in 1991-1994 (EPA 2006a). Tissue concentrations of contaminants have been consistently below standards set by regulatory agencies. (See Appendix 5E for detailed data.)

Post-Katrina Previous experience with hurricanes had indicated that saltwater species are not nearly as impacted as freshwater species. In keeping with past experience, Slack (2005) reported large freshwater fish kills from Hurricane Katrina in coastal Mississippi areas. The fall 2005 trawl surveys found no indication of reductions in offshore fish or shrimp populations or fish kills (NMFS 2006b). Trawl catches of certain species averaged 30 percent greater than average pre-Katrina catches, which may be a consequence of reduced fishing following the hurricanes. A full report is expected by early summer 2006.

Immediately following Hurricane Katrina, NOAA, EPA, USGS, and the Dauphin Island Marine Lab launched a joint sampling effort to assess potential fecal contamination levels in fish and shellfish tissues. Tissues of fish, shrimp, and crabs from these sites showed no indication of contamination by *E. coli, Enterococcus*, or *Vibrio cholera;* however, other *Vibrio* species were present. Peterson et al. (2005c and 2005d) indicate that where *Vibrio* spp. were encountered, concentrations were not beyond those expected under normal pre-Katrina conditions. Krahn et al. (2005a and 2005b) found that concentrations of persistent organic pollutants (PCB and DDT) and polycyclic aromatic compounds in fish tissues did not exceed FDA standards for consumption. In a January 2006 news release by NMFS (2006b), there was no indication of bacterial or organic chemical contamination in gulf fish populations.

From 29 September to 10 October 2005, NOAA sampled mussels under its Status and Trends-Mussel Watch Program, mostly along the Mississippi coast, and found elevated bacterial concentrations in proximity with shore sources of contamination consistent with a storm runoff event (NOAA 2005). They also found generally elevated levels of metals (selenium, copper, and cadmium). In contrast, organochlorine pesticides and polycyclic aromatic hydrocarbons were all lower than in past analyses. Subsequent sampling by the EPA and the Mississippi Department of Environmental Quality (EPA-MDEQ 2005) found few instances of elevated bacterial concentrations or other pollutants in Mississippi waters. As of 9 December 2005, the States of Mississippi and Louisiana, and the Food and Drug Administration issued news releases indicating that seafood, including oysters were safe to eat (FDA 2005). Quantitative data reports have yet to be found, however.

Pontchartrain-Borgne Estuary

Pre-Katrina. The fisheries of the Pontchartrain-Borgne estuary are similar to those described for the region (Penland et al. 2002). Information on the fish assemblages of Lake Pontchartrain, including a recent assessment of fish-habitat relationships, is summarized in Gosselink et al. (1998), O'Connell et al. (2004), and in the University of New Orleans Vertebrate Museum's database of fish collections from Lake Pontchartrain (UNO 2005).

Freshwater bass and sunfishes are abundant in the freshwater wetlands and ponds bordering Lake Pontchartrain. Fully marine species are infrequent visitors to Lake Pontchartrain where oligohaline and euryhaline species are most encountered. These include blue catfish, gizzard shad, channel catfish, bay anchovy, brown and white shrimp, blue crab, and common rangia clams. Oysters are also common, but not as abundant as in nearshore waters of Mississippi Sound. Many estuarine species enter Lake Pontchartrain only seasonally.

Information on fish and macroinvertebrate populations before Hurricane Katrina is available through the EMAP program of EPA (EPA 2006a). Fish resources appear to have declined at least 50 percent between 1900 and 1980 (Stone 1980) in proportion to the loss of wetland and submersed aquatic vegetation. Trawl samples were taken on an annual basis between 1991 and 1994 in the Pontchartrain-Borgne estuary and near coastal waters in Mississippi Sound. More recent data do not appear to be available. Metadata for species abundance and tissue contaminant concentration are available for download from the EMAP website (EPA 2006a).

Detailed data from EPA's EMAP program for benthic invertebrate assemblages of the Pontchartrain-Borgne estuary are also available for 1991 through 1994 (EPA 2006a; Appendix 5E). This includes benthic invertebrate abundances, sediment grain size information, water quality measurements, and sediment contaminant concentrations. (See Appendix 5E for details.)

Post-Katrina. The LDEQ (2005a, 2005b) observed fish kills along the northern shore of the lake and significant low dissolved oxygen conditions. They attributed these results to Hurricanes Katrina and Rita and not to pumping of the floodwaters from the flood protection system on the south side of the lake. LDEQ (2005b) also noted that "numerous bait fish", mullet and live crabs survived in the lake following the hurricanes (see Appendix 5E for details). LDWF plans to stock freshwater game species to replenish losses in 2006.

Post-storm sampling has been collected under EPA's EMAP program for benthic invertebrate assemblages of the Pontchartrain-Borgne estuary, sediment grain size information, water quality measurements, and sediment contaminant concentrations, but the data are not yet available for comparison to pre-storm conditions (EPA 2006a). The National Coastal Assessment (EPA 2006b) has summarized the pre- and post-storm results of these efforts. The Mississippi Department of Marine Resources and the LDWF reported physical damage to oyster beds from storm-caused scour, sedimentation, and debris deposition (MDMR 2005).

On 10 October 2005, NOAA sampled mussels in Lake Borgne under its Status and Trends-Mussel Watch Program and found fecal indicators to be relatively low (NOAA 2005) compared to other shore areas in proximity with shore sources of contamination consistent with a storm runoff event. Like other outer ecosystem sites farther east along the coast they found elevated levels of metals (e.g., selenium, copper, chromium, and nickel). No clear trend existed with respect to pumped water locations in Lake Pontchartrain, but no samples were collected in Lake Pontchartrain where oysters were decimated. In the shore waters off Mississippi, organochlorine pesticides and polycyclic aromatic hydrocarbons were lower than in past analyses.

Additional post-storm benthic data are available from a one-time sampling of Lake Borgne conducted in late November 2005 by ERDC (Ray 2006b, Appendix 5E). The sampling effort collected data on sediment grain size, invertebrate infauna, and water quality to assess foraging habitat of the endangered Gulf Sturgeon (*Acipenser oxyrinchus desotoi*). These data revealed that the benthic composition had changed markedly in Lake Borgne from that which existed in 1991-1994, toward a community more tolerant to high salinity. This may have been a temporary effect of Hurricanes Katrina and Rita, but the persistence of the change cannot be determined until further sampling is done.

Inner Ecosystem

Pre-Katrina. Commercial fish and invertebrate fisheries are insignificant in the inner ecosystem. Recreational fisheries existed locally, but no data documenting probable impacts associated with Hurricane Katrina have been found. Many urban fisheries are moderately to heavily fished, but the New Orleans area has many substitute recreational fisheries available to its anglers.

Post-Katrina. Ray (2006) is the primary source of information for assessing the effects of pumping Hurricane Katrina floodwaters on benthic invertebrate assemblages. Ray compared sites in the Violet Marsh where the pump stations were either active or inactive. They show differences in species relative abundances among pump locations, probably reflecting the local level of physical disturbance from pumping (two of the pumps had not operated), but all of the species assemblages were typical of low salinity, muddy, estuarine sediments in the Gulf of Mexico. There are no data on the condition of the recreational fishery. However, if there has been an impact from saline water, oxygen depletion or other event-related cause, any surviving populations are likely to recover quickly, if consistent with past hurricane experience. Common recreational species are easily restocked if necessary, consistent with LDWF stocking plans in the region.

7.5.3.3. Wildlife

Delta and Nearshore Gulf Region

Pre-Katrina. Many wildlife species are resident in the area for at least part of the year (Gosselink et al. 1998), and some reach great abundance. Most waterfowl using the central flyway winter in the lower Mississippi River valley and delta. Louisiana coastal areas support 19 percent of all wintering waterfowl (ducks and geese) in the United States. Herons, gulls, terns, coots, and other shorebird and seabird species are abundant; many year-round. National wildlife refuges (NWRs) in the area—including Breton, Delta, Bogue Chito, Mandalay, and Bayou Sauvage NWRs—are managed primarily to support water birds and neotropical migrants, especially during the winter, but also provide habitat for a large diversity of other species. Additional wildlife concentrations occur in several state wildlife management areas and Jean Lafitte National Park, just south of New Orleans.

Because of protective laws, bird populations have rebounded from market hunting for meat, eggs and feathers during the 19th century, and from more recent depression of predatory-bird abundance caused by pesticide contamination after World War II. The continued decline in wetland and barrier island habitat is the biggest threat to bird species in the area and especially those species that nest there. Numerous seabird and wading bird species nest on the barrier islands. Herons, egrets, ibises, and other species nest in mangroves and bald cypress groves. Neotropical migrants rely on these habitats as first and last stops before crossing the Caribbean during migrations. According to LDWF reports in the Louisiana Coastal Wetlands Conservation and Restoration Task Force and the Wetlands Conservation and Restoration Authority (1998), seabird, wading bird, and shorebird populations in the area are stable or increasing (see Appendix 5E for details).

The wetlands—especially the freshwater wetlands—support a large variety of mammals, reptiles, and amphibians. Fur trapping has in the past been an important source of income for coastal populations. Mink (*Mustela vison*), raccoon (*Procyon lotor*), muskrat (*Ondatra zibethicus*), otter (*Lutra canadensis*), beaver (*Castor canadensis*), and other native fur bearers are common. Other commercially important species include snapping turtles (*Chelydra serpentina*), American alligator (*Alligator mississippiensis*), softshell turtles (*Apalone*), diamond-back terrapin (*Malaclemys terrapin*), bullfrogs (*Rana catesbeiana*), and pig frogs (*Rana grylio*). A large variety of other vertebrate wildlife species inhabit the area.

Total potential abundances of wetland-dependent wildlife have declined as wetlands have disappeared. That trend will continue to the extent that wetlands continue to be lost. Per unit of habitat available, however, most wildlife populations appear to be stable or increasing because of changes in harvest regulation and improved environmental protection. Migratory birds have benefited from over-harvest protection since the early 20th century, now reflected in large regional abundances. After years of protection, alligators are now much more numerous. Fur-bearing mammals are more abundant because of the decline in demand for wild furs. While resident species are directly impacted by hurricanes, and many individuals die, most wildlife populations in the area are resilient.

Post-Katrina. Few data are available to support speculation about storm impacts on wildlife. The information so far discovered to evaluate potential impacts to wildlife populations is scarce and of limited utility. At least eight national wildlife refuges were closed as a consequence of the storm (FWS 2005a), but little information has been provided about wildlife impacts. Most areas of the refuges that were previously open to the public had reopened within a few months of the storm.

National bird monitoring data are collected at a scale that is too broad to distinguish hurricane-related impacts. For example, The Audubon Society and Cornell University (2006) maintain a Bird Source website, which posts results of the annual Christmas Bird Count and Great Backyard Bird Count. There are no similar sources of data on the status of mammals, reptiles, and amphibians.

While the extent of storm-caused mortality has not been quantified, damage was substantial. Photographic and other documentation chronicled the death of at least some residential mammals and reptiles exposed to storm surge and wind. Resident birds were also impacted. Many survivors had damaged wings and legs. Winter-resident birds were not in the area during the storm and several months following, but faced more limited resources once they returned. LDWF (2005b) reported that Early in the wintering season, coastal marshes were described as being nearly “devoid” of ducks but higher numbers occurred in many interior freshwater wetlands.

While pre-storm abundances of wildlife are likely to recover where suitable habitat remains, some damaged habitat is particularly scarce and critical, and may take decades to recover, if at all. Habitat damage extended to bottomland hardwood forests that serve as the last and first migration stop of neotropical birds. Resident roosting birds (e.g., pelicans, herons) also were impacted. However, most species in the area are likely to recover, much as they have following past hurricanes.

There is no indication in reports following Hurricane Katrina that New Orleans flooding and subsequent floodwater pumping from greater New Orleans contributed to wildlife loss in delta and gulf areas outside the city. The most probable pathway for any such damage would be through habitat contamination of Lake Pontchartrain and Violet Marsh. Based on contaminant modeling, floodwater contaminants did not persist in threatening concentrations in water leaving Lake Pontchartrain, but did contribute in relatively small fraction to existing sediment concentrations in both Lake Pontchartrain and Violet Marsh.

Pontchartrain-Borgne Estuary

Pre-Katrina. The status of wildlife around the margins of and on the Pontchartrain-Borgne estuary is similar to the region. One national wildlife refuge—Big Branch Marsh—is on the northeast shore of Lake Pontchartrain. Several Wildlife Management Areas (WMA) are managed by the state of Louisiana in the vicinity of Lake Pontchartrain, Lake Borgne, and Lake Salvador southeast of New Orleans. Most of these natural areas are wetlands with some upland areas managed mostly in support of water birds (especially during the winter), neotropical migrants, and species listed under the protection of the Endangered Species Act.

Exceptions to stable abundances appear along the south shore of Lake Pontchartrain, the most urbanized region, where alligators and fur bearers are in decline and shorebirds, waterfowl, and other wildlife are expected to decrease near Lake Borgne because of development trends (Louisiana Coastal Wetlands Conservation and Restoration Task Force and Wetlands Conservation and Restoration Authority 1998).

Post-Katrina. The same kinds of wildlife damage occurred around and on Lake Pontchartrain and Lake Borgne as was reported for the region. No quantitative data were discovered. The pumping of contaminated floodwater into Lake Pontchartrain temporarily raised levels of lead, arsenic, and other toxic materials in the southeastern quadrant of Lake Pontchartrain, and probably added a very small increment of contaminant to bottom sediments. This may have slightly elevated concentrations in food organisms of semi-aquatic mammals and birds, but no post-Katrina reports on food and wildlife tissue concentrations of contaminants have been discovered.

Inner Ecosystems

In addition to typical urban wildlife, wild mammals, birds, reptiles, and amphibians occur within wetlands of the inner ecosystem in subbasins at the margins of greater New Orleans. Located just east of urban development, and within the city limits of New Orleans, Bayou Sauvage NWR hosts “an enormous wading bird rookery from May until July… and tens of thousands of waterfowl winter in its…marshes” (FWS 2006b). The hurricane occurred during the interval between the seasons of greatest water bird use. Wildlife damage reports are anecdotal. Migratory waterfowl abundances probably decreased locally as they did regionally.

While no data on wildlife use has been discovered for Violet Marsh, it is undoubtedly used by wildlife much like those that use the nearby Bayou Sauvage NWR. The condition of bald cypress is especially relevant to use as bird nesting areas (rookeries). Because it requires fresh water for survival, elevated salinities associated with levee failure may have stressed the cypress and perhaps killed trees. That condition is being monitored with the onset of the spring growing season.

7.5.3.4. Pest Species

Delta and Nearshore Gulf Region

Pre-Katrina. Pest species often become abundant after a major disturbance, such as a hurricane might cause. Changes in abundance may occur because ecological suppression by predation and competition is reduced, or because populations disperse into areas where they are more likely to become a nuisance or health threat. A number of species that have been introduced intentionally or accidentally into the United States are generally considered to be nuisance species, even though, under some circumstances they may be positively valued. A long list of non-native invasive species known to occur in Louisiana and Mississippi is included in Appendix 5E.

Non-native, floating aquatic plants have had a long history of economic and environmental impacts in the region. Water hyacinths (*Eichhornia crassipes*), alligator weed (*Alternanthera philoxeroides*), hydrilla (*Hydrilla verticillata*), and other aquatic plant species clog waterways and cost millions of dollars annually to control. They can also degrade aquatic habitat for many aquatic species, by eliminating light transmission and oxygen-producing photosynthesis that counterbalances decomposition-caused hypoxia.

Among animals, the nutria *Myocastor coypus* is probably the biggest nuisance. A large aquatic rodent imported from South America for its fur, nutria escaped or were intentionally released starting in the 1930s. By 1960, the population in Louisiana had reached 20 million and had "devastated" large areas of herbaceous wetland vegetation, which it depended on for food. Trapping in the 1970s and 1980s reduced the populations, which have resurged since furs have lost favor with much of the public. Nutria appear to have contributed largely to recent declines in freshwater floating marsh and to failures in bald cypress regeneration. Predator-prey imbalances caused by past over-harvest of predators—especially alligators—contributed largely to the problem. Since alligators populations have rebounded, they better control nutria populations, but sometimes become a nuisance themselves, especially in suburbia. Threats to pets and humans are growing issues.

The humid, semi-tropical and watery landscape favors pest-level abundances of some insect species. Cockroaches are prolific outdoors most of the year, as well as indoors. Mosquitoes are a routine part of the delta experience. Temporary outbreaks can be caused when natural predators are forced out of habitats or are killed, which sometimes happens in freshwater wetlands following hurricanes. Fire ants (*Solenopsis wagneri*), another non-native invasive species, are widespread in the southern United States and notorious for their painful bites and deadly impacts on young wildlife. Out-of-place, large and toxic predators also can become a nuisance. In the delta region, poisonous snakes and alligators have the greatest nuisance potential.

Post-Katrina. Little has been reported about nuisance species following Hurricanes Katrina and Rita. Virtually all information encountered was provided in warning of and preparation for potential problems associated with hurricanes. Whatever additional nuisance might have resulted probably was minor in comparison with other problems. In many areas, floating mat plants were torn up by the storms. While it is possible that the hurricane temporarily reduced abundances of invasive species, they may rebound in greater abundance in hurricane-disturbed areas.

Pontchartrain-Borgne Estuary

The conditions that apply more generally also apply to Lakes Pontchartrain and Borgne.

Inner Ecosystem

Pre-Katrina. Similar to other urban areas, urban wildlife often are a nuisance. The most worrisome are non-native rodent species. All of the common insect pests found regionally occur in greater New Orleans. The Formosan termite (*Coptotermes formosanus*), an invasive species from Asia, is a particularly costly pest with potential for wider spread. This species is currently found throughout much of New Orleans, southern Louisiana, and parts of southern Mississippi.

Post-Katrina. Information is sparse and anecdotal. While there was some concern following Hurricane Katrina that conditions would increase the likelihood of encountering animal pest species—including poisonous snakes, rodents, biting insects, and diseased mammals (e.g., rabies)—there is no documentation of significant problems. People evacuated the inner ecosystems, greatly reducing the likelihood of encountering pest species. The large amounts of organic matter left to decay following the hurricanes may have been reduced by rodents and insects ordinarily considered pests. Breakdown in garbage collection services where people returned probably encouraged local rodent populations to increase, but apparently not enough to become a prominent issue. Flooding probably displaced and dispersed many wild animals more than normal rainfall flooding (alligators and snakes were reported seen), but most surviving wild animals probably returned to natural habitats before many people returned to the area.

There may have been encounters with poisonous snakes, alligators, rodents, or other terrestrial vertebrate species following Katrina, but no reliable reports of harm have been discovered. Concern about insect-borne diseases—such as St. Louis encephalitis, West Nile disease, and dengue—has not proved to be an issue. Concern that Formosa termites might be spread or encouraged to increase in abundance during debris disposal led the Louisiana Department of Agriculture and Forestry (2005) to quarantine all wood and cellulose materials on 3 October 2005. No wooden debris or temporary housing may be moved unless it is either fumigated, treated or specially permitted (See Appendix E for details). The LDEQ (2005a) provided guidance for disposal of potentially contaminated debris as part of the debris disposal plan. While much of the debris seems to have been retained in landfills within the flood protection system, analysis of possible disposal outside the system and pre-Katrina range of the termite is under way.

7.5.3.5. Special Status Species

Delta and Nearshore Gulf Region

Pre-Katrina. Globally vulnerable species with special state or federal status that occurred in the region before Hurricane Katrina are identified in Table 69. This list does not include any of a number of whale species that occasionally pass through the area. Many of the plant and animal species on the list inhabit wet to dry pine forests north of the Lake Pontchartrain-Borgne estuary. Most of these are terrestrial “disturbance species”, which live in well-illuminated areas in open forests that are maintained by fire or other disturbance. To the extent that the forest cover is

Table 69
Plant and Animal Species in the Coastal Region Impacted by Hurricane Katrina with Special Federal and State Status Ranked as G3 (Vulnerable To Extinction) or Below in Global Status and all Endangered Species Listed Under the Endangered Species Act. Shaded Species occur at least seasonally in the Pontchartrain-Borgne estuary within reach of contaminants from the flooded areas of Metropolitan New Orleans

Scientific Name	Common Name	State Rank	Global Status	Federal Status	State Status	Habitat
Acipenser oxyrinchus desotoi	Gulf sturgeon	S1S2	G3T2	LT	Threatened	River/estuary
Aimophila aestivalis	Bachman's sparrow	S3	G3			Riparian
Alosa alabamae	Alabama shad	S1	G3	C		River/estuary
Charadrius alexandrinus	Snowy plover	S1B, S2N	G4	PS:LT		Shore
Charadrius melodus	Piping plover	S2N	G3	LE, LT	Endangered	Shore
Calopogon multiflorus	Many-flowered grass-pink	S1	G2G3			Pine moist
Caretta caretta	Loggerhead sea turtle	S1	G3	LT	Threatened	Shore/ocean
Carex decomposita	Cypress-knee sedge	S1	G3			fresh wetland
Coreopsis nudata	Georgia tickseed	S2	G3?			Coastal lands
Crystallaria asprella	Crystal darter	S2S3	G3			Stream
Falco peregrinus	Peregrine falcon	S2N	G4	PS:LE	Endangered	General
Gopherus polyphemus	Gopher tortoise	S1	G3	PS:LT	Threatened	Upland pine
Graptemys oculifera	Ringed map turtle	S2	G2	LT	Threatened	River
Haliateetus leucocephalus	Bald eagle	S2N,S3B	G4	PS:LT,PDL	Endangered	Estuary/river
Isoetes louisianensis	Louisiana quillwort	S1	G2	LE		Stream
Liatris tenuis	Slender gay-feather	S1	G3			Open pine
Macranthera flammea	Flame flower	S2	G3			Open pine
Noturus munitus	Frecklebelly madtom	S2S3	G3			Stream
Obovaria unicolor	Alabama hickorynut	S1	G3			Stream
Percina aurora	Pearl darter	SH	G1	C		Stream
Percina lenticula	Freckled darter	S1	G2			Stream
Pelicanus occidentalis	Brown pelican	S2	G4	PS:LE	Endangered	Estuary/ocean
Physalis carpenteri	Carpenter's ground-cherry	S1	G3			Open woods
Physostegia correllii	Correll's false dragon-head	S1	G2			Fresh wetland
Picoides borealis	Red-cockaded woodpecker	S2	G3	LE	Endangered	Mature pine
Polygala hookeri	Hooker milkwort	S1	G3			Fresh wetland
Potamilus inflatus	Inflated heelsplitter	S1	G1	LT	Threatened	Stream
Pteroglossaspis ecristata	Giant orchid	S2	G2			Moist pine
Quercus arkansana	Arkansas oak	S2	G3			Pine/oak
Rana sevosa	Dusky gopher frog	SH	G1	LE		Pine/wetland
Ruellia noctiflora	Night-flowering wild-petunia	S1	G2			Pine wetlands
Scaphirhynchus albus	Pallid sturgeon	S1	G1	LE	Endangered	River
Trichechus manatus	Manatee	SNA	G2	LE	Endangered	Estuary
Ursus ameicanus luteolus	Louisiana black bear	S2	G5T2	LT	Threatened	Forest Wetland

Original data from Louisiana Department of Wildlife and Fisheries.

opened up, past hurricanes may have favored these species. Major threats to their survival include land development and fire suppression. One exception, the red-cockaded woodpecker, inhabits mature pine forests, which have been largely converted to second growth pine plantations. Another exception-- the Louisiana subspecies of black bear—inhabits a mix of bottomland and upland forests mostly to the north of Lake Pontchartrain. They appear to be rare because of habitat loss and past hunting.

Another large group of vulnerable species are fish, mollusks, and plants that inhabit streams. These include the darters, madtoms, freshwater mussels, and Louisiana quillwort, which do not tolerate much sedimentation of bottom habitat, chemical pollution, or hydrologic alteration. Most of the vulnerable stream species in the region inhabit the watersheds draining into the north shores of Lakes Pontchartrain and Borgne. Many of those streams are polluted with agricultural and local community runoff. Bottom siltation from eroded soils is common. Intense rains associated with hurricanes may have mixed effects. While intense rains accelerate loading of sediment from eroding watersheds, they also flush fine sediment out of bottom habitats, possibly improving them for species vulnerable to sedimentation.

A few species inhabit estuaries and rivers. These include the largest species on the list in Table 69, the manatee and two species of sturgeon. The manatee is a seasonal visitor during summer months, but no data have been found that confirm manatees were present at the time of the hurricane. The pallid sturgeon has not been observed in the area for decades, but the gulf sturgeon and Alabama shad occur in the estuaries and rivers draining into the Gulf of Mexico. These species have evolved with hurricanes, but individuals may succumb to storm damage.

Three species, the loggerhead sea turtle, piping plover, and snowy plover occur on barrier islands in the Mississippi Sound. The past high loss rate of barrier island area has been a major contributor to local threats. Hurricanes have contributed to this net loss, but the more fundamental limitation may be decreasing sources of sand in the system, which may starve the islands of material needed for regeneration. Sediment that once reached the shallow waters of the gulf via the Mississippi River has been trapped in the watershed or transported to deep offshore water by the confined river (Gosselink et al 1998).

Three species (Correll's false dragon-head, Hooker milkwort, and cypress-knee sedge) are emergent plants that inhabit freshwater wetlands. Most of these species occur sporadically in wet openings in pine forests or along low river banks. Hurricane flooding may kill some individuals of these species. No vulnerable plant species are endemic in tidal brackish to freshwater wetlands fringing the estuaries of the area or associated with the areas of wetland loss caused by storm surge. Development, pollution, and altered hydroregimes all contribute to the scarcity of these species.

Several of the National Wildlife Refuges in the area manage for threatened and endangered species in addition to migratory birds in general. Bogue Chito NWR is primarily bottomland hardwoods and is managed for several endangered reptiles as well as birds. Breton NWF, located on offshore barrier islands in Mississippi Sound, hosts the largest breeding colonies of brown pelicans in the Southeast and large concentrations of nesting terns and herons. Piping plovers use the area in winter. Big Branch Marsh NWR has nesting red-cockaded woodpeckers and bald eagles.

Post-Katrina. The U.S. Fish and Wildlife Service reported structural damage and closure to at least eight refuges that hosted species of special concern. Several dead gulf sturgeon were seen near Interstate 10 in Pascagoula, MS, immediately following the storm. Some loss of habitat occurred, including sea turtle nesting sites and dune habitat of Alabama beach mouse (*Peromyscus polionotus ammobates*) along the Alabama coast in Bon Secour National Wildlife Refuge (FWS 2005a). The Chandeleur Islands, where piping plover and nesting loggerheads have been known to occur, sustained substantial land loss. These locations are all remote from the flood protection system and not likely to have been impacted by levee failure in any measurable way.

Pontchartrain-Borgne Estuary

Pre-Katrina. Several threatened and endangered species that might potentially be harmed by levee failure have been observed in and near Lake Pontchartrain and Lake Borgne. These include the West Indian manatee, brown pelican, bald eagle, gulf sturgeon, and Louisiana quillwort. Alabama shad, listed under the ESA as a species of concern, occur commonly in the Mississippi Sound and Lake Borgne, and rarely in Lake Pontchartrain. Migrations into and out of the Pearl River have been in decline (NatureServe Explorer 2005). Bald eagle and brown pelican have been increasing in the area, as well as nationally.

Post-Katrina. There is little information of the impact of Katrina on species of special status. At the time of the storms, most gulf sturgeon were in their summer resting areas in the Pearl and Bogue Chito Rivers, well away from contaminant transport from New Orleans. Of 40 fish carrying telemetry tags, none have been located since the storm (Ruth 2005, Appendix 5E). The other threatened and endangered species occur incidentally and seasonally, and there is no reported knowledge of their occurrence since Katrina in the region under study (NatureServe Explorer 2005).

Other species that are not listed are considered vulnerable to extinction by NatureServe, which is a non-government organization that manages a database on species conservation status for the state natural heritage programs (NatureServe Explorer 2005). Few of these species, other than the threatened and endangered species listed above, are known to occur within Lake Pontchartrain and Lake Borgne, where the effects of levee structure failure might be encountered.

The populations of endangered gulf sturgeon in the Pearl River system have yet to be found and may have been significantly impacted by Hurricanes Katrina and Rita. If these prove to be losses, they have little to do with levee failure, the dewatering process, or water and sediment contamination. The populations were well removed from any of those impacts at the time of the storm.

The status of other threatened and endangered species in the area has not as yet been reported. Brown pelicans and bald eagles, which are relatively common in the area, could have avoided the worst of the storm. Piping plovers are uncommon on barrier beaches in the area and occur there primarily in winter. Other species occur only incidentally in the area and may not have been present during the storm, although summer is the season when manatees are most likely to occur in the area.

Several of the vulnerable species in the area have attained their present status because of past pesticide contamination in their aquatic food items. Yet contamination levels in the habitat and in fish, as indicated by data and model results, do not indicate much potential for additional risk to these species.

The Inner Ecosystem

Pre-Katrina. No state or federal threatened and endangered species have been definitely identified in Violet Marsh. Because the area is encircled by levees, no anadromous aquatic species or marine species that require fresher nursery habitats use the area. Bald eagle and brown pelicans occur nearby in the Bayou Sauvage National Wildlife Refuge and are likely to have hunted in Violet Marsh on occasion. Bald eagles have nested in cypress trees in the wildlife refuge (Penland et al. 2002).

Post-Katrina. Although other bird species might conceivably pass through the area, the probability of impact on the extant populations of all threatened and endangered species is likely to be small. Bald eagles and brown pelicans are the most likely to have been impacted by flooding and subsequent pumping of contaminated floodwater into the marsh. Significant harm from food contaminated as a consequence of pumping is unlikely. Low concentrations of metals and synthetic organics were found in the ecosystem and the two species are likely to hunt over large areas outside the marsh area as well as in the marsh.

Intrusion of salt water into Violet Marsh and Bayou Sauvage NWF, both of which are fresh water to brackish, may have had impacts on cypress trees and other freshwater vegetation that have yet to appear. Losses of the trees eventually would reduce eagle nesting sites and roosts in these areas.

7.5.4. Summary of Results for Actual and Hypothetical Katrina Scenarios

The results of data and other information reviewed for this study revealed that hurricanes have interacted with Mississippi River dynamics to sustain ecosystem dynamics and the resulting ecological resource condition of the delta and coastal environment for thousands of years. Viewed from the perspective of natural ecosystem sustainability, hurricanes have positive long-term effects, even as they have temporarily disrupted natural environmental services, such as support of commercial fishing and fish- and wildlife-based recreation. DeAngelis and White (1994), DeAngelis (1994), and Duever et al. (1994) describe the role of hurricanes and other forces of nature that drive the dynamics of the Everglades ecosystem, which is among the best studied in this regard. Past experience with hurricanes in the gulf region indicates that fish and wildlife population losses from hurricane winds, storm surge, and associated saline water intrusion into freshwater habitats are temporary where habitat is sustained, but a net loss in wetland habitat has occurred since the 1930s because of development effects (Gosselink et al 1998). No data discovered to date indicate that the response to Hurricanes Katrina and Rita will differ except where development, and its unintended impacts, may determine otherwise.
Table 70 summarizes these and other conclusions from the study, including implications that can be drawn from comparison of hypothesized and actual conditions observed following Hurricane Katrina.

Table 70
Summary of pre-and post-ecological resource conditions, including possible impacts associated with the failure of the flood protection system (actual conditions) around New Orleans to perform as planned (hypothesized conditions).

Ecological Resource	Pre-Katrina	Post-Katrina	
		Actual	Hypothetical Rainfall Flooding Alone
Ecosystem Support	Wetland loss from water resource and urban development caused an average wetland loss of 75 km^2/yr over the past 70 years. Lead and other metal and organic contaminants are concentrated in urban land and waters, and are more like the U.S. mean in rural areas. Rainwater pumping out of New Orleans and other drainage temporarily move chemical and biological contaminants in Lake Pontchartrain following heavy rainstorms. Lake Pontchartrain and Violet Marsh sediments are contaminated with metals and organic chemicals from various unidentified sources including rainwater pumping from greater New Orleans, but most concentrations remain below state environmental standards in Lake Pontchartrain. Violet Marsh salinity is low based on freshwater vegetation and averaged about 7.4 ppt in 1993-94. Marsh sediment toxicity to wetland organisms is unknown.	A wetland loss of about 295 km^2 was caused by storm-surge and wind throughout coastal Louisiana, and was consistent with the long-term wetland loss trend of about 75 km^2 when averaged with the lower loss rate over the 1983-2004 period without intense hurricanes. Floodwater pumping flushed potentially harmful chemical and biological contaminants in greater New Orleans floodwaters into Lake Pontchartrain and Violet Marsh. Based on model results water concentrations in Lake Pontchartrain and Violet Marsh returned to pre-Katrina concentrations and sediment contamination increased by a small fraction. Empirical data also indicate little change in Lake Pontchartrain sediment contamination. Violet Marsh salinity in December averaged 12.7 ppt at the same sites measured in 1993-94. Bioassay organisms exposed to Violet Marsh sediments do not tolerate something in them very well, but the agent and sources are unknown.	A wetland loss of 295 km^2 was caused by storm-surge and wind throughout coastal Louisiana, and was consistent with the long-term wetland loss trend when averaged with the lower loss rate over the 1983-2004 period without intense hurricanes. Floodwater pumping flushed potentially harmful chemical and biological contaminants in greater New Orleans rainwater into Lake Pontchartrain and Violet Marsh in about the same concentrations as occurred in the actual floodwaters. Based on model results, water concentrations in Lake Pontchartrain and Violet Marsh returned to pre-Katrina concentrations and sediment contamination increased by an order of magnitude smaller fraction than the actual condition. Violet Marsh salinity in December averaged closer to the concentrations measured in 1993-94 (7.4 ppt average). Marsh sediment toxicity to wetland organisms is unknown.

(Sheet 1 of 3)

Table 70 (Continued)			
Ecological Resource	**Pre-Katrina**	**Post-Katrina**	
		Actual	**Hypothetical Rainfall Flooding Alone**
Fisheries	Except for hurricane-caused losses of freshwater fish and estuarine invertebrates, which recover over a few years, aquatic populations have been stable. Oysters are especially vulnerable to the physical impacts of hurricanes. Except for temporary fecal contamination following storms, including the pumping of contaminated rainwater from greater New Orleans, the fisheries are generally safe for consumption. Important fisheries exist in the region. The fishery in Violet Marsh is limited to recreational fishing, but no data exist about the quality of the fishery, intensity of fishing, or vulnerability to past storms. Freshwater recreational fishing is augmented by stocking following storm-caused fish kills. There are no data on fish-tissue contamination in Violet Marsh. Estuarine species that depend on wetlands for juvenile nurseries are likely to decrease with further wetland decline.	Hurricane Katrina caused extensive freshwater fish and oyster kills from storm surge impacts, especially along the north shore of the Pontchartrain-Borgne estuary and the Mississippi coast, but had no identified direct impact on marine fish. Fecal contamination of fisheries in the Pontchartrain-Borgne estuary was accentuated because of floodwater pumping, but was opened to fishing within months, based on state appraisals. Salinity and hypoxia may have contributed to some local loss of freshwater recreational fisheries in Violet Marsh and other inner ecosystem waters, but there are no confirming data. Surviving fish populations are likely to rebound or are easily restocked. Further monitoring of metals and organic contamination in recreational fish would assure there has been no delayed uptake and transmission to humans. In keeping with past trends, estuarine species that depend on wetlands for juvenile nurseries are likely to decrease with wetland decline following Katrina.	Regardless of flood protection in greater New Orleans, Hurricane Katrina caused extensive freshwater fish and oyster kills from storm-surge impacts, especially along the north shore of the Pontchartrain-Borgne estuary and the Mississippi coast, but had no identified direct impact on marine fish. Fecal contamination of fisheries in the Pontchartrain-Borgne estuary was accentuated because of rainwater pumping but less extensively compared to the actual condition. Closed fisheries would be opened somewhat sooner based on state appraisals. Hurricane-caused hypoxia may have contributed to local loss of freshwater recreational fisheries in Violet Marsh and other inner ecosystem waters. Surviving fish populations are likely to rebound or are easily restocked. While less contaminants are pumped than in the actual condition, further monitoring of metals and organic contamination in recreational fish would assure there has been no delayed uptake and transmission to humans from previously contaminated sediments. In keeping with past trends, estuarine species that depend on wetlands for juvenile nurseries are likely to decrease with wetland decline following Katrina.
Wildlife	Hurricane wind and storm surge cause temporary wildlife losses, which recover within years. Total potential wetland wildlife numbers have declined with development-caused habitat loss, however. The area hosts large concentrations of wintering waterfowl and is an important migration stop for neotropical birds, including wetlands within the hurricane protection system. Habitat contamination with metals and organic chemicals occurs in the region, but no data on wildlife tissue contaminant concentration was discovered to determine if transfer from the habitat has occurred to any significant degree in recent years. A progressive loss of forested wetlands from increased salinity is reducing nesting and roosting habitat for bird species.	Hurricane Katrina storm surge and wind killed wildlife, as documented in photographs and narratives, but no quantitative data about total impact have been found. Wintering waterfowl were not present until months later, but winter use of the area by waterfowl was greatly reduced from previous years. Delayed contamination of wildlife from contaminant transport out of the flooded areas of greater New Orleans may occur to some degree, but no data on tissue contamination have been discovered so far. Regional bird roosting and nesting trees show signs of storm impact, both for wading birds and neotropical migrants, which may have negative long-term effects, but the effects are as yet uncertain and unquantified. Salinity increase in Violet Marsh also may ultimately cause additional loss of bird nesting trees.	Hurricane Katrina storm surge and wind killed wildlife, as documented in photographs and narratives, but no quantitative data about total impact have been found. Wintering waterfowl were not present until months later, but winter use of the area by waterfowl was greatly reduced from previous years. Delayed contamination of wildlife from contaminant transport out of the rain water flooded areas of greater New Orleans is possible but less likely than under the actual condition. Bird roosting and nesting trees show signs of storm impact, both for wading birds and neotropical migrants, which may have negative long-term effects, but the effects are as yet uncertain and unquantified. Unlike regional habitat changes, because of levee protection from saline water, Violet Marsh would remain freshwater marsh and a refuge for nesting and roosting trees.
			(Sheet 2 of 3)

Table 70 (Concluded)			
Ecological Resource	Pre-Katrina	Post-Katrina	
		Actual	Hypothetical Rainfall Flooding Alone
Pests	The humid subtropical climate and watery landscape favors various insect pests and the public is warned of possible outbreaks following flooding associated with tropical storms and hurricanes. Non-native invasive species in the region have been costly, especially several species of aquatic plants, nutria, and Formosan termite, which has been kept localized, so far, in the vicinity of New Orleans. Like other cities, non-native urban rodents have been a routine nuisance. Alligators and toxic snakes are both nuisance control and occasional nuisances mostly outside the flood protection system.	The humid subtropical climate and watery landscape favored various insect pests and pest outbreak warnings were sent out after Katrina flooding. Little has been explicitly reported about pest impacts, including Formosan termite, the transport of which in removed debris has been strictly controlled. Rodents and insect pests may have been displaced to upland areas by flooding, but the impacts, if any, appear to have been unremarkable in general. Massive evacuation until the cooler months may have been a factor. There were reported sightings of snakes and alligators in the flooded areas, which may have entered through levee breaches and overtopping.	The humid subtropical climate and watery landscape would favor various insect pests and pest outbreak and warnings would be routinely sent out after Hurricane Katrina flooding. Protection from outside sources of flooding in greater New Orleans would keep out snakes and alligators. There would be no concern about transport of Formosan termites to areas outside New Orleans. Rodents and insect pests would be displaced only from limited areas as usual after heavy rains. Because no extended evacuation would likely occur, people returning to the city would be exposed to temporary elevations of mosquitoes and other such pests.
Special Status Species	Some 34 species and subspecies are identified as globally vulnerable and locally of special status. Of those, 13 are federally protected under the Endangered Species Act. Many are found in upland, stream and marine habitats far from the New Orleans flood protection system. Gulf sturgeon, bald eagles, and brown pelicans are most likely to occur near the flood protection system. Alabama shad and manatees are rarely encountered in Lake Pontchartrain. Eagles and pelicans have increased in recent years and commonly use wetlands within and outside the flood protection system. Both birds were once much less common because of widespread persistent pesticide contamination, which has declined since their use was prohibited nationally. Cypress trees are used by bald eagles for roosts and nesting.	Most of the 34 special status species and subspecies live far from the potential impacts of habitat contamination associated with floodwater pumping from Hurricane Katrina. The data and model simulations suggest that the increment of contaminant threat caused by levee failure was real, but small. Gulf sturgeon were in the upper watershed of Lake Pontchartrain when Katrina occurred. Eagles and pelicans are most vulnerable to possible impacts. Roosting/nesting trees for eagles in the inner wetland ecosystems may have suffered some damage, but this remains to be confirmed. Violet Marsh contaminants toxic to bioassay organisms ought to be further monitored for potential to contaminate tissues of fish eating pelicans and eagles.	Most of the 34 special status species and subspecies live far from the potential impacts of habitat contamination associated with rainwater pumping from within an intact flood protection system. The data and model simulations suggest that the increment of contaminant threat caused by levee failure was real, but substantially less than under the actual conditions. Gulf sturgeon were in the upper watershed of Lake Pontchartrain when Katrina occurred. Eagles and pelicans are most vulnerable to possible impacts. Roosting/nesting trees for eagles in the inner wetland ecosystems may have suffered some damage, but this remains to be confirmed. Violet Marsh contaminants toxic to bioassay organisms ought to be further monitored for potential to contaminate tissues of fish eating pelicans and eagles.
			(Sheet 3 of 3)

Natural communities have adapted to river and coastal dynamics, including hurricanes, by redistributing in response to changes in water salinity and sediment deposition, which interact to redistribute and diversify the physical habitat. Although the patterns of habitat distribution changed dramatically, habitat destruction was more-or-less compensated by natural creation of new habitat. Water resources and urban development altered this variable equilibrium by unintentionally starving the delta of sediment and fresh water, and by opening up coastal wetlands to saltwater intrusion and erosive forces. As a consequence, the area of wetland habitat—especially vegetated freshwater wetlands—has decreased significantly over the past century.

The total abundance of wetland-dependent fish and wildlife has decreased in approximate proportion to wetland habitat loss. Wetland losses caused by Hurricanes Katrina and Rita appear to fit that general pattern of loss, which has varied annually with the frequency and intensity of hurricane events. When the mean annual wetland loss rate of 66 km^2 (25 square miles per year) estimated for the period of otherwise relatively low hurricane impact since 1983 (Gosselink et al. 1998) is averaged with the 295 km^2 (about 118 square miles) reported loss after Hurricanes Katrina and Rita, the result is about the same as the longer term loss rate of about 75 km^2 /year (nearly 30 square miles/year). This is a high estimate, however, because of some anticipated recovery and some impacts that occurred outside coastal Louisiana. The loss from Katrina and Rita was more than the combined loss of Andrew, Lili, and Isodore during that period of low impact (USGS 2006). The estimated land loss of about 180 km^2 (72.9 square miles) caused by Katrina and Rita east of the Mississippi River exceeded the 150-km^2 (60-square-mile) loss predicted from 2000 to 2050 by the Louisiana Coast Wetlands Conservation and Restoration Task Force and Wetlands Conservation and Restoration Authority (1998). A variable, but net annual loss rate of wetland and barrier beach to water is likely to continue if nothing is done to alter the human-caused conditions that have contributed to those trends.

Development in the area has also been accompanied by widespread pollution from agriculture, urban runoff, the oil and gas industry, and other sources. Investigations sponsored by the USGS, EPA, LDEQ, and others highlight the chronic pollution problems that exist in the delta's urban soils, and indicate that soil and sediment concentrations outside the city are lower and usually well within health standards. Concentrations of contaminants that exceed standards in sediments left by floodwaters in the greater New Orleans area appear to have come from contaminated soils in the flooded area rather than from Lake Pontchartrain or wetlands to the east of the urbanized drainage basins where contaminant concentrations are lower. Thus, flooding most likely redistributed contaminants within the flood zone and did not increase the total load by transporting contaminants from outside sources into the flood protection system. Those same city soils were a probable source of contaminants in pumped floodwater, although other sources probably existed in buildings, sewage systems, waste disposal areas, and refineries.

Fecal coliform bacterial contamination routinely follows major storm runoff, reflecting storm runoff through sewage treatment systems and livestock waste runoff. The response to Hurricane Katrina was not exceptional. Fisheries were declared safe for consumption by state authorities within a few months of the storm. Contaminant transport from the flooded city to outer ecosystems was the primary means by which levee breaching and overtopping, and subsequent floodwater management, might have imposed environmental damage on ecological resources. The model-estimated increment in contaminant concentrations was no more than a few percent at maximum sediment concentration and the upper estimated 95 percent confidence interval of loading concentration. The more probable increase in average sediment concentration at median loading concentrations in Lake Pontchartrain and Violet Marsh were likely to be less than 1 percent.

Based on measured sediment concentrations of contaminants and model simulation results, delayed transmission of elevated levels of habitat contaminants up through food webs to resource tissues in significantly elevated concentrations is unlikely. Many of the resource species included in this analysis either do not occur in the area reached by floodwater contaminants or feed over large areas, much of which was not contaminated by the floodwaters. However, post-Katrina assessments of tissue contamination in fish and wildlife within reach of the floodwater pumping has not as yet been made available in published data; thus, there is no confirmation that the small increments of habitat contamination caused by floodwater pumping have had correspondingly small consequences in fish and wildlife. In Violet Marsh, unexplained mortality in bioassay studies and concentrations of some sediment contaminants higher than standards indicate that further monitoring of resource species tissue for contamination may be warranted.

The ecological resource losses that did occur were a consequence of the hurricane and not extraordinary flooding or its management within the flood protection system. Many of those losses were economic and are treated in more detail in other studies. Losses of oyster beds were linked primarily to the physical impacts of the storm. Freshwater fish kills and temporary closure of shellfish fisheries because of fecal contamination is a common response to storm runoff, and was not the exceptional consequence of Hurricane Katrina or the specific consequence of city flooding and floodwater management. Some marine fish species in the area have, if anything, increased in abundance, perhaps because fishing intensity has decreased since the storms. Primarily because of damaged infrastructure, dockside revenues from commercial fisheries may be half of what it had been before Katrina during the year following Katrina. Losses in recreational benefit are expected as well, but the extent to which this derives from the condition of the resources versus access and other amenities is unclear.

It is even less clear how environmental benefits were impacted. Even if species in the region have persisted with hurricanes for millennia, resiliency diminishes as habitats and population numbers are reduced to critically low levels. The storm killed special-status species, such as Gulf sturgeon, and only time will tell how much the total damage was. The disappearance of a local population of the endangered gulf sturgeon in the Pontchartrain-Borgne estuary is not likely to be connected to pumped floodwater, however. The only dead sturgeon reported after the storm were observed in the Pascagoula River near Pascagoula, MS.

Wetland and other habitat damage may have negatively impacted other species of special status, but that impact was not, in general, linked to levee breaching and overtopping or to floodwater pumping afterwards. It is too early to determine if exposure of freshwater wetlands to higher salinity in Violet Marsh and Bayou Sauvage NWR will result in a less vegetated earlier stage of freshwater wetland succession. The most recent observations of bald cypress made by personnel at ERDC indicate the trees are undergoing some stress. Changes in wetland salinity in Violet Marsh, and perhaps Bayou Sauvage NWR, may prove to have some ultimate impact on nesting sites for bald eagles and other bird species if bald cypress trees die and disappear at a faster rate than new wetland forest growth replaces them.

7.5.5. Environmental Consequences of Future Hurricane Events

What would happen if a repeat of Hurricane Katrina were to occur in June 2006? Similar results are likely from a similar storm and context. Soil and sediment contaminants in the flooded area would be to some extent taken up in the floodwaters and transported to Lake Pontchartrain and Violet Marsh. There is no reason to believe that anything other than the same unidentifiably low increase in metal and organic contamination would occur in the surrounding environment. If anything, contaminant transfer might be reduced slightly because of reduced urban contamination of surface soils from less urban use and previous floodwater flushing. Fecal coliform contamination would also be reduced. The same changes in salinity would occur in Violet Marsh. A second salinity shock to the freshwater wetlands within the flood protection system would increase the probability that wetland vegetation would be killed and the wetland areas converted to less desirable open waters or earlier successional stages of wetland vegetation. Different results are likely if the flood protection system response to a future hurricane varies significantly from what happened in 2005 and floodwaters come in contact with new sources of contamination.

References

Burton, G.A., Jr., D. Gunnison, D. and G. R. Lanza. 1987. Survival of pathogenic bacteria in various freshwater sediments. *Applied and Environmental Microbiology* 53(4): 633-638.

DeAngelis, D. L., and P. S. White. 1994. Ecosystems as products of spatially and temporally varying driving forces, ecological processes, and landscapes: A theoretical perspective. In *Everglades: The ecosystem and its restoration*, ed. S. M. Davis and J. C. Ogden, 9-28. Delray Beach, FL: St. Lucie Press.

DeAngelis, D. L. 1994. Synthesis: Spatial and temporal characteristics of the environment. In *Everglades: The ecosystem and its restoration*, ed. S. M. Davis and J. C. Ogden, 307-320. Delray Beach. FL: St. Lucie Press..

Duever, M. J., J. F. Meeder, L. C. Meeder, and J. M. MeCollom. 1994. The climate of south Florida and its role in shaping the Everglades ecosystem. In *Everglades: The ecosystem and its restoration*, ed. S. M. Davis and J. C. Ogden, 225-248. Delray Beach, FL: St. Lucie Press.

Gosselink, J. G., J. M. Coleman, and R. E. Stewart, Jr. 1998. Coastal Louisiana. In *Status and trends of the Nation's biological resources. Volume 1*, ed. M. J. Mac, P. A. Opler, C. E. Puckett Haeker, and P. D. Doran, 385-436. Washington, DC: U.S. Geological Survey, U.S. Government Printing Office.

Guidry, K. M. 2005. *Assessment of damage in Louisiana agricultural, forestry and fishery sectors by Hurricane Katrina*. LSU Ag Center Research and Extension, Louisiana State University, Baton Rouge, LA.

Gulf States Marine Fisheries Commission (GSMFC). 2006. Southeast Monitoring and Assessment Program **http://www.gsmfc.org/**

Jin, G., A. J. Englande, H. Bradford, and H. Jeng. 2004. Comparison of *E. coli*, Enterococci, and fecal coliform as indicators for brackish water quality assessment. *Water Environmental Research* 76:245-255.

Krahn, M. M., D. W. Brown, G. M. Ylitalo, and T. K. Collier. 2005a. Analysis of edible tissue from fish collected in coastal waters of the Gulf of Mexico affected by Hurricane Katrina to determine recent exposure to persistent organic pollutants (POP's). **http://www.st.nmfs.gov/hurricane_katrina/water_sediment_survey.html**

Krahn, M. M., D. W. Brown, G. M. Ylitalo, and T. K. Collier. 2005b. Analysis of edible tissue and bile from fish collected in coastal waters of the Gulf of Mexico potentially affected by Hurricanes Katrina and Rita to determine exposure to persistent organic pollutants (POP's) and polycyclic aromatic compounds (PAC's). **http://www.st.nmfs.gov/hurricane_katrina/water_sediment_survey.html**

Lake Pontchartrain Basin Foundation. 2006. Water Quality Monitoring Within The Lake Pontchartrain Basin In Response to Hurricane Katrina *Summary September –October 2005* **http://www.saveourlake.org/pdfs/Katrina WQ.pdf**

Lin, J. P., and B. A. Kleiss. 2006. *Salinity measurements and general condition of Violet Marsh, post Hurricane Katrina*. ERDC/EL TN-06-1. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

Louisiana Coast Wetlands Conservation and Restoration Task Force and Wetlands Conservation and Restoration Authority. 1998. *Coast 2050: Toward a sustainable coastal Louisiana.* Louisiana Department of Natural Resources, Baton Rouge, LA. **http://www.coast2050.gov/2050reports.htm**

Louisiana Department of Agriculture and Forestry. 2005. Imposition of quarantine. (**http://www.ldaf.state.la.us/divisions/AES/katrinaquarantine.pdf**

Louisiana Department of Environmental Quality (LDEQ). 2005a. Post-Hurricane Information **http://www.deq.louisiana.gov/portal/Default.aspx?tabid=2245**

______. 2005b. *Post-Katrina water quality assessment: Lake Pontchartrain and surrounding water bodies*. Water Quality Assessment Division, Louisiana Department of Environmental Quality, Baton Rouge, LA.

Louisiana Department of Wildlife and Fisheries (LDWF). 2005a. Preliminary analysis of economic losses caused by Hurricane Katrina to Louisiana's fisheries resources. **http://www.laseagrant.org/hurricane/docs/Katrina_FisheriesLosses.pdf**

______. 2005b . Waterfowl Population Estimates in Louisiana's Coastal Zone Below U.S. Highway 90 and on Catahoula Lake **http://www.wlf.louisiana.gov/pdfs/hunting/programs/waterfowl/waterdec2005.pdf**

Louisiana State University. 2006. Formosan subterranean termites. **http://lsuagcenter.com/en/environment/insects/Termites/formosan_termites/**

Mielke, H. W. 1994. Lead in New Orleans soils: New images of an urban environment. *Environmental Geochemistry and Health* 16:123-128.

Mielke, H. W., G. Wang, C. R. Gonzales, E. T. Powell, B. Le, and V. N. Quach. 2004. PAHs and metals in the soils of inner-city and suburban New Orleans, Louisiana, USA. *Envir. Tox., and Pharm.* 18:243-7.

Mielke, H. W., G. Wang, C. R. Gonzales, B. Le, V. N. Quach, and P. W. Mielke 2001. PAHs and metals mixtures in New Orleans soils and sediments. *Sci of the Total Envir*. 281:217-27.

Mississippi Department of Marine Resources (DMR). 2005. Hurricane Katrina Recovery Begins for Mississippi Oyster Program. News Release LST-05-183 **http://www.dmr.state.ms.us**

National Marine Fisheries Service (NMFS). 2006a. **http://www.st.nmfs.gov/hurricane_katrina/socio_economic.html**

______. 2006b. **http://www.st.nmfs.gov/hurricane_katrina/press_releases.html**

National Oceanic and Atmospheric Administration (NOAA). 2005. **http://ccma.nos.noaa.gov/data/katrina/prelim.html**

NatureServe Explorer. 2005. **http://www.natureserve.org/explorer/index.htm**

O'Connell, M. T., R. C. Cashner, and C. S. Schieble. 2004. Fish assemblage structure over fifty years in the Lake Pontchartrain estuary: Comparisons among habitats using Canonical Correspondence Analysis. *Estuaries* 27:807-817.

Pardue, J. H., W. M. Moe, D. McInnis, L. J. Thibodeaux, K. T. Valsaraj, E. MacIasz, I. Van Heerden, H. Korevec, and Q. Z. Yuan. 2005. Chemical and microbiological parameters in New Orleans floodwater following Hurricane Katrina. *Environmental Science and Technology* 39:8591-9.

Penland, S., A. Beale, and J. Kindinger (Ed.). 2002 (Online posting). Environmental Atlas of Lake Pontchartrain Basin. USGS Open-File Report 02-206. **http://pubs.usgs.gov/of/2002/of02-206/index.html**

Peterson, M. E., W. B. Nilsson, R. N. Paranjpye, and M. S. Strom. 2005a. Analysis of water and sediments collected in coastal waters of the Gulf of Mexico potentially affected by Hurricanes Katrina and Rita to determine levels of human fecal indicators. **http://www.st.nmfs.gov/hurricane_katrina/water_sediment_survey.html**

Peterson, M. E., L. D. Rhodes, W. B. Nilsson, R. N. Paranjpye, and M. S. Strom. 2005b. Analysis of water and sediments collected in coastal waters of the Gulf of Mexico potentially affected by Hurricanes Katrina and Rita to determine levels of human fecal indicators and pathogenic Vibrios. **http://www.st.nmfs.gov/hurricane_katrina/water_sediment_survey.html**

______. 2005c. Analysis of fish and invertebrates collected in coastal waters of the Gulf of Mexico potentially affected by Hurricane Katrina to determine levels of human fecal indicators. **http://www.st.nmfs.gov/hurricane_katrina/water_sediment_survey.html**

Peterson, M. E., R. N. Paranjpye, W. B. Nilsson, and M. S. Strom. 2005d. Analysis of fish and invertebrates collected in coastal waters of the Gulf of Mexico potentially affected by Hurricanes Katrina and Rita to determine levels of human fecal indicators and pathogenic Vibrios. **http://www.st.nmfs.gov/hurricane_katrina/water_sediment_survey.html**

Plumlee, G. S., G. P. Meeker, J. K. Lovelace, R. Rosenbauer, P. J. Lamothe, E. T. Furlong, and C. R. Demas. 2006. *USGS environmental characterization of flood sediments left in the New Orleans area after Hurricanes Katrina and Rita, 2005—Progress Report*: U.S. Geological Survey Open-File Report 2006-1023.

Presley, S. M., T. R. Rainwater, G. P. Austin, S. G. Platt, J. C. Zak, G. P. Cobb, E. J. Marsland, K. Tian, B. Zhang, T. A. Anderson, S. B. Cox, M. T. Abel, B. D. Leftwich, J. R. Huddleston, R. M. Jeter, and R. J. Kendall. 2006. Assessment of pathogens and toxicants in New Orleans, LA, following Hurricane Katrina. *Environmental Science and Technology* 40:468-74.

Ray, G. L. 2006a. *A pilot study of Post-Hurricane Katrina floodwater pumping on marsh infauna*. ERDC/EL TN-06-2. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

______. 2006b (Draft). *An assessment of Gulf Sturgeon foraging habitat in Lake Borgne, Louisiana*. Draft Report. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

Ruiz, C. E, and T. Gerald. 2001. *RECOVERY version 2.0: A mathematical model to predict the temporal response of surface water to contaminated sediments*. ERDC/EL TR-01-3. Vicksburg, MS: U.S. Army Engineer Research and Development Center.

Ruth, T. 2005. Hurricane Katrina. Effects to Pearl River and Lake Pontchartrain drainages. Presentation at the *7th Annual Gulf Sturgeon Workshop*, November 11-12, 2005, Panama City, FL.

Slack, T. 2005. Mississippi update. Presentation at *7th Annual Gulf Sturgeon Workshop*, November 11-12, 2005. Panama City, FL.

Stone, J. H., J. Day, L. Bahr, and R. Darnell. 1982. Ecological effects of urbanization on Lake Pontchartrain, Louisiana between 1953 and 1978, with implications for management. In *Urban ecology,* ed. J. Lee and M. Seaward, 243-252. New York, NY: Blackwell Scientific Publications.

The Audubon Society and Cornell University. 2006. **http://www.birdsource.org/**

United States Environmental Protection Agency (EPA). 2006a. **http://www.epa.gov/emap/index.html**

______. 2006b. **http://oaspub.epa.gov/storetkp/DW_resultcriteria_geo**

United States Environmental Protection Agency and Mississippi Department of Environmental Quality (EPA-MDEQ). 2005. Water quality study of bays in Coastal Mississippi. Water quality report. Project #05-0926. USEPA Region, Athens, GA. Available online at **http://www.epa.gov/region4/sesd/reports/2005-0926/05msbay-report.WebFinal.pdf**

United States Fish and Wildlife Service (FWS). 2005a. Hunting, Fishing Programs on Eight Gulf Coast National Wildlife Refuges Closed due to Hurricane Katrina. **http://www.fws.gov/southeast/news/2005/r05-098.html**

______. 2005b. Southeast Louisiana national wildlife refuges. **http://www.fws.gov/southeastlouisiana/**

United States Food and Drug Administration (FDA). 2005. Gulf States, Feds Report on Seafood **www.fda.gov/bbs/topics/NEWS/2005/NEW01271.html**

United States Geological Survey (USGS). 2002. Environmental Atlas of the Lake Pontchartrain Basin: Environmental Issues—Water Quality. http://pubs.usgs.gov/of/2002/of02-206/env-issues/pathogens.html

______. 2006. USGS Reports Latest Land Change Estimates for Louisiana Coast **http://www.nwrc.usgs.gov/releases/pr06_002.htm**