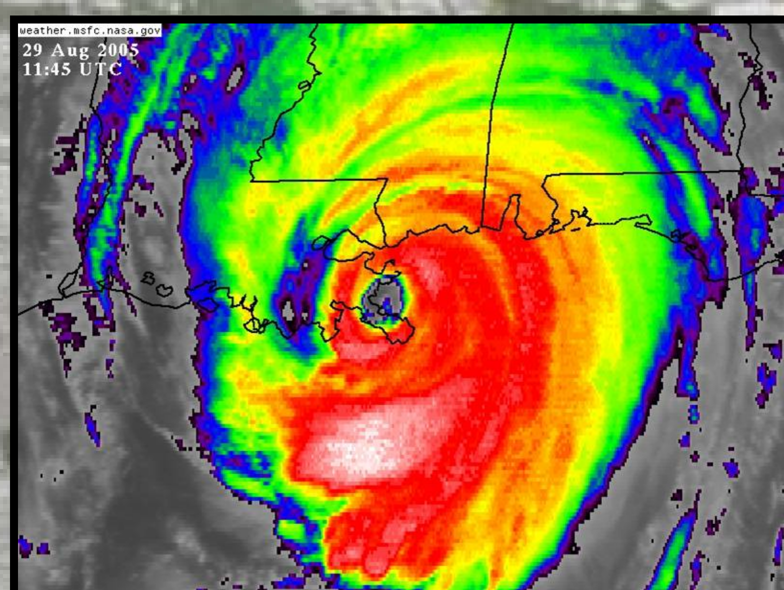
US Army Corps
of Engineers®

# Performance Evaluation Plan and Interim Status, Report 1 of a Series

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

by Interagency Performance Evaluation Task Force

10 January 2006




MMTF 00038-06

**FINAL DRAFT**
(Subject to Revision)

# Performance Evaluation Plan and Interim Status, Report 1 of a Series

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

by Interagency Performance Evaluation Task Force

10 January 2006

MMTF 00038-06

**FINAL DRAFT**

(Subject to Revision)

# Contents

**Part IV: Appendices**

# Executive Summary

This report is the first comprehensive formal documentation of the work of the Interagency Performance Evaluation Task (IPET) Force, initiated by the Chief of Engineers to provide credible and objective scientific and engineering answers to fundamental questions about the performance of the hurricane protection and damage reduction system in the New Orleans metropolitan area to assist in the reconstitution of hurricane protection. The Task Force is comprised of experts from government, academia, and industry; represents over 40 different organizations; and constitutes a broad spectrum of experience and expertise. This document is the first of four principal status reports on the performance evaluation. It provides: a strategic overview of the objectives, organization, and approach of the Task Force; a presentation of the participants, objectives, technical approach, and schedules for each major task being accomplished; and a task-by-task status report. The content of these discussions has been significantly influenced by the review and input of the American Society of Civil Engineers (ASCE) External Review Panel, also initiated by the Chief of Engineers to provide independent oversight of the performance analysis. While there are examples of the types of data, information, and products that are being generated by the performance evaluation, this report is not a presentation of findings or detailed technical analysis. Any conclusions in this report are preliminary and subject to revision. This report will also be submitted to the National Research Council New Orleans Regional Hurricane Protection Committee for their review and consideration. Report 2 will provide a task-by-task update on implementing the performance evaluation plan with emphasis on analysis to include the status of the analytical, numerical, and physical modeling performed to evaluate the hurricane system performance. Report 3 will provide a completed analysis of the structural performance of the hurricane protection system. The IPET Final Report, which will include the completed analyses for consequences and risk and reliability, is scheduled for 1 June 2006.

# Part I: Introduction

# Background

Hurricane Katrina struck the coasts of Louisiana, Mississippi, and Alabama on 29 August 2005. This hurricane caused the greatest loss of life and property damage to the New Orleans metropolitan area, St. Bernard Parish, Plaquemines Parish and the Mississippi Gulf Coast in recorded history. Hurricane Katrina created breaches in the floodwalls along the 17th Street Canal, the London Avenue Canal, and the Inner Harbor Navigation Canal. Water flowed from Lake Pontchartrain through the breaches and inundated large urban areas in New Orleans to depths of up to 20 feet, and the levees in St. Bernard Parish and Plaquemines Parish were overtopped causing the inundation of substantial additional urban areas.

The levels and magnitudes of destruction, the extensive damage to the flood protection system and the catastrophic failure of a number of structures raised significant issues about the integrity of the flood protection system prior to the storm and the capacity of the system to afford future protection even after repairs.

**Hurricane Protection System:** Historically, some hurricane protection had been provided to metropolitan New Orleans in a few areas but it was not until Hurricane Betsy hit the city in 1965, causing more than 8 billion dollars of damage (in 2002 dollars) and losing 75 lives, that a comprehensive hurricane protection program was initiated. The New Orleans and Southeastern Louisiana region consists of three hurricane protection projects.

*a.* ***Lake Pontchartrain and Vicinity****:* The “Lake Pontchartrain, La., and Vicinity Hurricane Protection Project” was authorized in 1965 and was modified in 1974, 1986, 1990, and 1992. The project lies between the Mississippi River and Lake Pontchartrain, and is located in St. Bernard, Orleans, Jefferson, and St. Charles Parishes in southeast Louisiana (generally the greater New Orleans metropolitan area), and also includes a mitigation dike on the west shore of the lake. The project was designed to protect residents from surges in Lake Pontchartrain driven by storms up to the Standard Project Hurricane (SPH). The SPH has been described as equivalent to a fast-moving category three hurricane. The project includes:

(1) New levee from the Bonnet Carré Spillway East Guide Levee to the Jefferson-St. Charles Parish boundary

(2) Floodwall along the Jefferson-St. Charles Parish line

(3) Enlarged levees along the Jefferson and Orleans Parish lakefronts

(4) Parallel protection (levees, floodwalls, and flood proofed bridges) along the 17th Street, Orleans Avenue, and London Avenue outfall canals

(5) Levees from the New Orleans lakefront to the Gulf Intracoastal Waterway (GIWW)

(6) Enlarged levees along the GIWW and Mississippi River Gulf Outlet (MRGO)

(7) New levee around the Chalmette Area.

*b.* ***West Bank:*** Urbanization into the wetlands and the potential hurricane threat led to construction of the West Bank hurricane protection project on the right descending bank of the Mississippi River. The project is located in Orleans, Jefferson and Plaquemines Parishes, and in metropolitan New Orleans on the west bank of the Mississippi River. The "West Bank and Vicinity, New Orleans, Louisiana, Hurricane Protection Project" was authorized in 1999 by combining three projects that were authorized in 1986 and 1996. The project is designed to protect residents on the west bank from storm surges from Lake Cataouatche, Lake Salvador and other waterways leading to the Gulf of Mexico driven by storms up to the SPH. The project includes

(1) 22 miles of earthen levee and 2 miles of floodwall extending from the Harvey Canal south to the V-levee near the Jean Lafitte National Historical Park and back up to the town of Westwego

(2) The Lake Cataouatche area eliminated the west-side closure in Westwego, and added about 10 miles of levee and 2 miles of floodwall

(3) The East of Harvey Canal area has a sector floodgate in the Harvey Canal and about 25 miles of levee and 5 miles of floodwall.

*c.* ***New Orleans to Venice:*** Just south of New Orleans, hurricane protection is provided by the "New Orleans to Venice Project." This project is located along the east bank of the Mississippi River from Phoenix, Louisiana (28 miles southeast of New Orleans), down to Bohemia, Louisiana, and along the west bank of the river from St. Jude, Louisiana (39 miles southeast of New Orleans), down to the vicinity of Venice, Louisiana. The project was authorized in 1962, as the "Mississippi River Delta at and below New Orleans, Louisiana Project" and later renamed as the "New Orleans to Venice Project." The project will protect residents from hurricane tidal overflows created by storms with a return period of 100 years. The protected area encompasses approximately 75% of the population and 75% of the improved lands in the lower Mississippi River delta region.

# Interagency Performance Evaluation Task Force

In response to Hurricane Katrina and these issues the Chief of Engineers, U.S. Army Corps of Engineers (USACE), established the Interagency Performance Evaluation Task (IPET) Force on October 10, 2005, by memorandum to the Director of Civil Works. IPET was sanctioned by the Secretary of Defense in a directive to the Secretary of the Army on October 19, 2005. The IPET mission is to provide credible and objective scientific and engineering answers to fundamental questions about the performance of the hurricane protection and flood damage reduction system in the New Orleans metropolitan area. These facts are being used as they are developed to assist in the reconstitution of hurricane protection in New Orleans in the ongoing repair phase and will form a foundation for more effective hurricane protection in the future in New Orleans and in other parts of the nation that face similar threats.

The activities of the Task Force represent an unprecedented in-depth analysis to be accomplished in a very short time frame. The sense of urgency is to gain as much knowledge as possible to support the ongoing reconstruction of the hurricane protection system in New Orleans and vicinity prior to the coming hurricane season and to establish a foundation for alternative protection measures for the future. This effort is feasible only because of the unique integration of the capabilities and expertise of the entire Corps of Engineers team with those of a broad spectrum of experts from other government agencies, academia, and industry and the most advanced technical tools and methods. This includes the very special expertise represented by the American Society of Civil Engineers External Review Panel and the National Research Council New Orleans Regional Hurricane Protection Committee who are guiding and reviewing these efforts.

The findings of this effort will be continuously provided to the Corps of Engineers teams engaged in planning, designing, and constructing the protection measures in New Orleans and vicinity and will be distributed, as validated, to the public and other organizations involved in analysis and decision making concerning hurricane protection in New Orleans and elsewhere.

# Purpose

This report, Report 1 in a series, provides a strategic overview of the IPET, the final IPET Scopes of Work on a task-by-task basis, including changes resulting from the review of the External Review Panel, and a status report on the work accomplished to date. It also provides a synopsis of the information and products generated to date and their distribution to Task Force Guardian, the Corps of Engineers, other agencies and the public. A number of appendices are included to provide more detailed information in specific areas where it is deemed necessary for clarity or completeness.

# Part II. Strategic Overview

# Area of Interest

The IPET area of interest is shown in Figure 1. From a detailed analysis perspective it comprises the New Orleans metropolitan area and vicinity to include the areas protected by hurricane protection projects located in the Orleans, St. Bernard, St Charles, Jefferson, and Plaquemines East Parishes. Some of the analysis, specifically the storm surge and wave modeling and analysis, requires consideration of the bulk of the Gulf of Mexico because of the dependency of the processes on the time history of the character of the storm prior to landfall near New Orleans. A synopsis of the New Orleans and Southeast Louisiana Flood Protection systems is provided in Appendix A of this report.

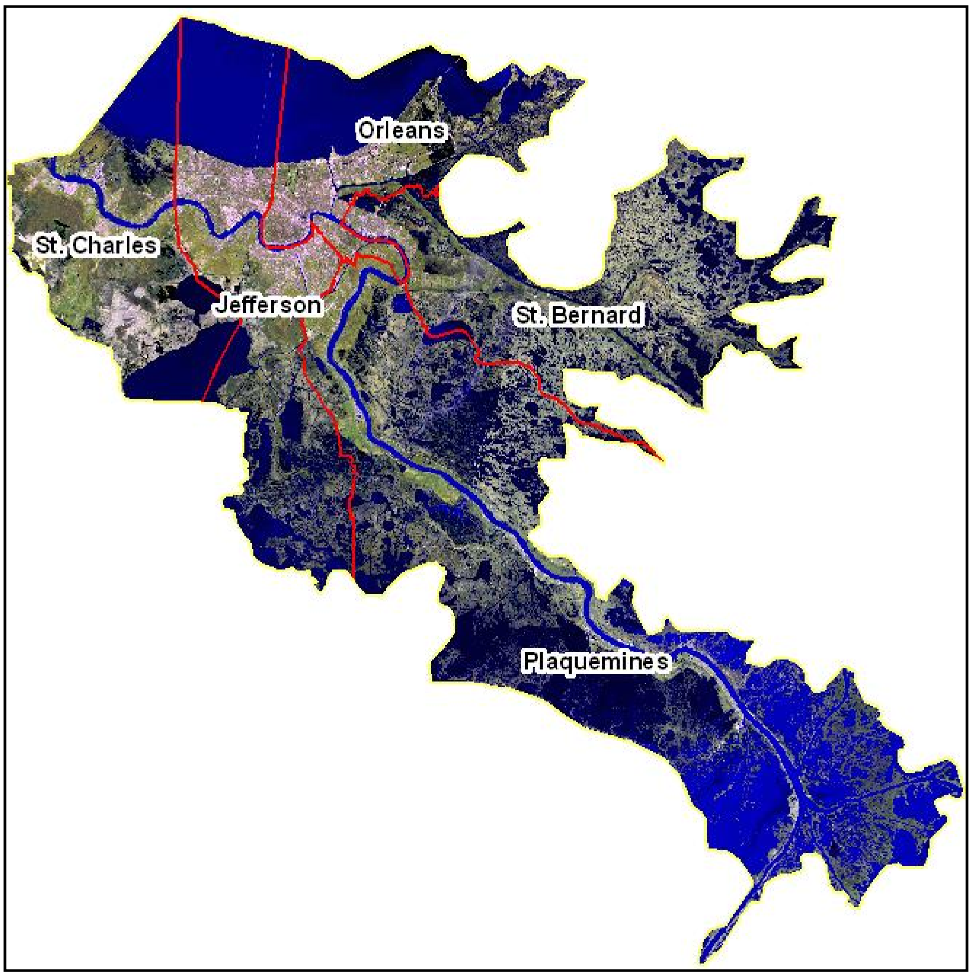



Figure 1. IPET principal area of analysis

# Objectives

The activities of the IPET are focused on answering the following strategic questions:

*a.* ***The Flood Protection System*****:** What were the design criteria for the pre-Katrina hurricane protection system, and did the design, as-built construction, and maintained condition meet these criteria?

(1) What were the design assumptions and as-built characteristics of the primary components of the flood protection system?

(2) What records of inspection and maintenance of original construction and post-Katrina repairs are available that documents their conditions?

(3) What subsurface exploration and geotechnical laboratory testing information was available as the basis of design, and were these conditions verified during construction?

(4) Were the subsurface conditions at the locations of levee failures unique, or are these same conditions found elsewhere?

*b.* ***The Storm*****:** What were the storm surges and waves used as the basis of design, and how do these compare to the storm surges and waves generated by Hurricane Katrina?

(1) What forces, as a function of location and time, were exerted against the hurricane protection system by Katrina?

*c.* ***The Performance*****:** How did the floodwalls, levees, pumping stations, and drainage canals, individually and acting as an integrated system, perform in response to Hurricane Katrina, and why?

(1) What were the primary failure mechanisms and factors leading to failure for those structures suffering catastrophic failure during the storm?

(2) What characteristics allowed components of the system to perform well under exceptional loads and forces?

(3) What was the contribution of the pumping stations and drainage system in the unwatering of flooded areas?

(4) What areas or components of the flood protection system have sustained damages that reduce their protection capacity and may need some reconstitution of capacity?

*d.* ***The Consequences*****:** What have been the societal-related consequences of the Katrina-related damage?

(1) How are local consequences related to the performance of individual components of the flood protection system?

(2) What would the consequences have been if the system would not have suffered catastrophic failure?

(3) What are the consequences of Katrina that extend beyond New Orleans and vicinity?

*e.* ***The Risk*****:** Following the immediate repairs, what will be the quantifiable risk to New Orleans and vicinity from future hurricanes and tropical storms?

(1) What was the risk to New Orleans and vicinity from hurricanes prior to Katrina?

(2) On June 1, 2006, what will be the condition and engineering integrity of the New Orleans hurricane protection system, including structural repairs?

In the process of answering these questions, it is the objective of the IPET to continuously provide insights and findings to Task Force Guardian to assist them in the most effective reconstitution of flood protection in the immediate repairs and rebuilding of the flood protection system and for the New Orleans District in the continued assessment and enhancement of the resilience of the system to withstand future storm forces.

# Organization

The IPET is comprised of experts from government (federal, state and local), industry and academia, working together as teams to accomplish a comprehensive analysis before the start of the next hurricane season. The work of the IPET is being accomplished as a number of interrelated tasks, each the focus of a team co-led by an expert from the Corps of Engineers and an expert from an external organization. The IPET is partnering with other organizations conducting related studies and analyses to maximize effectiveness within the short time frame of the study. The leaders and affiliations for the IPET and its principal teams are provided in Table 1.

The IPET teams are comprised of individuals from a wide variety of organizations, bringing together a unique diversity and depth of knowledge and experience. These organizations are listed in Tables 2 and 3.

**Table 1**
**IPET Organization and Leadership**

| **Task Force** | **Leader** |
|---|---|
| Project Director | Dr. Ed Link – U of Maryland |
| Technical Director | Dr. John Jaeger - CELRH |
| Project Manager | Jeremy Stevenson - CELRH |
| **Team** | **Leaders** |
| Data Collection and Management – Perishable Data, Systems Data, and Information Management | Dr. Reed Mosher – ERDC - GSL<br>Denise Martin – ERDC - ITL |
| Geodetic Vertical and Water Level Datum Assessment | Jim Garster – ERDC - TEC<br>Dave Zilkowski – NOAA/NGS |
| Hurricane Surge and Wave Analysis | Bruce Ebersole – ERDC - CHL<br>Dr. Joannes Westerink, U Notre Dame |
| Hydrodynamic Forces Analysis | Dr. Don Resio – ERDC – CHL<br>Dr. Bob Dean, U of Florida |
| Geotechnical Structure Performance Analysis | Dr. Mike Sharp – ERDC – GSL<br>Dr. Scott Steedman – Steedman Ltd, UK |
| Floodwall and Levee Performance Analysis | Dr. Reed Mosher – ERDC – GSL<br>Dr. Mike Duncan – Virginia Tech U |
| Pumping Station Performance Analysis | Brian Moentenich – CENWP-HDC<br>Bob Howard – South Florida WMD |
| Interior Drainage / Flooding Analysis | Jeff Harris – IWR – HEC<br>Steve Fitzgerald, Harris County FCD |
| Consequence Analysis | Dr. Dave Moser – IWR<br>Dr. Pat Canning – USDA/ERS |
| Risk and Reliability Analysis | Jerry Foster – HQ USACE<br>Bruce Muller – USBR |

**Table 2**
**IPET Government Participants**

**Federal Agencies**

- Corps of Engineers (Lead agency)
  - MVD/MVN/MVK/MVS
  - Task Force Guardian
  - Huntington District (Task Force Co-Lead)
  - Louisville District
  - Tulsa District
  - Jacksonville District
  - Portland District, Hydropower Design Center
  - Engineer Research and Development Center
  - Institute for Water Resources / HEC
- FEMA (Team member)
- NOAA
  - NGS (Team Co-lead)
  - CO-OP (Team Co-Lead)
  - NWS
  - HRD
- USBR (Team co-lead)
- USDA Economic Research Service (Team Co-lead)
- USGS (Team member)
- NIST

**State and Local Agencies**

- Louisiana DOT
- New Orleans Levee and Drainage Districts
- South Florida Water Management District (Team Co-Lead)
- Harris County Flood Control District, TX (Team Co-Lead)

**International**

- Japan
- Netherlands

**Table 3**
**IPET Non-government Participants**

**Academia**

- University of Maryland (Task Force Lead)
- Louisiana State University
- Jackson State University
- Utah State University
- Penn State University
- University of Florida (Team Co-Lead)
- University of Delaware
- University of North Carolina
- University of South Carolina
- University of Notre Dame (Team Co-Lead)
- University of Texas
- Stanford University
- Texas A&M University
- University of Wyoming
- Georgia Institute of Technology
- Massachusetts Institute of Technology
- Oklahoma State University
- Virginia Tech University (Team Co-Lead)
- Villanova University
- Rensselaer Polytechnic Institute
- Geo-Delft

**Industry**

- Steedman, Ltd., UK (Team Co-Lead)
- Ocean Weather, Inc.
- ARA, Inc.
- CH2M Hill
- URS
- RAC Engineering

In addition to the above organizations, international support is being received from the Netherlands GeoDelft Institute and the Government of Japan.

# Technical Approach

The basic approach of the IPET analysis is depicted in Figure 2. It approaches understanding of the performance of the flood protection system by examining the primary inputs, responses and outputs of the interaction of the hurricane and the flood control system. The inputs are the surge, waves and rainfall from the storm and the forces they created on the components of the flood control system. The response involves the behavior or performance of the structural components of the system, the performance of the components (primarily pumps and drainage canals) designed to un-water protected areas, and the degree of flooding in the protected areas due to failures or reduced performance by the components. Outputs are primarily the understanding of the performance in the context of principal failure mechanisms (as well as understanding marginal and exceptional performance), the consequences of the flooding due to component failures and the risk and reliability of the flood protection system (prior to and after repairs).

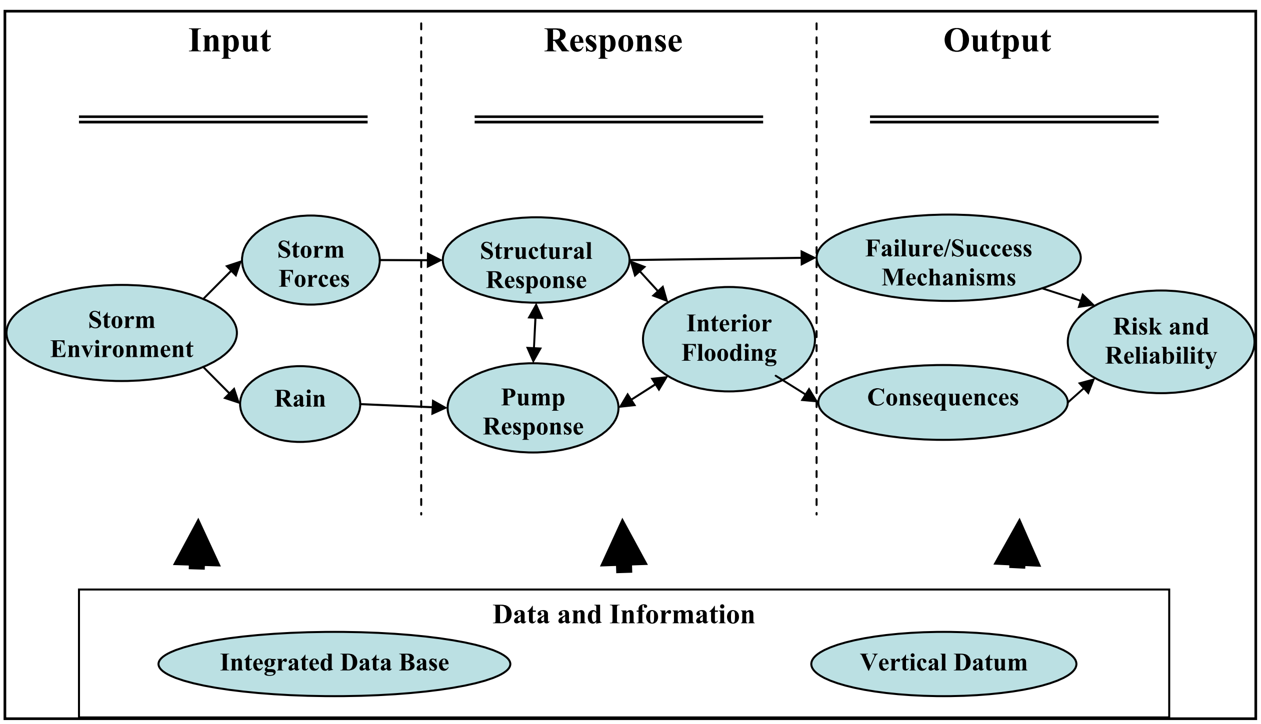



Figure 2. IPET systems approach

The IPET is using the most appropriate tools and available data to better understand what forces the storm placed on the New Orleans flood protection structures and why they performed as they did. These tools and how they are being applied are described in some detail in the individual scopes of work for the principal IPET Tasks described in a subsequent part of this report. Katrina and other relevant storms are being modeled to understand the magnitude and the variability of surge and wave conditions as a function of location and the storm character. This information, coupled with more detailed modeling for the confined spaces of the drainage canals and navigation channels and the physical evidence, allows determination of the magnitude and nature of the forces that individual structures experienced. The performance of the individual structures is being examined by first understanding their design and how they were intended to operate. Coupling this with how they were built and maintained allows application of physical and numerical models to examine their expected response to the storm generated forces. The most likely causes of failure and success will be determined, as well as gaining insights on how protection can be best reconstituted to be more resilient. While work will be ongoing in all tasks in parallel, there are critical junctures where the results will be integrated to meet our overall goal of completing the structural performance analysis by May 1, 2006, and the final report by June 1, 2006.

# Review

The review process is two-fold as depicted in Figure 3. Continuous detailed review is provided by the External Review Panel (ERP) under the auspices of the American Society of Civil Engineers (ASCE). Strategic oversight and synthesis of findings are provided by an independent panel, the New Orleans Regional Hurricane Protection Committee, under the auspices of the National Research Council (NRC). Both review entities will have broad participation by national and international experts from across government, academia and industry.

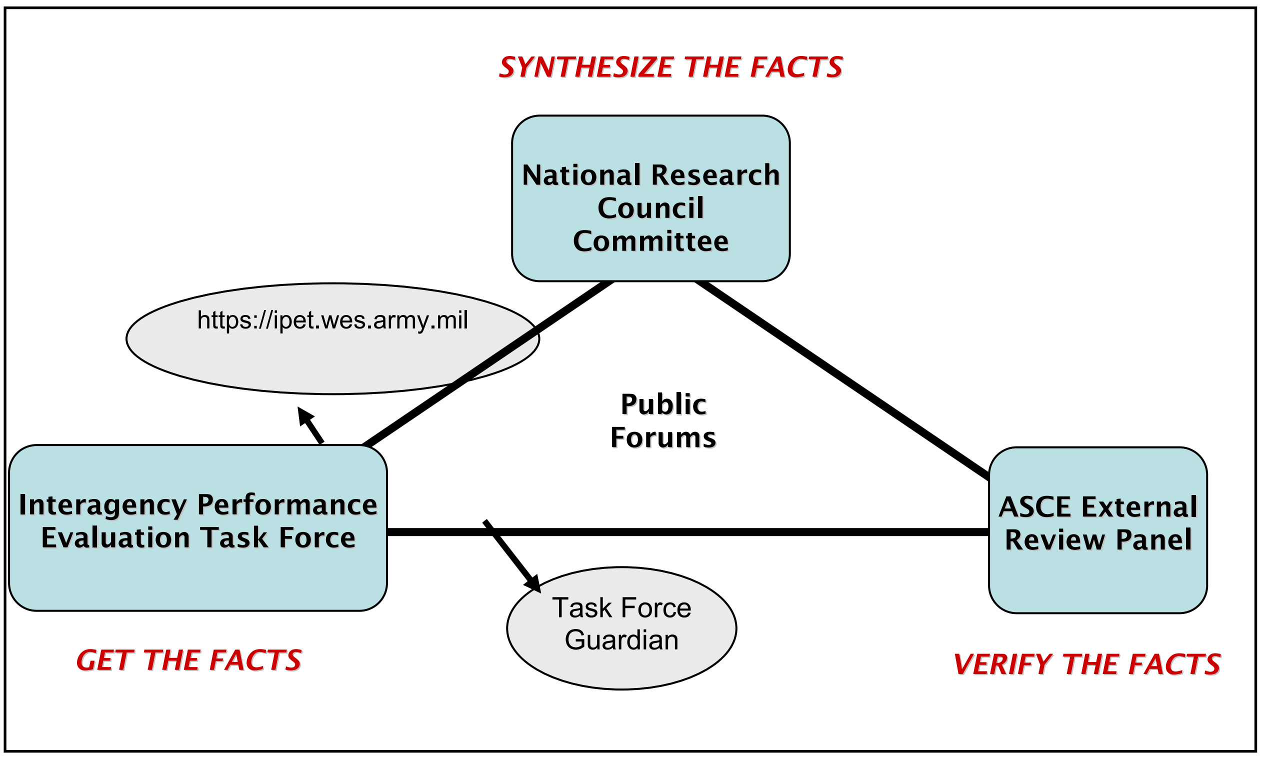



Figure 3. IPET review process and relationships

The ASCE ERP review is termed continuous because they are literally reviewing every major decision, assumption or analysis, providing cumulative credibility as the study progresses. The ERP has at least one expert assigned as the principal contact to each IPET team. The ERP also meets periodically to provide integrated reviews, notably at the 30 percent, 60 percent and 90 percent stages of the IPET activities as well as a review of the final report. The full scope of the IPET activities will be reviewed by the ERP, while the NRC Committee will review primarily the physical performance of the flood protection system. The NRC Committee will review IPET activities at the 30 and 60 percent levels as well as a final review of the Structural Performance Report scheduled to be completed by May 1, 2006. The NRC 30 percent level review will focus on the adequacy of the data collection and strategy for use of the data to answer the primary questions concerning physical performance concerning the flood protection system. The NRC 60 percent level review will examine the adequacy of the ongoing analysis for answering the principal structural performance questions. Members of the ASCE ERP are presented in Appendix B. The NRC Committee members are listed in Appendix C.

# Communications

A critical component of the IPET is communications — to the Task Force Guardian, to the Corps of Engineers and other agencies responsible for aspects of flood protection, to the organizations responsible for oversight, and to the public. A communication strategy, Appendix D, has been developed to guide these activities and to ensure that an orderly and efficient process is available to meet communications needs.

The IPET formal communications protocol with Task Force Guardian, the team that is accomplishing the immediate reconstruction efforts in New Orleans, is especially important in that it guides the continuous input of information and ideas from the IPET activities to the work of Task Force Guardian. In addition, 20 members of Task Force Guardian are participating in the IPET activities providing an embedded connection to both share information and transfer findings. This will include insights into structural performance issues as well as examining the risk and reliability of the flood protection and damage reduction system prior to and after Katrina. There will be an equally dedicated effort to publicly share the findings of the work of IPET as they are validated. A public website (*https://ipet.wes.army.mil*) has been established as a mechanism to share data, documents, analyses and findings with the public. A summary of the types and numbers of documents on the IPET website as of the end of December 2005 is provided in Appendix E. The products (insights and findings) provided to Task Force Guardian and Task Force Hope as of the end of December 2005 are listed in Appendix F.

# III. Scopes of Work

# Data Collection and Management

## Introduction

### Summary

This task, Data Collection and Management, involves the assembly of a comprehensive set of data and information on the hurricane protection and flood damage reduction system in the New Orleans metropolitan area. To provide a credible and objective scientific and engineering evaluation of the performance of the hurricane protection and flood damage reduction system in the New Orleans area, the IPET team must understand the pre-Katrina conditions of the system, the events that occurred during Katrina, and the effects of Katrina on the system. Thus, the data collected on the system in these three areas will form the basis for the IPET performance evaluation. The data collection was the first and most important task for IPET to get underway after the hurricane. The data collection plan has three components: perishable data, background data, and new data. Even before the IPET was fully formed, an initial team of engineers and scientists was deployed to the New Orleans area to identify and collect the critical data needed to accurately portray the performance of the system with a focus on capturing data that might otherwise be perishable.

Another team was deployed to collect background information on the terrain and geology of the area and the corresponding topographical and geological conditions along the system, hydrological conditions of the area, the subsystem configuration (basins), the history of the construction, design criteria and approach, actual design documents, the as-built drawings for the system, and the inspection and maintenance records. Data collection is a continuing activity with surveying to support the geodetic vertical datum assessment, the high water marks, and the elevations of specific system components, interviews to support creation of the flooding timeline, and cone penetration tests, soil borings and soil laboratory testing to support the structural performance evaluation. The system for storing the collected data will also serve as the repository for information and analytic results developed throughout the Performance Evaluation. A list of 104 data requirements was compiled based on input from each IPET Task Lead. Data requirements include perishable data, elevations, surveys, geographic information system (GIS) layers, historic data, pump station data, hydro data, field data, vertical datum information, timelines, photos, imagery, videos, environmental data, and model output data.

A USACE enterprise approach, based on existing corporate frameworks and standards, will be employed to manage the heterogeneous data required for this study. Metadata standards and naming conventions for all types of data will be developed to ensure the data are properly documented for use in this study as well as future studies. All data (District and project files) shall be geo-located (scanned if necessary). This will allow the data to be retrieved in three different manners:

*a.* All IPET members can access data via a web interface that allows users to browse an organized directory of documents, search for documents based on keywords, title, etc., and search for documents associated with a specific map location

*b.* GIS application developers can have direct access to the geospatial data to create specialized maps or analysis

*c.* Modelers or database administrators will have direct access to the data through Oracle to run models or generate reports.

A QA/QC group of subject manner experts has been established to authorize each data set that is stored in the repository. The data will reside in a common repository in a format suitable for archival and active use.

### Objective

The primary objective of the Data Collection and Management Task is to assemble a comprehensive set of data and information about the conditions before and after Hurricane Katrina as well as a complete history of the projects' construction and maintenance. This collection of data will serve as the primary information resource for the performance evaluation activities as well as the repository for analytic results developed throughout the performance evaluation.

## Scope of Work

### Team

The Data Collection and Management Team is led by Dr. Reed Mosher, USACE ERDC Geotechnical and Structures Laboratory, and Ms. Denise Martin, USACE ERDC Information Technology Laboratory. Dr. Mosher leads the perishable data collection portion of the task and Ms. Martin leads the system data collection and data management portion of the task. Data Collection and Management team members include:

- Harold Smith, ERDC-ITL
- Tom Rodehaver, ERDC-ITL
- Milton Richardson, ERDC-ITL
- Blaise Grden, ERDC-ITL
- David Stuart, ERDC-ITL
- Amanda Meadows, ERDC-ITL

- Greg Walker, ERDC-ITL
- David Moore, ERDC-ITL
- Dan MacDonald, ERDC-CRREL
- Tim Pangburn, ERDC-CRREL
- Jack Smith, MVD
- Rob Wallace, ERDC-CHL
- Don Stauble, ERDC-CHL
- Guillermo Riveros, ERDC-ITL
- Barb Comes, ERDC-ITL
- Paul Mlakar ERDC-GSL
- Maureen Corcoran, ERDC-GSL
- Eileen Glynn, ERDC-GSL
- Bob Larson, ERDC-GSL
- Joe Dunbar, ERDC-GSL
- George Sills, ERDC-GSL
- Steve Maynord, ERDC-CHL
- David Biedenharn, ERDC-CHL
- Gary Hawkins, MVN
- Ken Klaus, MVD

### Requirements

Data Collection and Management involves the assembly of a comprehensive set of data and information about the conditions before and after the storm as well as a complete history of the Hurricane Protection Projects' construction and maintenance. This collection of data will also serve as the repository for information and analytic results developed throughout the Performance Evaluation. A list of data requirements will be compiled based on input from each Task Lead. Data will include information about the conditions before and after the storm:

*a.* Original design documents

*b.* Construction and as-built record

*c.* Profile, topographic and section surveys

*d.* Inspection reports

*e.* Field investigations and inspections

*f.* Public interviews, forums or meetings

*g.* Levee design heights and latest survey data on actual levee heights

*h.* Levee properties including soil borings and test results near breaches and away from breaches. Photos and descriptions of exposed levee sections during excavations required for permanent repairs. Cross-sections of an area after levee repairs.

*i.* Aerial photography & videos

*j.* Data and analyses by other agencies or private firms

*k.* Surge heights, wind speed and direction, and waves (height, period and direction) time history with emphasis in the vicinity of the subject floodwalls and levees

*l.* All photos and videos of erosion patterns at/or near breaches and other areas. Measurement of erosion depth and breadth at a few locations. More photos and videos once the water is evacuated and we have access to the levee toes.

*m.* Wall deflections in areas with and without erosion behind the wall

*n.* Evidence of wall yielding in breached and other areas

*o.* Pump station layouts showing locations and elevations of all equipment which could become inoperable due to potential inundation, discharge pool locations, along with any optional discharge directions

*p.* Detailed list of which pumps and other equipment were operable or not, both before and after the storm

*q.* Design, as-built, and field-measured sheet-pile tip elevations on all I-walls

*r.* Pump curves for all pumps at all pumping stations

*s.* Pumping station operators (with skill levels) on duty during the storm

*t.* Hourly rainfall records during the event

*u.* Pool-to-pool heads during the event (i.e., suction water surface elevations, flood stage elevations for interior flood protection and discharge surface water elevations on a time unit basis)

*v.* Any other data and observations relevant to meeting IPET objectives.

There will be a Central Data Manager who has the lead responsibility for organizing and supporting this effort. All data shall be easily accessible to all members of the team.

## Approach

This Task will be accomplished by three coordinated teams: 1) Data Assembly and Coordination, 2) Data Storage and Management, and 3) Data Synthesis.

The objective of the Data Assembly and Coordination team is to identify and acquire the data required to support all IPET Tasks, as well as data that must be retained for future reference. These data include, but are not limited to, scanned Design Manuals, Inspection Reports, Plans and Specifications, computer-aided design and drafting (CADD) drawings, photographs, videos, geologic profiles, soil boring, seepage analysis reports, piezometer readings, levee profiles, pump station characteristics, wall deflections, topographic surveys, aerial photography, high water marks, surge heights, wind speed/direction, wave characteristics, time history of events, and briefing slides. A list of data requirements and associated data sources will be prepared based on input from each Task Leadership Team. Metadata standards and naming conventions for all types of data will be developed to ensure the data are properly documented for use in this study as well as future studies. A staging area will be set up for data collectors to upload data.

The objective of the Data Storage and Management team is to define and build the hardware and software framework required to store, organize, manage, and deliver the data associated with this study. A USACE enterprise approach, based on existing corporate frameworks and standards, will be employed to manage the heterogeneous data required for this study. Data sets will be stored and managed according to the component that best fits the type of data. For example, scanned documents will be stored and managed within the corporate framework for unstructured data, while GIS layers will be stored and managed within the corporate framework for geospatial data, and model data will be stored and managed within the appropriate corporate framework. An overall data manager will manage the metadata for all datasets. A web-based interface will be developed to support user access to the data. A QA/QC group of subject matter experts will be established to authorize each data set that is stored in the repository. See Appendix D for the QA/QC data process. The base data will reside in a common repository in a format suitable for archival and active use.

The objective of the Data Synthesis team is to develop mechanisms for adapting data to meet the needs of specific applications. The data stored and managed in this repository will be used by many different applications, including computational models, risk analyses, GIS analysis, etc. Each of these applications may require the data in a different format or representation. For example, elevation data is available from several different sources and must be processed into a common Digital Elevation Model (DEM) that will be the basis for all applications used in this study. The DEM and related surface and surface characterization data will support urban hydrology, levee related structural, geotechnical, and hydraulic analysis.

### Expected Products

The following list describes the expected deliverables of the Data Collection and Management Task:

*a.* The primary product of this Task is the IPET Data Repository, a data management system for storing, delivering, and maintaining the ‘official’ data associated with this study. The interface to this repository is a website.

*b.* Establishment of a Groove Virtual Office to facilitate virtual workspaces for team collaboration.

*c.* A public website that provides access to data that has been legally cleared for public access.

## Status

Task 1 accomplishments to date include:

*a.* A master list of data requirements has been compiled based on input from each Task lead. The list includes a description of the required data item, which Task(s) requested the data item, the source of the data and/or who is responsible for collecting it, the date the data item will be available in the Data Repository, and the dates that each Task needs the data item. This data requirements matrix is stored in the IPET-All Tasks Groove workspace in the Data Collection & Management folder as Data Requirements.xls. This matrix is provided in Appendix G, Data Repository – Organization and Content.

*b.* A public website was created on Nov. 2, 2005 at *https://ipet.wes.army.mil* (Figure 4). Documents are posted to the website daily with 236 documents currently posted. A standard protocol for posting documents was established in conjunction with ERDC, MVD, MVN, and USACE HQ Offices of Counsel. Metrics are collected daily on number of website hits. As of Dec. 23, 2005, the average daily number of hits was 99, while the average weekly number of hits was 635. More information on the public website is provided in Appendix E.

*c.* The IPET Data Repository (Figure 5) is comprised of three main components: an unstructured data component, a GIS data component, and a large datasets component. Unstructured data is stored in a Microsoft SQLServer database managed by Bentley ProjectWise software. GIS data is stored in an Oracle SDO database registered through ArcSDE. This component leverages the existing CorpsMap corporate database that resides in the USACE Central Processing Center. Large datasets, such as Lidar and imagery, are stored on a terabyte server, with metadata and geospatial extents of each dataset stored in an Oracle SDO database to provide search capability. The ProjectWise software provides the overall data management functionality by managing the metadata for all data sets. Currently, the IPET Data Repository is accessible by IPET members only via the website, *https://erdcpw.erdc.usace.army.mil/wel*. Access is controlled by the use of UPASS usernames and passwords for USACE members and by the use of system-managed usernames and passwords for non-USACE members. Currently, all IPET members (with the exception of one foreign national member) have been provided access to the Repository. A staging area was created within ProjectWise for specific users to upload data for QA/QC before publishing the data to the actual Repository. Users with upload permissions were provided the ProjectWise Explorer client (or stand-alone) application to more efficiently upload data sets. Standard metadata fields and file naming conventions were established to ensure all data are adequately documented and available for future use. The organization and content of the Data Repository is provided in Appendix G. As of Dec. 28, 2005, 930 documents have been published in the IPET Data Repository.

*d.* Five Groove Virtual Office workspaces have been set up for IPET:

(1) IPET – Management

(2) IPET – Communication

(3) IPET - All Tasks

(4) IPET - ASCE ERP

(5) IPET – NRC

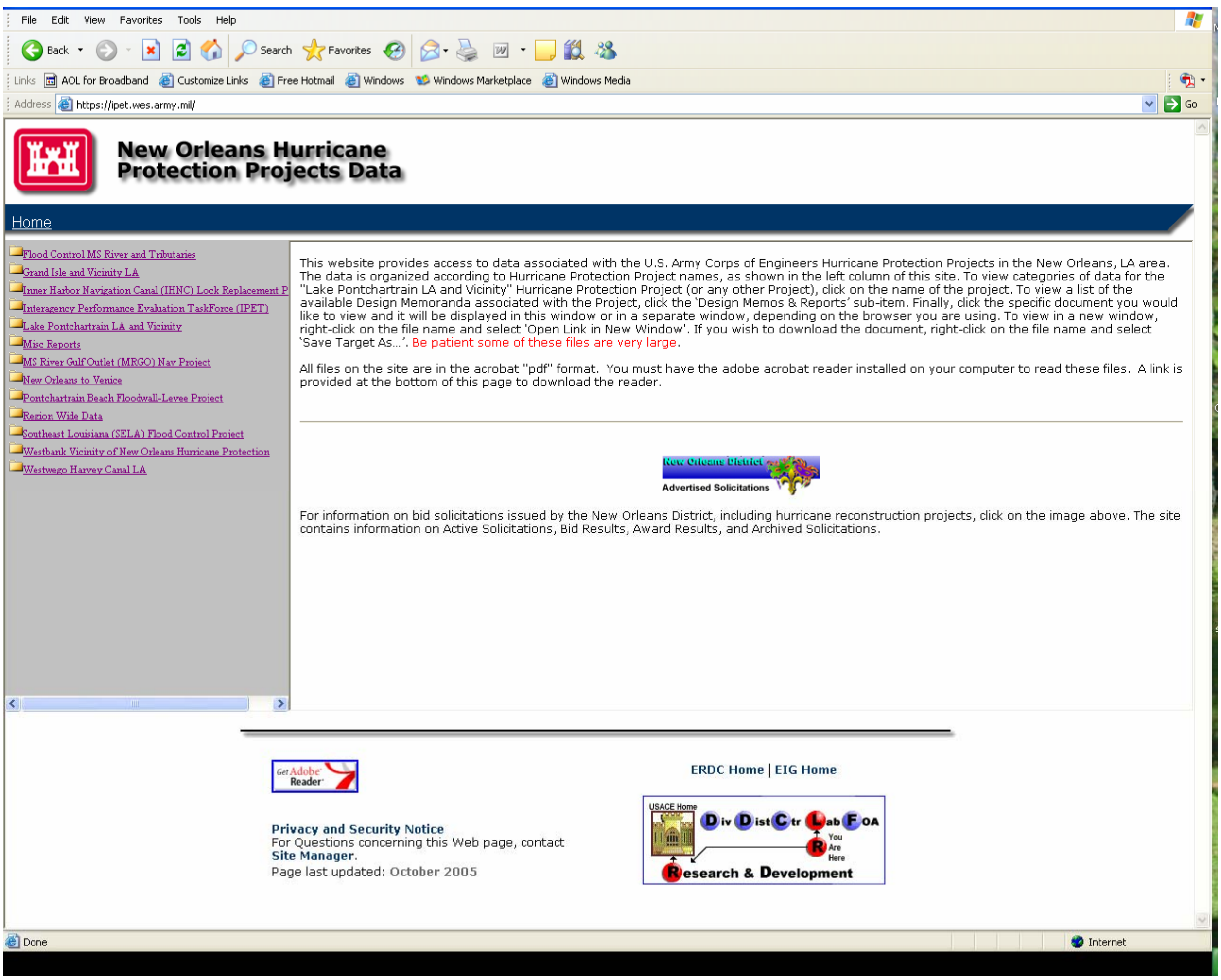



Figure 4. Screen capture of the IPET public website

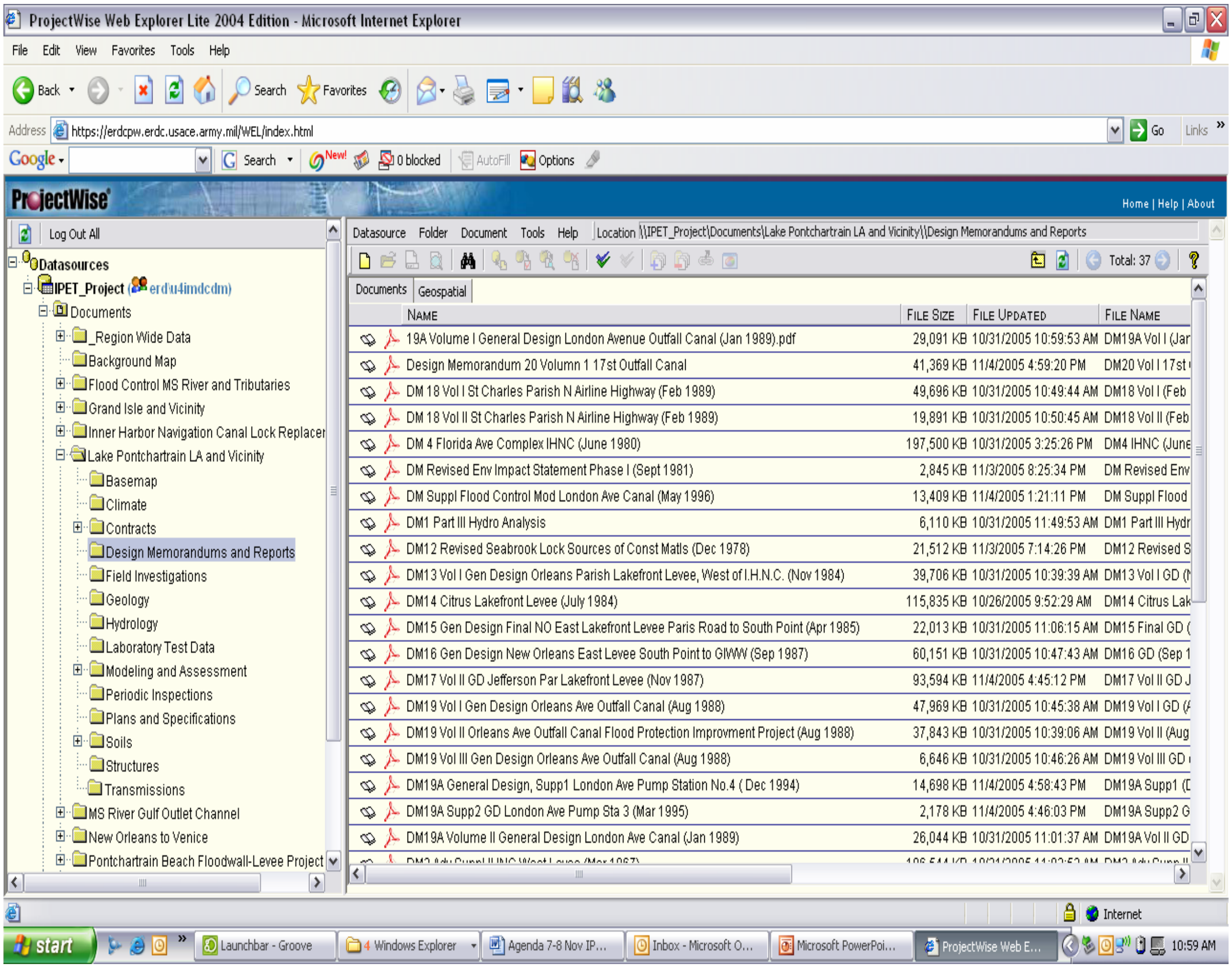


Figure 5. Screen capture of the IPET Data Repository

## The Way Ahead

The expected accomplishments for the 60% milestone are as follows:

*a.* Most of the data sets listed in the Data Requirements matrix will be stored in the IPET Data Repository.

*b.* The IPET public website will be populated with much more data.

*c.* The Groove workspaces will continue to be managed.

*d.* Users will be able to search for data more easily with expected improvements in the ProjectWise Explorer website.

# Geodetic Vertical and Water Level Datum Assessment

## Summary

The entire Gulf Coast region and especially southern Louisiana has been experiencing significant subsidence creating considerable uncertainty with regard to the precise elevations of flood protection structures and their relationship to the local water surface. Because the subsidence is spatially variable it is not easy to extrapolate to current elevations from the elevations determined in reference to past benchmarks with different reference datums or adjustments to the same datum. Establishing the capacity of the pre-Katrina and post-Katrina flood protection systems, as well as being able to understand how the flood protection system should have performed during Katrina, will require more observations to both densify and update the elevations to North American Vertical Datum of 1988 (NAVD 88) at the epoch 2004.65 or new epochs as changes in elevation occur.

## Objective

The objective is to improve upon the current vertical reference system (NAVD88 2004.65) for consistently evaluating previously constructed and proposed flood control and hurricane protection structures in New Orleans and Southeast Louisiana.

To ensure that the levee heights have remained relevant to sea level rise and local land subsidence in the greater New Orleans area, all elevations need to be measured relative to the latest NAVD 88 as determined by ongoing studies being conducted by CEMVN and NOAA. This should include sea levels, lake levels, river levels, projected protection levels, and the top of the levees and floodwalls. NOAA is progressing on an effort to update geodetic elevations in the entire Gulf Coast region and dramatic changes are being reported. The entire region is so dynamic that NOAA is no longer going to rely on the accuracy of local bench marks, but instead is using a combination of GPS and conventional leveling surveying techniques to measure elevations relative to stable areas that are hundreds of miles away. NOAA, in conjunction with the LSU Louisiana Spatial Reference Center, has also developed a new time-dependent vertical reference framework from which all measured elevations will have time stamps on them so the values could be adjusted on some regular interval.

# Scope of Work

## Approach

The primary focus of this task is to establish a consistent, vertical reference framework model to support IPET performance evaluation activities. This geodetic framework--currently NAVD88-2004.65--will allow long-term monitoring of absolute flood/hurricane protection elevations relative to the local water surface reference datum, e.g., local mean sea level, river low water reference planes, etc. Controlling elevations on floodwalls, levees, pump stations, and bridges through the Southeast Louisiana region will be surveyed relative to this framework. The framework will additionally provide a consistent reference system for numerical and physical model studies performed in the region. This Task will assess the impact of potential reduced flood/hurricane protection resulting from elevation changes (i.e., net land subsidence and sea level rise) throughout the region. Figure 6 shows an example of datum shift at the 17th Street Canal and the potential subsidence. The IPET will additionally evaluate and compare flood/hurricane structure protection elevations (and older reference datums) at the time of original design/construction with the current elevations (“pre-Katrina”). Quality control field checks on recent aerial and LIDAR mapping will also be performed.

All of this work will be accomplished in the field using water level gages, static GPS observations, and conventional topographic surveying methods. Archival data from the New Orleans District and NOAA (National Geodetic Survey (NGS) and Center for Operational Oceanographic Products and Services (CO-OPS)) will be used in these assessments.

## Team Members

Jim Garster, ERDC-TEC, Lead
Dave Zilkoski, NOAA-NGS, Co-Lead
Bill Bergen, USACE-HQ, Co-Lead
Mike Szabados, NOAA CO-OPS, Co-Lead
Jerry Hovis, NOAA CO-OPS
Tom Landon, NOAA CO-OPS
Ronnie Taylor, NOAA NGS
Brian Shannon, ERDC-TEC
Jeff Navaille, USACE SAJ
Mark Huber, USACE MVN
Bob Mekso, USACE MVS

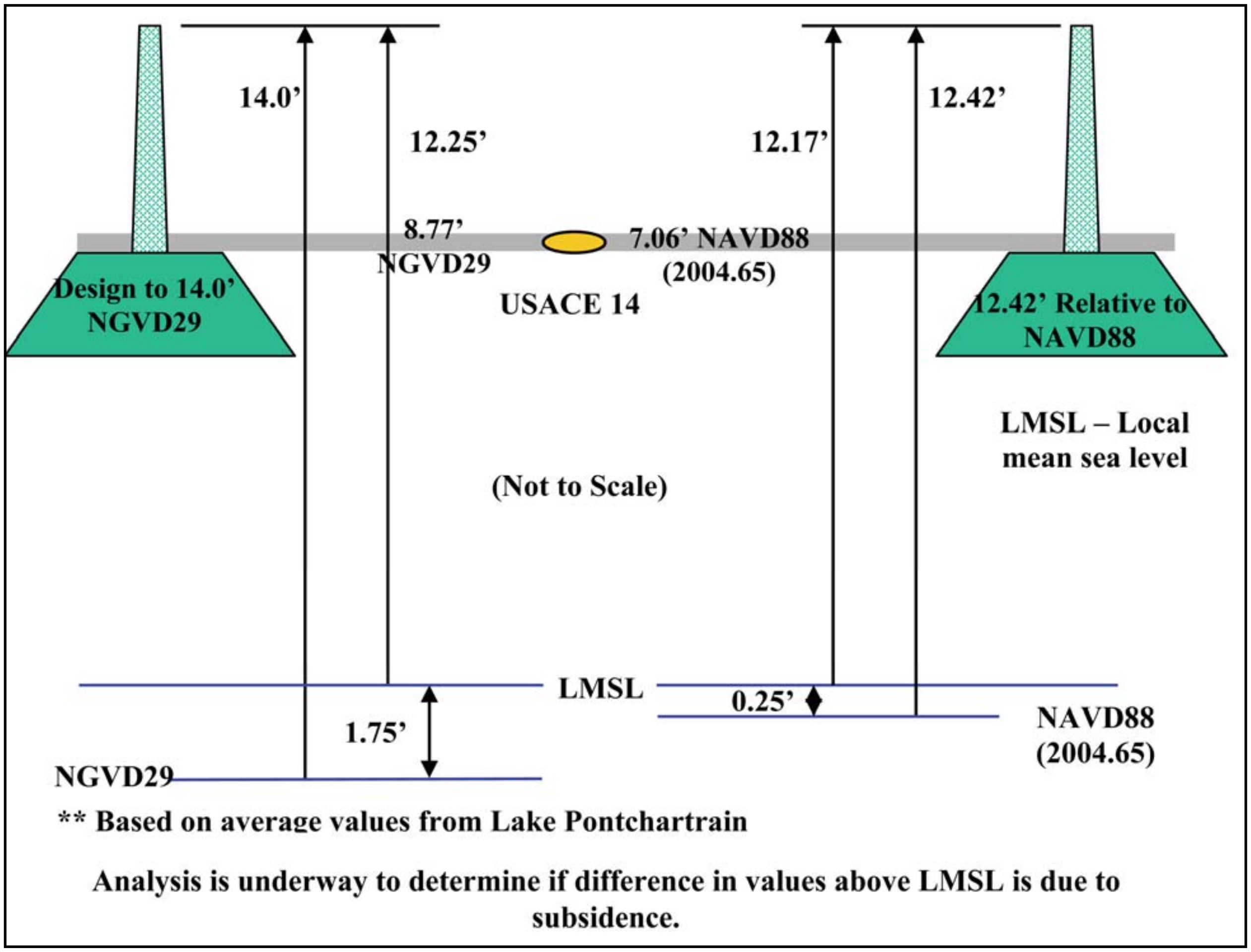



Figure 6. Example datum shift at the 17th Street Canal

## Status

### Completed Milestones

a. *Data Collection Plan.* Prior to field data collection, a detailed data collection plan was developed which outlined the surveying and data collection requirements to accomplish the above objective. The plan called for 3 phases of surveying data collection:

(1) Phase 1: Tidal model connections to the NAVD88 (VTDP 2004) reference
- Phase 1a: Northern Zone (New Orleans to Mississippi area)
- Phase 1b: Southern Zone (lower Miss River & vicinity area)

(2) Phase 2: Supplemental GPS elevation control adjacent to FC & HP structures, pump stations, etc.

(3) Phase 3: Vertical control surveys of designated FC & HP structures and topographic survey support to other IPET Teams ... bridge surveys, pump station surveys, LIDAR mapping ground truth, etc.

This plan included development of two Statements of Work for task orders to accomplish the field data collection. This milestone was completed on 5 Dec.

b. *Relationship between Local Mean Sea Level (LMSL) and NAVD 88 (2004.65) 30% Solution.* Based on an analysis of NAVD 88 (2004.65) benchmark elevations relative to historical tidal datums at three tidal stations, NOAA CO-OPS computed a preliminary relationship between the LMSL and the NAVD88 (2004.65) values. More information on this relationship is contained in Appendix I.

### Current Milestones in Progress

a. *New Field Data Collection: Phase 1 and Phase 2.* New Field data collection began on 5 Dec and is currently expected to continue until the end of Jan 2006. As of 9 Jan:

   (1) Reconnaissance surveys have been performed for 75% of the static surveys that will tie NAVD 88 (2004.65)

   (2) 100% of the 68 pump stations have been surveyed

   (3) 100% of the High Water mark surveys have been completed

   (4) 40% of the Bridge surveys have been completed

   (5) 100% of the Phase 1a data collection has been completed

b. *Relationship between Local Mean Sea Level (LMSL) and NAVD 88 (2004.65) 60% Solution.* This milestone is expected to be completed by 20 Jan 06.

### Near Future Milestones

a. *Data Processing of Phase 1 Survey Data.* This will involve GPS data processing and network adjustments by USACE and NOAA NGS personnel and result in “Blue Booking” or publishing the result to NGS standards.

b. *Data Analysis of Phase 1 Survey Data and Ties to Historical Records.* This will involve review and analysis of historical datums and relationships between the various datums used over the years in the southern Louisiana area. Based on additional NAVD 88 (2004.65) ties to NOA Tidal Benchmarks, further analysis of NAVD88 (2004.65) to historical tide stations and LMSL can be completed.

c. *Historical Evaluation of Designed and Constructed Elevations on Various Flood Control and Hurricane Protection Projects.* This will provide the changes over time of the benchmarks used in the design and constriction of flood control and hurricane protection projects in the study area.

# Storm Surge and Wave Analysis

## Hurricane Katrina Storm Surge & Waves (Regional Perspective)

### Summary

To conduct the performance evaluation, information is needed concerning the storm surge and wave conditions to which the hurricane and flood protection projects in New Orleans and southeastern Louisiana were subjected. This task will primarily involve a regional hindcast of water level and wave conditions for Hurricane Katrina, but it also will involve analysis of measured data. Coastal wave and storm surge models will be developed and applied to predict time-varying water levels and wave conditions (heights, periods, directions, energy spectra) along levees fronting the various parishes, within main navigation channels, and at the entrances to canals situated along the southern Lake Pontchartrain shoreline. Maximum wave and water level conditions throughout the study domain also will be computed for Katrina. Measured water level and wave conditions (high water marks and hydrographs) are only available at a few locations, and most measurement devices failed during the peak of the storm. Measurements and model results are complementary. Measurements will be used to assess the uncertainty in model results, and they will be used to assess the adequacy of using model results in the majority of areas where measurements were not made or where gauges failed to capture the maximum conditions.

Results generated by this Task will be compared to the wave and water level conditions used in the original design of the projects being examined. Results from this Task also will serve as input to a number of the other IPET tasks that will: 1) examine and quantify interior flooding, 2) quantify hydrodynamic loadings on levees where breaches occurred, and 3) assess levee overtopping. This Task will also characterize the regional wave and water level conditions that are possible for other storms (actual historical and hypothetical storms). This information will help assess the susceptibility of the projects, as currently designed, to overtopping and flooding in the future; and it will enable examination of Hurricane Katrina wave and water level conditions within the context of what has occurred in the past and what might occur in the future.

A phased approach will be adopted, providing information early in the study process then refining that information as time goes on. Solutions representing the following levels of comprehensiveness, 75%, 90%, and 95% will be generated as

new and better information on winds, water levels, topography, and structure/ levee crest elevations becomes available during the course of the work. An increasingly more rigorous modeling approach will adopted during the evolution from the 75% solution to the 95% solution. The 75% solution will focus on state-of-the-engineering practice approach to modeling storm surge and waves (without consideration of contributions of waves to storm surge). The 95% solution will involve more rigorous treatment of the interaction between storm surge and waves.

The surge and wave information generated by this effort will be coordinated with appropriate authorities in the Corps, NOAA, FEMA, USGS, and USBR to achieve a consensus among federal agencies on water elevations. These same agencies will also collaborate to determine the frequency of occurrence related to elevations and conditions.

### Objectives

*a.* Develop best estimates of temporal variation of water level and wave conditions (height, period, direction, energy spectra) during Hurricane Katrina at entrances to canals along the Lake Pontchartrain south shoreline, in the Inner Harbor Navigation Canal, Mississippi River Gulf Outlet, in the MS River, and the exposed sides of levees that are part of the various flood and Hurricane Protection Projects (HPP), in the allotted time.

*b.* Provide preliminary information to characterize the level of vulnerability (risk) of the projects within the study domain to hurricane water levels and wave conditions.

## Scope

The scope for each of five subtasks is provided below. The five subtasks are: (1) hydrograph and high water mark analysis, (2) generation of wind and atmospheric pressure fields (used to drive the storm surge and wave modeling), (3) offshore wave modeling at the Gulf of Mexico and regional scales as well as local wave modeling in the vicinity of the projects, (4) regional storm surge modeling covering both the Gulf and local scales, and (5) simulation of historical and hypothetical storms to assess susceptibility of the current projects to future hurricane wave and water level conditions.

The local modeling domain encompasses existing hurricane and flood protection projects in the New Orleans and Southeast Louisiana area. Projects are: Lake Pontchartrain, LA, and Vicinity Hurricane Protection Project (HPP), the New Orleans to Venice, LA, HPP; the West Bank and Vicinity, New Orleans, LA, HPP; and the Grand Isle and Vicinity LA, HPP.

### Products

*a.* Time series of water level and wave conditions for Katrina at points of interest for 75%, 90%, and 95% solutions.

*b.* QA'd and QC'd measured data sets used in the analysis, model development and model skill assessment (high water marks, water surface elevation, wave, wind, atmospheric pressure).

*c.* Report chapters for each sub-task that document methods and results.

*d.* Model input data sets, and other model-generated products (maximum water level and wave fields, animations of water level and wave heights) using the 95% solution method.

A number of data products from the IPET data collection task are required as input for this work, such as topography, levee elevations, high water marks, and hydrographs, as well as datum and datum conversions/corrections from the IPET datums task. The wave and surge task will also generate data products during the course of its work (both measured data products such as wind or wave data, and model-generated products such as time series of water levels and wave conditions) for use by other Task teams. At the conclusion of the work (the 95% solution), these data products will be made available to the public through the IPET public website (*https://IPET.wes.army.mil*).

### Team Leaders

Bruce Ebersole, ERDC-CHL, and Dr. Joannes Westerink, University of Notre Dame.

### Schedule/Milestones

Nov 18 – Delivery of winds and pressures using real-time H*Wind fields
Dec 9 – Complete initial assessment of high water marks, water level and wave data
Dec 16 – 75% solution on Katrina waves and water levels
Jan 13 – 90% solution on Katrina waves and water levels (with coupling)
Jan 16 – Delivery of winds and pressures using post-processed H*Wind fields (for 95% solution)
Feb 10 – 95% solution on Katrina waves and water levels
Mar 31 – completion of waves and water level risk assessment for all projects using 95% solution methodology/models
Apr 10 – Delivery of all products

The 30%, 60%, and 90% ERP touch points will involve review of the 75%, 90%, and 95% solutions, respectively. A detailed report on the surge and wave modeling work to date will be provided as a separate report to Task Force Guardian and the ERP. Other information developed for the other tasks (data and graphical products) also will be provided to the ERP. Delivery of this evolving summary report, the technical appendix, and information products to the ERP will lag the above milestone dates by approximately two to three weeks.

### *Hydrograph and High Water Mark Analysis*

#### Team

Andrew Garcia, ERDC CHL, lead, Phil Turnipseed, USGS, Stephen Maynord, ERDC, CHL, Brian Jarvinen (retired NOAA).

#### Approach

The group will aid in assembling available high water mark data that were acquired by FEMA, USGS, USACE, Louisiana State University and any other organization that acquired this type of data. Several members of this team participated in the actual collection of high water mark data (work funded by Task 1). High water marks will be examined and the quality of each high water mark will be assessed for use in surge and wave model skill assessment and in developing information products produced by this task. Each high water mark will be rated in terms of quality/uncertainty, and wave and water level processes reflected in each high quality mark will be identified. The group will also analyze and evaluate available measured water surface elevation hydrographs provided by NOAA, USACE and any other sources. These data will be critical in assessing model accuracy, and in establishing confidence in model-derived results and model-generated information products.

### *Generation of Winds and Atmospheric Pressures*

#### Team

Jeff Hanson, ERDC-CHL, lead (with Robert Jensen, ERDC-CHL), Oceanweather, Inc. (OWI) (Vince Cardone and Andrew Cox), NOAA Hurricane Research Division (HRD) (Mark Powell), Joannes Westerink, University of Notre Dame.

#### Approach

This task will produce the best possible wind and atmospheric pressure fields for Katrina utilizing models such as the Planetary Boundary Layer (PBL) model and measured wind and pressure data. Wind and pressure fields are crucial input to wave and storm surge models. Accuracy of wave and surge estimates is only as good as the accuracy of the winds in particular, and pressures to a lesser degree. Note that there is a cubic dependence between surge and wind speed for winds less than 60 knots and a quadratic relationship for winds greater than 60 knots – assuming a drag coefficient cut-off which recent research suggests might be appropriate.

Due to the urgent nature of this work and the desire to produce information in stages, both preliminary and finals set of wind/pressure fields will be developed. To develop the preliminary winds, Hurricane Katrina winds/pressures will be generated using HRD H*Wind snapshot analyses that HRD developed in real-time during the course of executing their forecast mission for the storm. For the final winds, a series of gridded wind field "snapshot" analyses will be constructed for Hurricane Katrina during the period of 26-29 August, at 3-hr intervals. Analyses will use all available data gathered during and after the storm to produce a comprehensive depiction of the wind field at the ocean surface for an area encompassing the entire modeled domain. Marine gridded fields will be produced. This work includes the following subtasks:

*a.* Storm track refinement: All aircraft wind center fixes will be evaluated in H*Wind. Land based WSR-88D Doppler radar velocity circulation centers and geometric reflectivity centers will also be evaluated to construct a storm track at 1-hr frequency.

*b.* SFMR Update: The Stepped Frequency Microwave Radiometer (SFMR) measurements will be updated with the latest calibration information based on detailed comparisons to GPS sondes.

*c.* Reduction method update: SFMR data from 1998-2005 will be reprocessed with the latest calibration to revise the SFMR-based method for adjusting Air Force Reconnaissance flight-level wind measurements to the ocean surface (10 m).

*d.* Airborne Doppler radar analyses will be conducted for NOAA research flights on 27, 28, and 29 August. Doppler data from 500 m will be adjusted to the surface with the HRD PBL model. Land-based Doppler Velocity Azimuth Display (VAD) and Ground-based Velocity Track Display (GBVTD) techniques will be evaluated and incorporated if possible.

*e.* Land and marine mesonet data will be compiled and wind exposures and metadata will be gathered using aerial images and remote sensing sources. All observations will be processed to standard marine and open terrain frameworks.

*f.* Gust factor relationships will be provided for 1-, 10-, and 30-min averaging time periods for marine and open terrain fetches.

*g.* All observations will undergo detailed quality control by hurricane research meteorologists using H*Wind. All failed observations will be flagged and removed from consideration for each analysis. Four- to six-hour overlapping time windows will be used to ensure sufficient data coverage for analysis while minimizing the effects due to intensity changes.

*h.* A series of H*Wind analyses will be conducted on the above mentioned data at 3-hr intervals. Marine gridded fields will be produced.

For both the preliminary and final results, OWI will be responsible for incorporating the H*Wind snapshots into its IOKA (Interactive Objective Kinematic Analysis) system, which blend in far-field winds, to develop basin- and regional-scale wind/pressure fields for application in the surge and wave modeling. The basin scale winds will be 0.1-degree resolution (~10km) on the domain 18N to 30.8N, 98W to 80W for the entire time Katrina is present on the grid. Snapshot time intervals will be 30 min. The regional-scale grid will be .025 degree (~2km) on the domain 28.5N to 30.8N, 91W to 88W with 15-min time interval. All winds will be 30-min average, 10-m neutral marine exposure; all pressures will be at sea level in OWI's standard WIN/PRE format. The preliminary winds and pressures will be used for the 75% and possibly the 90% solutions; the final winds and pressures will be used in the 95% solution.

A PBL model will be used to generate winds and pressures for approximately five or six of the most significant historical hurricanes that have influenced the study domain and for approximately 20 hypothetical events that will primarily involve different tracks of historical storms, including Katrina. These PBL-generated winds and pressures will be used to drive wave and storm surge models (using at least the 90% solution modeling methodology that will involve some wave-surge model coupling), and the resulting wave and water level conditions will be used to assess vulnerability of the flood and HPPs to future extreme wave and water level conditions. For this wave and surge modeling, post-Katrina topography and the current grid mesh will be used in all simulations.

## *Wave Modeling*

### Team

Jane Smith, ERDC-CHL, lead, with Robert Jensen and Jeff Hanson, ERDC-CHL, Hendrik Tolman, NOAA, and Don Resio, ERDC-CHL.

### Approach

The task will involve running a time-dependent Gulf-of-Mexico-scale wave prediction model on basin and regional scales to provide boundary conditions to shallow water wave models of the entire southern and southeastern Louisiana coastal domains, including Lake Pontchartrain, and the Mississippi coast. The focus will be on using Corps of Engineers modeling technology which has been extensively validated and tested, and for which linkage between wave and surge models has been done to a degree already. In light of the limited amount of time, the large domain to be modeled in detail, the fact that this IPET task is on the critical path and on the front end of the performance evaluation schedule, and a desire to examine the critical linkage between short waves and storm surge, emphasis is being placed on wave and surge model technologies most familiar to the Corps of Engineers. As the study progresses, wave modeling technology used by NOAA and other agencies will also be applied to help quantify uncertainty in model results and gain confidence in model computations.

As part of a National Ocean Partnership Program (NOPP) R&D project, a basin-scale wave model (using the WAM model) had been developed for the entire Gulf of Mexico. The WAM model has been used in an experimental forecast model for the past two hurricane seasons, and calibrated to maximize agreement between model predictions and measured wave data for Gulf hurricanes that have occurred during that time. This basin-scale wave model will be forced with the basin-scale winds produced by OWI (which include NOAA HRD H*Wind products). A second nest of the WAM model will be set up. The inner nest will correspond to the domain of the regional-scale winds being produced by OWI. The domain and resolution specifics are defined above in the wind subtask description. In addition to running the WAM model, NOAA NCEP's WaveWatch III model (as it is presently set up in forecast model for the Gulf of Mexico) will be applied on the same two domains as the WAM model, forced with the same wind inputs from OWI. The WAM model will be used to provide information for the 75%, 90%, and 95% solutions. The WaveWatch III model also will be utilized for the 95% solution. These deep-to-intermediate water depth models will provide the boundary conditions to even higher resolution shallow water wave models of Lake Pontchartrain, the southern and southeastern Louisiana and the Mississippi coasts. The MS domain is needed to maintain consistency and continuity in wave fields and avoid discontinuities in the iterative process to couple wave and surge models as well as to generate wave set up on the Mississippi shelf which interacts with Lakes Borgne and Pontchartrain.

WAM and WaveWatch III predictions will be compared to available wave measurements from NDBC buoys, proprietary data from oil platforms (if they can be acquired), and satellite altimetry data. NOAA staff will obtain NRL quality-controlled altimetry data, and unpack, reformat, and apply tri-linear interpolation (in space and time) of model data along the altimeter track. Comparisons will be made using model-generated hourly or half-hourly significant wave height spatial grids. NOAA will provide CHL with NCEP's altimetry assessment technology including data reformatter, tri-linear interpolation tools, and graphical data/model overlay tools. This work will require the development of a custom WAM interface to the altimetry data tools. Tests will be done to examine sensitivity of wave model predictions to wind drag coefficient cut-off and choice of wind time-averaging interval. Hurricane Katrina will be simulated, as will the set of historical and hypothetical storms.

Resolution of the regional wave model is not adequate for generating information where it is needed for each of the flood and HPPs. Higher resolution models of the near-coastal region (50- to 100-m resolution) will utilize the STWAVE model to simulate local wave transformation right up to the hurricane and flood protection projects of interest for the 75%, 90%, and 95% solutions. STWAVE, a full-plane, time-independent wave, will be set up for the four domains, and run either in half-plane or full-plane model, as necessary. The model will treat the processes of refraction, sheltering and diffraction, wave growth, wave breaking and dissipation due to bottom frictional effects. The

STWAVE model is a Corps model, and we have considerable experience with its theoretical underpinnings and its application.

Adequacy of a time-independent model for simulating the final stage of nearshore wave transformation will be examined and evaluated during the development of the 95% solution. Presently, the working hypothesis is that wave conditions in the nearshore local domains will be very much controlled by depth effects (wave breaking and refraction) and that the time-independence of STWAVE will not be much of a factor on the accuracy of wave predictions (it is expected to slightly overestimate wave conditions due to the steady-state assumption). This hypothesis will be evaluated using comparisons of model results to measured data where possible, analysis of wave travel time in light of changing wind conditions, and examination of the importance of depth-limitations on the computed wave field. The STWAVE model will use input boundary conditions from the time-dependent WAM model, and wind input will be varied with time at fairly fine temporal resolution (30-min intervals). To also examine the adequacy of the time-independent assumptions of STWAVE, limited applications of a time-dependent model, SWAN, are planned during the course of arriving at the 95% solution, for one or two of the four local model domains (starting with Lake Pontchartrain domain, for which only shallow water wave data exist, and then possibly the southeastern Louisiana domain).

Since SWAN is not a model that is supported by the Corps of Engineers, we have less familiarity with its theoretical underpinnings. The implications, in terms of resources and impact on schedule, associated with its application for an intense hurricane, applying it at 50- to 200-m resolution over complex topography and a very large coastal wetland domain (the four domains cover nearly the whole Louisiana/Mississippi coast), and no experience linking it to the ADCIRC storm surge model with feedback, are unknown. Based on our limited experience with SWAN, it will require significant computer resources to apply it at this resolution and for this large of a domain. We will pursue the possibility of collaborative work with the Naval Research Laboratory, whose staff have more experience applying SWAN and linking SWAN with ADCIRC. We have applied SWAN to half-plane cases, with smaller domains where propagation dominated local wave growth, and have found STWAVE and SWAN to give very similar answers for non-hurricane wave conditions, with STWAVE being much faster computationally. Accuracy of both shallow water wave models will be evaluated with measured wave data where data exist. We believe the STWAVE model to be fully adequate for developing the 90% and 95% solutions sought in this fast-track IPET study.

Work will be done to examine varying degrees of coupling between wave (STWAVE) and surge (ADCIRC) models to maximize accuracy of water level predictions. Wave set-up is an important component of the storm surge. Coupling will involve passing water depths from ADCIRC (which includes wind, tide and atmospheric pressure generated water level changes) to STWAVE, radiation stress gradients from STWAVE to ADCIRC, and possibly iteration on this feedback loop. Tests will be run to examine sensitivity of wave model results to bottom frictional resistance, wind drag coefficient cut-off at higher wind speeds (which recent evidence suggests) and choice of time-averaging interval for the winds. Hurricane Katrina will be simulated, as will a set of historical and hypothetical storms.

### *Storm Surge Modeling*

#### Team

Joannes Westerink, University of Notre Dame, lead, with Mary Cialone, ERDC-CHL, and Raymond Chapman, ERDC-CHL.

#### Approach

This task will begin its work using the existing ADCIRC model set-up developed by University of Notre Dame for the New Orleans District. For the 75% and possibly the 90% solutions, ADCIRC simulations will utilize hindcasts of Hurricane Katrina winds and atmospheric pressures using either a PBL model or H*Wind-based wind fields and pressure fields from OWI (the preliminary fields). The PBL model will be run with observed maximum winds speeds and pressures from NOAA – NWS. Both sets of wind fields from HRD/OWI will not include land masking. Masking will be implemented in a directional sense within ADCIRC using roughness estimates based on USGS land usage maps. Both sets of wind fields will be applied at 15-min intervals to avoid aliasing of wind energy, for this relatively fast moving storm, within ADCIRC's Eulerian wind field interpolator. The H*Wind fields will be interpolated to the necessary 15-min intervals using a Lagrangian-based interpolator.

In addition, STWAVE-based wave radiation stress gradient snapshots will be applied in critical regions including Lake Pontchartrain, regions to the east of New Orleans and east and west of the Mississippi River and along the Mississippi and Alabama coasts. The STWAVE simulations will be done at CHL in cooperation with the Notre Dame team. For the 75% and 90% solutions, the STWAVE coupling will be one-way (ADCIRC to STWAVE for the 75% solution, and then also include STWAVE to ADCIRC coupling for the 90% and 95% solutions). Initially, the STWAVE wave radiation stress gradient fields will be calculated using ADCIRC surge fields from preliminary ADCIRC simulations which do not include the wave radiation stress fields. Thus the coupling will be quasi two-way. Most of the wave-surge interaction will be captured with this coupling, but iterative coupling will be examined if time allows. Wave radiation stress gradients in deeper waters will be obtained from the WAM model and will provide additional forcing to ADCIRC. Momentum transfer due to whitecapping will be examined.

Astronomical tides and river flows will also be included in the ADCIRC simulations. A modified version of the S08 Southern Louisiana grid will be the starting point used in the initial work. Simulation results will be compared to high water marks and available measured water surface elevation hydrographs. Sensitivity tests will be performed to examine impact of input data uncertainties and modeling assumptions. Tests will examine sensitivity of surge model results to wind drag coefficient cut-off and choice of wind time-averaging interval, bottom frictional resistance of the marsh (using pre- and post-storm marsh conditions), and condition of the barrier islands off the coast of eastern Louisiana and Mississippi.

Breaching will only be simulated in the ADCIRC storm surge model to the degree that the pre-storm levee elevations are overtopping by the surge. In that case, water is allowed to flow over the levee. However, no dynamic breaching, where the breach changes dimensions during the storm, is simulated. Interior flooding is being modeled in other IPET Tasks, and this Task is providing boundary conditions to that work.

For the 95% solution, a higher resolution Southern Louisiana grid mesh will be used, which is LIDAR based and has significantly more detail in eastern Louisiana, the S14 grid. The model will incorporate the best topographic and levee/structure elevation data that are being made available in the IPET project (Task 1 with datum corrections provided by Task 6). S14 also currently includes the Mississippi and Alabama coastlines in detail with the adjacent floodplains. Necessary additional detail will be added to the S14 grid in and around New Orleans. ADCIRC-STWAVE coupling will be improved to be truly two–way dynamic within a high performance shell. A subset of sensitivity tests will be done using the 95% solution methodology

The modeling approach adopted for the 90% or 95% solution will be used to simulate the historic and hypothetical hurricanes for input to the vulnerability assessment subtask. A post-Katrina topography/levee/structure condition that reflects current project conditions will be defined and incorporated into the mesh for these simulations.

A sensitivity test will also be performed to examine the effect on storm surge of closing off the MRGO. The scenario that will be examined will be the following: eliminating the dredged channel from the Gulf of Mexico to the confluence of the GIWW/MRGO and not eliminating the connection from the GIWW to the IHNC. This issue has been one of great concern to the public, and the effect will be examined with the storm surge model being developed and applied here.

## *Vulnerability Assessment for Waves and Water Levels*

### Team

Don Resio, ERDC-CHL, lead, with Jeff Melby, ERDC-CHL, Leon Borgman, University of Wyoming, and Peter Vickery, ARA, Doug Bellomo, FEMA.

### Approach

A lower level of effort will be spent to develop frequency of occurrence estimates for waves and water levels. This will not be a rigorous effort, simply a preliminary look to aid in assessing vulnerability of the existing projects in the aftermath of Hurricane Katrina to future storms. A PBL model will be used to define the wind and pressure input to the wave and surge models. The frequency analysis will begin with a straight application of the Empirical Simulation Technique using historical storms. Work will progress into a more rigorous treatment involving other hypothetical events that allow for other possibilities other than the historical storms as they actually occurred. Frequency estimates will be produced for the same locations as Katrina-specific output products. These results will provide information regarding the susceptibility of the current projects to waves and storm surge which dictate the potential for overtopping and flooding, and the results will place the wave and surge conditions experienced during Katrina in the context of other conditions that are possible and their frequency of occurrence.

## Status

### *Hydrograph and High Water Mark Analysis*

The data used to prepare this report were acquired by teams from USACE New Orleans District, USACE Engineer Research and Development Center (ERDC), Louisiana State University (LSU), US Geological Survey (USGS), the Federal Emergency Management Agency (FEMA), the Orleans Levee District, the National Weather Service, and individuals who offered documented personal accounts. The data elevations are referenced to NAVD88 vertical datum, and where necessary to account for recent subsidence, are compliant with NGS NAVD88 2004.65. The focus to date has been on high water marks and hydrographs in the metropolitan New Orleans area.

Based upon gauge records and the recounts of observers, the peak water level along the south shore of Lake Pontchartrain occurred between 9:00 a.m. and 11:00 a.m. local time (CDT) on 29 August 2005 (this time frame corresponds to between 2:00 and 4:00 p.m. GMT or UTC). The precise time of peak water level depends upon the specific location, but for general discussion purposes a time of 10:00 a.m. is probably acceptable. Observed peak water levels (excluding wave crest and wave run-up effects) along the south shore of Lake Pontchartrain were up to 12.6 ft NAVD88. At the entrance to the 17$^{th}$ Street Canal, high water marks (HWM) thought to best capture the peak water level, interior marks, ranged from 10.6 to 11.8 ft NAVD88. At the entrance to London Avenue Canal, HWMs ranged from 10.2 to 12.4 ft NAVD88, with the majority of marks being debris lines. One interior HWM measured 12.2 ft NAVD88. At the entrance to Inner Harbor Navigation Canal (IHNC) from Lake Pontchartrain, HWMs indicating the peak water level ranged from 11.9 to 12.6 ft NAVD88, with interior marks ranging from 12.2 to 12.6 ft NGVD.

HWMs measured approximately midway between the I-10 crossing of the IHNC and the IHNC entrance to Lake Pontchartrain show elevations of 12.1 to 13.0 ft NAVD88.

Just to the north of the I-10 crossing over the IHNC, interior HWMs indicate peak water levels of 12.9 to 13.1 ft NAVD88. Just to the south of the junction of the IHNC and the Mississippi River Gulf Outlet (MRGO), HWMs along the

IHNC were about 15.5 to 15.8 ft NAVD88. Figure 7 shows the hydrograph record from the IHNC Lock which was the most complete hydrograph recovered. The peak water level from the hydrograph record is about 14.2 ft NAVD88, and the time of maximum water level is about 9:00 a.m. CDT, or just slightly later. HWM data from roughly the same location show elevations of 13.5 to 14.0 ft NAVD88.

Along the MRGO, at Paris Road, an interior HWM measured 16.3 ft NAVD88. The hydrograph at Paris Road (see Figure 7) shows an elevation that consistently tracks approximately 3.5 ft above elevations recorded at the IHNC Lock. The Paris Road gauge failed when the water level reached about 12.5 ft NAVD88, but using the rather consistent offset and the peak measured at IHNC Lock, the estimated peak water level at Paris Road would be about 17.7 ft NAVD88, which is similar to the interior 16.3-ft HWM measured nearby. At Bayou Bienvenue floodgate, on the MRGO with exposure to Lake Borgne, measured HWMs ranged from 16.7 to 18.8 ft NAVD88. Further eastward along the MRGO, at Bayou Dupre flood gate, also exposed to Lake Borgne, HWMs ranged from 16.9 to 21.6 ft NAVD88.

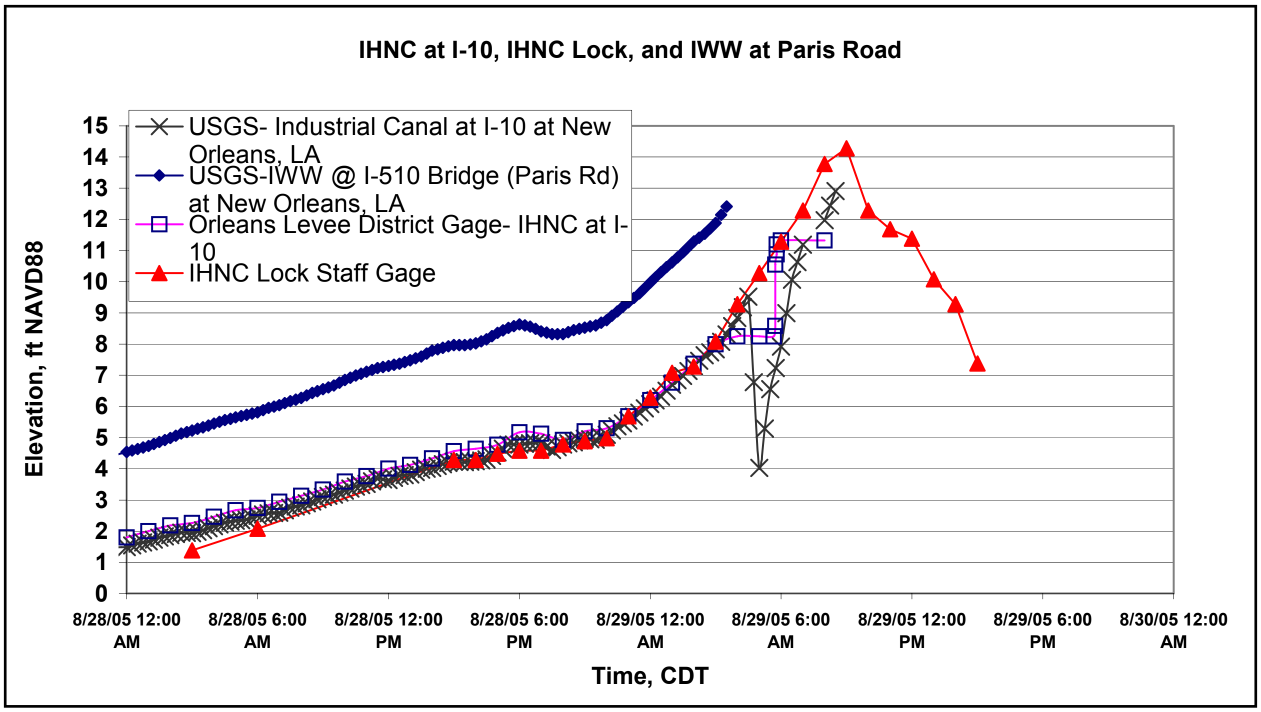



Figure 7. Hydrograph data at IHNC, IHNC Lock, and IWW

The HWMs and hydrograph data reflect a high gradient in maximum water level between Lake Borgne and Lake Pontchartrain, via the MRGO/GIWW and IHNC. The change in peak water level from the MRGO at Paris Road, which reflects the higher surge that is present in Lake Borgne, to Lake Pontchartrain is approximately 4 ft. The peak water level experienced along the IHNC varied considerably, depending on location.

Figure 8 illustrates the typical distribution of recovered HWM in the New Orleans area. HWM designated LA1036 is at the Municipal Yacht Harbor very near the location where Mr. Michael Howell stayed on his boat during Katrina's passage. Mr. Howell took time-tagged digital pictures showing various water levels that are being used to generate a hydrograph (work in progress).


Figure 8. Recovered HWM locations, Lake Pontchartrain 17th Street Canal to Bayou St. John

In addition to the hydrographs and HWMs located in the immediate New Orleans vicinity, numerous HWMs were recovered to the south and east of New Orleans extending as far as the Mississippi-Alabama border by USACE, USGS, and FEMA. The highest reported exterior HWM is 32.5 ft NAVD88 located in Harrison County, Mississippi. The highest reported interior HWM is 27.8 ft NAVD88 also located in Harrison County, Mississippi. Additional images may be viewed on the IPET website at: *https://maps.crrel.usace.army.mil/cmkat/kmapbrowser.mapbrowser*.

### *Winds and Atmospheric Pressures*

For the preliminary storm surge modeling (75% solution), wind and atmospheric pressure fields were generated using a Planetary Boundary Layer (PBL) model. The ADCIRC-PBL model coupling was already in place as a result of prior work done for CEMVN. The PBL model employs a moving nested-grid approach (five levels or nests with increasingly higher resolution nearest the storm center) to compute wind and pressure fields as a function of time. For input, the PBL model requires information about the storm position (track), the maximum sustained wind speed and central pressure. Radius-to-maximum-wind values are computed internally within the five-level model using the method presented in Jelesnianski, C.P., and Taylor, A.D., "A Preliminary View of Storm Surges Before and After Storm Modifications," NOAA Technical Memorandum ERL WMPO-3, 1973, as programmed by Ed Thompson (ERDC-CHL). Radii-to-maximum-winds are calculated as a function of central pressure and maximum sustained wind speed.

Table 4 shows the corrected and interpolated storm data that were input to the PBL model for Hurricane Katrina. Columns in the table indicate a designator number, latitude and longitude of the storm center, time relative to GMT (UTC) when the storm center occupied that position, maximum sustained wind speed in knots, central pressure in millibars, and the storm's status (tropical depression, tropical storm or hurricane, and if a hurricane the Saffir-Simpson categorization, 1 through 5). Data highlighted in light green are from NOAA/NWS initial storm postings. Data highlighted in dark green or gray were interpolated from nearby values. Data at 1.5-hr intervals were interpolated in between green and gray highlighted values. These data are the basis of the 75% PBL-forced simulations.

**Table 4**
**Hurricane Katrina Storm Parameters**

Date: 25-31 AUG 2005
Hurricane KATRINA

| ADV | LAT | LON | TIME | WIND | PR | STAT |
|---|---|---|---|---|---|---|
| 5A | 26.00 | -77.60 | 08/25/00Z | 50 | 1001 | TROPICAL STORM |
| 5Q | 26.00 | -77.80 | 08/25/01.5 | 48 | 1001 | TROPICAL STORM |
| 6 | 26.00 | -78.00 | 08/25/03Z | 45 | 1001 | TROPICAL STORM |
| 6Q | 26.05 | -78.20 | 08/25/04.5 | 45 | 1001 | TROPICAL STORM |
| 6A | 26.10 | -78.40 | 08/25/06Z | 45 | 1000 | TROPICAL STORM |
| 6Q | 26.15 | -78.55 | 08/25/07.5 | 45 | 1000 | TROPICAL STORM |
| 7 | 26.20 | -78.70 | 08/25/09Z | 45 | 1000 | TROPICAL STORM |
| 7Q | 26.20 | -78.85 | 08/25/10.5 | 46 | 1000 | TROPICAL STORM |
| 7N | 26.20 | -79.00 | 08/25/12Z | 47 | 999 | TROPICAL STORM |
| 7R | 26.20 | -79.15 | 08/25/13.5 | 48 | 998 | TROPICAL STORM |
| 8 | 26.20 | -79.30 | 08/25/15Z | 50 | 997 | TROPICAL STORM |
| 8Q | 26.20 | -79.45 | 08/25/16.5 | 54 | 992 | TROPICAL STORM |
| 8M | 26.20 | -79.55 | 08/25/18Z | 57 | 990 | TROPICAL STORM |
| 8R | 26.18 | -79.68 | 08/25/19.5 | 61 | 989 | TROPICAL STORM |
| 9 | 26.10 | -79.90 | 08/25/21Z | 65 | 985 | HURRICANE-1 |
| 9Q | 25.95 | -80.05 | 08/25/22.5 | 69 | 985 | HURRICANE-1 |
| 9M | 25.85 | -80.25 | 08/26/00Z | 70 | 985 | HURRICANE-1 |
| 9R | 25.72 | -80.48 | 08/26/01.5 | 69 | 985 | HURRICANE-1 |
| 10 | 25.50 | -80.70 | 08/26/03Z | 65 | 984 | HURRICANE-1 |
| 10Q | 25.42 | -81.00 | 08/26/04.5 | 61 | 989 | HURRICANE-1 |
| 10M | 25.35 | -81.20 | 08/26/06Z | 60 | 990 | TROPICAL STORM |
| 10R | 25.30 | -81.35 | 08/26/07.5 | 61 | 989 | TROPICAL STORM |
| 11 | 25.30 | -81.50 | 08/26/09Z | 65 | 987 | HURRICANE-1 |
| 11Q | 25.30 | -81.73 | 08/26/10.5 | 65 | 987 | HURRICANE-1 |

```
11M 25.25 -81.90 08/26/12Z 65 987 HURRICANE-1
11R 25.17 -82.05 08/26/13.5 66 986 HURRICANE-1
 12 25.10 -82.20 08/26/15Z 70 981 HURRICANE-1
13Q 25.02 -82.36 08/26/16.5 85 970 HURRICANE-2
13A 24.90 -82.60 08/26/18Z 85 969 HURRICANE-2
13R 24.85 -82.75 08/26/19.5 85 967 HURRICANE-2
 14 24.80 -82.90 08/26/21Z 85 965 HURRICANE-2
14Q 24.75 -83.10 08/26/22.5 85 965 HURRICANE-2
14A 24.70 -83.30 08/27/00Z 85 965 HURRICANE-2
14Q 24.65 -83.45 08/27/01.5 87 965 HURRICANE-2
 15 24.60 -83.60 08/27/03Z 90 965 HURRICANE-2
15Q 24.50 -83.80 08/27/04.5 92 964 HURRICANE-2
15A 24.40 -84.00 08/27/06Z 95 963 HURRICANE-2
15R 24.40 -84.20 08/27/07.5 97 954 HURRICANE-2
 16 24.40 -84.40 08/27/09Z 100 945 HURRICANE-3
16Q 24.40 -84.50 08/27/10.5 100 943 HURRICANE-3
16A 24.40 -84.60 08/27/12Z 100 940 HURRICANE-3
16R 24.45 -84.80 08/27/13.5 100 940 HURRICANE-3
 17 24.50 -85.00 08/27/15Z 100 940 HURRICANE-3
17Q 24.50 -85.20 08/27/16.5 100 944 HURRICANE-3
17A 24.50 -85.40 08/27/18Z 100 949 HURRICANE-3
17R 24.55 -85.50 08/27/19.5 100 947 HURRICANE-3
 18 24.60 -85.60 08/27/21Z 100 945 HURRICANE-3
18Q 24.70 -85.75 08/27/22.5 100 945 HURRICANE-3
18A 24.80 -85.90 08/28/00Z 100 944 HURRICANE-3
18R 24.90 -86.05 08/28/01.5 100 942 HURRICANE-3
 19 25.00 -86.20 08/28/03Z 100 939 HURRICANE-3
19Q 25.05 -86.50 08/28/04.5 100 937 HURRICANE-3
 20 25.10 -86.80 08/28/06Z 125 935 HURRICANE-4
20Q 25.25 -87.10 08/28/07.5 125 935 HURRICANE-4
 21 25.40 -87.40 08/28/09Z 125 935 HURRICANE-4
21Q 25.55 -87.55 08/28/10.5 132 922 HURRICANE-4
 22 25.70 -87.70 08/28/12Z 140 908 HURRICANE-5
22Q 25.85 -87.90 08/28/13.5 145 908 HURRICANE-5
 23 26.00 -88.10 08/28/15Z 150 907 HURRICANE-5
23Q 26.25 -88.35 08/28/16.5 150 907 HURRICANE-5
23A 26.50 -88.60 08/28/18Z 150 906 HURRICANE-5
23R 26.70 -88.80 08/28/19.5 148 904 HURRICANE-5
 24 26.90 -89.00 08/28/21Z 145 902 HURRICANE-5
24Q 27.05 -89.05 08/28/22.5 143 903 HURRICANE-5
24A 27.20 -89.10 08/29/00Z 140 904 HURRICANE-5
24R 27.40 -89.25 08/29/01.5 140 904 HURRICANE-5
 25 27.60 -89.40 08/29/03Z 140 904 HURRICANE-5
25Q 27.83 -89.48 08/29/04.5 140 907 HURRICANE-5<
25M 28.05 -89.55 08/29/06Z 138 909 HURRICANE-5<
25R 28.35 -89.60 08/29/07.5 134 911 HURRICANE-4<
 26 28.80 -89.60 08/29/09Z 130 915 HURRICANE-4
26Q 29.02 -89.60 08/29/10.5 126 917 HURRICANE-4>
26M 29.40 -89.60 08/29/12Z 120 920 HURRICANE-4
26R 29.83 -89.60 08/29/13.5 114 924 HURRICANE-4
 27 30.20 -89.60 08/29/15Z 110 927 HURRICANE-3
```

| | | | | | | |
|---|---|---|---|---|---|---|
| 27Q | 30.65 | -89.60 | 08/29/16.5 | 95 | 937 | HURRICANE-2< |
| 27M | 31.10 | -89.60 | 08/29/18Z | 85 | 947 | HURRICANE-2< |
| 27R | 31.53 | -89.60 | 08/29/19.5 | 76 | 956 | HURRICANE-1< |
| 28 | 31.90 | -89.60 | 08/29/21Z | 65 | 960 | HURRICANE-1 |
| 28Q | 32.40 | -89.25 | 08/29/22.5 | 60 | 962 | HURRICANE-1 |
| 28A | 32.90 | -88.90 | 08/30/00Z | 55 | 965 | TROPICAL STORM |
| 28R | 33.20 | -88.70 | 08/30/01.5 | 53 | 969 | TROPICAL STORM |
| 29 | 33.50 | -88.50 | 08/30/03Z | 50 | 973 | TROPICAL STORM |
| 29Q | 33.80 | -88.48 | 08/30/04.5 | 49 | 974 | TROPICAL STORM |
| 29N | 34.10 | -88.45 | 08/30/06Z | 48 | 976 | TROPICAL STORM |
| 29R | 34.40 | -88.43 | 08/30/07.5 | 47 | 978 | TROPICAL STORM |
| 30 | 34.70 | -88.40 | 08/30/09Z | 45 | 980 | TROPICAL STORM |
| 30Q | 35.10 | -88.18 | 08/30/10.5 | 42 | 981 | TROPICAL STORM |
| 30N | 35.50 | -87.95 | 08/30/12Z | 38 | 982 | TROPICAL STORM |
| 30R | 35.90 | -87.73 | 08/30/13.5 | 34 | 983 | TROPICAL STORM |
| 31 | 36.30 | -87.50 | 08/30/15Z | 30 | 985 | TROPICAL DEPRESSION |
| 31Q | 36.73 | -87.15 | 08/30/16.5 | 29 | 986 | TROPICAL DEPRESSION |
| 31N | 37.15 | -86.80 | 08/30/18Z | 27 | 988 | TROPICAL DEPRESSION |
| 31R | 37.58 | -86.40 | 08/30/19.5 | 26 | 989 | TROPICAL DEPRESSION |
| 32 | 38.00 | -86.00 | 08/30/21Z | 25 | 991 | TROPICAL DEPRESSION |
| 32Q | 38.35 | -85.50 | 08/30/22.5 | 25 | 991 | TROPICAL DEPRESSION |
| 32N | 38.70 | -85.00 | 08/31/00Z | 25 | 992 | TROPICAL DEPRESSION |
| 32R | 39.05 | -84.50 | 08/31/01.5 | 25 | 993 | TROPICAL DEPRESSION |
| 33 | 39.40 | -84.00 | 08/31/03Z | 25 | 994 | TROPICAL DEPRESSION |
| 33Q | 39.85 | -83.40 | 08/31/04.5 | 23 | 994 | TROPICAL DEPRESSION |
| 33N | 40.30 | -82.80 | 08/31/06Z | 20 | 995 | TROPICAL DEPRESSION |

For preliminary Gulf-scale and regional-scale wave modeling (the 75% solutions), wind fields produced by Oceanweather, Inc. (OWI) were used, which include H*Wind snapshots from NOAA/HRD. This approach was taken because the method to link these wind inputs to the Gulf-scale wave modeling had been previously developed as part of a National Ocean Partnership Program project, and was readily usable. This same methodology for generating winds will be adopted for all final storm surge and wave modeling.

The techniques used to construct these wind fields rely on point-source measurements (buoys, land-based meteorological platforms), hurricane resonance data consisting of Drop Windsonde (radio-transmitted gauges measuring wind speed, pressure and other meteorological information), satellite-based scatter-ometer wind estimates (e.g., QuikScat, SSMI). At the time of the preliminary analyses, the majority of measurements were obtained in near real time, so they did not encompass all available meteorological data. The Step Frequency Microwave Radiometer (SFMR, Uhlhorn et al. 2003), a new measurement device estimating the winds at the air-sea boundary, was used as the most reliable wind estimate. Prior to the 2005 hurricane season the Global Positioning Dropwind sonde estimates controlled the characteristics of the inner core of a tropical system. The inner core of a hurricane is now constructed using a method developed at NOAA's Hurricane Research Division (HRD) called the HRD Surface Wind Field Analysis System (H*Wind *http://cat5.nhc.noaa.gov/Hwind/*).

All measurements are transformed to a standard 10-m elevation, averaging period (1-min sustained wind speed) and set exposure (marine or land). The data are scrutinized for quality. The product (Figure 9) of this man-machine mix is a streamline and isotach contour plot.

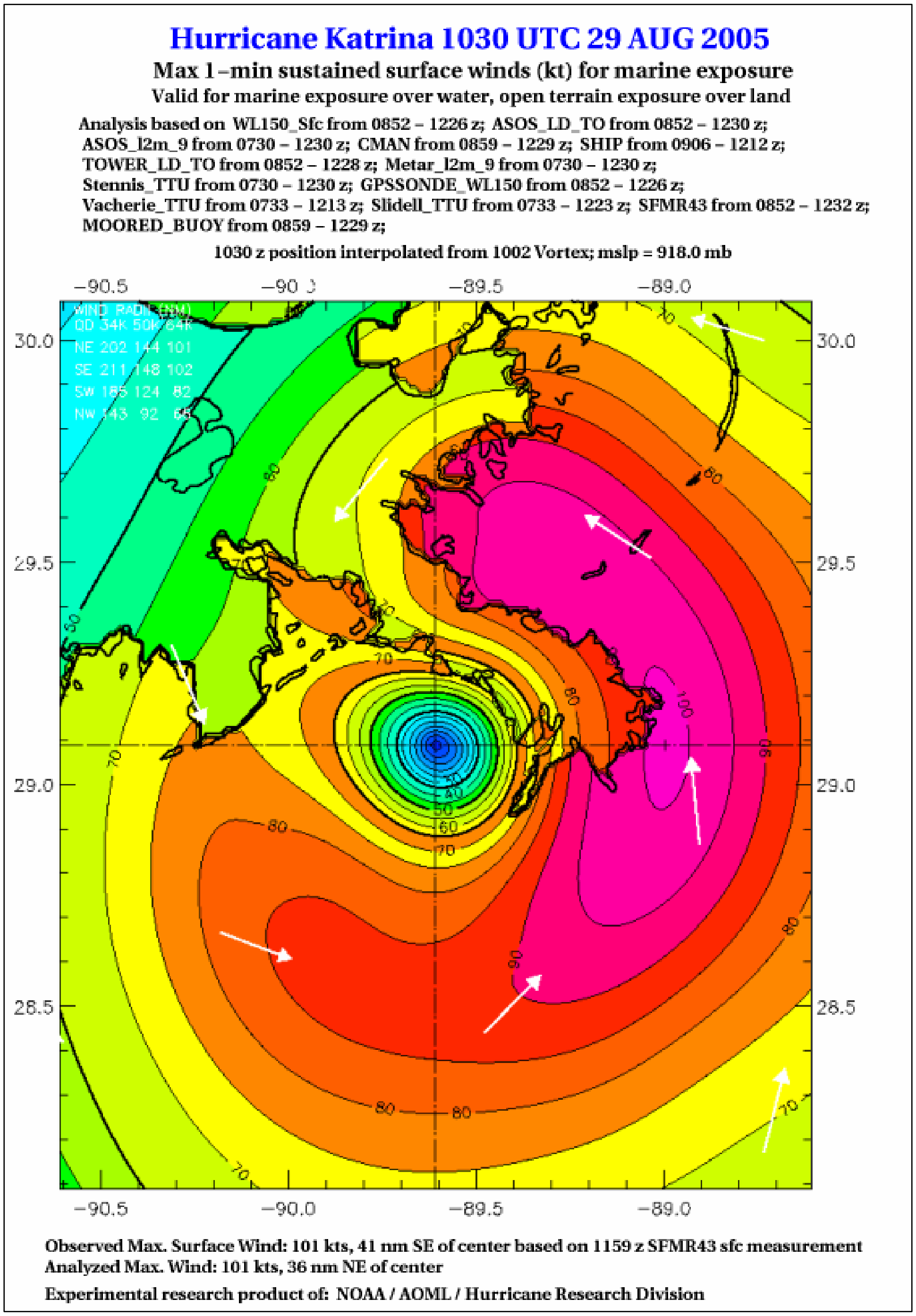



Figure 9. Example of H*Wind on 29 August 2005 1030 UTC. The wind speeds are color contoured in knots, representing 1-min sustained wind speeds (Note this wind field includes marine and land exposures identified by the abrupt change in color contours over the land)

There are 36 unique H*Wind analysis snapshots for the duration of this storm. These are fixed (storm centered) in space and time (see Figure 10). They represent the best wind estimate for the target domain it is placed on. For the example shown in Figure 9, it represents a 2-deg by 2-deg longitude/latitude target as noted by the distinct orthogonal lines that cross at storm center.

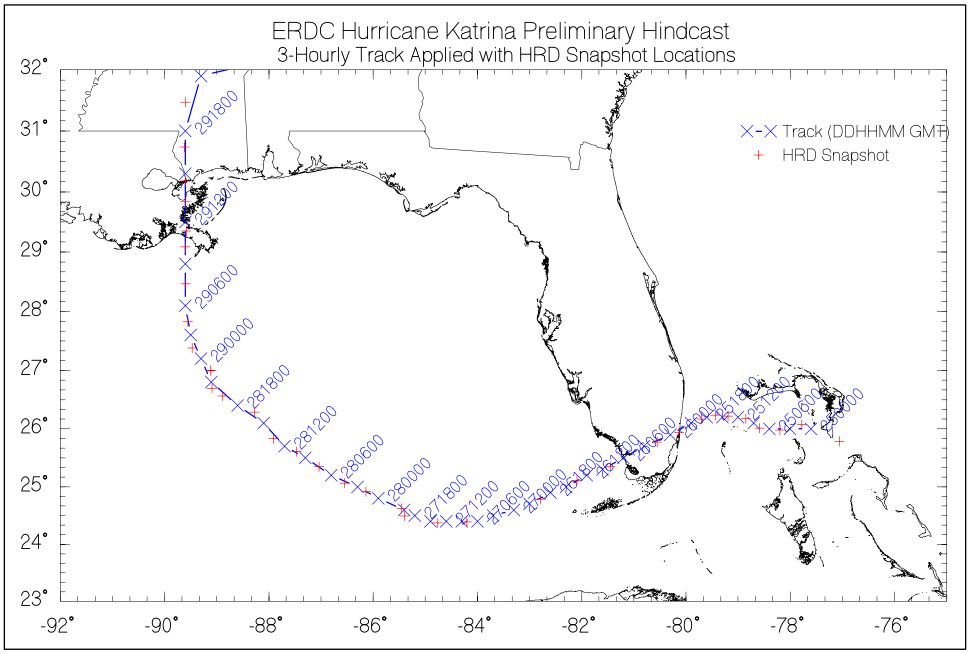



Figure 10. Spatial and temporal location of the 36-H*Wind snapshots relative to the forecast official storm track of Hurricane Katrina

The development of the full domain winds requires two straightforward procedures. Snapshot H*Wind fields are repositioned to the working track (Figure 10, blue symbols) and a moving center interpolation algorithm is applied to preserve the characteristics of the tropical storm wind core in space and time. Until the official National Hurricane Center storm track for Katrina is published, all real-time estimates of the Katrina's position and ensuing track are dictated by aircraft resonance fixes during the operational forecast period. The wave and surge modeling activities require complete wind field specification for the entire target modeling domain. Accomplishing this task requires background wind estimates which are derived from the NOAA National Center Environmental Predictions/National Center for Atmospheric Research (NCEP/NCAR) Reanalysis Project (Kalany et al. 1996). The NCEP/NCAR winds are rigorously analyzed and rely on assimilation methods with data not originally used in the NCEP operational forecast. A final step is to inject local marine data (adjusted to a consistent 10-m elevation and adjusted for neutral stability). This procedure uses an Interactive Objective Kinematic Analysis System (Cox et al. 1995) applied by Oceanweather, Inc.

Generation of the surface pressure fields follows a slightly different approach, involving use of the TC96 model. This model (TC96) was first developed over thirty years ago (Thompson and Cardone 1996). The model solves, by numerical integration, the vertically averaged equations of motion that govern a boundary layer subject to horizontal and vertical shear stresses. Upgrades and modifications of the TC96 have been made over the development cycle (Cox and Cardone 2000). The pressure fields generated for the Katrina study are built from parameters that are derived from data in meteorological records and the ambient pressure field. The symmetric part of the pressure field is described in terms of an exponential pressure profile from Holland (1980). The pressure field snapshots aligned to the storm track are spatially and temporally interpolated in a similar fashion as described in the wind field preparation and placed on the identical fixed latitude/longitude grid. No synoptic-scale inputs were considered in this application. All wind and pressure fields used in the Hurricane Katrina study were produced by Oceanweather, Inc. (http://www.oceanweather.com) on two domains summarized in Table 5 and depicted in Figures 11 and 12.

**Table 5**
**Wind and Pressure Field Domain Characterization**

| Domain | Longitude (deg) | | Latitude (deg) | | Res. (deg) | Duration (yr/mnt/day/hr) | Interval (sec) |
|---|---|---|---|---|---|---|---|
| | West | East | South | North | | | |
| Basin | 98 W | 80 W | 18 N | 30.8 N | 0.1 | 2005082500 – 2005083100 | 900<br>30 min ave |
| Region | 91 W | 88 W | 28.5 N | 30.8 N | 0.025 | 2005082906 - 2005082918 | 900<br>30 min ave |

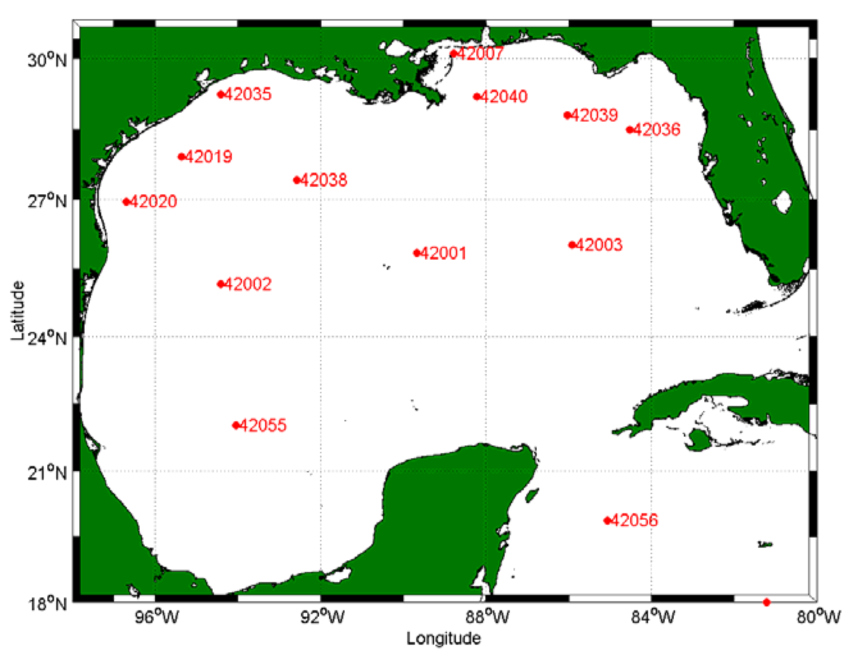



Figure 11. Target domain of the basin-scale OWI wind and pressure fields for Hurricane Katrina simulations (Locations of NOAA/NDBC buoys are shown in red)

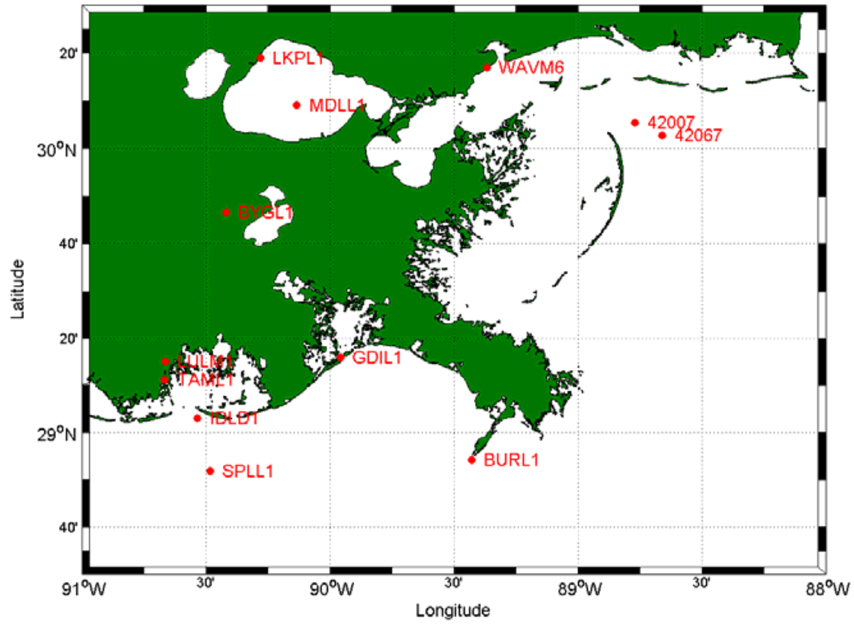



Figure 12. Target domain of the region-scale OWI wind and pressure fields for Hurricane Katrina simulations (Point source measurement sites are identified in red)

More details about wind and pressure field generation are provided in the technical appendix, including comparisons between the wind fields produced by OWI and measured data at a number of locations.

### *Waves*

Two offshore wave-modeling domains were generated, one for the basin-scale (Gulf of Mexico) and a more refined domain for the regional-scale modeling effort. The final water depth for both grids are displayed in Figures 13 and 14. Both target domains are fixed in geographical space identical to the wind fields described in the previous section. For convenience, the color contours are limited to 500 ft to focus on the areas just offshore (the shallow shelf regions).

In general, there is a substantial shelf area west of Florida and along northern Texas. This gentle slope also exists along the Mississippi-Alabama Gulf coast. Offshore of the southeastern portion of Louisiana (at the entrance of the Mississippi River) there is a strong water depth gradient (Figure 14) that will have a significant impact on the wave results. It would be an area of geographical focusing of the wave energy (from principles of refraction).

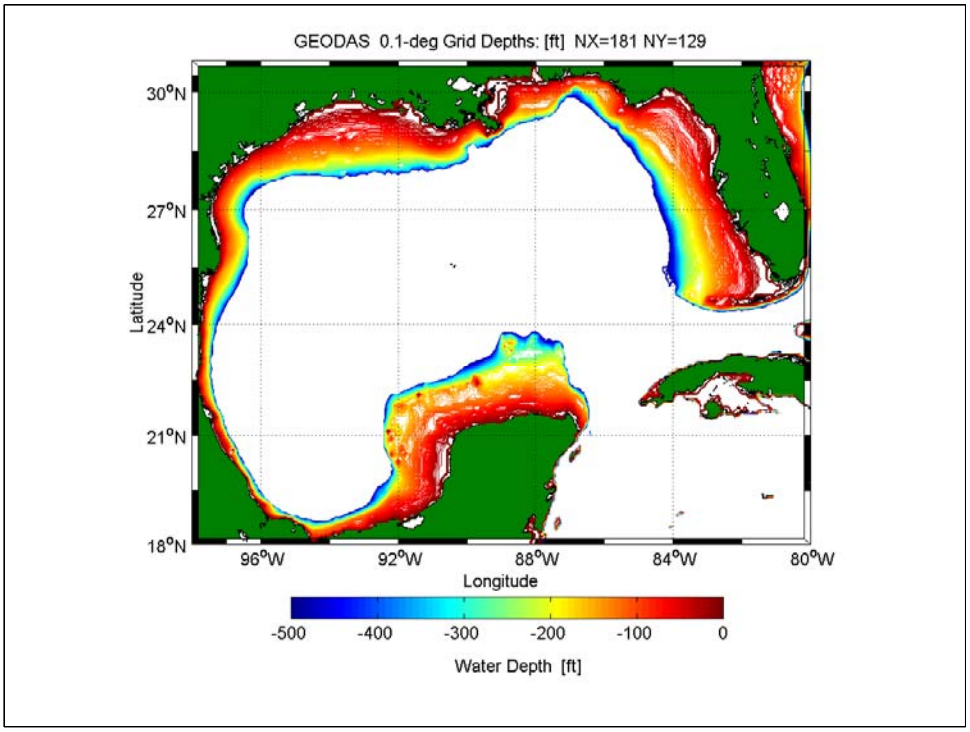



Figure 13. Color contour of the basin-scale wave model domain

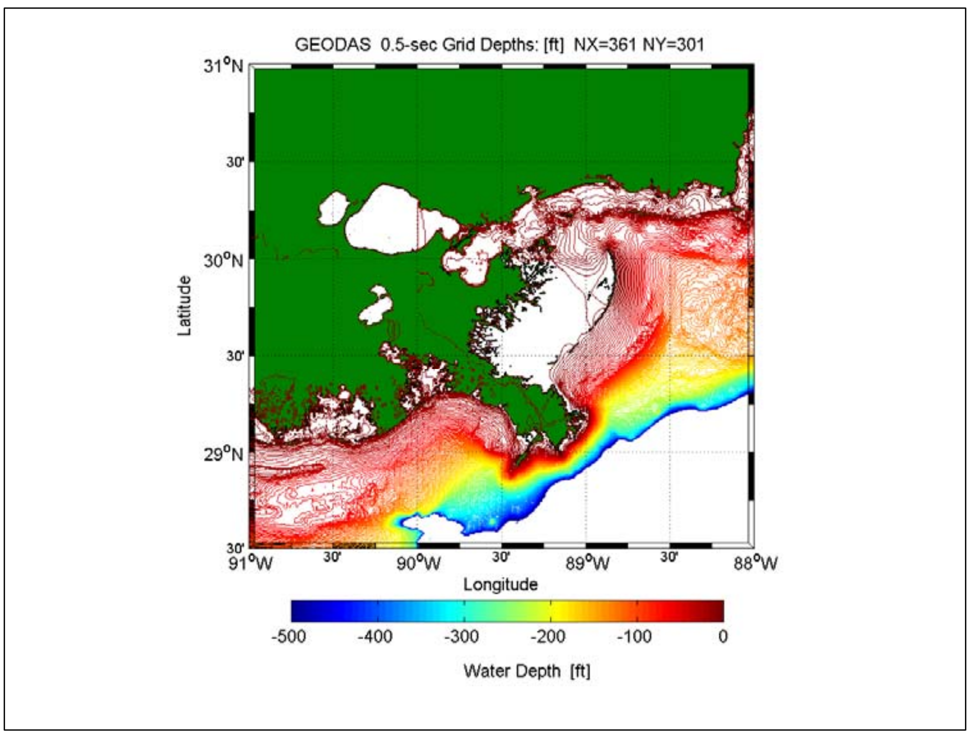



Figure 14. Color contour of regional-scale wave modeling domain

Two wind fields are used as input to the two WAM offshore wave simulations. One component of these winds, constructed from H*Wind snapshots defining the core of Hurricane Katrina, was generated using techniques described in Powell et al. (1998). The full-domain scale wind fields were then developed using the techniques defined in the previous "Wind and Atmospheric Pressures" section. These files were then re-formatted to WAM standard input constraints.

Figure 15 illustrates the complexities of the wave field generated by Hurricane Katrina. The entire simulation period is 12 hr, starting on 29 August 0600 UTC and completing at 29 August 1800 UTC. The overall maximum significant wave height occurs at 89.1417W 28.966N with a value of 52.4 ft. Shallow water effects of shoaling and more importantly refraction focus the offshore energy toward very distinct capes. The entire tip of southeastern Louisiana is in the high-energy environment. There is another wave convergence zone at Southwest Pass (Burrwood, LA). The wave height maxima follow the bathymetry (Figure 14) remarkably well, an indication of depth limited breaking effects. To the west of Southwest Pass, the $H_{mo}$ values tend to decay rapidly with distance compared to that in the front right quadrant of Katrina. The northern motion of Katrina also forces waves through the gaps between Chandeleur, Cat, Ship and Horn Islands. One must note the WAM simulation assumes constant water depths (i.e., no changes due to storm surge) and the results will be lower compared to expected results in the areas landward of these offshore islands when storm surge effects on water depth are considered. The nearshore wave modeling will consider this effect.

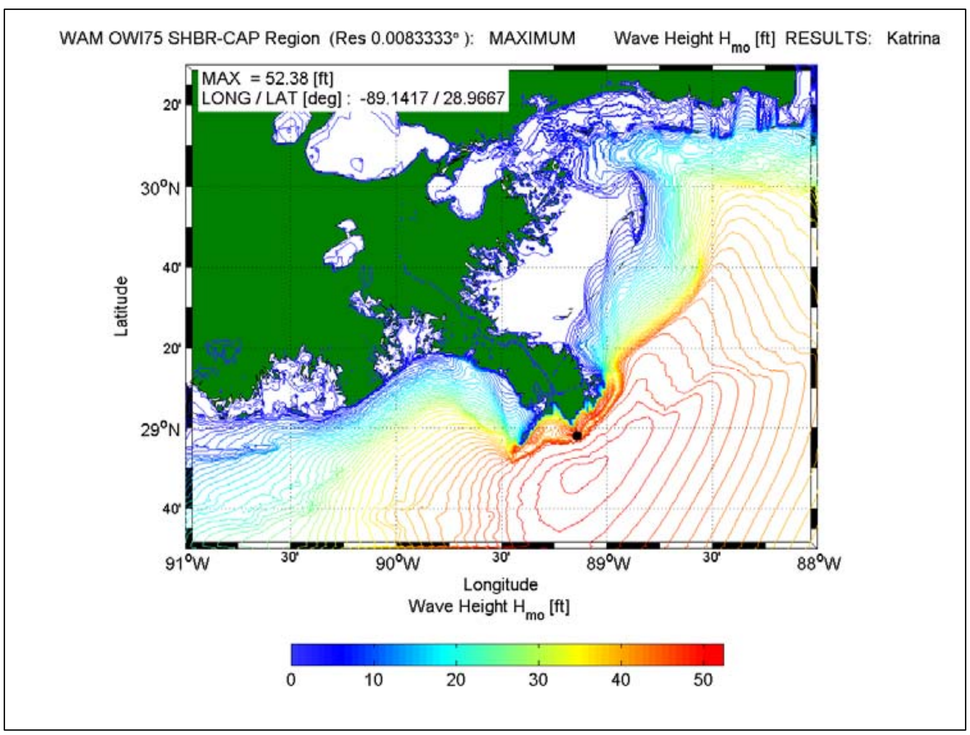



Figure 15. Color contour of the maximum wave height conditions in the Region domain for the simulation period 2005082906 through 2005082918

The maximum mean wave period results for the regional WAM Cycle 4.5 simulation are provided in Figure 16. This again illustrates the diverging wave climate east and west of Hurricane Katrina's path. To the west, the mean wave period is dominated by swells, reflected in higher values (ranging from 12 to more than 15 sec), whereas, in the front right hand quadrant of Katrina, local wind seas abound with limited, yet distinct long period swell lobes. Shadow zones appear (lower $T_{mean}$ values) in the lee of geographical capes, or offshore islands. Also evident are zones of large mean period values that are landward of island gaps (around Horn and Dauphin Islands) in the eastern portion of the Mississippi Sound.

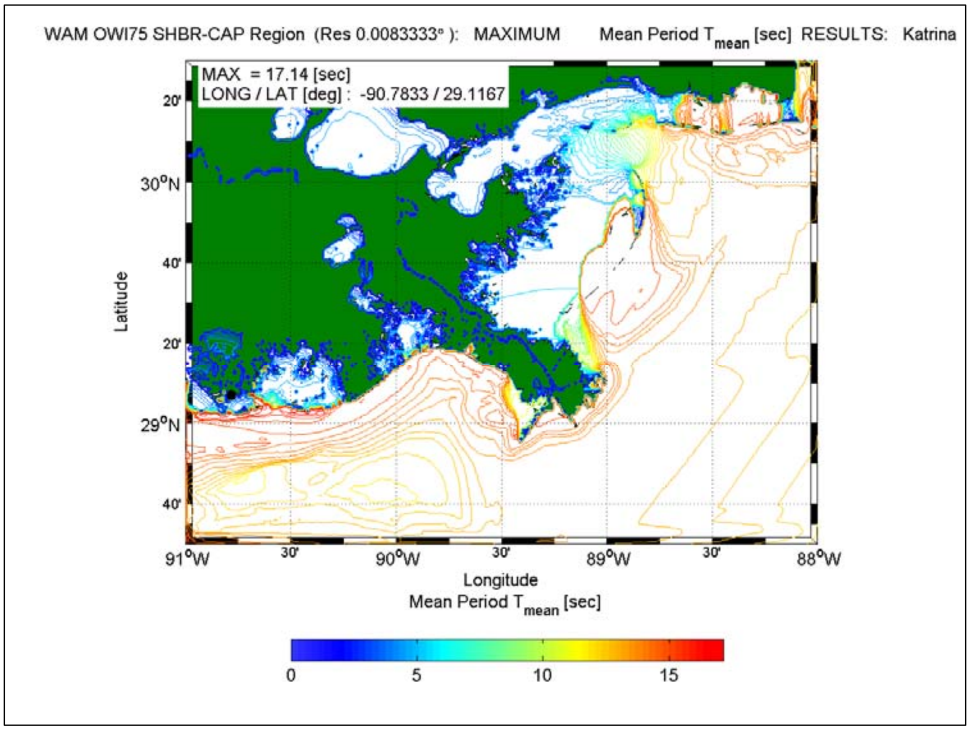



Figure 16. Color contour of the maximum mean wave period conditions in the region domain for the simulation period 2005082906 through 2005082918

These graphics provide an overview of the maximum energy level contained in the wave climate resulting from Katrina. One must realize that all results presented thus far are a culmination of the 75% solution and there is room for improvement. To assess model predictive skill and the need for improvements, a number of comparisons between model results and measurements were made. Those comparisons are presented in the technical appendix.

The culmination of this task is to provide boundary condition information to the nearshore wave modeling effort. Accomplishing this task requires decision on where to save boundary information relative to selection of STWAVE model domains. The selection process was bound by the nearshore model domain size, the number of WAM points available, and, most importantly, assurances these results would be seaward of any possible depth limited breaking. A boundary was constructed along the 30-m (or 98.4-ft) water depth contour. A total of

357 individual stations from the regional scale WAM simulation were defined and directional wave spectra (28 frequency bands and 24 directional bands) every 900 sec from 29 August 0615 UTC to 29 August 1800 UTC were saved at these points. This provides adequate coverage of the offshore conditions, and captures the spatial variation evident from offshore wave model simulations. An example of the directional wave spectrum is shown in Figure 17 and the station locations are provided in Figure 18.

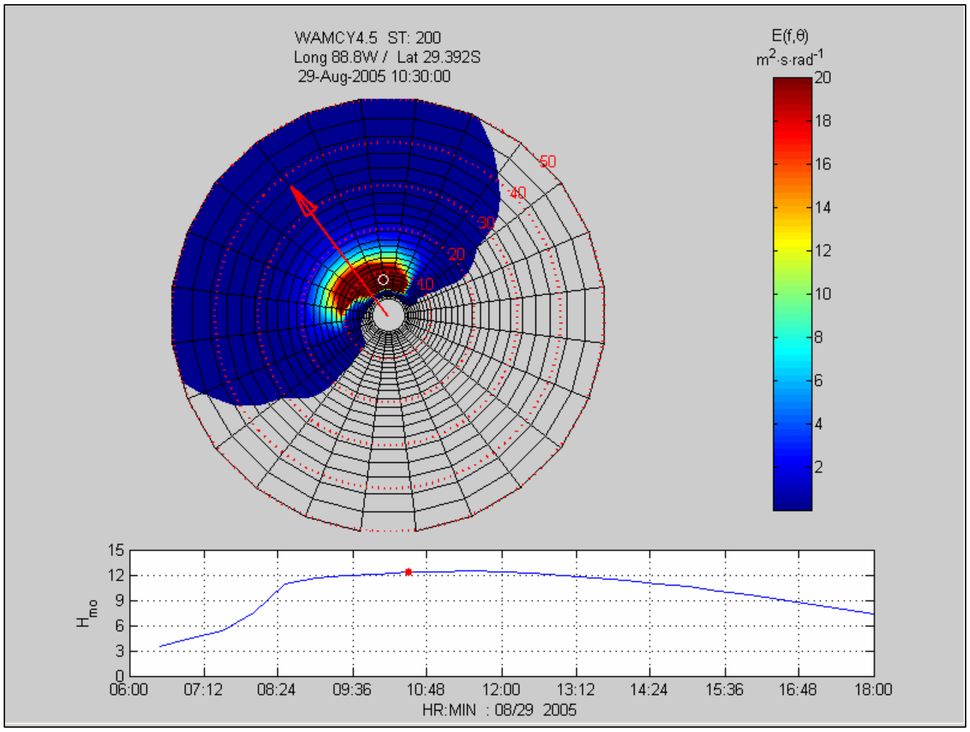



Figure 17. Example of the directional wave spectra color contoured in the upper panel and the wave height trace in the lower panel (Note units are in CGS)

STWAVE was applied on three grids for the southern Louisiana area. The input for each grid includes the bathymetry (interpolated from the ADCIRC bathymetry), surge fields (interpolated from ADCIRC output), and wind (from 75% wind fields). At each time interval, the wind applied in STWAVE is held constant over the entire domain and is taken from approximately the center of each grid. Spatial variability of the winds will be considered in future simulations. STWAVE was run at 30-min intervals from 0630 to 1800 UTC on 29 August 2005.

### *Lake Pontchartrain Grid*

The first grid covers Lake Pontchartrain at a resolution of 164 ft (50 m) (north-south) by 328 ft (100 m) (east-west). The domain is approximately 15.5 by 24.9 miles (25 by 40 km). Lake Pontchartrain is run with the full-plane STWAVE to include generation and transformation along the entire lake shoreline. The grid parameters are given in Table 6. Figure 19 shows the bathymetry for the Lake Pontchartrain Grid relative to Mean Tide Level (MTL). Brown areas in the bathymetry plots indicate land areas at 0 ft MTL.

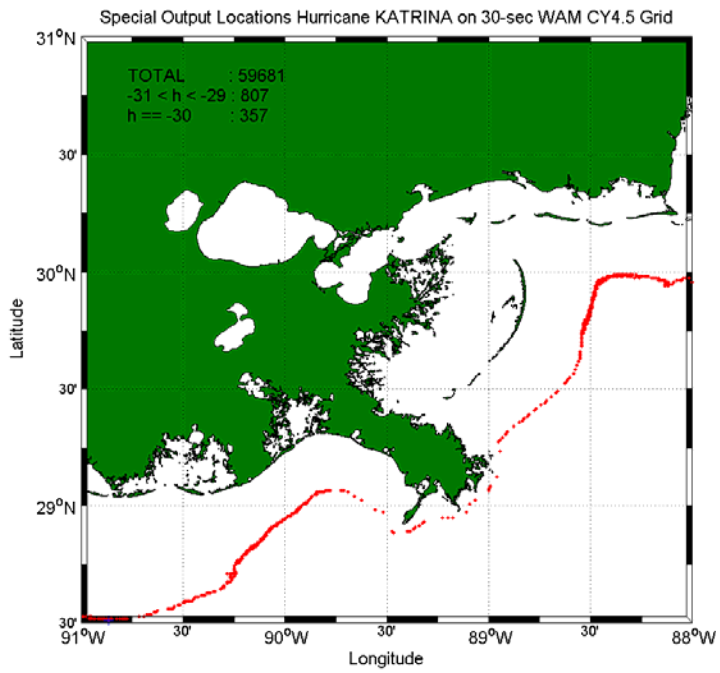



Figure 18. Location of the 357 spectral files consisting of two-dimensional wave spectra output every 900-sec from the regional WAM Cycle 4.5 nested simulation

**Table 6**
**STWAVE Grid Specifications**

| Grid | State Plane | X origin ft | Y origin ft | Δx ft | Δy ft | Orient Deg | X cells | Y cells |
|---|---|---|---|---|---|---|---|---|
| Lake Pontchartrain | LA South | 3563779.5 | 690485.6 | 164 | 328 | 270 | 832 | 674 |
| Louisiana Southeast | LA Offshore | 4294586.6 | 1639491.5 | 656 | 656 | 141 | 683 | 744 |
| Louisiana South | LA Offshore | 3997126.0 | 1264895.0 | 656 | 656 | 108 | 664 | 839 |

### *Louisiana Southeast and South Grids*

The second and third grids cover the coastal area southeast and south of New Orleans at a resolution of 656 ft (200 m). The domain for the southeast grid is approximately 84.9 by 92.4 miles (136.6 by 148.8 km) and extends from Mississippi Sound in the northeast to the Mississippi River in the southwest. The domain for the south grid is approximately 82.5 by 104.2 miles (132.8 by 167.8 km) and extends from the Mississippi River in the east to the Atchafalaya River in the west. The southeast and south grids are run with the half-plane STWAVE for computational efficiency. The grid parameters are given in

Table 6. Figures 20 and 21 show the bathymetry for the southeast and south grids, respectively. These simulations are forced with both the local winds and waves interpolated on the offshore boundary from the regional WAM model described in the previous section.

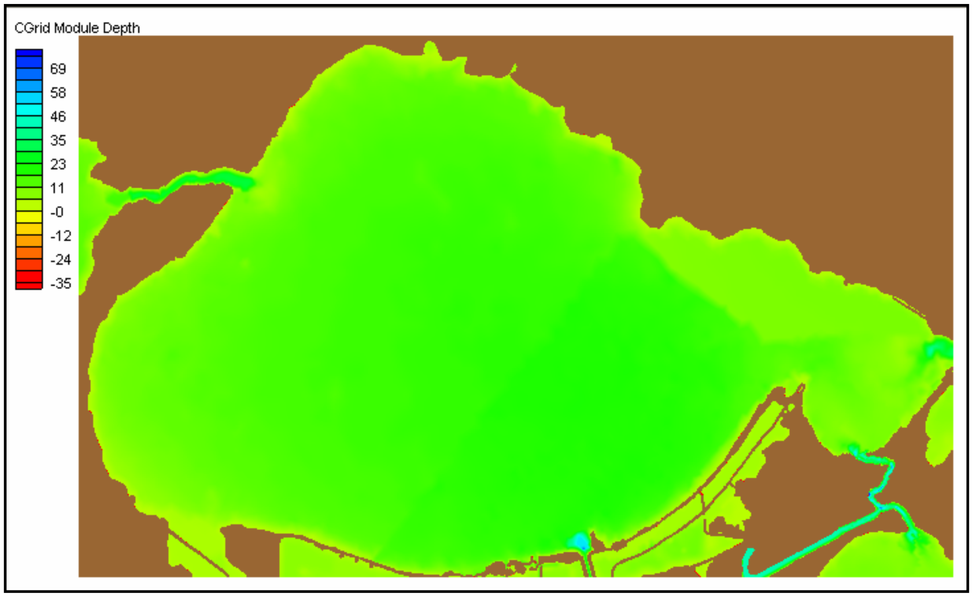



Figure 19. Lake Pontchartrain bathymetry grid (depths in feet, MTL)

### *Lake Pontchartrain Results*

The peak wave conditions on the south shore of Lake Pontchartrain occur at approximately 1400 UTC on 29 August 2005. Figure 22 shows a snapshot of wave height and wave direction at this time. The wind is 59.5 knots (30.6 m/sec) approximately from the north. The maximum wave height is 9 ft with a peak wave period of 7 sec. Figure 23 shows the maximum wave height for the entire simulation period for each grid cell within the domain. Figure 24 shows the peak wave period corresponding to the maximum wave height for each cell. The maximum wave heights range from 8 to 9 ft on the New Orleans lakefront and the associated periods are 7 to 8 sec.

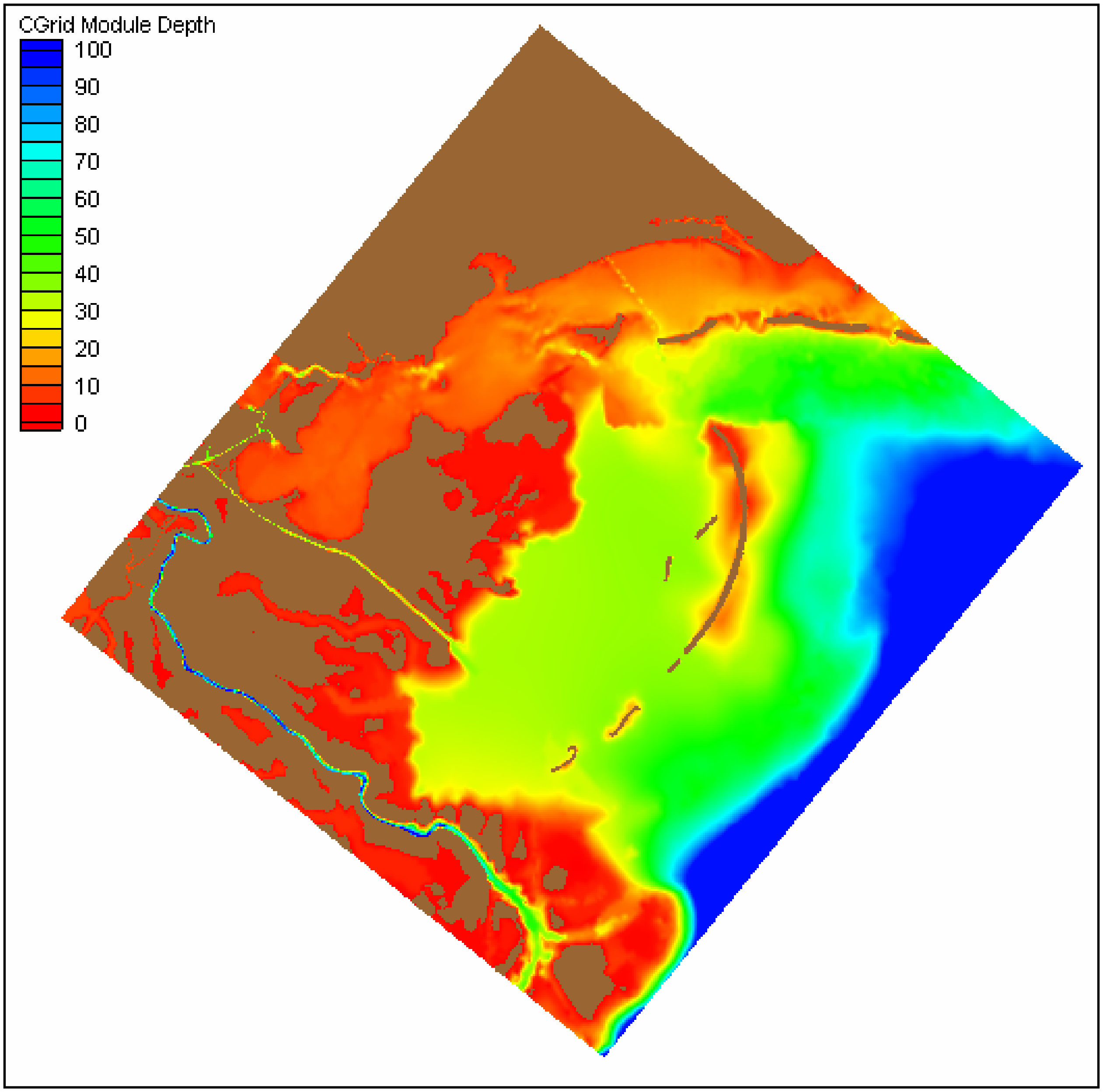



Figure 20. Southeast Louisiana bathymetry grid (depths in feet, MTL)

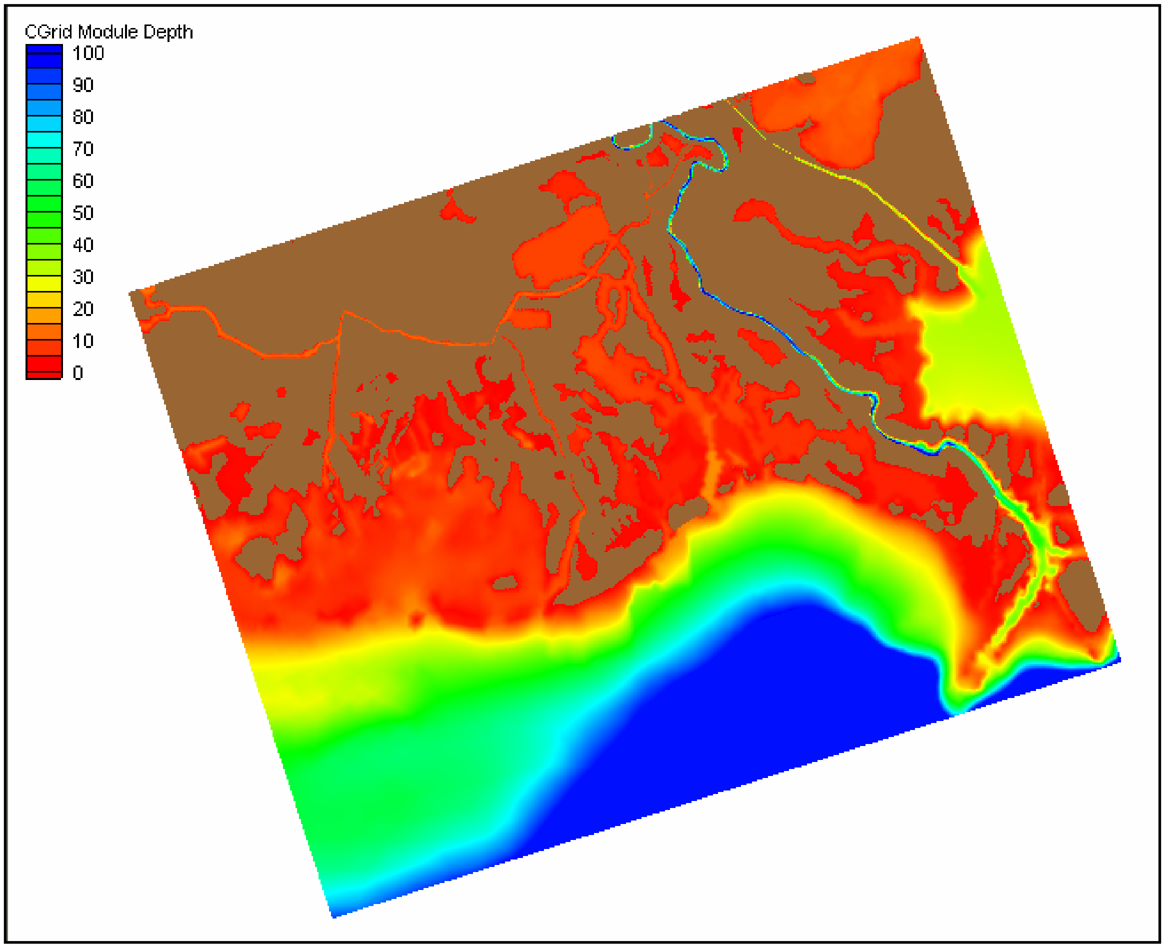



Figure 21. South Louisiana bathymetry grid (depths in feet, MTL)

Three small wave buoys were deployed in Lake Pontchartrain on 27 August 2005 to capture wave conditions in Hurricane Katrina. Two of those gauges were recovered and provide valuable comparison data. The deployment locations were 30 deg 2.053' North, 90 deg 7.358' West for Gauge 22 and 30 deg 1.989' North, 90 deg 7.932' West for Gauge 23. Gauge 22 was directly north of the 17th Street Canal entrance and Gauge 23 was west of Gauge 22. Both gauges were in approximately 13 ft (4 m) water depth. The sampling records were a relatively short 8.5 min, so there is a lot scatter in the data. Also, at the peak of the storm, the wave heights drop from approximately 8 ft to 5 ft, indicating that the buoy may have been submerged or overturned at that time. Figures 25 and 26 show comparisons of wave height and wave period for the buoy locations, respectively. The symbols without lines are the 8.5-min measured wave parameters; the blue lines are the measurements with the spectra averaged over 3 records (25.5 min), and the red lines are the modeled parameters (30-min average). The STWAVE results are essentially the same for the two gauge sites. The modeled wave heights are approximately 1.6 ft (0.5 m) lower than the measurements in the building part of the storm (0630-1200 UTC) and comparable to the measurements in the waning part of the storm (1500-1800 UTC). The measurements at the peak do not appear to be reliable. The modeled peak periods are consistent with the measurements, but 0.5 to 1.0 sec shorter.

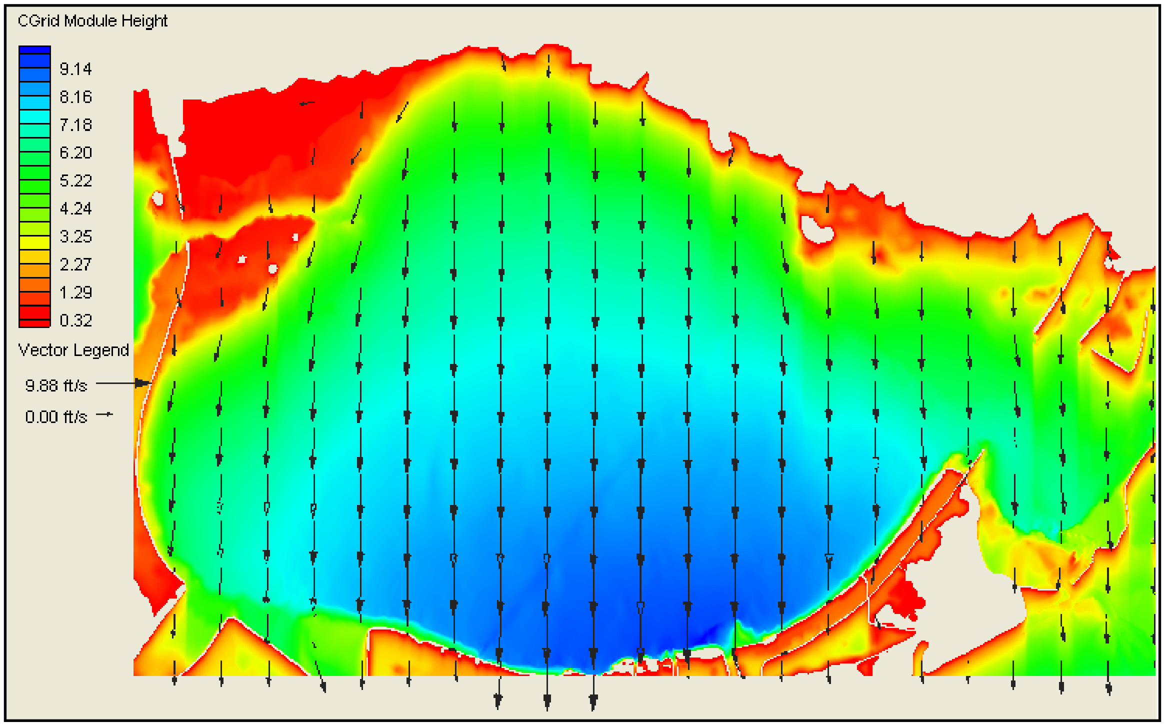



Figure 22. Lake Pontchartrain modeled wave height and direction for 1400 UTC on 29 August 2005 (wave heights in feet)

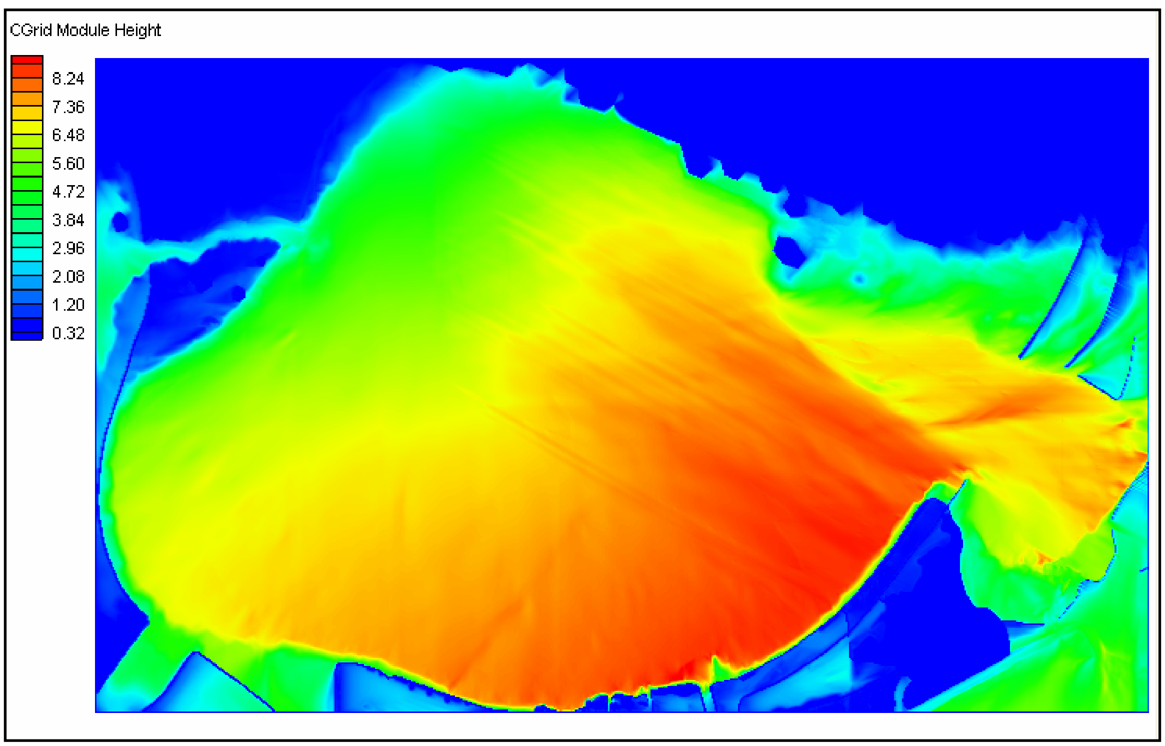



Figure 23. Lake Pontchartrain maximum modeled wave height for 0630 to 1800 UTC on 29 August 2005 (wave heights in feet)

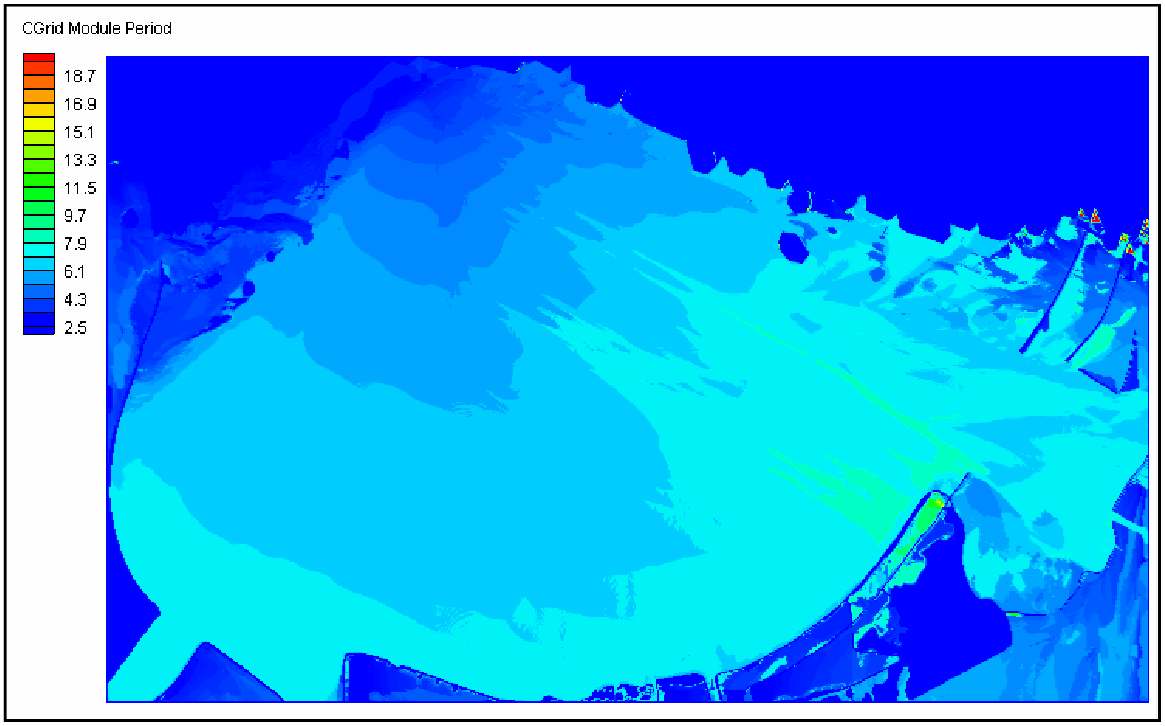



Figure 24. Lake Pontchartrain modeled peak wave period corresponding to the maximum wave height for 0630 to 1800 UTC on 29 August 2005 (periods in sec)

### *Louisiana Southeast Results*

The peak wave conditions on the southeast grid occur between approximately 1100 and 1200 UTC on 29 August 2005. The highest waves along the Mississippi River levee occur around 1100 UTC and along the Lake Borgne shoreline around 1200 UTC. Figure 27 shows a snapshot of wave heights and direction at 1200 UTC. Figures 28 and 29 show the maximum wave height and corresponding wave period for the entire simulation period for each grid cell within the domain. The maximum wave heights range from 7 to 10 ft along the levees and the associated periods are 7 to 16 sec. The longer wave periods originate from wave energy traveling between the islands from the Gulf of Mexico. Figure 29 shows only the periods corresponding to the maximum wave height, so peak period at the shoreline can change appreciably as the offshore wave direction varies, allowing swell to propagate through the island gaps.

Results for the Louisiana South domain are shown in the technical appendix.

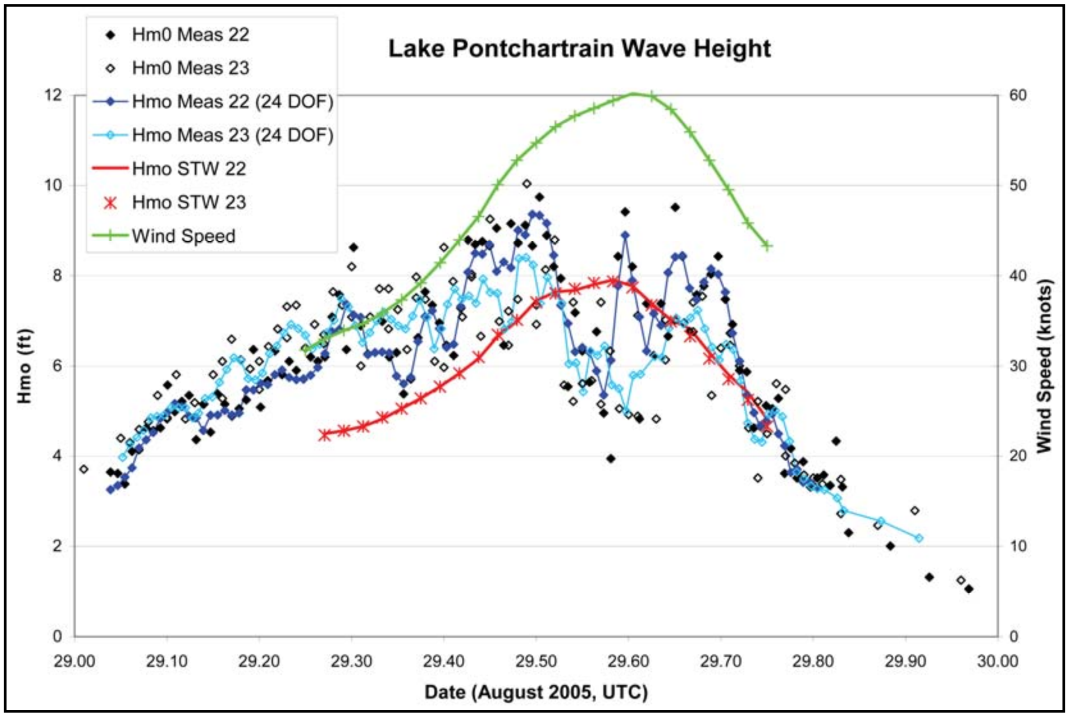



Figure 25. Lake Pontchartrain measured and modeled wave height

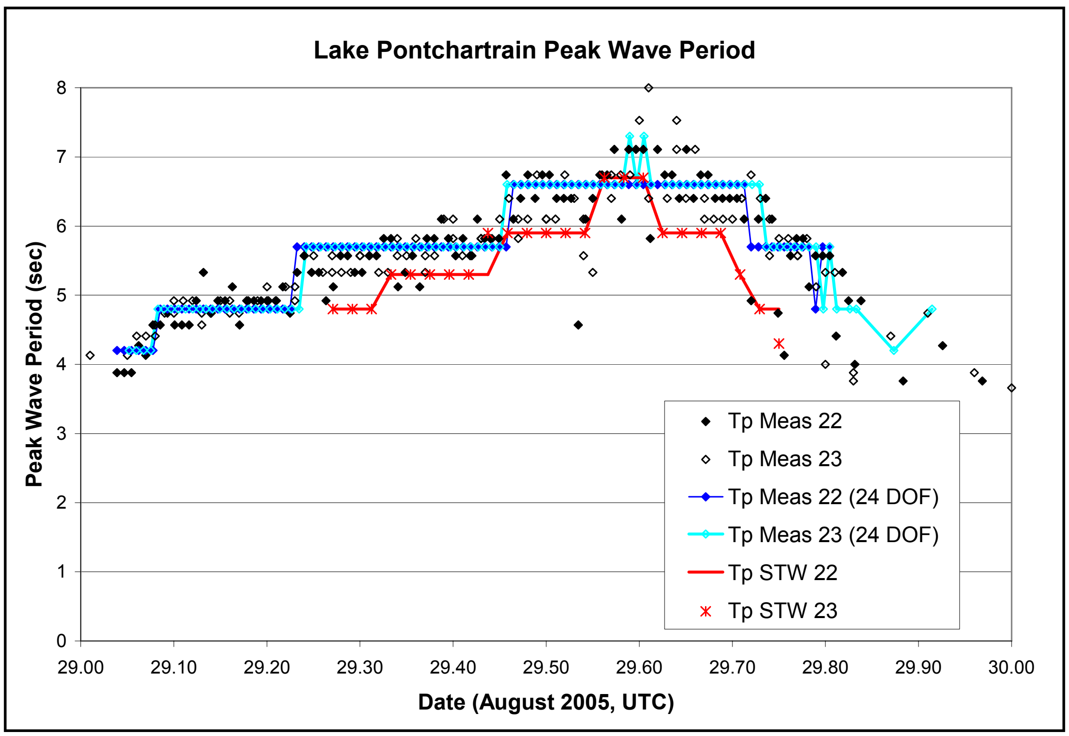



Figure 26. Lake Pontchartrain measured and modeled peak wave period

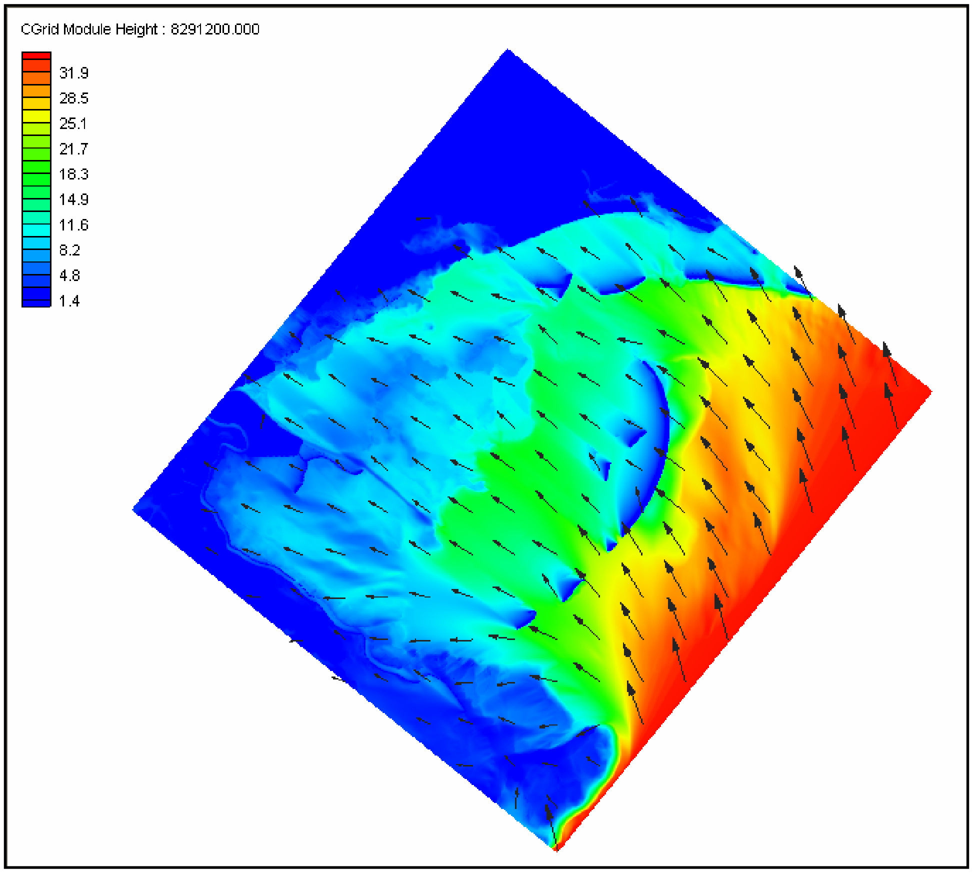



Figure 27. Southeast Louisiana modeled wave height and direction for 1200 UTC on 29 August 2005 (wave heights in feet)

## *Storm Surge*

The storm surge modeling done with the ADCIRC model, for the 75% solution, incorporates only riverine and PBL model wind and atmospheric pressure forcing. Tide, which is much less of a factor (tide range is a foot or less), will be added at the next stage, as will wave radiation stresses and their contribution to the storm surge. Figures 30 and 31 show the model topography/ bathymetry and very high grid resolution that was utilized in the modeling, for the southeastern Louisiana area including the metropolitan New Orleans vicinity. High grid resolution is needed to most accurately capture the buildup of storm surge against the complex and highly irregular levee system, propagation of the storm surge wave through the many circuitous channels and other conduits for water movement, and accurately simulate storm surge propagation over the wetlands as they first become inundated and then overwhelmed by the very large storm surge created by Katrina.

Prior to landfall, the counterclockwise rotating winds of Hurricane Katrina began to push water from east to west. This water began to pile up against the east- and northeast-facing levee systems throughout the Southeast Louisiana region. As the storm made landfall in southern Louisiana and continued in a

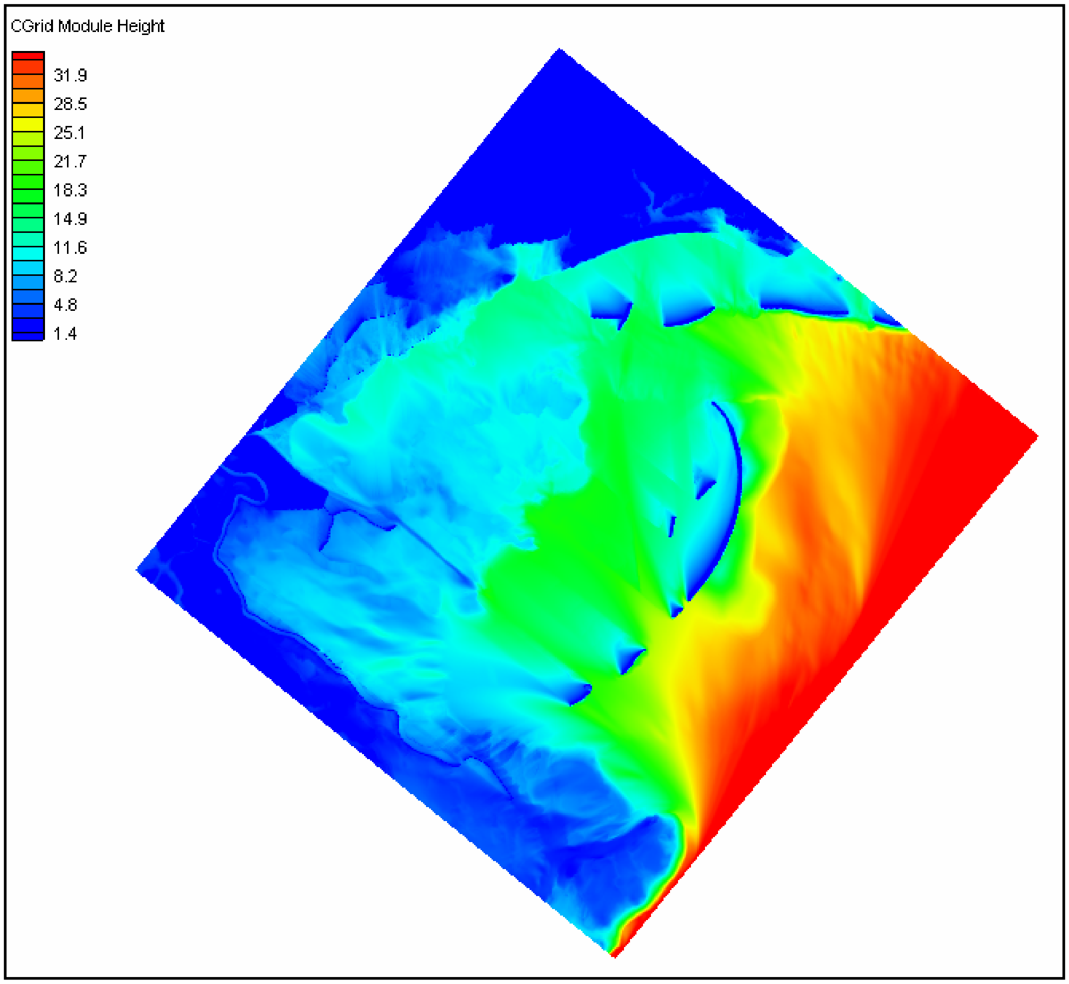



Figure 28. Southeast Louisiana maximum modeled wave height for 0630 to 1800 UTC on 29 August 2005 (wave heights in feet)

north-northeast direction, the buildup in surge along the levee systems increased until the storm center passed, and then the surge began to decrease. The greatest buildup of water occurred about halfway down that portion of the MS River and "back" levee system in Plaquemines Parish, which is located southeast of New Orleans. A slightly smaller buildup in storm surge occurred in Lake Borgne as water piled up against the eastern-facing levees protecting St. Bernard Parish/Chalmette.

In addition to the local buildup of water against the levees, these local surges propagate away from their region of initial generation. The surge generated against the river and back levees of Plaquemines Parish propagated up the Mississippi River as well as across Breton and Chandeleur Sounds. The latter surge interacts with the wind fields and propagates to the north-northeast paralleling the path of the storm center as it advanced. As the storm pushed this surge to the north-northeast, piling the water up against the Mississippi Gulf coast and combining with more locally generated surge, water levels reached their highest values along the Mississippi coast. This local maximum storm surge region to the right of the storm track is typical of hurricanes.

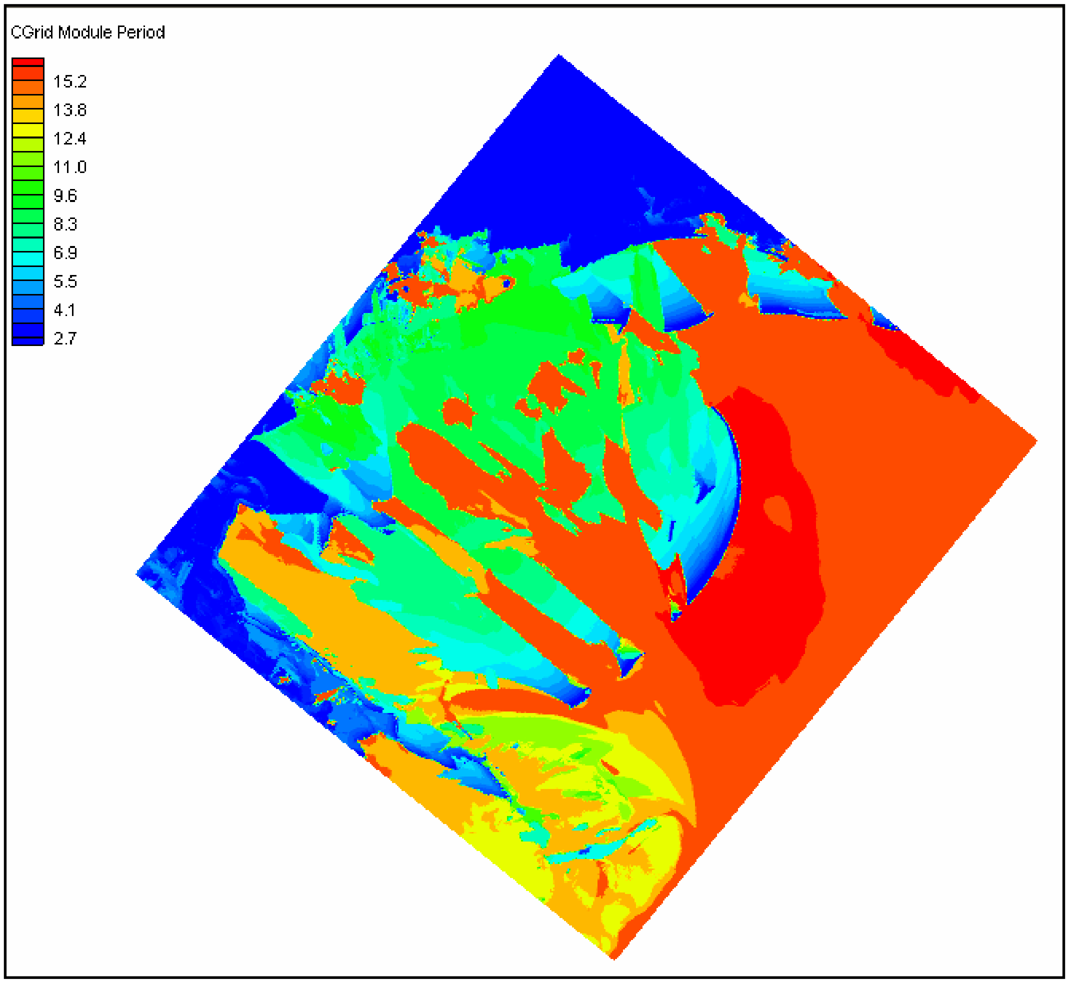



Figure 29. Southeast Louisiana modeled peak wave period corresponding to the maximum wave height for 0630 to 1800 UTC on 29 August 2005 (periods in sec)

Figure 32 shows color-shaded contours of the maximum storm surge, in feet NGVD29, for the entire Louisiana and Mississippi coastal region computed with the ADCIRC model. Peak surges in southeastern Louisiana were computed to be about 20 to 21 ft (dark orange contours), NGVD29, along the east-facing Mississippi River and back levees that protect communities along the river. At the levees facing Lake Borgne along the MRGO, maximum computed surges where 18 to 19 ft (light orange contours). Along the south shore of Lake Pontchartrain, maximum surges were computed to be between 9 and 13 ft (green contours). Along the coast of Mississippi, maximum surges were computed to be 27 to 29 ft (pink contours).

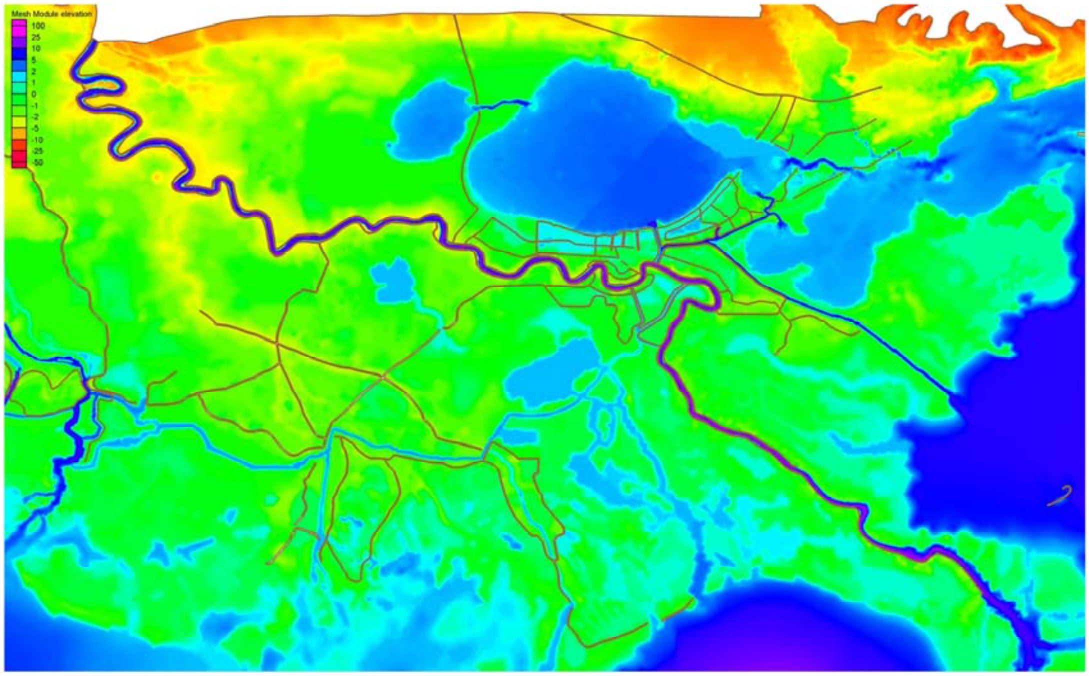



Figure 30.  Bathymetry/topography used in the ADCIRC storm surge model

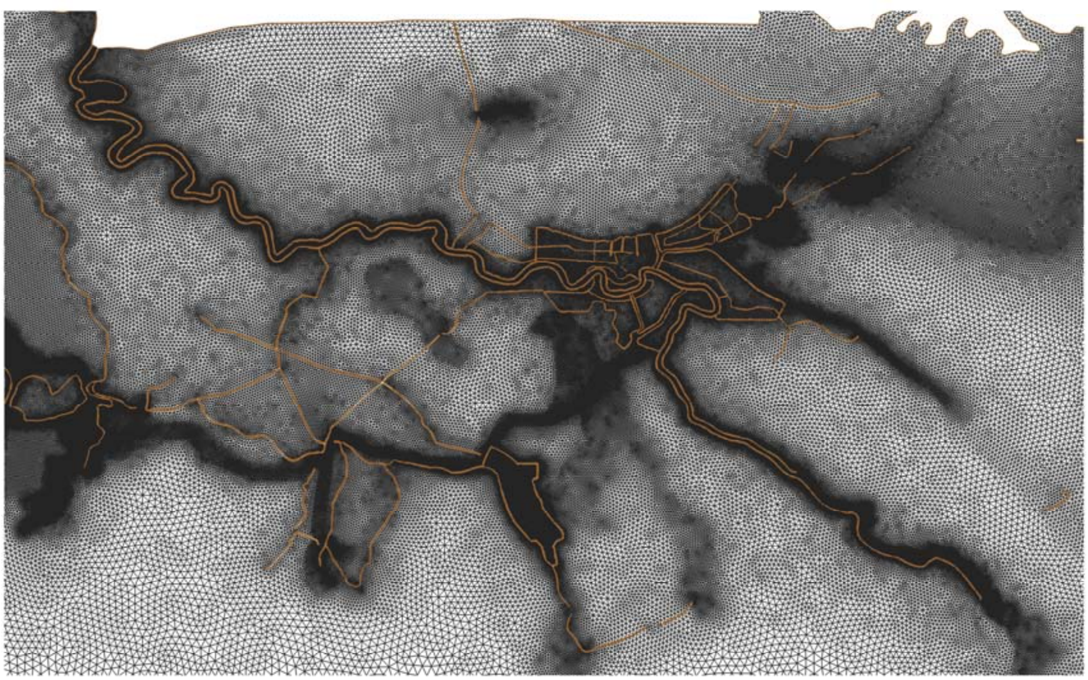


Figure 31.  Grid resolution used in the ADCIRC storm surge model

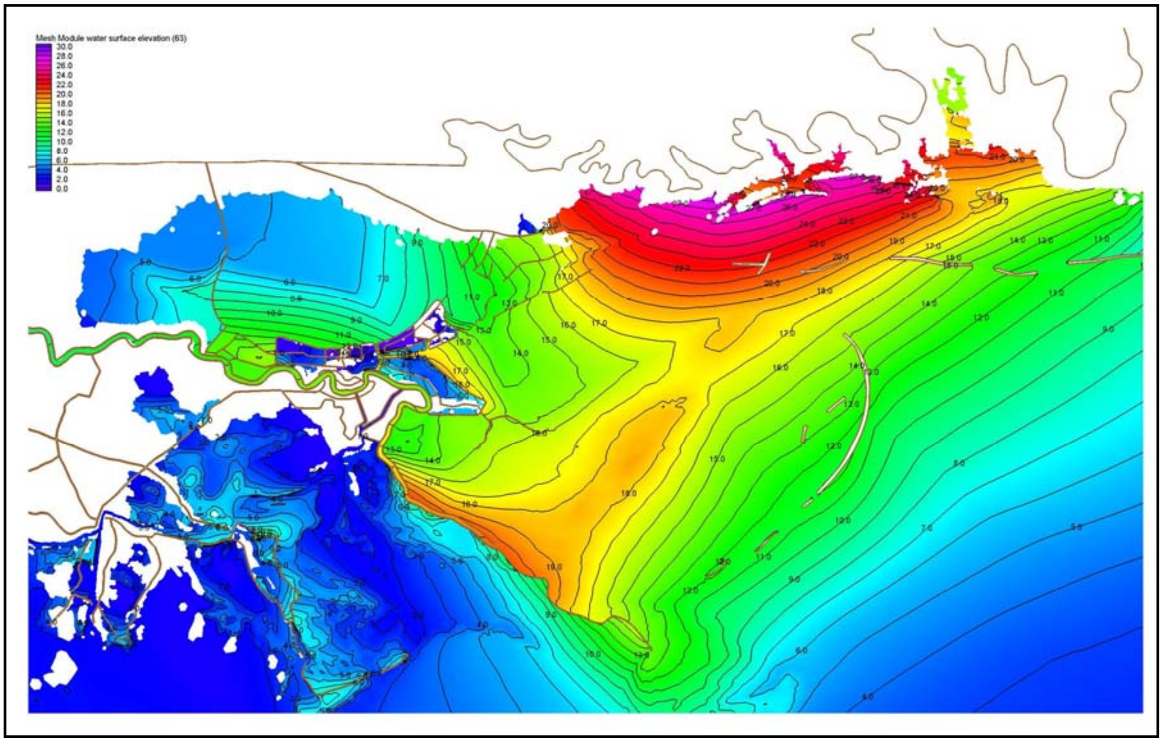



Figure 32. Maximum computed storm surge using the ADCIRC model, Mississippi to Louisiana region (water levels in feet, NGVD29)

Figure 33 shows the maximum calculated storm surge (red numbers) in feet, NGVD29, and measured HWMs (black numbers in parentheses, in feet, NAVD88) for the metropolitan New Orleans area. Note the difference in vertical datums. At present we believe that approximately 0.6 to 1.0 ft should be subtracted from elevations relative to NGVD29 (the computed surges in red) to convert them to NAVD88 for direct comparison with the HWMs which are in NAVD88. Ongoing work in the IPET datums task will lead to more accurate information regarding datums and datum conversions. The observed trends and magnitudes of peak water levels are reasonably well represented by the present state of the storm surge modeling.

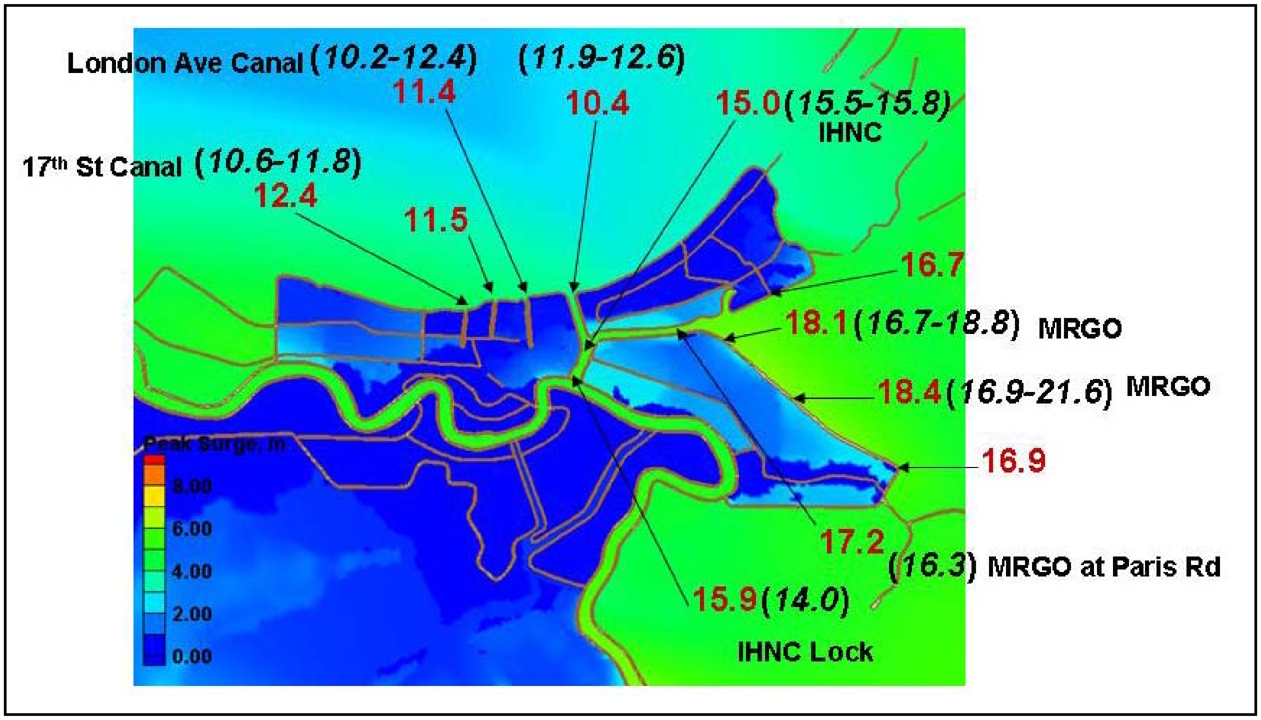



Figure 33. Comparison of maximum computed storm surge and measured high water marks in metropolitan New Orleans area (water elevations in feet); red numbers are model results relative to NGVD29; black numbers are HWMs relative to NAVD88

Figures 34 through 36 show computed time series of water surface elevation, in feet NGVD29, at twelve locations throughout the metropolitan New Orleans area. Figure 34 shows locations along the south shore of Lake Pontchartrain. The computed time of arrival of the peak surge is about 13:45 GMT on August 29, 2005 (or about 8:45 a.m. local time, CDT). The simulated time of arrival for the peak surge is a bit ahead of the observed time of arrival, which is estimated to have occurred between 9:00 a.m. and 11:00 a.m. CDT. Figure 35 shows the same information for locations in the IHNC and MRGO. The computed time of arrival of the peak surge at the IHNC Lock is about 13:15 GMT (8:15 a.m. CDT). The observed hydrograph at the Lock shows arrival of the peak surge at about 9:00 a.m. CDT, or slightly later.

The present state of the modeling appears to compute the predicted time of peak surge about 45 min to an hour earlier than the observed times of arrival. This difference, applied to model-predicted times of arrival along Lake Pontchartrain, suggests that the arrival of peak surge along Lake Pontchartrain was about 9:30 to 9:45 a.m. CDT, which is more consistent with observations. Inclusion of astronomical tide, improved wind fields, and inclusion of wave radiations stresses in the next phase of modeling might change and possibly improve the predictions of peak surge arrival time. Model results indicate that the peak of the storm surge wave took approximately 45 min to propagate from the southeastern corner of the levee along the MRGO in St. Bernard Parish to the junction of the IHNC and MRGO, as the storm tracked to the north-northeast.

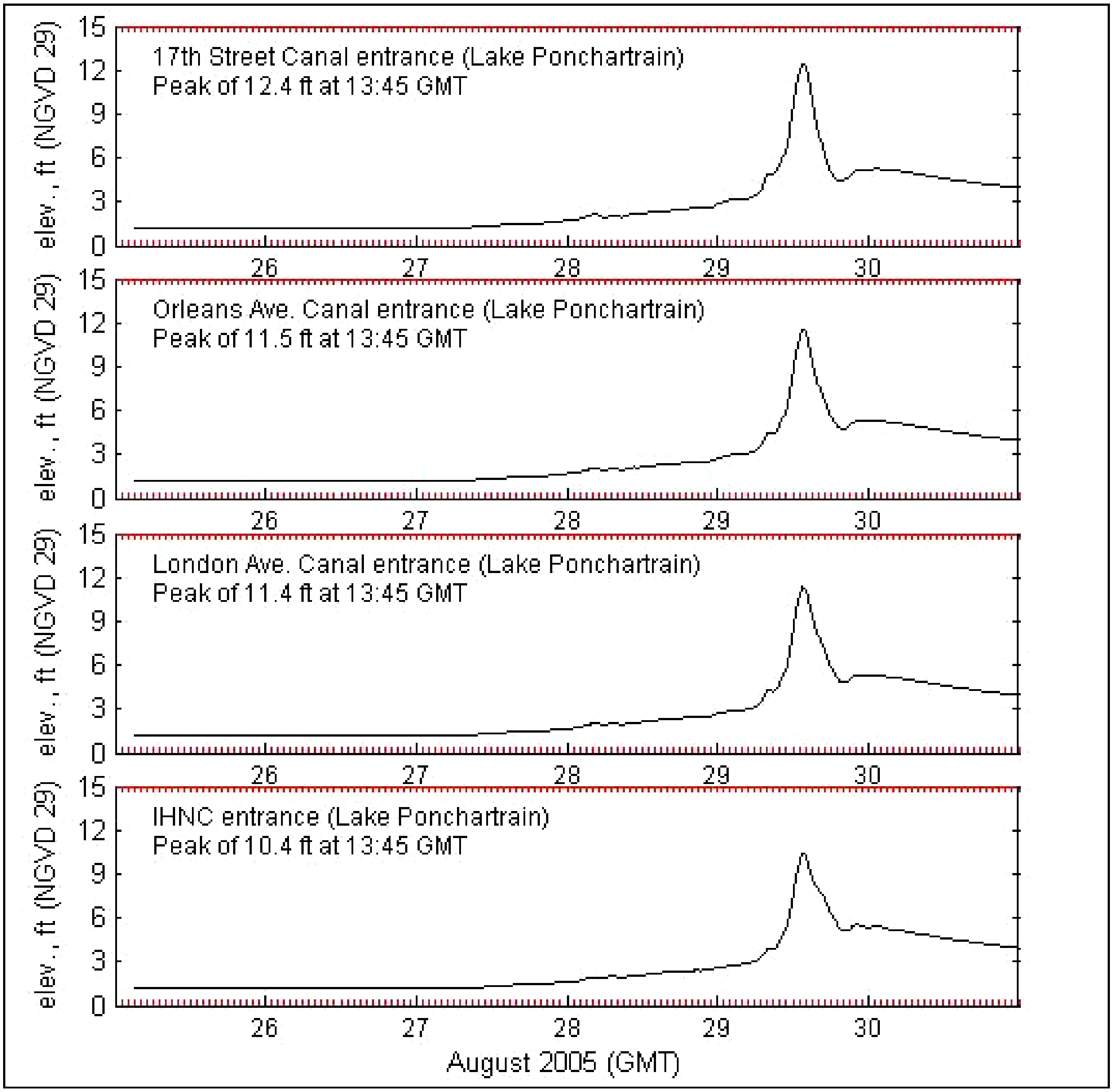



Figure 34. Change in water surface elevation, with time, for locations along the south shore of Lake Pontchartrain

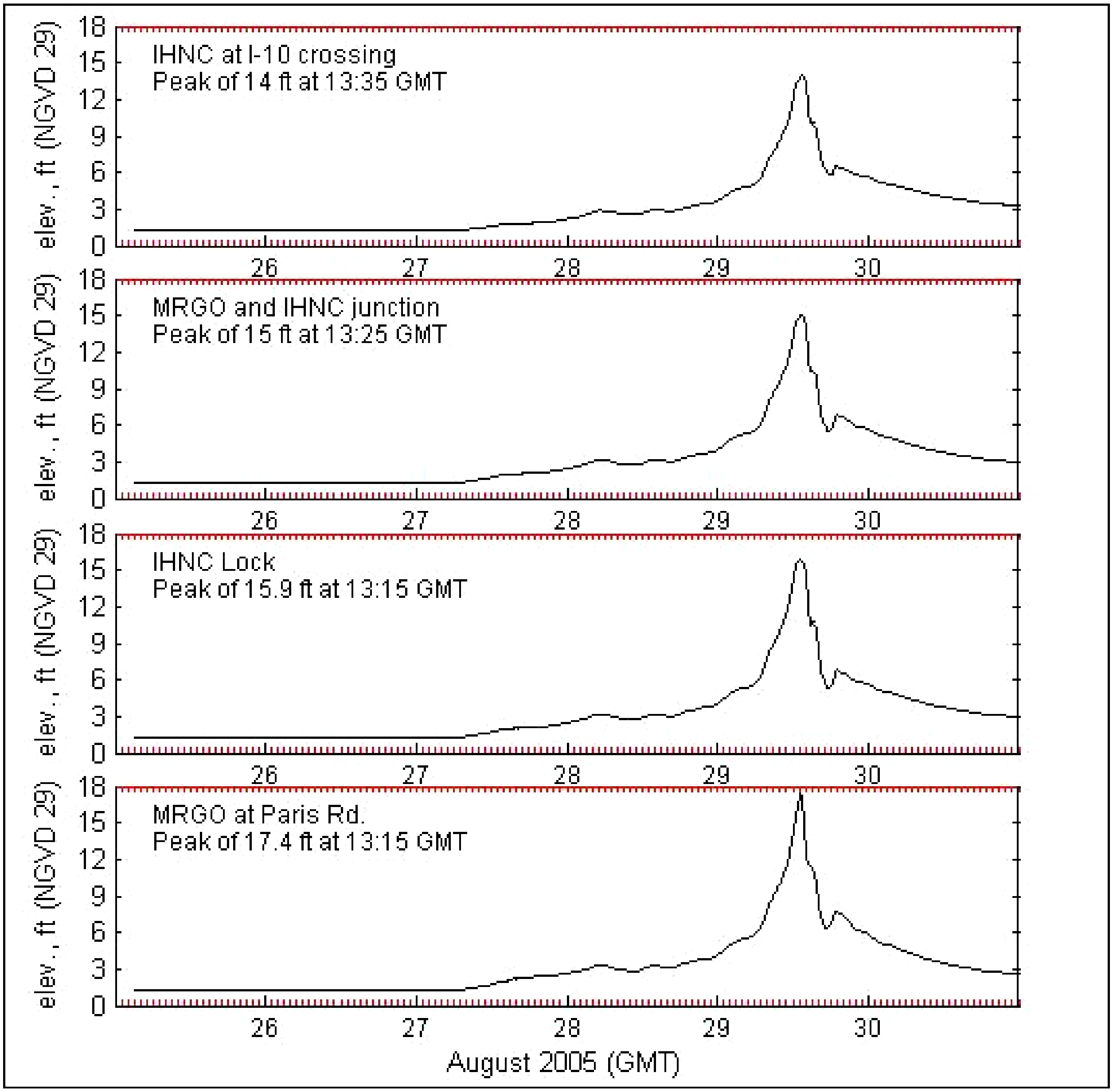



Figure 35. Change in water surface elevation, with time, for locations in the IHNC and MRGO

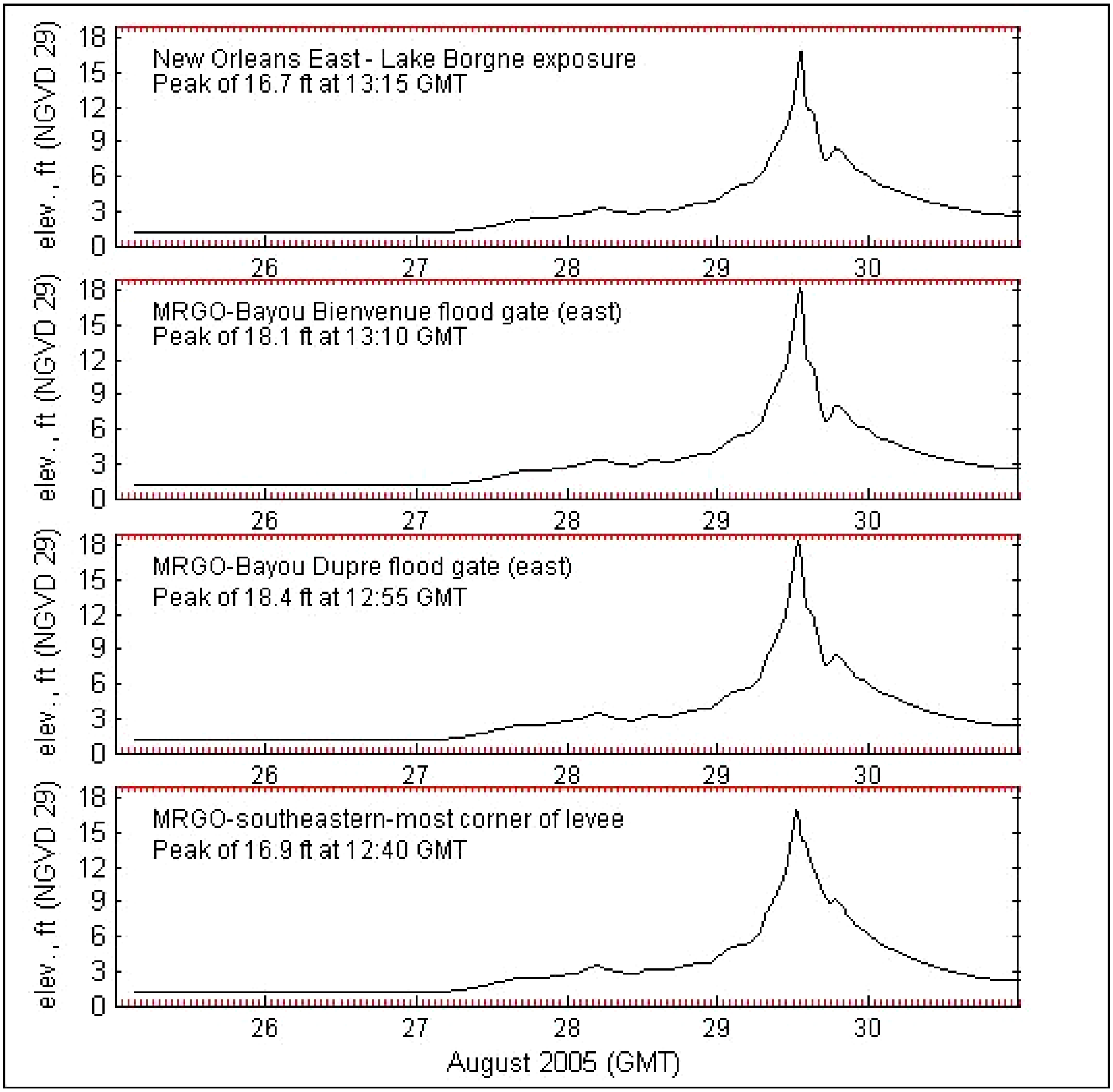



Figure 36. Change in water surface elevation, with time, for locations along the MRGO with exposure to Lake Borgne

## The Way Ahead

The next phase of work will involve continued examination and analysis of all high water marks and the hydrographs, comparison of model predictions to high water marks and the hydrographs, and comparison of the high water marks to water levels considered in the original design of the flood protection projects. High water marks collected in areas outside the metropolitan New Orleans area will be added to the analysis.

In the area of winds and pressures, work will include improvements to the wind fields by maximizing use of measurements in the method to create the wind fields, measurements that were not available at the time the preliminary wind fields were created. The work will evolve from using PBL-generated winds in the storm surge modeling toward use of H*Wind snapshots and the OWI process of blending various wind information products into wind fields to be used in the modeling.

For nearshore wave modeling, the next step will be to add a grid for the Mississippi coastline. Wave setup in that region will increase the surge elevations in Lake Pontchartrain, and setup must be treated consistently in all the wave model domains. Grid resolution will also be increased in the south and southeast grids from 200 m to 100 m to determine if the gradients are being sufficiently resolved. Iteration between the wave and surge will also be investigated. Spatially variable wind fields will be evaluated, as will the importance of temporal variability of the winds. This may not prove to be important because wave growth is generally depth-limited in the shallow, nearshore areas. Although no wave data are available in the marsh area to establish fictional losses due to vegetation, sensitivity analysis will be performed to estimate a range of impacts. Finally, the contribution of white capping to the wave momentum fluxes will be investigated. Offshore wave modeling work will include an update with the improved wind fields and further examination of some of the technical issues and differences between model results and measurements that were identified in the preliminary analysis. Time series of wave conditions will be produced at key locations.

The next phase of storm surge modeling work will involve use of improved wind fields, inclusion of tide and riverine inflows for the specific time period of Katrina, and comparisons with high water mark and hydrograph data. Differences in predicted arrival time of the peak surge, between observations and model predictions, will be examined. Work will include linking the storm surge and wave models, focusing first on inclusion of wave radiation stresses into the computation of storm surge to capture the momentum contributions from breaking waves, and white-capping effects will be examined. Sensitivity tests will also be performed to examine the influence of a drag coefficient cut-off which has been suggested by recent research on hurricane winds and hurricane wave and surge modeling, as well as the influence of temporal wind-averaging interval (conversions from 1-min, to 10-min, to 30-min average winds). Time series results for other flood protection projects in the study domain will be produced.

# References

Cox, A. T., and V. J. Cardone, 2000. Operational system for the prediction of tropical cyclone generated winds and waves. *6th International Workshop on Wave Hindcasting and Forecasting*, November 6-10, 2000, Monterey, CA

Cox, A.T., J.A. Greenwood, V.J. Cardone, and V.R. Swail, 1995. An interactive objective kinematic analysis system. Preprints, *Fourth International Workshop on Wave Hindcasting and Forecasting*, Banff, Alberta, Canada, Atmospheric Environment Service, 109-118.

Holland, G.L., 1980. An analytical model of the wind and pressure profiles in hurricanes. *Mon. Wea. Rev.,* Vol 108, 1212-1218.

Kalany, E., M. Kanamitsu, R. Kistler, W. Collins, D. Deaven, L. Gandin, M. Iredell, S. Saha, G. White, J. Woollen, Y, Zhu, M. Chelliah, W. Ebisuzaki, W. Higgins, J. Janowiak, K.C. Mo, C. Ropelewski, J. Wang, A. Leetmaa, R. Reynolds, R. Jenne, and D. Joseph, 1996. The NCEP/NCAR 40-year reanalysis project. *Bull. American Met. Society*, Vol. 77, No. 3, 437-471.

Powell, M. D., S. H. Houston, L. R. Amat, and N. Morisseau-Leroy, 1998. The HRD real-time hurricane wind analysis system. *J. Wind Engineer. Ind. Aerody*., 77&78, 53-64.

Thompson, E. F., and V. J. Cardone, 1996. Practical modeling of hurricane surface wind fields. *ASCE J. of Waterway, Port, Coastal and Ocean Engineering,* Vol 122, No. 4, 195-205.

# Hydrodynamic Forces and Overtopping Analysis

## Introduction

To understand the performance of levees and floodwalls during Hurricane Katrina, it is necessary to obtain detailed estimates of hydrodynamic forces and overtopping rates throughout the storm. Essentially no measured information exists in the vicinity of the levees and floodwalls; consequently, it is necessary to obtain such estimates from a combination of theoretical/empirical analyses, numerical models, and physical models. Information from the IPET task on Hurricane Katrina Storm Surge and Waves (Regional Perspective) will be used as boundary conditions to much more detailed analyses and simulations in localized areas surrounding the levees and floodwalls. This Task will model all areas within the primary New Orleans drainage/navigation canals (17th Street Canal, Orleans Canal, London Avenue Canal, and Inner Harbor Navigation Canal), as well as along the hurricane protection levees surrounding parishes in the vicinity of New Orleans.

Similar to the approach followed in the regional perspective on storm surges and waves during Hurricane Katrina, we will adopt a phased approach with solutions representing nominal 75%, 90%, and 95% levels of comprehensiveness. Due to the nature of the dependence of the detailed work on the regional perspective, work under this task will lag the regional specification by two to four weeks. Information from this task will be communicated to all other IPET task groups.

The task co-leaders for this effort will be Donald T. Resio, Senior Scientist, ERDC-CHL, and Robert G. Dean, Professor Emeritus, University of Florida.

## Objectives

The objective of this Task is to develop time histories of local wave and water-level forces acting on flood protection structures within the areas referenced above, including mean flow over the levee/floodwall, wave over-topping, and static and dynamic pressure forces acting on levees and floodwalls. These estimates will consider uncertainties in boundary forcing, local conditions, and model-to-model differences. All available information will be used to ensure that results are consistent with high water marks and other physical evidence in the study area. The possibility of levee/floodwall damage due to possible barge impacts will also be investigated under this task.

## Scope

The overall scope of this effort includes three primary elements:

*a.* general analyses of forces and overtopping;

*b.* numerical and physical modeling of hydrodynamic phenomena; and

*c.* estimates of possible impact forces due to a barge striking a floodwall.

### ***1. General Analyses of Forces and Overtopping***

The intent here is to use simple analytical solutions to determine the following for Hurricane Katrina:

*a.* Waves and water levels within the canals including wave transmission past bridges

*b.* Wave and flood overtopping of floodwalls

*c.* Hydrodynamic loading on floodwalls

*d.* Wave and flood runup and overtopping on earthen levees

*e.* Lakefront revetment armor damage

It is expected that these results will provide bracketing solutions for the more detailed numerical and physical model studies that are underway.

### Canal Floodwall Overflow and Hydrodynamic Force Analysis

For the 17th Street Canal, the Municipal Marina at the east side of the entrance and the Coast Guard harbor on the west side both acted to limit waves from entering the canal. A foot bridge and the Hammond Highway Bridge also acted to limit wave energy entering the canal when water levels were near the bridges. The other canals also had obstructions from bridges during conditions of high water.

### Wave and Water Level Input

Wind wave generation in Lake Pontchartrain is fetch-limited. So the wave field during Hurricane Katrina was likely to have been very three-dimensional (short-crested). The penetration of directional random waves into either the 17th Street or London Avenue Canals is analyzed using the angular spreading method given in Goda (1985). The method is modified to account for wave reflection from the floodwall. The principal wave direction is assumed to be in the same direction as the canal alignment. This wave direction is from the north and corresponds to a time when the hurricane was just east and slightly north of Lake Pontchartrain and the wind was blowing from the north. The wave penetration is expected to be the largest for the straight penetration. However, this may not be the condition of maximum load on the floodwalls. The maximum load may have occurred when the water level was lower and larger waves were able to penetrate further into the canals. The timing of maximum loading will be further investigated in later deliverables.

The incident directional random wave spectrum is denoted by $Si(f,\theta)$ where $f$ = frequency and $\theta$ = direction clockwise from the principal wave direction. Definition sketches are shown in Figures 37 and 38.

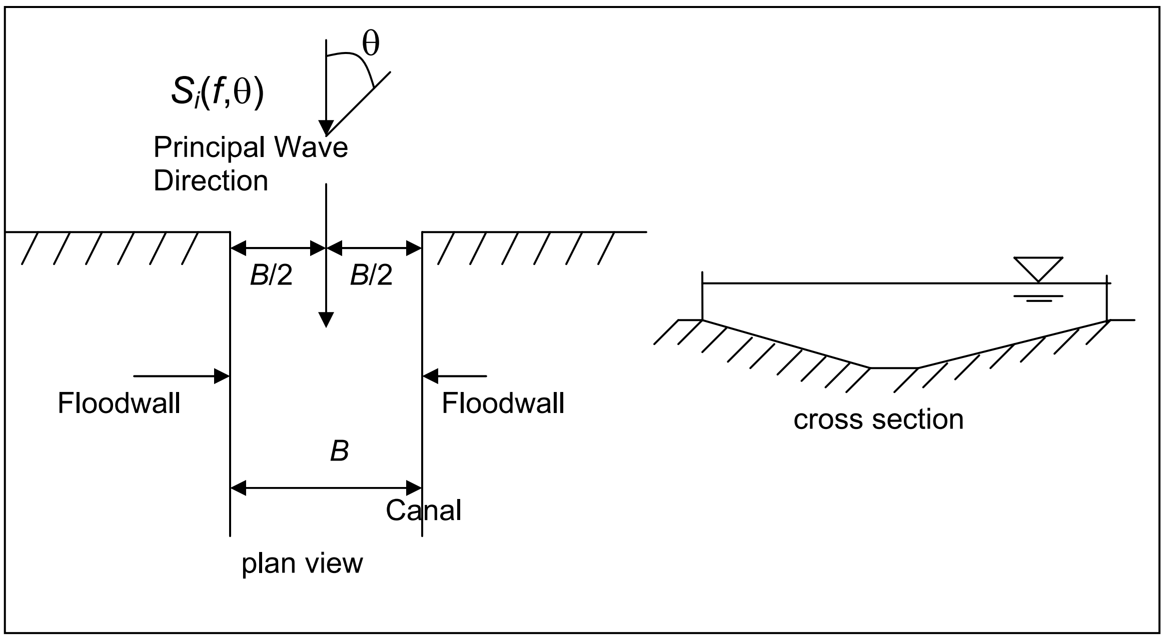



Figure 37. Definition sketch of plan view of irregular directional wave spectrum entering canal and canal cross section

Relations for the wave spectra, angular spreading, reflection, diffraction, are used to derive a relation for the wave height attenuation as a function of distance down the canal. The initial equation is

$$F^2(x) = \frac{2}{\pi}\left[\theta_1 + \frac{1}{2}\sin 2\theta_1\right] + \sum_{n=2}^{\infty}\frac{2}{\pi}R^{2(n-1)}\left[\theta_n - \theta_{n-1} + \frac{1}{2}(\sin 2\theta_n - \sin 2\theta_{n-1})\right] \quad (1)$$

with $\tan\theta_n = \dfrac{(2n-1)B}{2x} \quad for \quad n = 1, 2, 3...$

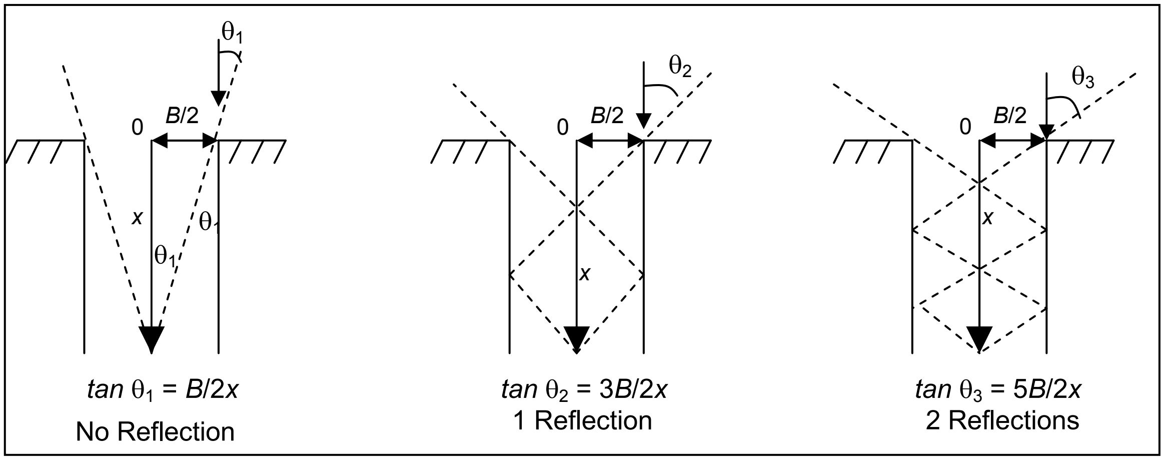



Figure 38. Definition sketch of directional waves entering canal and reflecting from floodwalls

where the value of $F2$ can be computed as a function of $x/B$ for the given reflection $R$.

### Wave Transmission Under Canal Bridges

The interaction of a bridge deck with wind waves is very complicated due to wave overtopping and air entrapment between beams as shown in Figure 39. However, the wave transmission coefficient $Kt = Ht/Hi$ may not be very sensitive to the detailed wave mechanics in the vicinity of the bridge deck. As a first approximation, the bridge deck may be approximated as a rectangular box and linear wave theory may be applied by neglecting energy dissipation and wave energy transmission over the bridge.

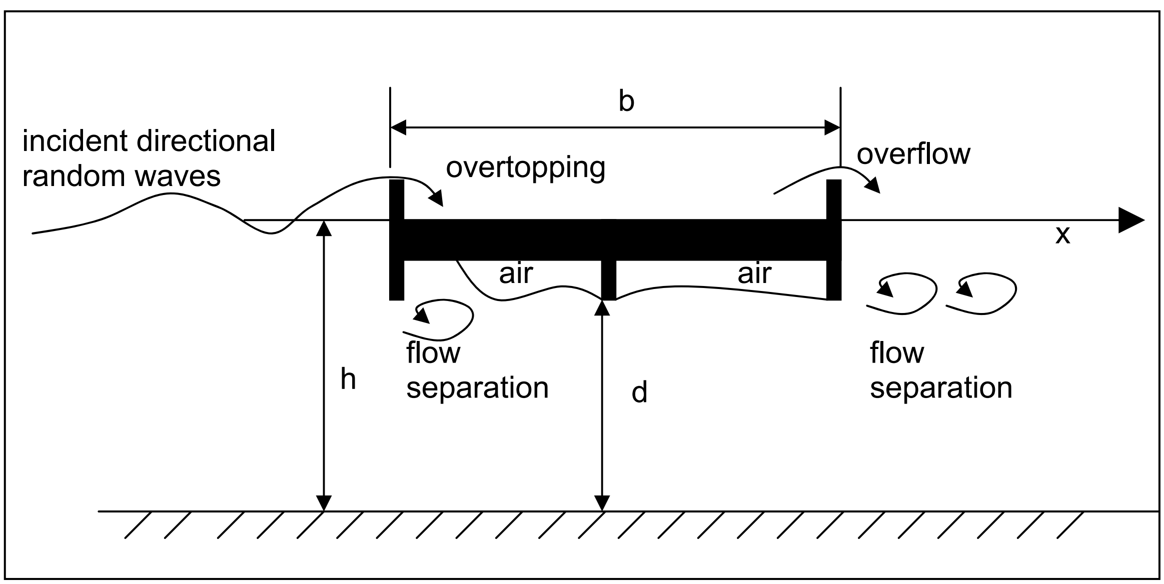



Figure 39. Conceptual sketch of wave interaction with bridge deck

The simple analytical solution is derived here as

$$K_t^2 = \frac{4}{4+\left(kb\frac{h}{d}\right)^2} \approx \frac{4}{4+(kb)^2} \approx \frac{4}{4+(2\pi)^2(b/L)^2} \qquad (2)$$

where $k = 2\pi/L$ = wave number; $b$ = bridge deck width; $d$ = water depth below the bridge deck; and h = water depth in canal. Since it is difficult to estimate an equivalent depth below the actual bridge deck, it is assumed that $d \approx h$. Equation 2 can be used to determine the expected range of wave transmission through the bridges.

## Overflow at Floodwall

Water overflowing the floodwalls along the Inner Harbor Navigation Canal caused extensive scour and erosion in some locations. The proposed simple model is based on elementary fluid mechanics as depicted in Figure 40 where η = free surface elevation above the top of the floodwall; *Hw* = floodwall height above the horizontal ground. The overflow is assumed to be critical and its horizontal velocity *vo* is assumed to be given by *vo* = (*g*η)1/2. The overflow is assumed to drop as a body in free fall over the vertical distance of (*Hw* + η/2). Then, the free fall duration *t* is given by *t* = [(2*Hw*+η)/g]1/2. The horizontal distance *W* of the free fall is given by *W* = *vot* which can be expressed as

$$W = \sqrt{\eta(2H_w + \eta)} \quad \rightarrow for\ \eta << H_w \rightarrow \quad \frac{W}{H_w} \approx \sqrt{2\eta / H_w} \qquad (3)$$

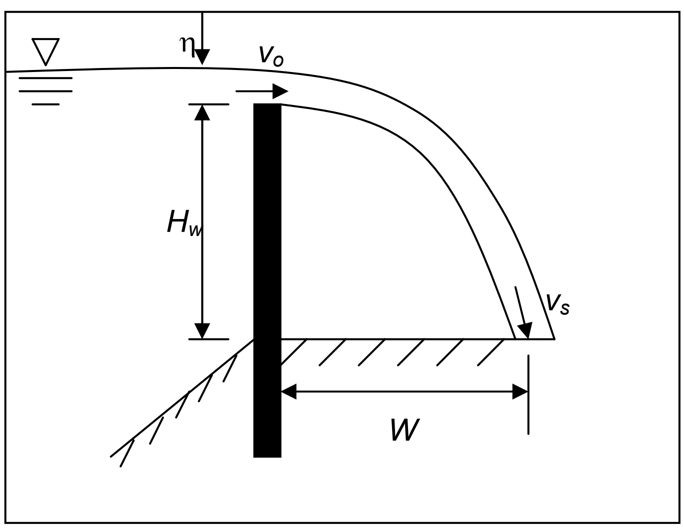



Figure 40. Definition sketch for overflow of floodwall

On the other hand, the vertical velocity at the time of overflow impact is given by *gt*; whereas, the horizontal velocity *vo* remains constant during the free fall. The impact *vs* for scour is hence estimated as

$$v_s = \sqrt{2g(H_w + \eta)} \approx \sqrt{2gH_w} \quad for\ \eta << H_w \tag{4}$$

Seijffert and Philipse (1990) showed experimentally that water velocities of 13 ft/s essentially parallel to the grass mats on the Dutch dikes would cause erosion after about 10 hours. The approximate Equation 3 for *h*<<*Hw* yields *h* = *W*2/(2*Hw*) may be used to estimate the variation of h along the canal for the measured values of *Hw* and *W*. Since no free surface elevation data are available, an inverse method based on this simple relationship should be useful. The estimated variation of *h*(*y*) as a function of distance *y* from the end wall, which is assumed to satisfy the no flux boundary condition may be used to estimate the discharge *Q* in the canal induced by overflow (Figure 41). Assuming steady state at the time of peak water level, the overflow is approximately given by

$$Q(y) = 2\int_0^y \sqrt{g}\left[\eta(y')\right]^{1.5} dy' \tag{5}$$

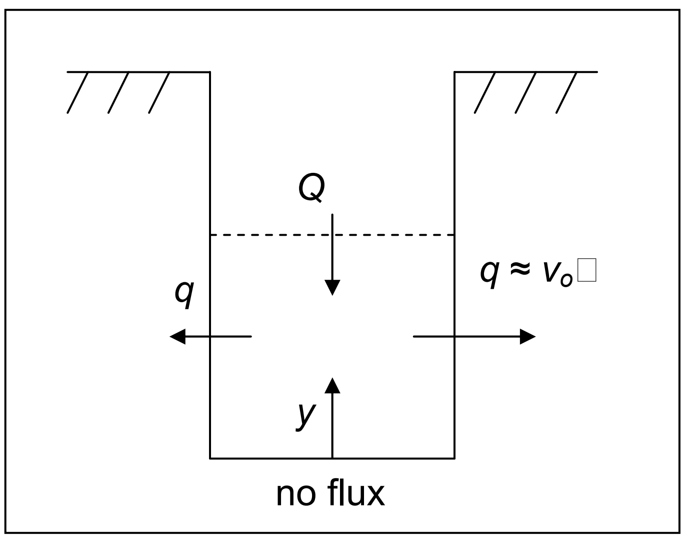



Figure 41. Canal flow

where the overflow rate *q* per unit length of the floodwall is estimated as *q* ≈ *vo*η with *vo* = (*g*η)1/2. It is noted that a large-area storm tide model will predict a very small value of *Qc* in the canal in the absence of overflow, where *Qc* is the discharge at the entrance to the canal. Assuming that the free surface elevation ηc in the canal does not vary much along the canal, the conservation of the water volume in the canal yields

$$Q_c = lB\frac{d\eta_c}{dt} \tag{6}$$

where *l* = canal length; and *B* = canal width.

### Hydrodynamic Forces on Floodwall

The hydrodynamic input required for the analysis of seepage flow and geotechnical stability is the pressure distribution on the floodwall (only on the segment exposed to water directly) and the canal bottom (Figure 42). In the absence of wind waves, the pressure may be assumed to be hydrostatic below the still water level (SWL) due to storm tide varying hourly. The hydrostatic bottom pressure *Ps* is hence given by *Ps* = ρ*gh* with *h* = local water depth below SWL. The major question is which wave-induced pressure varying every second is appropriate for the analysis of slow seepage flow and geotechnical stability analysis. Moreover, it is not clear whether the repeated wave-induced pressure reduces the geotechnical strength of the foundation.

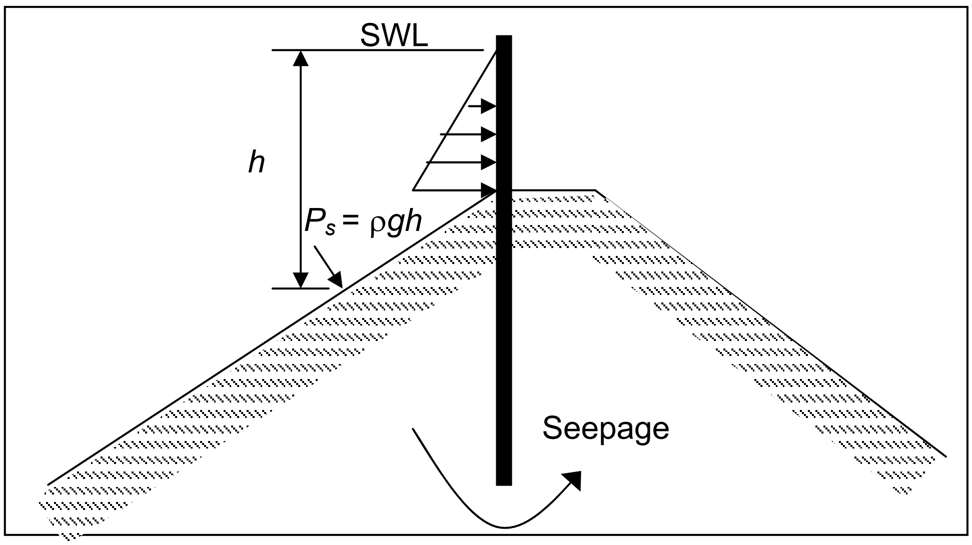



Figure 42. Definition sketch for forces on floodwall

Formulas for the wave-induced pressure, such as that of Goda (1985), were developed for vertical breakwaters that respond to individual waves. The formulas also assume that the maximum wave force acts simultaneously along vertical wall. This assumption results in the overestimation of the instantaneous wave force on the floodwall caused by the multi-directional mostly oblique waves in the canal. The formula of Goda (1985) predicts the wave-induced pressure *Pw* of the order of

$$P_w \approx 1.5 \rho g H \tag{7}$$

which was proposed by Hiroi (1919) according to Goda (1985). The design wave height *H* for a vertical breakwater on a rubble mound is normally taken as the maximum wave height *Hmax* ≈1.8*Hmo*. It appears reasonable to use *H* ≈ *Hmo* for the geotechnical stability analysis.

## Wave Runup on Levees and Revetments

In order to evaluate the performance of the Mississippi River-Gulf Outlet Levees and Mississippi River Levees, an analysis of wave runup and wave and steady flow overtopping is required. As discussed in the Coastal Engineering Manual (CEM 2002), the modern form for empirical prediction of irregular wave runup on coastal structures was given by Battjes in 1974. De Wall and Van der Meer (1992) and van der Meer and Janssen (1995) extended these results for various types of structures and incident wave conditions. The equations given for the 2-percent exceedance value of irregular wave runup on a slope are

$$\frac{R_{2\%}}{H_s} = 1.5\xi_{op}\gamma_r\gamma_b\gamma_h\gamma_\beta \qquad 0.5 < \xi_{op} \leq 2.0 \tag{8}$$

$$\frac{R_{2\%}}{H_s} = 3.0\gamma_r\gamma_b\gamma_h\gamma_\beta \qquad 2.0 < \xi_{op} < 3-4 \tag{9}$$

$$\xi_{op} = \frac{\tan\alpha}{\sqrt{s_{op}}} \qquad s_{op} = \frac{H_s}{L_{op}} \qquad L_{op} = \frac{gT_p^2}{2\pi} \tag{10}$$

where

| | | |
|---|---|---|
| *R*2% | = | wave runup height on the structure with 2 percent probability of exceedance |
| *Hs* | = | significant wave height, *Hmo* in this case, where *Hmo* = 4(*mo*)1/2 and *mo* is the zero moment of the incident wave spectrum |
| γ*r* | = | slope roughness correction, 1.0 for smooth slope |
| γ*b* | = | berm influence factor, 1.0 for non-bermed slope |
| γ*h* | = | depth-limited wave correction, 1.0 for Rayleigh distributed waves |
| γ*β* | = | wave direction and directional spreading correction, 1.0 for head-on waves |
| *ξop* | = | Iribarren parameter based on the peak period |
| *Lop* | = | airy wave length based on the peak period |
| *sop* | = | wave steepness based on the local wave height, deep water wave length, and peak period |
| α | = | structure seaward slope |
| *Tp* | = | wave period corresponding to spectral peak |
| *g* | = | acceleration of gravity |

The runup reduction formula for depth-limited waves is the Raleigh relationship between the 2 percent exceedance value of wave height and the spectral significant wave height or

$$\gamma_h = \frac{H_{2\%}}{1.4 H_s} \tag{11}$$

This relation requires measurement of H2%. The physical model may be used to determine this value. The correction for slope roughness is given as

$\gamma r$ = 0.9 – 1.0 for grass slope
$\gamma r$ = 0.50 – 0.60 for stone armor

The correction for wave direction is given by:

$$\text{Long-crested waves: } \gamma_\beta = \begin{cases} 1.0 & \text{for } 0^0 \le \beta \le 10^0 \\ \cos(\beta - 10^0) & \text{for } 10^0 < \beta \le 63^0 \\ 0.6 & \text{for } \beta > 63^0 \end{cases}$$

$$\text{Short-crested waves: } \gamma_\beta = 1 - 0.0022\beta \tag{12}$$

For rock-armored slopes, appropriate for lakefront revetments, the CEM gives similar equations for runup. Also, De Waal and van der Meer (1992) provided similar equations for determining irregular wave runup on a compound slope. These relations can be used to determine the extent of the wave runup on the slopes of structures.

### Wave Overtopping of Levees

For impermeable rough slopes, the volume rate of irregular wave overtopping per unit length of structure $q$ is given by van der Meer and Janssen (1995) as

$$\frac{q}{\sqrt{gH_s^3}} \sqrt{\frac{s_{op}}{\tan\alpha}} = 0.06 \exp\left( -5.2 \frac{R_c}{H_s} \frac{\sqrt{s_{op}}}{\tan\alpha} \frac{1}{\gamma_r \gamma_b \gamma_h \gamma_\beta} \right) \tag{13}$$

$$\textit{for} \quad \xi_{op} < 2 \quad \textit{and} \quad 0.3 < \frac{R_c}{H_s} \sqrt{\frac{s_{op}}{\tan\alpha}} \frac{1}{\gamma_r \gamma_b \gamma_h \gamma_\beta} < 2 \tag{14}$$

and

$$\frac{q}{\sqrt{gH_s^3}} = 0.2\exp\left(-2.6\frac{R_c}{H_s}\frac{1}{\gamma_r\gamma_b\gamma_h\gamma_\beta}\right)$$
$$for \quad \xi_{op} > 2 \qquad (15)$$

These equations and similar equations for impermeable smooth and permeable rough slopes will be used to evaluate the degree of wave overtopping on structures where there was no steady flow overtopping.

### Stability of Stone Armor

Incipient stability and accumulated damage to armored levees along the Lake Pontchartrain lakefront will be analyzed using basic armor stability relations in order to provide some degree of insight into the amount of damage that was observed along these structures.

## *2. Numerical and Physical Modeling of Local Hydrodynamic Forces and Overtopping*

In the vicinity of the large protective levees (i.e. those not associated with the inner-city canals), the local water levels will be estimated from the Task 4 results. A combination of this water level information with Boussinesq model runs and statistical wave/wave run-up properties will be used to estimate near bottom velocities for potential scour. Estimates of the time histories of both wave-related and mean-flow overtopping velocities will also be given for these levees. The model selected for application (pCOULWAVE) has been developed by Professor Patrick Lynett of Texas A&M University. It is based on a highly nonlinear extension of the original mildly nonlinear form of the Boussinesq equation and has been shown to be capable of handling run-up and overtopping of steep-sided features. A team consisting of Jeff Melby (ERDC-CHL), Nobu Kobayashi (University of Delaware), and Patrick Lynett (Texas A&M University) will perform this work.

Inside the canals (i.e. 17th Street, Orleans, London Ave, IHNC, MRGO), the situation is quite complex. No existing model includes all of the phenomena that potentially are significant in this region. For this reason, a suite of different models will be utilized that should collectively represent all of these phenomena very well. Since little or no information exists on waves within the canal areas, this approach should provide valuable information pertaining to model-related differences in wave estimates within the canals. The models and teams utilized here are described below:

**ADCIRC model.** The ADCIRC model will be exercised on a very small grid (1-5 meters) along all of the canals. This model will provide estimates of mean water levels along the canal related to direct wind forcing over the duration of the storm. This model will use boundary conditions from the combined wind and wave set-up along the canal entrances (which will be calibrated to high-water marks as part of Task 4). The limited high-water marks from the interior of the canals and information from the forensics team (described below) will be used to calibrate the results inside the canals. A team consisting of Ray Chapman (ERDC-CHL), Mary Cialone (ERDC-CHL) and Rick Luettich (UNC) will perform this work.

**Physical model.** A physical model (1:40-1:50 scale) will be constructed for the 17th Street Canal. This model is needed to estimate wave transmission under submerged (or near submerged) bridges. None of the numerical models can provide this information; hence, the physical model will provide calibration/ validation information for the numerical models in this effort. The physical model will also be used to help quantify the potential for wave groups to create surging currents within the canals (resonant and non resonant), as well as overtopping rates due to both wave and mean water levels exceeding the sides of the levees. Bill Seabergh, Jeff Melby, Robert Dean, and Nobu Kobayashi will lead this effort.

**STWAVE model.** This model is the only model among the model suite being utilized that can estimate wave generation along the canal. STWAVE can be run in either a coupled mode or an uncoupled mode with the ADCIRC model, depending on the degree of wave set-up due to wave energy losses along the canal. Besides wave generation by the wind, this model contains all phase-averaged source terms required for modeling at this scale (for example: wave breaking, bottom dissipation, nonlinear four-wave interactions, refraction, shoaling, and side reflection). Information from the physical model will be required to calibrate wave energy losses as waves pass under submerged or near-submerged bridges. Don Resio (ERDC-CHL), Jane Smith (ERDC-CHL), and Mary Cialone (ERDC-CHL) will perform this work.

**Boussinesq model.** This model provides an excellent representation of phase resolving phenomena within a wave field (for example complex diffraction-refraction-reflection patterns). It also allows for nonlinear (three-wave) interactions among wave components of a spectrum. Such interactions are potentially significant contributors to long-period (10's of seconds to minutes) oscillations within the canals. Boussinesq models are depth averaged, so these model runs will also require calibration information from the physical model for the situation of submerged or near-submerged bridges. The Boussinesq model does not contain a validated wave generation source term; consequently, information on any significant wave generation along the canal will have to be gained from the STWAVE model. Jeff Melby (ERDC-CHL), Patrick Lynett (Texas A&M University), Nobu Kobayashi (University of Delaware) will perform this work.

**Analysis of forensics evidence for hydrodynamic forcing.** A study of the evidence for various phenomena – water levels and slopes of water levels in canals, evidence of some/massive overtopping, wave action (debris size/ distribution), erosion of earthen levees (back side/front side), distribution of water levels within canals (trapped/resonant standing waves), failure pattern will be used to be as sure as possible that no physical process acting on the waves and water levels is overlooked and that all results are consistent with the physical evidence. Site visits, analyses of collected data, analytical models, and other such methods will be used in this investigation. Don Resio, Robert Dean, Jeff Melby, and Nobu Kobayashi will perform this work.

### *3. Analysis of Possible Barge Impacts on Floodwall*

We will address the issue of whether the barge that traversed from the Industrial Navigation Harbor Canal (INHC) through the flood wall to the Lower Ninth Ward could have been a potential cause of the levee failure in this area or whether the barge was simply transported through the levee subsequent to its failure. Emphasis will be on establishing the associated forces relative to this issue.

This effort will examine wind forces exerted on the barge and the associated velocity, momentum and energy of the barge as it traverses a path across or diagonally along the canal to the location of levee failure. This analysis considers the situation prior to levee failure and no water current forces are considered. Following development of the velocity and trajectory equations, examples are presented to illustrate application of the methodology.

## Product Delivery Schedule

Estimates of time varying forces on levees during Hurricane Katrina (water levels, wave heights [statistics of forces], overtopping rates, vertical distribution of essential hydrodynamics and forces, total force, total moment) will be delivered on the following schedule:

30% level – January 15
60% level – March 15
90% level – April 15.

These results will include estimate of uncertainty (model-type-related, boundary forcing, local forcing [wind, reflections, etc.], local reflection coefficients, and wave generation/decay over the length of the canal.

## Status

### *1. General analyses of forces and overtopping*

Preliminary estimates of near bottom velocities relative to their ability to erode material have been completed but will be reported at a later date.

### *2. Numerical and Physical Modeling*

Numerical grids for the ADCIRC and STWAVE modeling have been developed along the following lines:

**Industrial Canal.** It has been determined that simulations of the Industrial Canal would be best handled within the existing 374,000-node New Orleans grid (TF_01) to appropriately account for interactions between Lake Pontchartrain and Lake Borgne. Resolution in the existing model is most likely sufficient to determine detailed hydrodynamics within this canal; however, bathymetry needs to be updated (Figure 43).

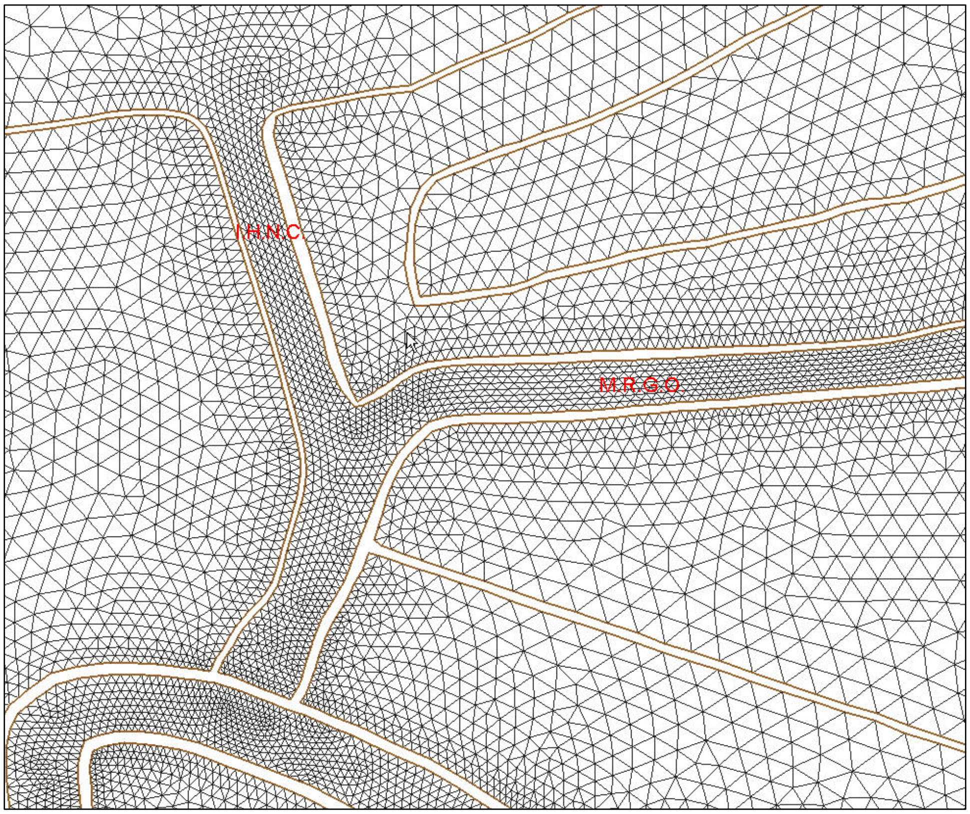



Figure 43. Existing IHNC and MRGO ADCIRC TF_01 grid resolution

**17th Street and London Avenue Canals.** The 17th Street and London Avenue Canals are connected only to Lake Pontchartrain. Therefore, separate, smaller grid(s) will be used to determine detailed hydrodynamics in these canals. Preliminary versions of grids for these areas have been developed and are in the progress of undergoing sensitivity tests. Figure 44 provides an example of results from one test.

Modification of the STWAVE model to allow side reflections has been completed and preliminary testing within the 17th Street Canal is underway.

**Boussinesq testing.** Testing of wave propagation, run-up, and overtopping of a section of St. Bernard Parish has been completed.

The physical hydraulic model for the 17th Street Canal has progressed to the model design stage as of the report date. A facility has been selected for the model site. This basin (see Figure 45) is located in Building 6006 at the Vicksburg ERDC site and is the most modern facility for performance of physical hydraulic model work. As of this date, an existing model is being removed and site preparation is underway.

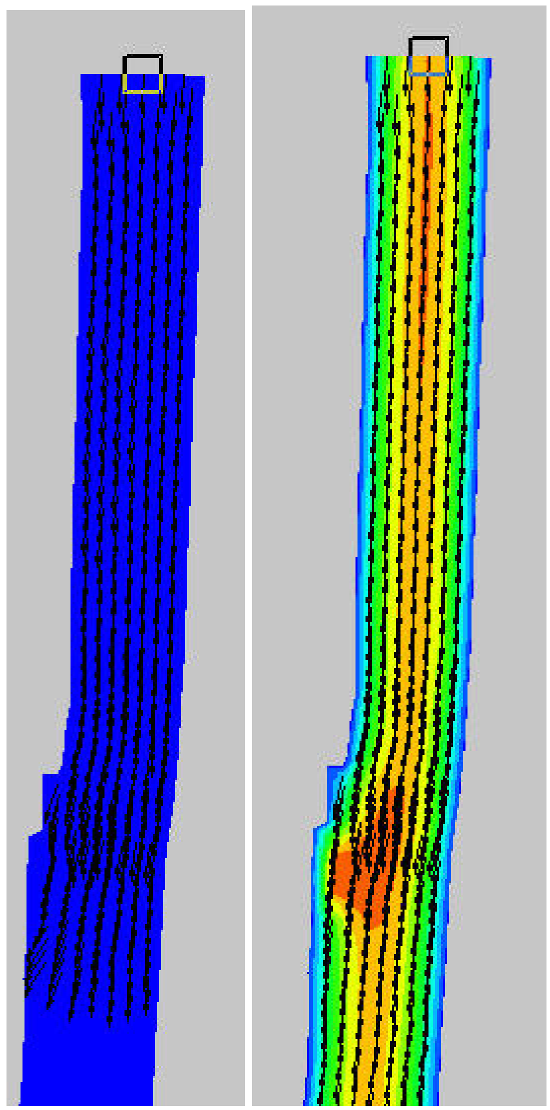


Figure 44. Example velocity vector and contour plots from the northern portion of the 17th Street Canal simulation. The left panel shows the initial velocity field development and the right panel shows snapshot at a later time

Model scale is selected as 1:50. This scale will permit the full length of the canal to be included within the basin with two turns, as seen in Figure 37. Numerical simulations are being used to design the bends to have limited impact on correct short and long wave transmission and reflection in the canal.

The lake area is being designed to accommodate both uni-directional and directional spectra wave generators. A unidirectional wave generator will be used in the first phase of testing and the directional spectral wave generator will be placed in the facility for more detailed study of the wave field. Water level will be varied as well as wave direction, height and period. Bridge structures will be constructed to scale. Surge water variation time history will also be able to be reproduced in order to examine flow fields through the canal.

Model construction will be under way next week. The only problem we are having is obtaining the latest bathymetry and topography at the Lake Pontchartrain portion, north of the Hammond Street Bridge, as shown in Figure 46.

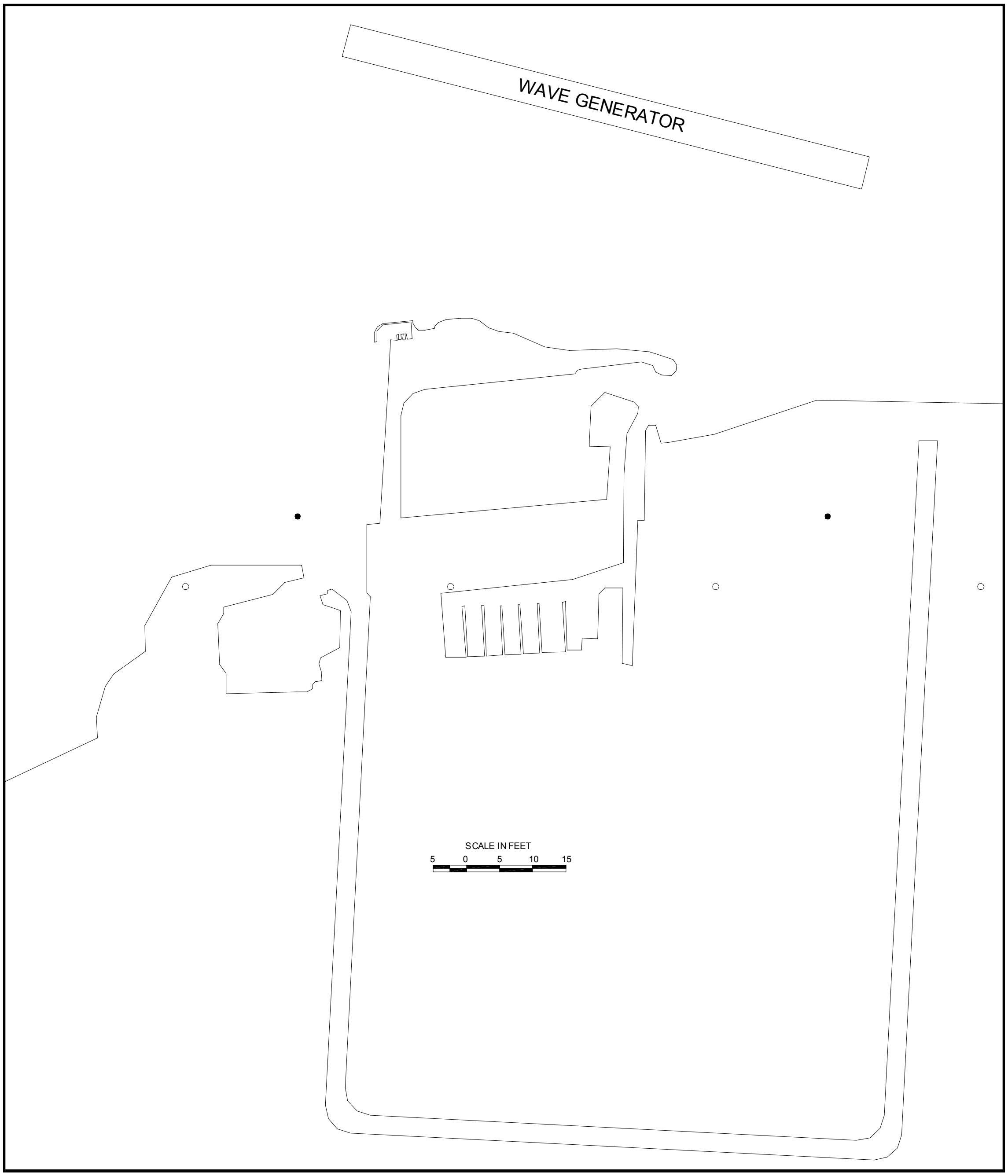



Figure 45. Physical model layout (1:50 scale)

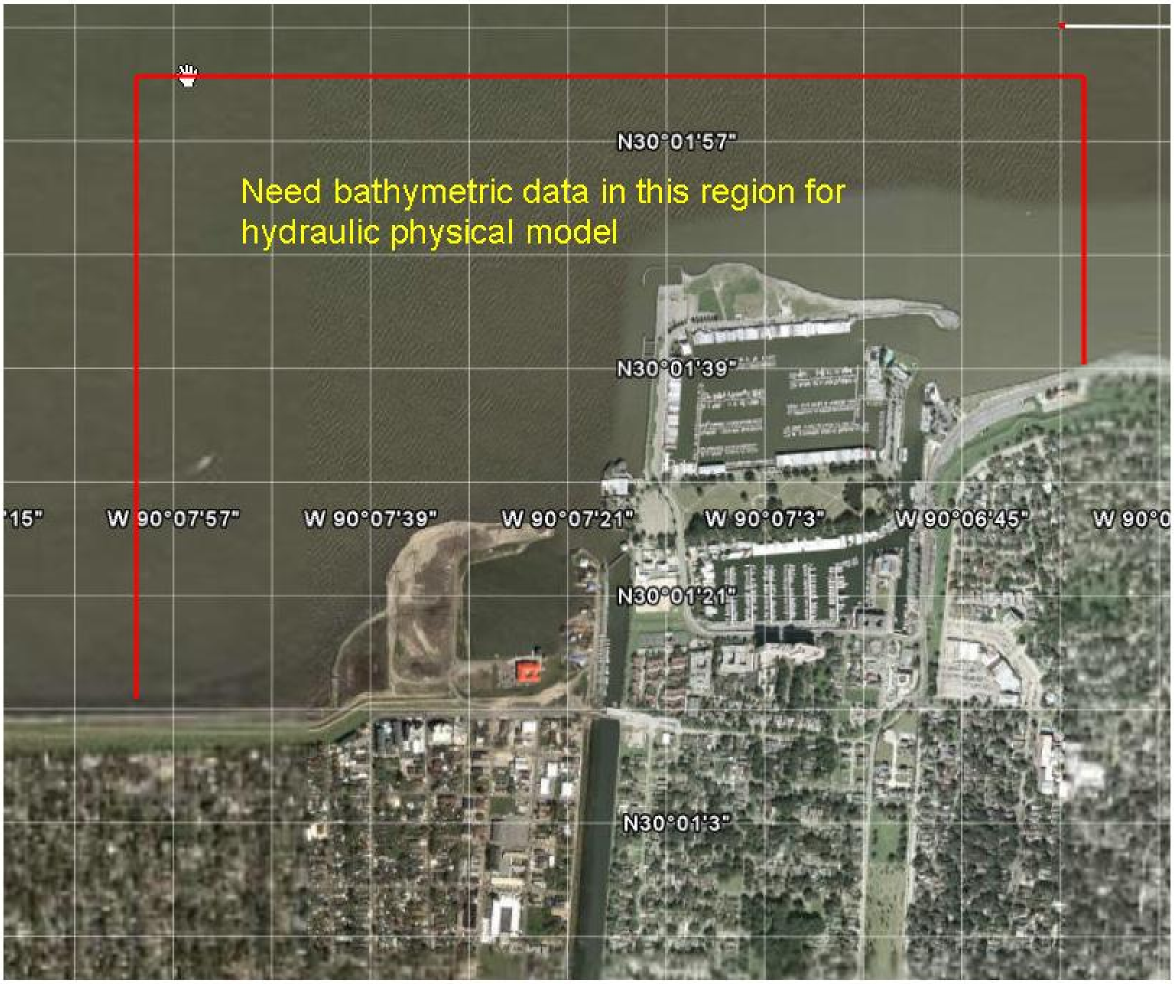



Figure 46. Bathymetric needs

## *3. Potential Forces Due to Barge Impact*

The main focus of this report is to provide a method for quantifying the barge characteristics relative to its possible role in failure of the IHNC east flood wall. The detailed calculations employing this methodology will require improved estimates of the barge and other characteristics required by the methodology.

Figure 47 shows a plan view of the barge in the INHC and the winds that were directed on the barge.

**Barge Characteristics:**

During the site visit on December 22, 2005, the dimensions of the barge identified as "ING 4727" were estimated as:

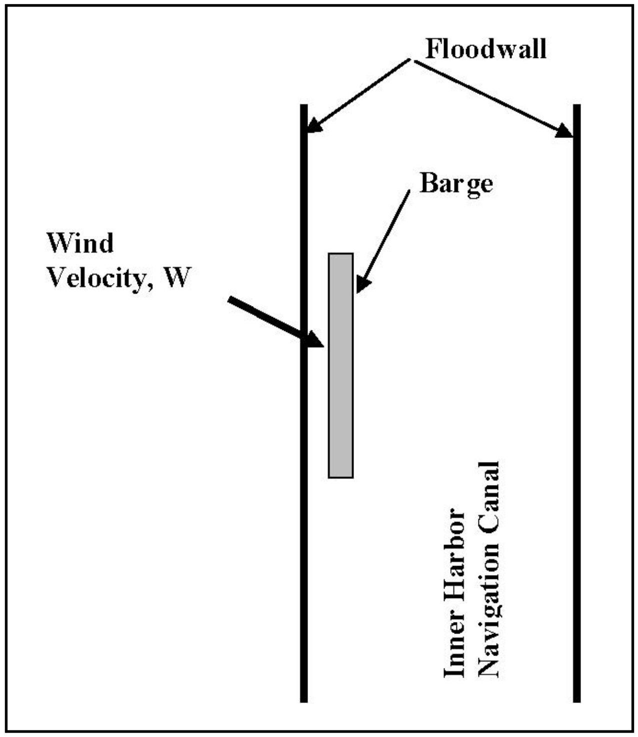



Figure 47. Definition sketch of Inner Harbor Navigation Canal and wind blowing on the barge

Hull Depth = 12 feet
Superstructure Height Including Covers for Contents = 11 feet
Barge Length = 200 feet
Barge Width = 35 feet

Figure 48 presents these barge dimensions.

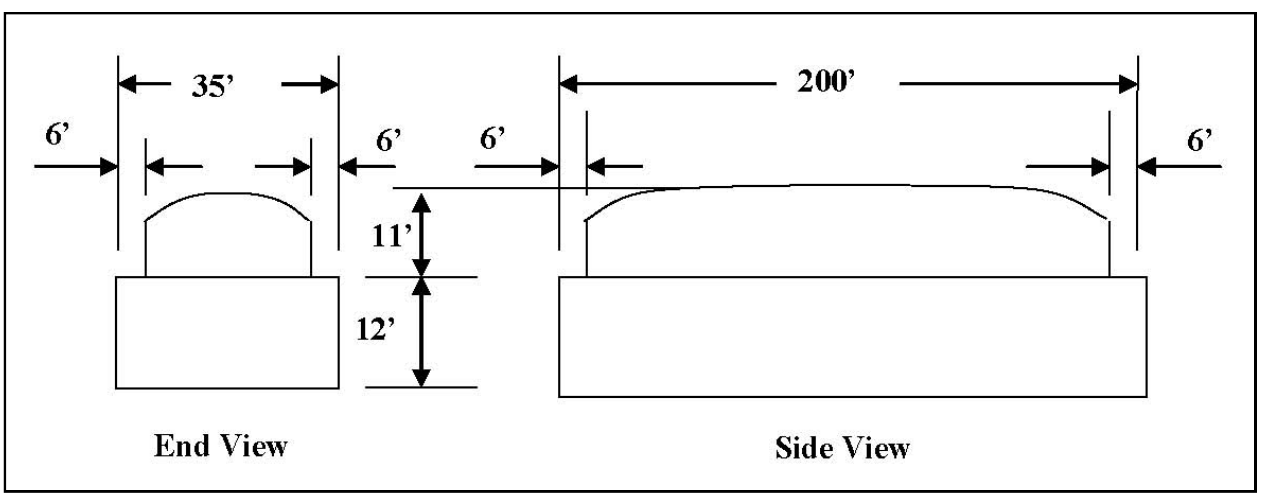



Figure 48. Estimated dimensions of barge observed on site visit to Lower Ninth Ward

**Wind Loading and Comparison with Hydraulic Forces on East Flood Wall:**

The relevant wind speed is that which is exerted on the barge. For a drag force relationship, this is the root-mean square of the wind speed over the vertical dimension of the above water portion of the barge. For purposes here, the following simple relationship for the vertical distribution of wind speed is considered

$$W(z) = W(30)\left(\frac{z}{30}\right)^{1/7} \tag{16}$$

in which z is the elevation above the water surface in feet and $W(30)$ is the reference wind speed at 30 feet above the water surface. The draft of the barge will be denoted as $d$ . Thus the vertical dimension of the barge exposed to the wind is $(23-d)$ feet. The effective wind speed, $W_{eff}$ for drag force computations is therefore

$$W_{eff} = \sqrt{\frac{\int_0^{23-d} W^2(z)\ell(z)dz}{\int_0^{23-d} \ell(z)dz}} \tag{17}$$

in which $\ell(z)$ is the length of a barge element at elevation z and $23-d$ is the height of the barge above the water level. Although the length of a barge element does vary slightly with elevation as shown in the previous section, this variation is reasonably small and for purposes here we will consider that $\ell(z)$ is uniform over the height, 23 - *d*. This results in the effective velocity, $W_{eff}$

$$W_{eff} = 0.882\left(\frac{23-d}{30}\right)^{1/7} W(30) \tag{18}$$

The drag force, $F_{D,a}$ exerted by the wind on the barge are given by

$$F_{D,a} = \frac{\rho_a C_{D,a} A_a W_{eff}^2}{2} \tag{19}$$

in which $\rho_a$ is the mass density of air, $C_{D,a}$ is the so-called “drag coefficient” of the barge to winds and $A_a$ is the “projected area” of the barge perpendicular to the wind velocity vector.

For purposes of examples presented in this report, we will consider the wind to be directed broadside to the barge, a wind mass density, $\rho_a$ = 0.002 slugs/ft3 and a barge length = 200 feet. Thus, the relevant area in Equation 19 is

$$A_a = 200(23 - d) \quad (20)$$

**Static Hydraulic Forces and Moments on Flood Wall Immediately Before Overtopping**

Figure 49 depicts a typical section of the flood wall at an imminent overtopping condition.

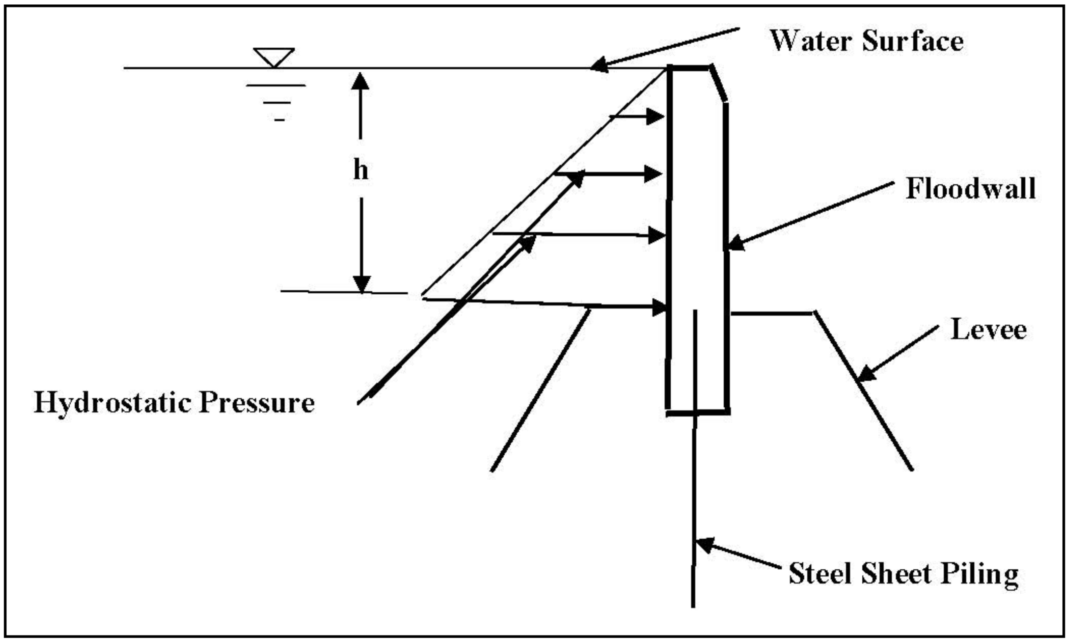



Figure 49. Definition sketch for east floodwall at imminent overtopping condition

The hydrostatic force, $F_{HS}$, on the floodwall per unit floodwall length for the imminent overtopping condition shown in Figure 39 is

$$F_{HS} = \rho_w g \frac{h^2}{2} \quad (21)$$

in which $\rho_w$ is the mass density of water taken here as 1.94 slugs/cu ft and $g$ is the acceleration of gravity.

The hydrostatic moment, $M_{HS}$, about the base of the floodwall per unit length of flood wall is given by

$$M_{HS} = \rho_w g \frac{h^3}{6} \quad (22)$$

**Comparison of Hydrostatic Forces and Moments with Static Wind forces and Moments**

To calculate wind forces, we need to select a reference wind speed, $W(30)$ as shown in Equation 16. For most of the examples presented in this report, a reference wind speed of 100 miles per hour (146.7 ft/sec) and a wind drag coefficient, $C_{D,a}$ = 0.5 have been selected for illustration purposes. To illustrate the maximum wind force, a lightly loaded barge condition is selected with a barge draft, $d$ = 4 feet. Applying Equation 18, the reference wind speed, $W_{eff}$ =121.2 ft/sec. The wind drag force per unit barge length $f_{HS}$ , is then

$$f_{D,a} = \frac{\rho_a C_{D,a}(23-d)W_{eff}^2}{2} = 139.5 \text{ pounds/foot} \tag{23}$$

This value is compared to the hydrostatic force per unit length of 1,999 pounds/foot based on a floodwall height = 8 feet. Thus, the static wind force is equal to approximately 7% of the hydrostatic force. However this result is based on a uniform transfer of the wind load on the barge to the floodwall. If this transfer is concentrated, the local wind related loads acting on the floodwall per unit length could be much greater than those calculated above.

The wind related moments about the bottom of the floodwall are considered to result from application of the wind related forces at the mid-elevation of the barge draft, i.e., 2 feet below the crest of the floodwall. In this case, the moment due to the wind is 837 foot-pounds per foot compared to the hydrostatic moment of 5,331 foot-pounds per foot or the wind moment is approximately 16% of the hydrostatic moment. However, the same comment applies to moments as was presented for forces regarding the consideration that the wind forces were applied uniformly along the wall.

The following section examines the dynamics of the floating barge.

The equation of motion of the barge is:

$$m_T \frac{dV}{dt} = K_1 W_{eff}^2 - K_2 V^2 \tag{24}$$

in which $m_T$ is the total effective mass of the floating barge and is the sum of the physical mass and the added mass, V is the barge velocity, t is time after the barge starts to float free, $W_{eff}$ is the effective wind speed acting on the barge as described earlier. The factor, $K_1$ has been defined earlier as

$$K_1 = \frac{\rho_a C_{D,a} A_a}{2} \tag{25}$$

The factor $K_2$ is defined as

$$K_2 = \frac{\rho_w C_{D,w} A_w}{2} \tag{26}$$

in which $\rho_w$ has been defined as the mass density of water, $C_{D,w}$ is the so-called "drag coefficient" of the barge to the water and $A_w$ is the "projected area" of the barge perpendicular to the water velocity vector. In subsequent calculations, the following values of drag coefficients will be applied: $C_{D,a}$ = $C_{D,w}$ = 0.5. The dimensions of both $K_1$ and $K_2$ are "force/velocity squared". The complete barge dimensions were presented in Section 2.

From Equation 22, it is seen that the steady state (or terminal) velocity of the barge, $V(\infty)$ is given by

$$V(\infty) = \sqrt{\frac{K_1}{K_2}}\, W_{eff} \tag{27}$$

The values of $K_1$ and $K_2$ will be estimated for the case of the barge fully loaded and loaded very lightly. The barge is considered broadside to the wind. The results of these estimates are presented in Table 7. The values of the dimension-less terminal barge velocity, $V(\infty)/W_{eff}$ are also presented in Table 7. Note that the length of the barge acted upon by winds has been taken as 188 feet.

**Table 7**
**Estimation of $K_1$ and $K_2$ for Two Cases**

| Case | Description | $K_1$ (Pounds-sec2/ft2) | $K_2$ (Pounds-sec2/ft2) | $V(\infty)/W_{eff}$ |
|---|---|---|---|---|
| 1 | Fully Loaded, Draft $d$ = 9 feet | 1.32 | 873 | 0.039 |
| 2 | Lightly Loaded, Draft $d$ = 4 feet | 1.79 | 388 | 0.068 |

It is useful to cast the equation of motion in non-dimensional form as:

$$\frac{m_T}{K_1 W_{eff}^2} \frac{dV}{dt} = 1 - \frac{K_2}{K_1} \frac{V^2}{W_{eff}^2} \tag{28}$$

from which the solution can be shown to be:

$$V(t) = V(\infty)\tanh\left(\sqrt{\frac{K_1 K_2}{m_T}} W_{eff}\, t\right) \tag{29}$$

The nondimensionalizing time, $t_*$, is defined as

$$t_* = \frac{m_T}{\sqrt{K_1 K_2 W_{eff}}} \tag{30}$$

and is the time at which the barge velocity is 76.2% of its terminal velocity. Choosing the nondimensionalizing velocity as the terminal velocity, $V(\infty)$, and denoting nondimensional quantities by primes (e.g., $t' = t / t_*$), the solution for the nondimensional velocity, $V'(t')$ is

$$V'(t') = \tanh(t') \tag{31}$$

The nondimensional barge displacement, $x'(t') = x(t)/x_*$, can be shown to be

$$x'(t') = \ln[\cosh(t')] \tag{32}$$

where $$x_* = \frac{m_T}{K_2} \tag{33}$$

The advantages of the nondimensional solutions presented is that they depend on only one variable, $t'$.

Figure 50 presents the nondimensional solutions for the range $0 < t' < 5$ which will be shown to provide adequate information to analyze the case of the barge motions and forces in the INHC canal.

The nondimensional relationships are plotted in a different manner in Figure 41 which has advantages for our particular applications. Figure 51 presents the nondimensional barge velocity, $V'(t')$ as a function of the non-dimensional barge displacement, $x'(t')$. In applications, the quantity $x$ is the path of the barge from its starting point to its ending point where it would impact the east flood wall of the INHC canal. This quantity is based on barge and other conditions and is the nondimensional distance, $x'$. Entering Figure 41 with this $x'$ quantity on the abscissa, the nondimensional velocity, $V'$ is determined. The dimensional velocity, $V$ is then quantified. Finally the momentum and energy of the barge upon impact are determined as:

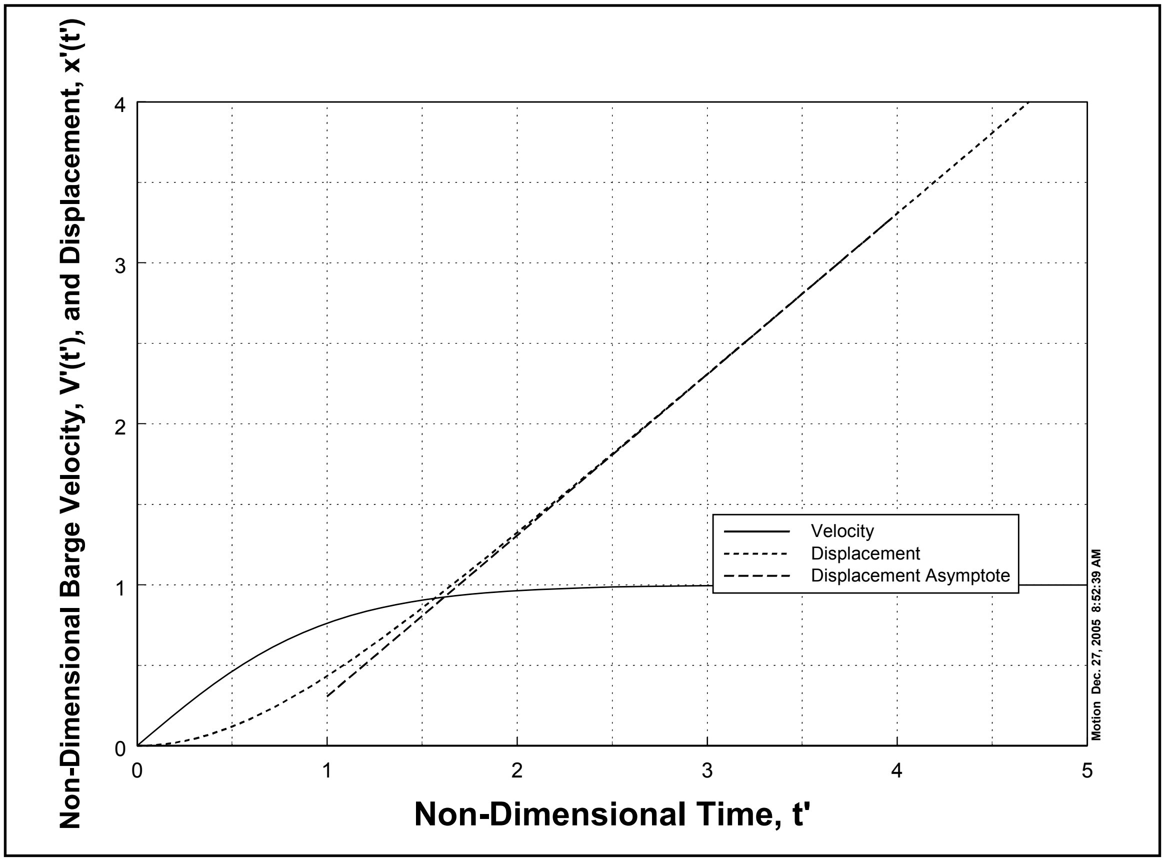



Figure 50. Nondimensional barge velocity and displacement

$$\text{Momentum} = m_T V \tag{34}$$

$$\text{Energy} = \frac{m_T V^2}{2} \tag{35}$$

The barge displacement, $x$, should increase linearly with time after the barge has reached its terminal velocity, $V(\infty)$ and this appears to be the case from Figure 40 but is not so apparent from Equation 32. However, from Equation 30, for large $t'$,

$$x'(t') = t' - \ell\text{n}(2) \tag{36}$$

which is plotted as the asymptote in Figure 40. Expressing Equation 36 in dimensional form, this equation becomes

$$x(t) = V(\infty)t - \frac{m_T}{K_2}\ell\text{n}(2) \tag{37}$$

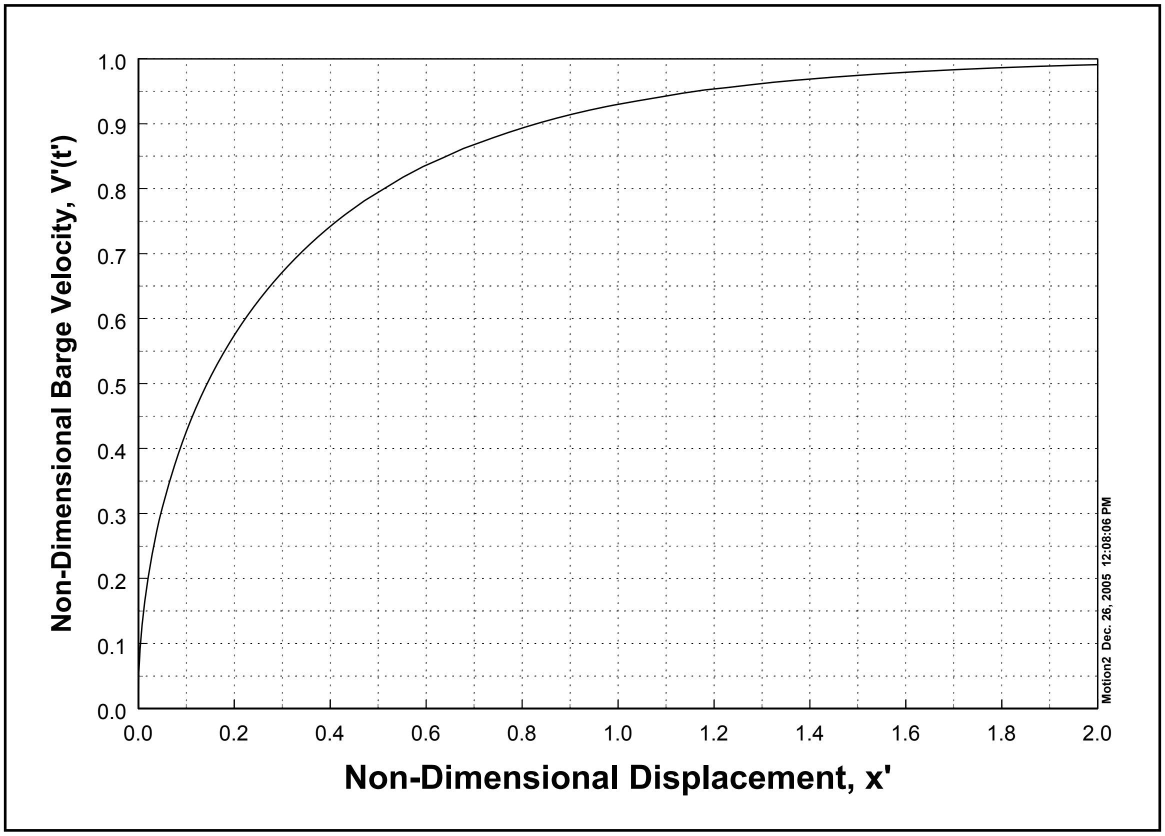



Figure 51. Relationship between nondimensional barge velocity, $V'(t')$ and nondimensional displacement, $x'(t')$

which demonstrates the expected linearity of the relationship for large time. The second term on the right hand side of the above equation accounts for the acceleration phase of the barge response, as can be appreciated by the role of the total mass, $m_T$, such that a larger mass tends to prolong the acceleration phase and thus reduce the displacement at any particular time.

The procedure for calculating barge motion characteristics will be illustrated in the following section of this report.

Consistent with the results in Table 7, two cases are considered: Case 1 in which the barge is fully loaded with a draft of 9 feet and Case 2 for which the barge draft is 4 feet. It is noted that the examples presented here are for illustrative purposes of the methodology. After the detailed characteristics of the barge are more fully established, the motion and force characteristics can be more fully quantified.

For Case 1, the total mass, $m_T$ is the sum of the physical mass, $m_P$ and the added mass, $m_A$. The physical mass is equal to the mass of the displaced water or 122,220 slugs. Assuming an added mass coefficient of 0.2, the total mass, $m_T$ = 144,664 slugs.

For a barge exposure above water of 14 feet ($d$ = 9 feet), based on Eq. 18, the reference wind velocity, $W_{eff}$ is 0.791 × $W$(30). Considering, as an example, $W$(30) = 100 mph = 146.7 ft/sec, $W_{eff}$ = 116.0 ft/sec. The $K_1$ and $K_2$ values are 1.32 pound-sec$^2$/ft$^2$ and 873 pound-sec$^2$/ft$^2$, respectively as given in Table 7. The non-dimensionalizing quantities are $t_*$ = 36.7 sec, $V(\infty)$, the barge terminal velocity = 4.52 ft/sec, and $x_*$ = 165.7 ft.

The distance across the IHNC from the western floodwall to the eastern floodwall is approximately 1,100 feet. Considering that this is the trajectory of the barge, the translation distance is 1,082.5 feet (the width of IHNC minus one-half the barge width). Thus the value of $x'$ is 6.53. Referring to Figure 41, it is clear that the barge would have achieved its terminal velocity, $V(\infty)$ of 4.52 ft/sec. Thus the momentum and energy upon impacting the wall are:

Impact Momentum = 653,900 pound-sec.
Impact Energy = 1.48 million foot-pounds.

This example is provided as an illustration of the application/interpretation of the impact momentum. Consider this momentum to be transferred in, say 10 seconds allowing for barge deformation. If the form of the transfer is triangular, that is the force starts at zero, rises to twice the average value, then decreases to zero force in 10 seconds, then the maximum force acting on the flood wall would be 130,780 pounds. This is compared to the hydrostatic force of 399,000 pounds over the barge length of 200 feet. Thus, for this impact time of 10 seconds, the maximum impact force is 33% of the hydrostatic force. It is cautioned that: (1) The actual impact time would require a careful analysis of the barge and floodwall deformation characteristics and consideration of various barge orientations upon impact. Shorter impact times will result in greater maximum impact forces, and (2) The impact forces may be localized thus resulting in greater impact forces per unit length of the floodwall.

The draft for this case is 4 feet as shown in Table 7. As for Case 1, the total mass, $m_T$ is the sum of the physical mass, $m_P$ and the added mass, $m_A$. The physical mass is equal to the mass of the displaced water or 54,320 slugs. Again assuming an added mass coefficient of 0.2, the total mass, $m_T$ = 65,184 slugs.

For a barge exposure above water of 19 feet ($d$ = 4 feet), based on Equation 18, the reference wind velocity, $W_{eff}$ is 0.826 × $W$(30). Considering $W$(30) = 100 mph = 146.7 ft/sec, $W_{eff}$ = 121.2 ft/sec. Considering $C_{D,a} = C_{D,w}$ = 0.5, the $K_1$ and $K_2$ values are 1.79 pound-sec$^2$/ft$^2$ and 388 pound-sec$^2$/ft$^2$, respectively as given in Table 7. The non-dimensionalizing quantities are $t_*$ = 20.4 sec, $V(\infty)$, the barge terminal velocity = 8.24 ft/sec, and $x_*$ = 168.0 ft.

Considering the same barge trajectory as for Case 1, the value of $x'$ is 6.44. As for Case 1, referring to Figure 41 it is clear that the barge would have achieved its terminal velocity, $V(\infty)$ of 8.24 ft/sec. Thus the momentum and energy upon impacting the wall are:

Impact Momentum = 537,120 pound-sec.
Impact Energy = 2.21 million foot-pounds.

It has been demonstrated that for a reference wind speed of 100 miles per hour, the barge will reach its terminal velocity regardless of the draft and with a minimum distance of the IHNC width translation distance (minus one-half the barge width). Thus, it is possible to develop the following simple equations for impact momentum and energy for the barge of interest.

For the barge of interest and considering that the barge had reached its terminal velocity at impact, the equation for the terminal momentum can be written as

Terminal Momentum = $275.2\sqrt{d}\left(23-d\right)^{9/14} W\left(30\right)$ (in pound-sec)

Note that consistent units must be used in these equations. Thus $W(30)$ is in ft/sec.

For the same considerations as above for terminal momentum, the terminal energy can be shown to be

Terminal Energy = $2.32\left(23-d\right)^{9/7}\left(W\left(30\right)\right)^{2}$ (in foot-pounds)

Plots of the impact momentum and impact energy are presented in Figure 43.

Figure 52 presents non-dimensional plots of terminal momentum and energy versus barge draft. For purposes here, the non-dimensional terminal momentum and velocity have been defined as the ratio of these quantities to the values for a 9 foot barge draft and for a wind speed, $W(30)$ = 144.67 ft/sec (100 miles per hour).

Thus the terminal momentum for any draft and wind speed is determined by multiplying the value for 9 feet (653,900 pound-sec) by the appropriate value in Figure 7 and the ratio of the wind speed of interest, $W(30)$ to 146.7 (all in feet/sec).

Similarly, the terminal energy is determined by multiplying the terminal energy for a draft of 9 feet (1.48 million foot pounds) by the appropriate value in Figure 42 and the ratio of the square of the wind speed of interest , i.e., $W^2(30)$ to $(146.7)^2$ where all wind speeds are in ft/sec.

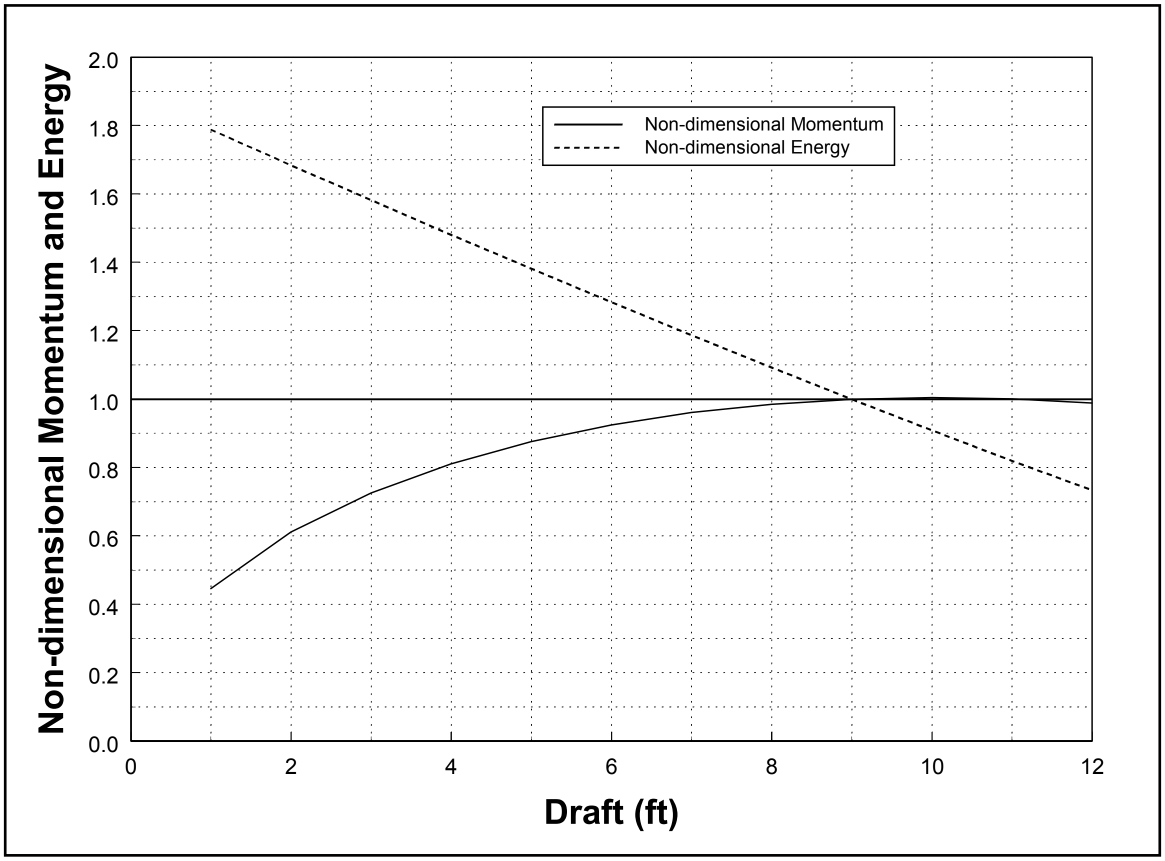



Figure 52. Nondimensional barge terminal momentum and energy vs barge draft

Although it has been demonstrated that the barge terminal momentum and energy could have been considerable and thus possible contributors to the levee failure at the Lower Ninth Ward, this is not evidence that the barge *did* contribute to the failure. Thus it is recommended that other types of forensic evidence be sought including indications of whether evidence of substantial impact with the flood walls is present on the barge and as much as possible about the mooring arrangement and conditions of the mooring lines after levee failure. Other types of forensic evidence may also be available.

## References

CEM (2002). *Coastal Engineering Manual*. U.S. Army Engineer Research and Development Center, Vicksburg, MS.

De Wall, J. P. and Van der Meer, J. W. (1992). "Wave run-up and overtopping on coastal structures," Proc. 23rd Intl Conf on Coast Eng., ASCE, Reston, VA, 1758-1771.

Goda, Y. (1985). *Random Seas and Design of Maritime Structures.* Univ. of Tokyo Press, Tokyo, Japan.

Seijffert, J. W., and Philipse, L. (1990). “Resistance of grassmat to wave attack,” Proc. 22nd Coast. Eng. Conf. ASCE, Reston, VA, 1662-1674.

Van der Meer, J. W., and Janssen, W. (1995). ”Wave run-up and wave overtopping at dikes,” In *Wave Forces on Inclined and Vertical Wall Structures,* Kobayashi and Demirbilek, eds., ASCE, Reston, VA, 1-27.

# Geotechnical Structure Performance Analysis

## Introduction

### Summary

The work reported in this Task is focused on physical modeling of the levee and floodwall performance. It is specifically directed at understanding the primary failure modes for those structures that failed catastrophically as well as understanding the contributing factors to those failures. The results will directly assist in answering the question of how the flood protection structures performed and why they performed as they did.

Based on the planned physical modeling, to be highlighted in following sections, information directly related to the performance of the levees and floodwalls will be obtained. Additionally, information related to the mechanisms leading to breaching and ultimate failure of selected sections of the levee system will be evaluated. This information will serve as direct indicators of the failure mechanisms and will also support the numerical modeling work that is being conducted as part of the IPET Structural Performance Analysis Task. The physical and numerical modeling will establish the most likely cause of breaching and failure that can be supported and substantiated based on sound engineering principles. To understand the conditions of the flood protection system prior to Katrina, the stability of selected sections of the levee system prior to hurricane Katrina loading will be determined. The modeled levee will then be subjected to hurricane Katrina flood loading. The results of the physical modeling in conjunction with the numerical modeling should provide insights as to improvements or modifications that could be made to increase the stability of the levee system.

As previously stated, the Physical Modeling of Structure Performance Task team will work very closely with the Structure Performance Evaluation Team numerical modeling team. Additionally, this task will require input from the Storm Surge and Wave Analysis and High Resolution Hydrodynamic Forces Modeling Teams to establish the height of flood loading that occurred in the 17th Street Canal, London Avenue Canal, and Inner Harbor Navigation Channel. Coordination will also occur with the High Resolution Hydrodynamic Forces Task related to the planned physical modeling to quantify wave overtopping rates and associated parameters. Information will also be obtained from the Vertical

Datum Team and survey teams to establish the pre- and post-hurricane geometry of selected sections of the levee. Of course, frequent interaction will occur with the Data Collection and Management Team as data is both delivered from this team for posting and required from other Tasks.

### Background

Levees are soil structures, with or without structural components, constructed to provide flood protection during and after high-water events. The failure of structures such as a floodwall or levee system may be due to a single dominant mechanism, or a combination of mechanisms. Generally, the levees are well constructed, engineered structures which perform adequately during their expected life. Problems arise either in the foundation or at isolated zones of weak material in the levee. One of the more attractive means of investigating the performance of these systems is through scaled physical modeling. Body forces are all important in the engineering behavior of soils, which poses a problem in conducting geotechnical model tests in the laboratory in a normal gravity field. For specific problems, the use of appropriate boundary forces can provide an adequate replacement for body forces. However, in general, if body forces are to be properly represented in geotechnical model testing it is necessary to turn to centrifuge modeling. Centrifuge modeling allows for the increase in self weight of a soil model at varying scales. For example, in a slope of height ‘h’ in soil with self weight $\gamma$ and strength characterized by cohesion, a well defined slope stability number can be determined. If the slope is reduced to a scale 1/N such that the slope height is now h/N, the soil having the same cohesion in model and prototype, then the model slope will fail in exactly the same way as the prototype if the self weight of the soil is increased to $N\gamma$. This is accomplished by increasing the acceleration to N times the earth’s gravity. This is exactly the procedure that is used in the well known Casagrande Liquid Limit test. The specimen of clay has its self weight increased sharply every time the specimen is tapped against the base plate. In a scaled physical model on the centrifuge, the self weight is held steady at some determined N times the earth’s gravity throughout the loading and testing of the model. To account for the complexity and combination of mechanisms that contributed to the breaches and ultimate failure of the levees; physical modeling on the centrifuge is the only viable alternative.

There are numerous papers in the literature that point to the use of centrifuge modeling for levee, embankment and small dam performance subjected to static and dynamic loading. Also, numerous papers exists dealing with the behavior of well constructed structures founded on weak or inadequate foundations. Many papers point to the use of centrifuge modeling to explore the behavior of soil models with structural components such as sheet piles. There are papers dating as far back as 1988 when the centrifuge community began to have frequent international conferences. Researchers from numerous countries such as China, Japan, United Kingdom, USA, France, Netherlands, Canada, Australia and Malaysia have reported results of centrifuge testing related to levee/embankment behavior.

One example highlighting the benefits of centrifuge modeling directly related to levees will be presented. There was a failure in a section of the Wilnis Levee System in the Netherlands as shown in Figure 53. Both physical (Figure 54) and numerical (Figure 55) modeling of the failed levee section was conducted. Numerical modeling of the levee utilizing limit equilibrium methods and circular failure surfaces indicated the levee had a factor of safety equal to 1.24. Additionally, limit equilibrium analysis with noncircular failure surfaces and finite element modeling indicated factor of safety for the levee equal to 1.04. A scaled physical centrifuge model of the levee was conducted to substantiate the failure mechanism. The resulting failed section is shown in Figure 56 and confirms that a very large noncircular failure surface associated with low weight free field soil and uplift pressures were responsible for the failure. In addition to validating the failure mechanism, the centrifuge models allowed for the validation of a new limit equilibrium methodology that could reliably predict failure associated with uplift without the need for finite element modeling (Figure 57).

Figure 53. Failure of a section of the Wilnis levees in the Netherlands.

The very early preliminary observations of levee performance in and around New Orleans indicate that foundation soils possibly played a large role in the performance. Evaluation of levee performance including the effects of the foundation in the overall behavior will be conducted through scaled physical centrifuge modeling. The physical data collected from the centrifuge model will be used for direct observations of levee performance and primarily to improve numerical model predictions. Results from centrifuge modeling of the failed levees in and around New Orleans will result in a detailed set of well controlled data that can be used to validate any numerical models used in analysis, confirmation of the failure mechanisms, and additional insights of factors that may have played a part in the failure as of yet unrecognized.

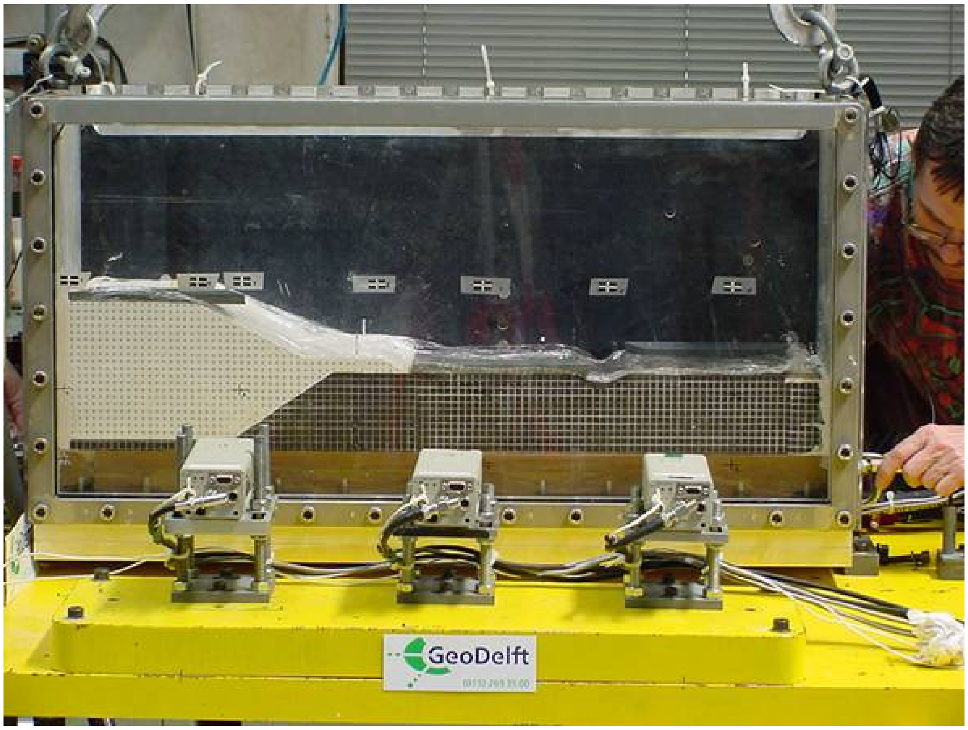



Figure 54. Scaled physical centrifuge model of levee.

## Objectives

The objectives of this task are to physically model selected sections of the New Orleans levees to determine plausible mechanisms of failure and to provide data for use in validating and verifying the numerical modeling tools. Specifically, typical levee sections along the 17th Street Canal, London Avenue Canal, and Industrial Canal representative of the failed sections will be modeled. Each of these systems represents unique challenges in evaluating performance that could be greatly enhanced by physical modeling. The specific objective for the 17th Street Canal levee model is to explore the foundation peat and clay layers and their role in the failure. For the London Avenue Canal levee model, the specific objective is to explore the role of the fine sand foundation material in the failures (North and South). The specific objective for the Industrial Canal levee model is to explore the overtopping phenomena that led to erosion of material behind the wall.

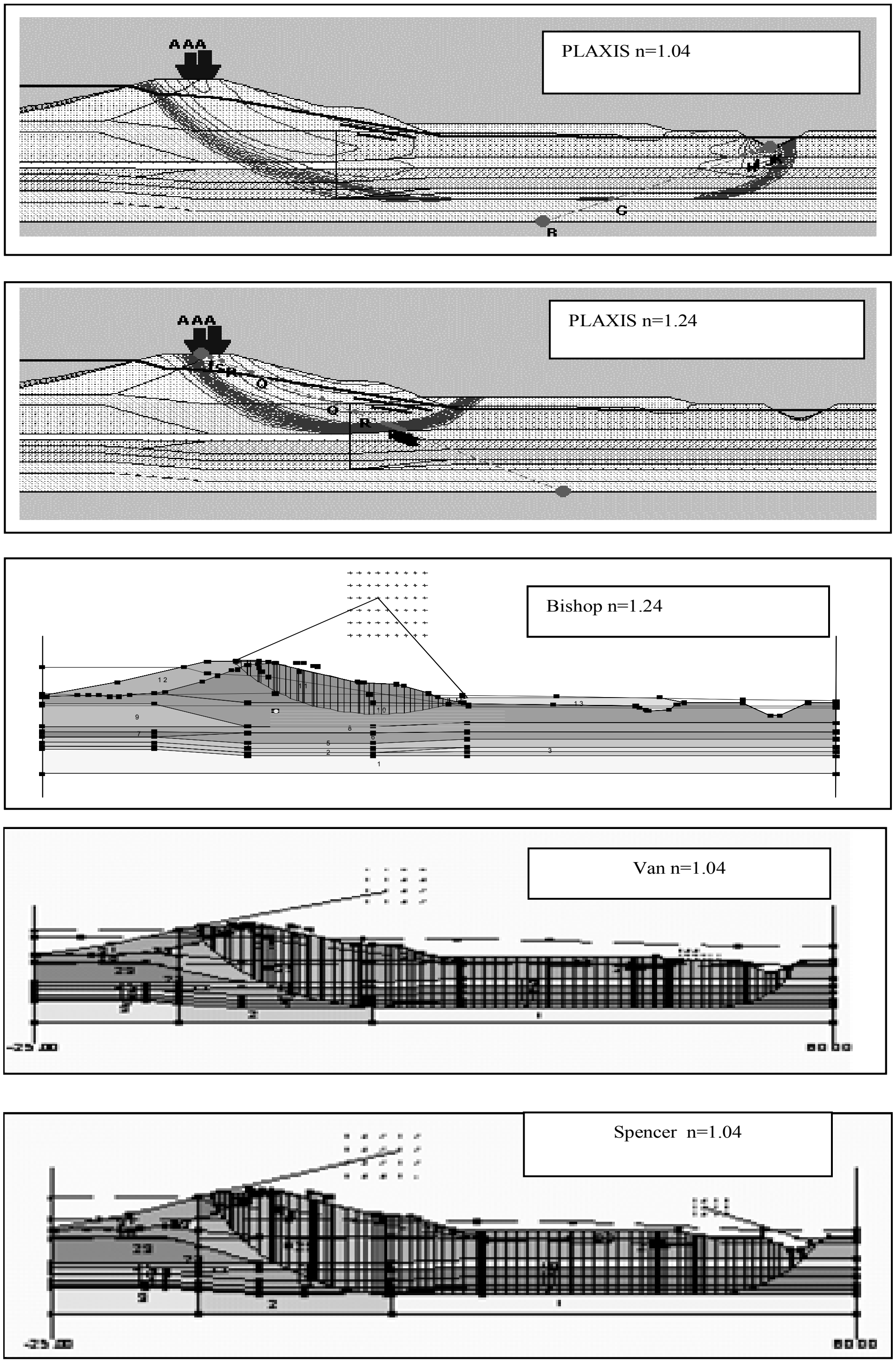



Figure 55. Numerical calculations of failure surfaces and factors of safety.

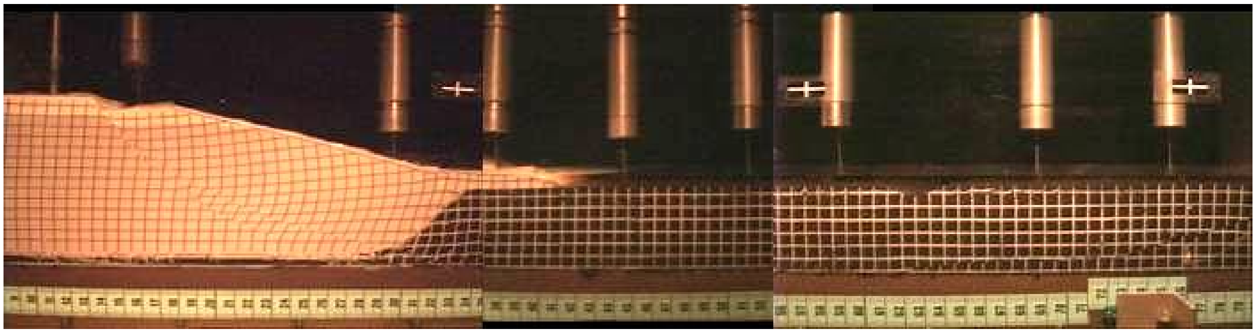


Figure 56. Failed centrifuge model showing very large noncircular failure.

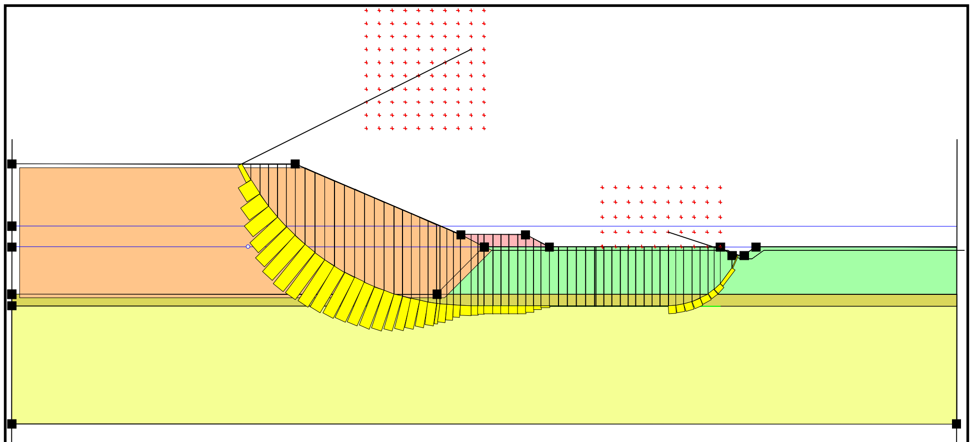



Figure 57. Developed new method for analysis.

# Scope

## Team

The Task team is comprised of subject matter experts as highlighted in Table 9. Numerous participants contributing to this effort but not listed in the table should also be mentioned: Engineers and soils/laboratory technicians of the Geotechnical & Earthquake Engineering Branch, Geotechnical and Structures Laboratory (GSL); Geologists, Geophysicists and Geoscientists of the Engineering Geology & Geophysics Branch, GSL; machinists, carpenters, model builders, etc. of the Directorate of Public Works, Engineer Research and Development Center (ERDC); Electrical Engineers, Physicists, and technicians of the Information Technology Laboratory; and graduate students at Rensselaer Polytechnic Institute (RPI).

| Table 9. Physical Modeling of Structural Performance Task Team | | | |
|---|---|---|---|
| **Position** | **Name** | **Affiliation** | **Role/Expertise** |
| Task Leader | Michael K. Sharp, PhD, PE | GSL, ERDC | Geotechnical Engineer with expertise in soil dynamics and physical modeling |
| Task Co-Leader | R. Scott Steedman, PhD | Steedman & Associates | Geotechnical Engineer and International Consultant with varied experience in physical modeling, sheet pile behavior, and soil dynamics |
| Lead Engineer | Wipawi Vanadit-Ellis | GSL, ERDC | Geotechnical Engineer with experience in soil mechanics and physical modeling |
| Lead Engineer | Tarek H. Abdoun, PhD | Rensselaer Polytechnic Institute | Professor of Civil Engineering, expertise in physical modeling and soil structure interaction |
| International Consultants | Paul Schaminee<br>Adam Bezuijen | GeoDelft | Engineers with extensive experience in physical modeling, soft soils, peat |

## Approach

**17th Street Canal.** A scaled physical model of a section of the 17th Street Canal levee where the failure occurred will be conducted. The geometry and soil characteristics of the pre-failure section will be determined based on the Design Memorandum, As Builts, survey data, borings, cone penetrometer testing, and field observations. The levee section will be scaled down from the prototype in the range of 50 to 75 times, appropriate for centrifuge modeling at an increased earth gravity of 50 to 75 times. A depiction of the model is shown in Figure 58.

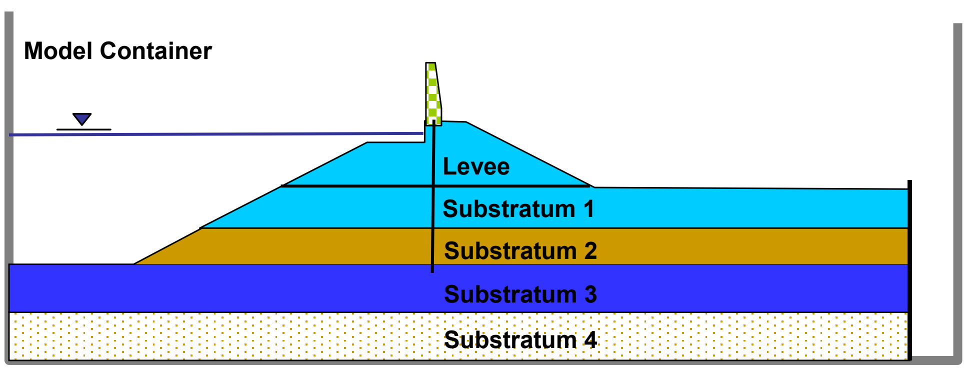



Figure 58. Depiction of model for evaluation of 17th Street Canal levee.

The major issue of concern in this levee section is the foundation materials, which are a combination of peat and/or weak clays. This material in the foundation may have served as a failure plane for the levee system. Models of this levee system will duplicate the field conditions of the levee and foundation prior to failure and subject the levee to flood loads.

In the model, the layers marked as Levee and Substratum 1 in Figure 58 will be modeled with synthetic clay (Spesswhite) placed at a strength, density, and moisture content to replicate the actual field soil for these layers. The layer marked as Substratum 2 is the peat layer. For model construction, this layer will be made from actual peat from the site and possibly a synthetic material placed at a density to duplicate the light weight of the peat. Substratum 3 is clay that will be simulated in the model with synthetic clay placed at a strength, density and moisture content to replicate the actual field soil. Substratum 4 is sand and will be placed at a relative density to duplicate the actual field soil. Appropriate care will be given to the model to get the placed clay layers back into the correct consolidation ratio prior to flood loading. After model construction, the appropriate prehurricane canal water level will be applied and held constant until full saturation of the model is achieved. This will be verified by pore pressure transducers located throughout the model. Subsequent to this, the water level will be raised to a level equivalent to the maximum hurricane flood loading. Behavior of the levee subjected to the flood load will be continuously monitored with instrumentation inside and outside of the model in addition to recorded video.

Based on field observations and engineering judgment it is anticipated that the failure occurred somewhere near the peat/clay interface (substratum 2 and 3). Therefore several models will be constructed to vary the properties of this material and explore the resulting displacements/failure of the levee. Table 10 presents an outline of the planned test for 17th Street Canal.

**Table 10. Planned Test for 17th Street Canal**

| Model | Levee/Substratum 1 | Substratum 2 | Substratum 3 | Substratum 4 |
|---|---|---|---|---|
| 17-1 | Synthetic clay (need to add props. for model const) | Field peat | Synthetic Clay (need to add props. for model const) | Nevada sand (need to add props. for model const) |
| 17-2 | Synthetic clay (need to add props. for model const) | Field peat | Synthetic Clay (need to add props. for model const) | Nevada sand (need to add props. for model const) |
| 17-3 | Synthetic clay (need to add props. for model const) | Synthetic material (need to add props. for model const) | Synthetic Clay (need to add props. for model const) | Nevada sand (need to add props. for model const) |
| 17-4 | Synthetic clay (need to add props. for model const) | Synthetic material (need to add props. for model const) | Synthetic Clay (need to add props. for model const) | Nevada sand (need to add props. for model const) |

**London Avenue Canal.** A scaled physical model of a section of the London Avenue Canal levee where the failures (North and South) occurred will be conducted. The geometry and soil characteristics of the pre-failure section will be determined based on the Design Memorandum, As Builts, survey data, borings, cone penetrometer testing, and field observations. The levee section will be scaled down from the prototype in the range of 50 to 75 times, appropriate for centrifuge modeling at an increased earth gravity of 50 to 75 times. A depiction of the model is shown in Figure 59.

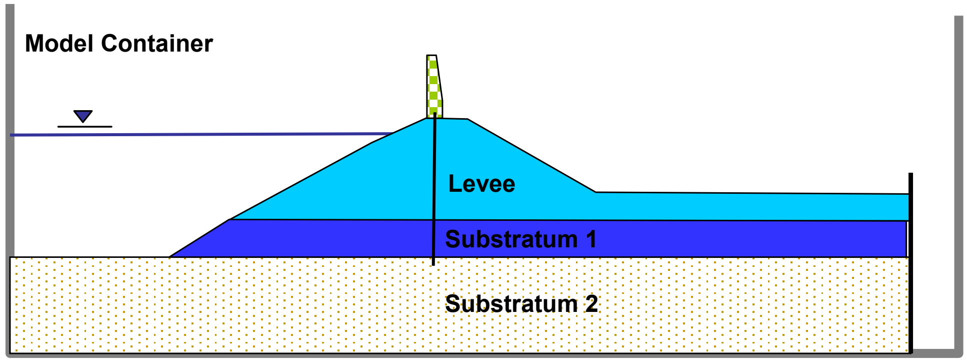



Figure 59. Depiction of model for evaluation of London Avenue Canal levee.

The major issue of concern in this levee section is the foundation materials, which are a combination of fine sand and clays. This material in the foundation may have played a major role in the subsequent failure of the levee. Models of this levee system will duplicate the field conditions of the levee and foundation prior to failure and subject the levee to flood loads.

In the model, the layers marked as Levee and Substratum 1 in Figure 59 will be modeled with synthetic clay (Spesswhite) placed at a strength, density, and moisture content to replicate the actual field soil for these layers. The layer marked as Substratum 2 is the fine sand layer and will be placed in the model at a relative density to duplicate the field soil. Actual fine sand from the site will be used in the model construction. Appropriate care will be given to the model to get the placed clay layers back into the correct consolidation ratio prior to flood loading. After model construction, the appropriate prehurricane canal water level will be applied and held constant until full saturation of the model is achieved. This will be verified by pore pressure transducers located throughout the model. Subsequent to this, the water level will be raised to a level equivalent to the maximum hurricane flood loading. Behavior of the levee subjected to the flood load will be continuously monitored with instrumentation inside and outside of the model in addition to recorded video.

Based on field observations and engineering judgment it is anticipated that the failure occurred as a result of increased uplift pressures in the fine sand (substratum 2) and inadequate strength/weight of the clay layer (substratum 1). One plausible mechanism is that the wall moved slightly and created a flow path down the sheet pile wall into the sand layer. Therefore several models will be constructed to explore the behavior of the levee to this sand layer and also varying the strength properties of the clay layer. Table 11 presents an outline of the planned test for London Avenue Canal.

| Table 11. Planned Test for London Avenue Canal | | | | |
|---|---|---|---|---|
| **Model** | **Levee** | **Substratum 1** | **Substratum 2** | **Comment** |
| L-1 | Synthetic clay good strength (need to add props. for model const) | Synthetic clay low strength (need to add props. for model const) | Field sand (need to add props. for model const) | Model allows water to flow around the pile with uplift |
| L-2 | Synthetic clay good strength (need to add props. for model const) | Synthetic clay low strength (need to add props. for model const) | Field sand (need to add props. for model const) | Model allows water to flow around the pile with uplift |
| L-3 | Synthetic clay good strength (need to add props. for model const) | Synthetic clay low strength (need to add props. for model const) | Field sand (need to add props. for model const) | Model allows movement of wall with weak clay layer |
| L-4 | Synthetic clay good strength (need to add props. for model const) | Synthetic clay low strength (need to add props. for model const) | Field sand (need to add props. for model const) | Model allows movement of wall with weak clay layer |

**Industrial Canal.** A scaled physical model of a section of the Industrial Canal levee where the failure occurred will be conducted. The geometry and soil characteristics of the pre-failure section will be determined based on the Design Memorandum, As Builts, survey data, borings, cone penetrometer testing, and field observations. The levee section will be scaled down from the prototype in the range of 50 to 75 times, appropriate for centrifuge modeling at an increased earth gravity of 50 to 75 times. A depiction of the model is shown in Figure 60.

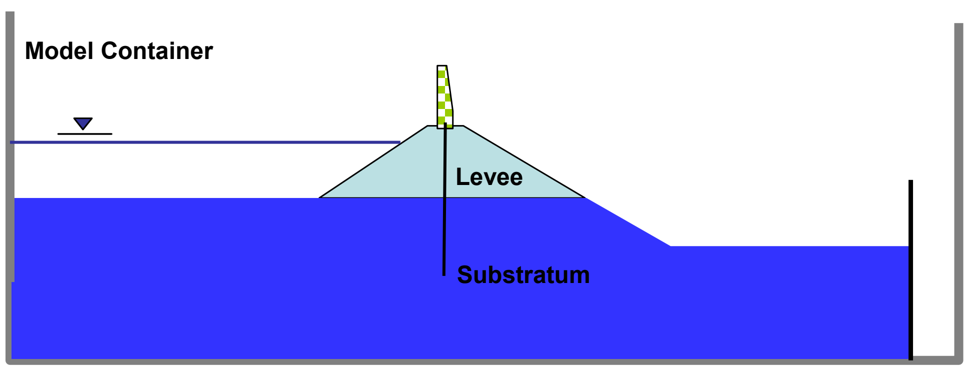



Figure 60. Depiction of model for evaluation of Industrial Canal levee.

The major issue of concern in this levee section is the erosion material behind the levee wall as a result of overtopping. Models of this levee system will duplicate the field conditions of the levee and foundation prior to failure and subject the levee to flood loads and overtopping.

In the model, the layer marked as Levee in Figure 60 will be modeled using the soil directly from the field. The material marked as Substratum will be modeled with synthetic clay (Spesswhite) placed at a strength, density, and moisture content to replicate the actual field soil for this layer. Appropriate care will be given to the model to get the placed clay layer back into the correct consolidation ratio prior to flood loading. After model construction, the appropriate prehurricane canal water level will be applied and held constant until full saturation of the model is achieved. This will be verified by pore pressure transducers located throughout the model. Subsequent to this, the water level will be raised to a level equivalent to the maximum hurricane flood loading. Behavior of the levee subjected to the flood load and overtopping will be continuously monitored with instrumentation inside and outside of the model in addition to recorded video.

Based on field observations and engineering judgment it is anticipated that the failure occurred as a result of erosion behind the wall, loss of material supporting the wall, and subsequent failure of the wall. Therefore several models will be constructed to explore the behavior of the levee to this phenomenon. Table 12 presents an outline of the planned test for Industrial Canal.

**Table 12. Planned Test for Industrial Canal**

| Model | Levee | Substratum |
|---|---|---|
| I-1 | Field material | Synthetic clay (need to add props. for model const) |
| I-2 | Field material | Synthetic clay (need to add props. for model const) |
| I-3 | Field material | Synthetic clay (need to add props. for model const) |

For all models, sensors and other monitoring techniques will be used to measure vertical and horizontal deformation of the levee, foundation, and wall. Additionally, pore pressure transducers will be used to track the development and evolution of the phreatic surface inside the levee. Cameras will be mounted around the test model for visual observation of the levee performance.

The expected results from each model will be measurements of displacements of all components of the model (levee, wall, foundation, etc), video of complete loading and subsequent failures, estimates of internal stress and strain, and failure mechanisms.

## Status

The following items have been accomplished for the Physical Modeling for Structural Performance Task to date and will be briefly highlighted.

- Development of post-hurricane failure sections for 17th Street Canal, London Avenue Canal and Industrial Canal
- Development of geology and soil profiles for the three canal levees
- Development of pre-hurricane sections for the three canal levees
- Meeting with GeoDelft personnel to obtain understanding and knowledge of their vast experience modeling (both physically and numerically) levees with and without peat. Obtaining knowledge from them on properties and behavior of peat. Securing their participation in this task and continued support.

- Development of physical modeling test plan between all parties involved in the task (ERDC, RPI, Steedman, GeoDelft)
- Completing design/construction/acquisition of needed equipment

## The Way Ahead

The following items highlight the planned activity for the near future and expected accomplishments for the 60% report.

- Finalize physical modeling test plan.
- Finalize the cross sections and soil properties for the physical models.
- Begin centrifuge modeling at ERDC and RPI with approximately 25% of the models being completed.

# Floodwall and Levee Performance Analysis

## Summary

The IPET mission is to provide credible and objective scientific and engineering answers to fundamental questions about the performance of the hurricane protection and flood damage reduction system in the New Orleans metropolitan area. The IPET approach to understanding the performance of the flood protection system is by examining the primary inputs, responses and outputs of the interaction of the hurricane and the flood control system. This task, Structural Performance Evaluation, has the responsibility to determine how the flood protection structures performed in the face of the forces to which they were subjected by Hurricane Katrina, and to compare this performance with the design intent, the actual as-built condition, and observed performance as depicted in Figure 61.

This task includes understanding why certain structures failed catastrophically and why others did not. It is also charged with understanding if any components suffered significant loss of capacity to protect against future storms. The team listed below will evaluate the performance the floodwalls and levees providing the hurricane and flood protection system in the New Orleans area to include St. Bernard Parish and Plaquemines Parish as shown in Figure 62.

This task will determine in detail how the levees and floodwalls performed during Hurricane Katrina. The studies to be conducted under this task will involve compiling available information concerning the as-built conditions of the levees and floodwalls, and eye-witness accounts of their performance during the hurricane to establish the underlying set of facts; performing field investigations including mapping and soil borings to determine post-failure conditions; performing laboratory tests to determine properties of soils and structural materials for use in analyses of performance; developing analytical models in the form of cross sections at areas where breaches occurred and areas where the levees and floodwalls were stable, and performing limit equilibrium and soil-structure interaction analyses to develop a full understanding of the performance of the levees and floodwalls and to provide guidance for future design analyses. These studies will be documented in a series of reports.

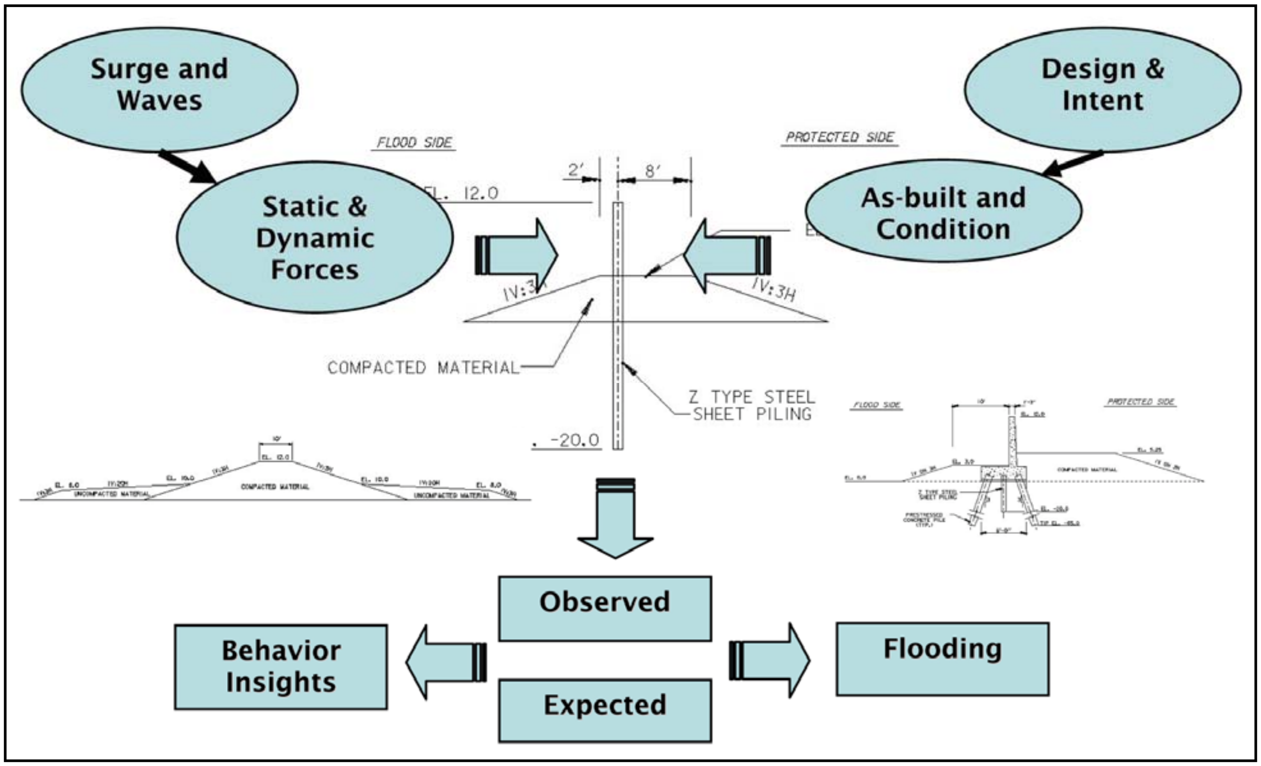



Figure 61. Physical Performance Analysis

**Team**

- Reed Mosher – ERDC/GSL, Co-Lead
- Mike Duncan –Virginia Tech, Co-lead
- Paul Mlakar – ERDC/GSL, Structural
- Joe Paluda - ERDC/GSL, Structural
- George Sills – ERDC/GSL, Geotechnical
- Noah Vroman – ERDC/GSL, Geotechnical
- Ellen Glynn - ERDC/GSL, Geotechnical
- Joe Dunbar – ERDC/GSL, Geologist
- Maureen Corcoran - ERDC/GSL, Geologist
- Robert Ebeling – ERDC/ITL, Geotechnical Modeling
- Don Yule – ERDC/GSL, Geotechnical Modeling
- Ron Wahl – ERDC/GSL, Geotechnical Modeling
- Kevin Abraham – ERDC/ITL, Geotechnical Modeling
- Mike Pace – ERDC/ITL, Geotechnical Modeling
- Benita Abraham – ERDC/GSL, Data Support
- Tony Young – MVD
- Ken Klaus – MVD

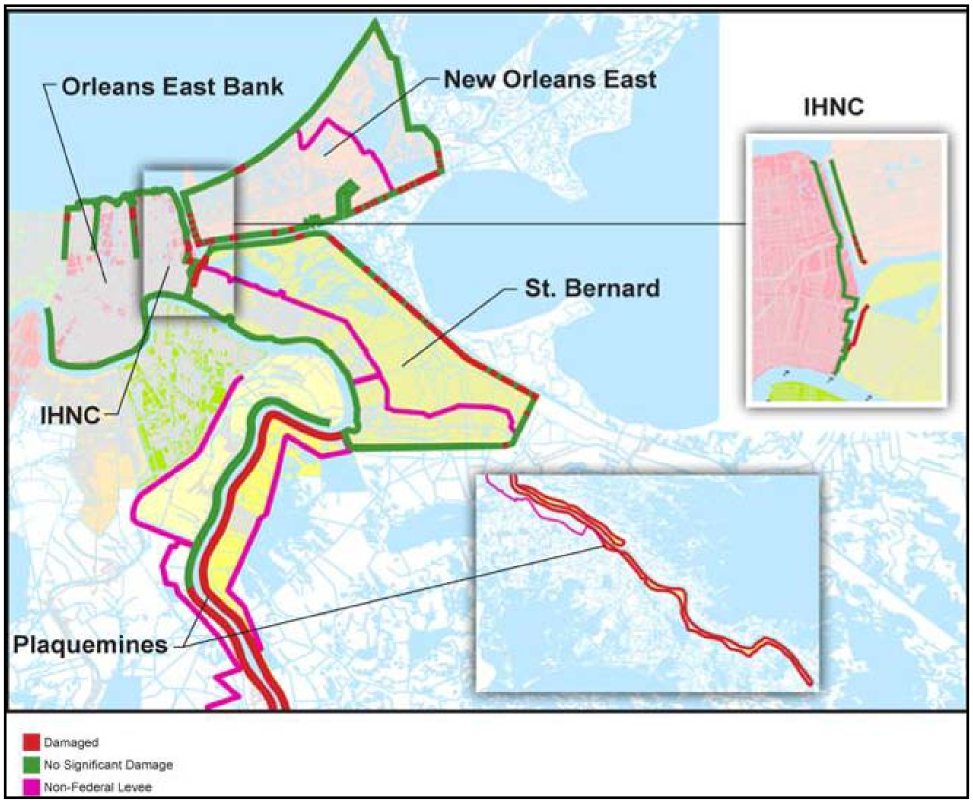



Figure 62. Damage to the Hurricane and Flood Protection System

- Richard Pinner – MVN
- Pete Cali – MVN
- Dave Bentler – STAGE Analysis
- C.Y. Chen – Geomatrix – FLAC Analysis
- Steve Wright – UT – Slope Stability
- TBD - PLAXIS Analysis

## Objective

The objective of this task is to analyze the levees and floodwalls used in the New Orleans flood protection system to determine their performance during Hurricane Katrina. Levee and floodwall systems are comprised of earth structures and/or structural elements constructed to provide flood protection during and after high water events. The failure of structures such as floodwalls or levees may be due to a single dominant mechanism, or a combination of mechanisms. Generally, the levees should be well constructed, engineered structures that perform well during their expected life. Problems arise in these structures from either inadequate foundation or isolated zones of weak material in the levee or the foundation or from unexpected loading conditions from higher water levels than anticipated in their design.

The performance of levees and floodwalls varied significantly throughout the New Orleans area. Initial preliminary observations indicate that both overtopping with erosion and soil foundation failure may have played major roles in the breaches in the floodwall and levee system. This Task will investigate the most likely causes of the damage and failure of the levees and floodwalls in the system and compare them with similar sections or reaches where the performance was satisfactory. It is important to understand in detail the most likely mechanisms that led to the breaches along a reaches in order evaluate the potential performance of the similar unbreached reaches of the protective system.

## Approach

The approach for the evaluation of the performance of the levees and floodwalls making up the New Orleans area (including Saint Bernard and Plaquemines Parishes) hurricane and flood protection system will involve conducting a comprehensive assessment of the background information of the geology of the area and the corresponding geological conditions along the system, the history of the construction, design criteria and approach, actual design documents and the as-built drawings for the system, and inspection and maintenance records. The entire levee system will be examined to identify areas or reaches that have performed satisfactory and those that have suffered damage. The damage areas or reaches will be characterized based on the type of damage and the surge height and the wave action.

Initial observations have revealed that breaches occurred along the 17th Street Canal, London Avenue Canal North and South, Inner Harbor Navigation Canal, Mississippi River Gulf Outlet, Gulf Intracoastal Waterway, and the Mississippi River. The evaluation of these breaches will involve investigating, characterizing, and analyzing representative levee sections separately in detail to ensure that no important site conditions or breach mechanisms are overlooked. All potential failure possibilities and mechanisms will be considered and evaluated.

Observations made at the breaches at the 17th Street Canal and London Avenue Canal North and South show that the most likely cause of breach is due to a soil foundation failure. Extensive observations by a number of teams found no signs of major overtopping of these canals at the breach sites. These breaches are being examined in-depth so a complete understanding of the failure mechanism can be determined. A number of factors are being examined, individually and in combination, at each breach location in order to fully understand what happened. The foundation soils in the breached areas of these levee sections vary in thickness of peat and/or weak clays overlaying sand and/or clay layers thus increasing the potential that different mechanisms may have caused the failure at each breach. Special attention will be paid to determine the trigger mechanisms of these failures that appear not to have involved overtopping. The performance of the floodwalls and the levees on the 17th Street Canal and London Avenue Canal will be compared with the performance of the nearby Orleans Canal that did not breach during Hurricane Katrina.

Observations indicate that water overtopping the floodwalls led to extensive scour and erosion in some locations, which may ultimately have resulted in breaches in the flood protection system. This was most dramatic along the Inner Harbor Navigation Canal adjacent to the Lower 9th Ward where the I-wall (floodwall) was breached. It appeared that water flowing over the floodwall scoured and eroded the levee on the protective side of the I-wall, exposing the supporting sheet piles and reducing the passive resistance. The erosion appeared to be so severe that the sheet piles may have lost all of their foundation support, resulting in failure. Perhaps the best evidence of this scour can be seen along the unbreached reaches of the I-walls on the Inner Harbor Navigation Canal where U-shaped scour trenches could be found adjacent to the I-walls. As the scour increased, the I-wall may have moved laterally and leaned to the protective side, causing the scour trench to grow as the water began shooting farther down the slope until sufficient soil resistance was lost and the wall was carried landward. I-walls along the Mississippi River Gulf Outlet and the Mississippi River in Plaquemines Parish show similar response to overtopping where the greater the scour, the greater the lateral translation and tilting of walls. While it appears that overtopping of the I-walls led to significant scour and possible breaching in multiple cases, it appears that if overtopping of T-walls did occur, it did not lead to extensive scour and erosion on the protective side of the floodwalls. Generally scour behind T-walls was less than that of I-walls most likely because of the T-walls base slab that extended 4 to 6 feet beyond the vertical wall preventing immediate erosion on the protective side. However, there were some T-walls that had significant scour, but none showed evidence of distress or movement either lateral or rotational. There was one T-wall failure in Plaquemines Parish where the wall was undermined from a large adjacent scour. This task will study these breaches to determine the amount of scour that would lead to a critical loss of support and instability. The results of this assessment will be used in examining the behavior of other I-walls along the Gulf Intracoastal Waterway and the Mississippi River in Plaquemines Parish.

The performance of levees varied significantly throughout the New Orleans area. In some areas the levees performed well in spite of the fact that they were overtopped. While in other areas the levees were completely washed away after being overtopped. Several possible factors could explain the differences in performance. One would be the type of material that was used to construct the levees. Another could be the direct wave action on the levees. The degree of dependence of overtopping versus wave action on the scour and erosion of the levees is yet to be determined and will be addressed in the high resolution analysis if the hydrodynamic environment experienced by the structures in the confined canals and channels. This task will examine the type of material used in construction of the levee versus the surge height and wave height to investigate their interdependence.

A common problem observed throughout the flood protection system was the scour and washout found at the transition between structural features and earthen levees. In many cases, the structural features were at a higher elevation than the connecting earthen levee, resulting in scour and washout of the levee at the end of the structural feature. At these sites, it appears the dissimilar geometry concentrates the flow of water at the intersection of the levee with the structural feature, causing turbulence that resulted in the erosion of the weaker levee soil. This task will examine the transitions to investigate their performance during Hurricane Katrina, highlighting both satisfactory and unsatisfactory performance of these transitions.

Penetrations through the flood protection systems required in order to permit through passage of trains and other surface transit produced additional transitions between dissimilar sections. Gate closures are provided at these locations in order to prevent flood waters from flowing into the protected area. This task will examine these gate closures to assess whether they were closed prior to the storm surge and to evaluate their performance during the storm surge.

### Sequence of Steps

The first phase of the study will involve collecting all available information on geologic conditions in the breach areas, design criteria, pre-design soil and foundation information, design procedures, design dimensions, and "as-built" dimensions. Information on the breaches will be examined to establish, as well as possible, the causes and mechanisms of failure at each breach location.

The simplified soil profiles and cross sections that were used in the design will be compared to soil and foundation information based on previous borings and new soil borings made since the breaches. Because a great deal of erosion has taken place at some of the breach locations, it is anticipated that it will not be possible to determine with precision what the soil conditions were before the failures. The available data will be used to develop the most likely conditions, and a range of possible conditions for each breach location. Establishing the possible range of conditions will be of use in comparing the results of analyses to field observations, and to estimate probabilities of failure for use in the risk and reliability analysis. Additional laboratory tests will be performed to better define material strengths and deformation characteristics of soils that do not already have the necessary laboratory data for the proposed analyses to be performed.

The data regarding high water marks, storm surge, and wave predictions and hydrodynamic forces analysis will be used to estimate variations of water loads with time. The available piezometer data will be examined to estimate the pore pressures at each location prior to the storm, and seepage analyses will be used to estimate pore pressure conditions during the storm. If possible a full-scale field seepage test will be conducted to determine piezometric levels in the underlying layers as a result of water level changes in the canals.

Limit equilibrium analyses and classical cantilever wall analyses will be used to examine stability of the levees and I-walls, and to examine possible mechanisms of failure at each breach site. The results of these analyses will be interpreted in terms of factors of safety and probabilities of failure. The results will be compared to the results of the limit equilibrium analyses and cantilever wall analyses that were used as the basis for design.

Numerical analyses of soil-structure interaction will be performed to investigate how the levees and floodwalls would be expected to respond to the estimated water loads and seepage conditions. The results of these analyses will help to provide a better understanding of failure mechanisms, and will provide a more complete picture of behavior for comparison with field observations and the results of the physical model tests examining structural performance. These numerical analyses will be capable of modeling movements of the levee slopes, seepage through and under the levees, and soil-structure interaction between the levee and the embedded sheet piling. They will also provide a basis for evaluating the effects of erosion on the behavior of the levees and the sheet piles. Two-dimensional (2-D), and possibly three-dimensional (3-D), soil-structure interaction models will be used to estimate the degradation, damage, and breaching of the wall and levee system due to the dynamic loading applied by the pulsating and pounding of the storm surge and waves. The results from these analyses will be compared to the results for the physical modeling conducted in the centrifuge, with scale models, and to field observations.

The information derived from these studies will be input to the risk and reliability analyses for use in estimating the risks associated with levee and floodwall performance during future hurricanes and tropical storms.

### Computer programs to be used in the assessment

**Limit equilibrium analyses:** These are the types of analyses used for design of the levees and I-walls. They will be useful in this investigation because they will provide results that can be compared directly with the results of the design analyses, and because they require relatively small amounts of computer time and engineering time, and are therefore useful for performing parametric studies.

The following limit equilibrium computer programs will be used for this part of the study:

- *UTEXAS4* – for stability analyses of embankments and flood walls. The strength of *UTEXAS4* is its unique ability for two-stage stability analyses, which is required to evaluate the possibility of undrained stability during the short-term storm loadings on low-permeability soils.
- *SLIDE v5.0* – also for stability analyses of embankments and flood walls. The strength of *SLIDE* lies in its graphical user interface and ability to perform all of the needed types of analyses except two-stage analyses. It will be very useful for independent verification of many of the analyses performed using *UTEXAS4*.
- *CSHTWAL* - for stability analysis of sheet pile walls by limit equilibrium methods. The role of *CSHTWAL* in the study stems from the fact that it was used in the design of the New Orleans I-walls, and results calculated using it can be compared directly to the design analyses.
- Another computer program, as yet unidentified – for analyses of the sheet pile walls. It will be important to have a computer program that can include the effects of groundwater pressures as they contribute to loads on the walls, and as they influence the shear strengths of the soils in which the walls are embedded.

**Soil-structures interaction analyses:** These are more advanced numerical analyses that involve deformation characteristics of the soils and structures, as well as their strengths. They provide information about deformations, and indirectly about stability.

The following soil-structure interaction computer programs will be used for this part of the study:

- *SAGE* (Finite Element Program for **S**tatic **A**nalysis of **G**eotechnical **E**ngineering Problems) – A two-dimensional (2-D) finite-element code developed for use in geotechnical engineering problems where earth and water pressures, movements, and soil-structure interaction are of interest. Models nonlinear stress-strain behavior by modeling processes such as construction on levees and walls in a series of steps that simulate the actual physical processes. Provides nonlinear and stress-dependent elastic and elasto-plastic stress-strain relationships. *SAGE* is capable of performing analyses with coupled (i.e. consolidation) or uncoupled deformation and pore fluid flow.
- *FLAC2D/3D* (Fast LaGrangian Analysis of Continua) – A 2-D/3-D continuum modeling code for geotechnical analysis of rock, soil, and structural supports using an explicit finite-difference formulation. Like *SAGE*, it can be used to model problems that consist of several stages, such as sequential excavation, backfilling, and loading. It has groundwater flow modeling that is coupled to calculation of deformations (including negative pore pressure, unsaturated flow, and phreatic surface calculation).
- *PLAXIS/3D* Foundation and 3D Tunnel (Finite-Element Code for Soil and Rock Analysis) – A finite-element package intended for the 2-D and 3-D analysis of deformation and stability in geotechnical engineering problems. The code is used for geotechnical applications that require advanced constitutive models for the simulation of the nonlinear, time-dependent, and anisotropic behavior of soils and/or rock. In addition, since soil is a multi-phase material, special procedures are being provided to deal with hydrostatic and nonhydrostatic pore pressures in the soil. It has the capability for modeling of structures and the interaction between the structures and the soil.

**Seepage analysis:** *SLIDE, SAGE*, *PLAXIS*, and *FLAC* all have capabilities for seepage analyses. *SAGE* and *FLAC* can be used for analyses of transient seepage, *SLIDE* only for steady seepage. However, *SLIDE* has automatic mesh generation features that make seepage analyses very simple. Pore pressures are seamlessly integrated into slope stability analyses performed using *SLIDE*.

The different codes will be validated against each other. The centrifuge models will be used in defining specific breach mechanisms that codes can be validated against.

## Work Plan - Subtasks

1. Data Collection and Assessment (target for completion - January 6, 2006).
   - Locate, obtain, and review all geological and soil/foundation investigations and soil borings.
   - Locate, obtain, and review all soil laboratory test data.
   - Locate, obtain, and review all information on piezometric levels in the foundation soil layers in the surrounding area.
   - Locate, obtain, and review all levee, sheet pile, and I-wall design information, plans and specifications, and "as-built" drawings.
   - Locate, obtain, and review the elevation of sheet pile tips and the top of the I-walls.
   - Determine if additional soil borings and laboratory testing are needed.

2. Assessment of Field Evidence (target for completion - January 6, 2006).
   - Locate and obtain all the information related to the geometry of individual failures.
   - Locate and obtain all the information on piezometers at or near the failure sites.
   - Examine the ground surface and soil profile information related to failure sites.
   - Locate and obtain all the information related to the position of the known parts of the wall and levee after the failure.

3. Define Soil Profile (target for completion - January 6, 2006).
   - Using the geological data, the pre- and post-Katrina soil borings and CPT data will be used to construct soil profiles for:
     - 17th Street Canal
     - London North Canal
     - London South Canal
     - Industrial Canal in the 9th Ward
   - Representative profiles for:
     - Mississippi River Levee System
     - Mississippi River Gulf Outlet
     - Gulf Intracoastal Waterway

4. Material Characterization (target for completion - January 6, 2006).
   - Based on the assessment of the site-specific data, create representative material properties for nonlinear soil models.

5. Conventional Analysis - Limit equilibrium and classical cantilever analyses (target for completion - March 31, 2006).
   - Seepage analysis

- Sliding/slope stability of the levees
- Floodwall stability

6. Numerical Modeling (target for completion - March 31, 2006).
   - Seepage analysis
   - Sliding/slope stability of the levees
   - Floodwall stability

7. Comparison to Physical Model (target for completion - March 31, 2006).

8. Comparison to Failure Evidence (target for completion - March 31, 2006).

9. Final Report (target for completion - May 1, 2006).

### Expected formal "touch" (review) points

- January 15, 2006
  - o Data collection and assessment
  - o Assessment of field evidence
  - o Define soil profile
  - o Material characterization

- March 1, 2006
  - o Conventional analyses and numerical modeling, preliminary results, and comparisons to physical models and failure evidence.

- April 15, 2006
  - o Conventional analyses and numerical modeling, near-final results, and comparisons to physical models and failure evidence.

- May 1, 2006
  - o Final report ready for review.

## Status

A draft plan has been developed for the analysis of the floodwall and levee performance (see the above Draft Scope of Work). Subtask 1 - *Data Collection and Assessment*, will be completed on 6 Jan 2006. Subtask 2 - *Assessment of Field Evidence*, will be completed on 6 Jan 2006. Under Subtask 3 - *Define soil profile*, the soil profiles will be defined by 6 Jan 2006 for 17th Street Canal, London Avenue Canal North and South, Inner Harbor Navigation Canal. The soil profiles for Mississippi River Gulf Outlet, Gulf Intracoastal Waterway, and the Mississippi River will be completed by 15 Feb 06, which will not impact the completion of the overall effort. Subtask 4 - *Material Characterization*, will not be completed until 30 Jan 06 which should not affect the overall schedule.

IPET has made additional Cone Penetration Tests (CPT) and soil borings to help better define soil conditions at the breach areas at 17th Street Canal, London Avenue Canal North and South, Inner Harbor Navigation Canal. This information was provided to Task Force Guardian on 2 Dec 2005. The Structural Performance Evaluation Task members provided Task Force Guardian an interim report entitled “Summary of Field Observations Relevant to Flood Protection in New Orleans, LA” on 1 Dec 05. This report provided Task Force Guardian with an independent assessment of the observations presented in the “Preliminary Report on the Performance of the New Orleans Levee Systems in Hurricane Katrina” released by the American Society of Civil Engineers and the National Science Foundation on 2 November 2005. The intent was to provide Task Force Guardian with additional insights (beyond those gained from their own review) with regard to what aspects of the field observations presented in the report could be immediately applied to the repairs to the flood protection system and what aspects may need additional analyses prior to implementation. The Structural Performance Evaluation Task members have been working with Task Force Guardian members on design criteria and analysis procedures for the designs to be done for the repairs for the floodwalls and levees in the New Orleans area. Structural Performance Evaluation Task team members have been traveling to New Orleans and participating in conference calls to support Task Force Guardian in this effort.

## The Way Ahead

The schedule presented in the draft scope of work is being followed with some minor changes as noted in the above Status section. This schedule will lead to completion of this Task by 1 June 2006. By the 60 percent report date and the 60 percent meeting with the ERP, the Structural Performance Evaluation Team will be ready to present preliminary results on the conventional analyses and numerical modeling, and comparisons to physical models and failure evidence.

# Pumping Station Performance Assessment

## Summary

The greater New Orleans metropolitan area is served by approximately 80 pumping stations in four parishes (Orleans, Jefferson, St. Bernard and Plaquemines) with a combined capacity of approximately 30 billion gallons per day. All stations are equipped with pumps which are either directly driven by diesel engines or by electrical motors which receive their power from diesel-electric generators. No remote or automatic controls are used. All pump stations need to be manned during startup and operation of the pumps.

The main metropolitan area (Orleans Parish) is drained by 13 pump stations which discharge directly to Lake Pontchartrain, the 17th Street, Orleans and New London canals, and the Inner Harbor Navigation Channel. A single diesel-electric (25 Hz) generating station powers virtually all of the pumps in this area. The pump stations in other areas in Orleans Parish as well as the other parishes have pumps which are directly driven by diesel engines.

This assessment will address how the pumping stations performed to evacuate the flooded areas. The assessment will determine if the state of inoperability of pumping stations was due to conditions that exceeded the original design/operating criteria, actual post-storm conditions, or lack of readiness. This information is needed to determine if the pumping station system performed as well as could have been expected considering the magnitude of the storm and its impact on nearby flood control features, or if the original design criteria needs to be revised. It should also determine if operation, maintenance, and inspection procedures are adequate, and if improvements, such as automation and remote control of equipment, should be considered. This work is essential to the accurate interior drainage and flooding modeling which directly inputs to the consequence and risk and reliability assessments.

**Task Co-Leaders:** Brian Moentenich, CENWP-HDC-M (Hydroelectric Design Center) and Bob Howard, SFWMD (South Florida Mater Management District). Independent Technical Review is being provided by Jim Norlin, CENWP-HDC-M.

**Geographic Area of Assessment:** This Task is performing the assessment of all significant pumping stations (a total of 76) within Jefferson Parish (East and West banks), Orleans Parish (East and West banks), St. Bernard Parish, and Plaquemines Parish (East and West banks). Performance (i.e. determining the daily pumping rates for each station) will be performed for most (68 of 76) stations. Only stations in Jefferson Parish with a rated discharge of less than 5% of the aggregate (i.e. less than 900 cu ft/sec) were excluded from determining the daily pumping rate. A damage assessment of all 76 pump stations is being performed. In addition, all temporary pump units for which discharge information were obtained were included in determination of the daily pumping rates.

**Objectives:** This objective of this Task is to document how the pumping stations performed to evacuate the flooded areas. The assessment will determine if the state of inoperability of pumping stations was due to conditions that exceeded the original design/operating criteria, actual post-storm conditions, or lack of readiness. This information will be used to determine if the pumping station system performed as well as could have been expected considering the magnitude of the storm and its impact on nearby flood control features, or if the original design criteria needs to be revised. It will also determine if operation, maintenance, and inspection procedures are adequate, and if improvements, such as automation and remote control of equipment, should be considered.

## Approach

### Temporary Pumping Units

Temporary pump locations and discharge data has been obtained from the Task Force Unwatering server. The server contained daily reports on temporary and fixed station pumping discharges. Hourly discharges were not obtained at this time and the assumption was the recorded daily data was for a 24-hour period. Information was also obtained from the Project Managers (PMs) of the Parishes in question. From this information it was determined that the smaller pumps (12 inches in diameter and smaller) were ineffective because of the height of the levee walls. Nevertheless the collected data was then entered into an excel program to determine the full pumping capacity, the available pumping capacity, and the assumed actual discharge of the temporary pumps and plotted on graphs. According to the collected data, to date, the total temporary pump assumed discharge was 5% of the total fixed pump assumed discharge, which can be considered scientifically insignificant.

### Fixed Pump Stations

The task force assigned for unwatering the New Orleans area was formed on October 11th. They reported on daily operation of pump stations beginning at that time. The rated discharges of individual pumps (or the discharge rates reported by the parishes) were reported as actual discharges. These numbers will be updated when better data is obtained (e.g. individual pump performance curves and head data). Prior to September 11th, no station flow data was reported. However, a partial list of station operational status was reported.

An Architect-Engineering firm (CH2M Hill) was hired (notice to proceed was given on 12-16-2005) to determine and document relevant physical attributes of identified diesel generating stations, pump stations and individual pumping units including:

- Key drawings showing the plant layout (i.e., station plan and section, pump unit cross-section, etc.), elevations of the pump stations, and long discharge conduit information (i.e., location of exit, length, and cross section area).
- Photographs of all plants.
- Latitude and longitude of each plant for which daily flow data is needed.
- Identification of any plants provided with "safe houses" or reinforced control rooms for operators to use during a hurricane.
- Existing operation, inspection, and maintenance records (i.e., logbooks, operating plan, or other documents pertinent to operations).
- Design and operating criteria (for plants for which performance data is needed), including but not limited to:
  - Inlet and outlet water surface elevation range.
  - Rated head, discharge and pump speed.
  - Pump curves (head-speed-discharge).
  - Trash rack design head.
  - Type of bearing water lubrication (water or oil).
  - Pump start intake water surface elevation.
  - Pump stop intake water surface elevation.
  - Water surface elevation which impacts station operation.
  - Pump unit discharge outlet location.
- Elevation (or height above pump house floor) of any observed or reported high water marks.
- State of plant and unit availability one day (August 28) prior to Katrina's landfall (for the plants for which daily flow data is needed).
- Operation and availability histories of plants for the period from 24 hours prior to Katrina's landfall until the un-watering pumping was complete for the plants for which daily data is needed.
- Information on any events of reverse flow through pump and reverse rotation including determining if pump stations have back flow gates, backstops or brakes installed to prevent rotation (for plants for which daily flow data is needed).
- Reasons for lack of availability of pump stations/units (for the plants for which daily flow data is needed).
- Storm-caused damage (due to wind or flooding), and projected repairs required after June 1, 2006, for all plants.

- Impact of debris on trash racks on pump operation (for the plants for which daily flow data is needed).
- Fuel supply issues and related shutdowns (for the plants for which daily flow data is needed).
- Record of interviews with pump station personnel, including any plant or parish recommendations or lessons learned (for the plants for which daily flow data is needed).
- Information on the fuel systems such as the capacity of fuel storage facilities, location, elevation, fuel delivery system (underground piping, above ground, etc.).

### Daily Pumped Discharge from Individual Pump Units

A “system” curve will be developed for all fixed pump units for which daily flow data is needed. This curve relates flow to “pool-to-pool” head. Water level data (on both the protected side as well as the discharge side) is needed to determine this head. This information will be provided by the Interior Drainage/Flooding Analysis team who is numerically modeling the drainage basins. For a “first cut,” these pool levels may need to be estimated at to provide the modeling teams with approximate daily discharges to enable them to more accurately model daily water levels at the pump stations. Daily unit operation records (gathered by CH2M Hill) from the plants will be used together with daily “pool-to-pool” heads to determine daily discharges from each pumping unit. For the temporary pumps, records of their daily pumped flow will be provided to the team doing interior drainage and flood modeling.

### Reverse Flow Through Pumping Units

Most of the pump units do not have a gate or bulkhead to prevent water from flowing backwards when the unit is shut down and the water level on the discharge side exceeds the high point of the floor of the discharge conduit. When the station is manned, some stations have the capability of admitting compressed air into the discharge conduit to prevent this from happening. If this is not done and the water level (on the normal discharge side) gets high enough, water will flow backwards to the protected side of the levee. This did occur at pump stations in Jefferson Parish and perhaps elsewhere as well. System curves will be developed for the pump units where reverse flow was suspected to occur *and was a significant factor in local flooding*. In areas where huge levee breaches occurred (such as the Orleans East bank and St. Bernard Parishes) and where significant portions of the levees were overtopped (such as in Plaquemines Parish), contributions to the flooding from reverse flow through the pumps would have been minor and will not need to be accounted for numerically modeling the actual event. For the interior drainage/flooding analysis of the scenario assuming no catastrophic structural failures, reverse flow will need to be accounted for. In this case, reverse flow system curves will be needed only for pump stations which were unmanned or ones which had no way to control reverse flow (i.e. no backflow gates or compressed air backflow prevention system.

Hydraulic engineers will use well proven formulas for determining flow in open and closed portions of the conduit and the dimensions of the conduits for each pump unit to develop a reverse flow system curve. Some pump units have brakes or a mechanical backstop (to prevent reverse rotation). Stopped and reverse rotation of the pump impeller will be accounted for when the system curves are developed.

Since reverse flow will be a function of plant elevation, any subsidence which has occurred over time needs to be known. The Vertical Datum Team will be surveying at least one key elevation (such as the operating floor) at each pump station where daily flow data is needed.

### Risk and Reliability

On December 5 and 6, Bob Howard (Task co-leader) participated in a risk and reliability workshop hosted by the IPET Risk and Reliability Analysis Team. The Interior Drainage/Flooding Analysis Team will be responsible for providing risk and reliability information on the pumping stations to the Risk and Reliability Team.

### Suggested Pump Station Improvements

Based on input from the parishes, record of damage sustained at various pump houses, mechanical engineers from New Orleans District and from personnel from South Florida Water Management District (which owns and operates a system quite similar to that of New Orleans), both short-term and long-term improvements will be suggested.

## Status

During the week of 7 November 2005, the Pumping Station Performance Assessment team and representatives of the AE Contractor (CH2M Hill) met with New Orleans district personnel (Task Force Hope) and representatives of all four parishes to develop contacts, discuss the team's data needs, determine what information has already been collected and to plan for the collection of the remaining needed information. Daily operation data, location and discharge of the temporary pumps was retrieved. Lists of the fixed pump stations needing to be surveyed (to determine exact elevation) as well as specific items of data were developed. During the week of 3 January 2006, field collection of data from the engineering offices and pumping plants by CH2M Hill commenced.

Bob Howard (Co-Leader) participated in a workshop the week of 5 December in Vicksburg District hosted by the Reliability and Risk team.

## The Way Ahead

Daily pump station design and operation data for all stations except those on the west bank of Jefferson Parish is expected to be collected by January 27, 2006. System curves for each "family" of pump units will then need to be developed. Once this is done, water level information (on both the protected side as well as the normal discharge side) for each station is needed (from the Interior Drainage/Flooding Analysis team) to determine flow. If this water level data is not available, assumed water levels will be used as a "first cut" to provide flow information to the Interior Drainage/Flooding Analysis Team.

Once pump design data is obtained, a reverse flow system curve can be determined. Determination of actual subsidence (from the survey) and water levels are then needed to determine reverse flow rates.

Because modeling of the west bank was judged to have lower impact on flooding during Katrina, pump station design and operation data for the west bank stations of Jefferson Parish will not be available until February 17, 2006. Pump station damage and repair information is not expected to be fully collected until February 10, 2006.

Condition of the pump stations will be projected to June 1, 2006. Only uncompleted repairs will be identified for stations which are not yet returned to 100% of their Pre-Katrina condition.

# Interior Drainage/Flooding Analysis

## Introduction

### Summary

To help answer the questions regarding how the hurricane protection system would perform under various conditions, this Task focuses on the filling and unwatering of the separate areas protected by levees and pump stations. Interior drainage models will be developed for St. Charles, Jefferson, Orleans, St. Bernards and Placquemines Parishes that simulate water levels for what actually happened during Hurricane Katrina and what would have happened had all the hurricane protection facilities remained intact, functioned as designed, and operated as planned.

Other IPET task teams will be providing data needed to estimate the flow into and out of the modeled parishes. Data provided includes storm surge and wave heights, levee breach geometry, and stormwater pump station operation. Since these data are needed at many locations for the duration of the event itself, it is anticipated some of the data will be difficult to obtain due to the extent and severity of the hurricane and the resulting flooding.

The primary final products for the public will be water elevations (stage) plotted versus time (as illustrated in Figure 63) and inundation area maps (illustrated in Figure 64). Results from this task will be used in the Consequence and Risk and Reliability analyses to assess, measure, and report risks for various scenarios to help the public and officials make decisions.

### Background

Interior drainage/flooding models are not necessary to estimate water elevations in an interior leveed area for a catastrophic condition such as Hurricane Katrina where water levels rise rapidly until they reach the level of Lake Pontchartrain, the IHNC, or Lake Borgne. However, interior drainage/flooding models are essential for estimating the peak water elevation and extent of possible flooding, if any, when the hurricane protection system performs satisfactorily or without catastrophic failure. The models can also be used to estimate the time needed to unwater an area once it is flooded.

Many people will want to know the level of risk to which they are subjected on or before June 1, 2006 when the pre-Katrina level of protection will be achieved at the levee breach locations. The interior drainage/flooding models will be used to examine the resultant flooding for Hurricane Katrina rainfall, storm surge, wave heights, and pump station operations given the observed flood protection system performance and for the situation of no catastrophic structural failures. As such, the models will determine estimated peak water elevations and areas inundated within the protected areas for these two situations. These models will also be useful to examine the degree of flooding that would result from other storm or structural and pumping station performance scenarios.

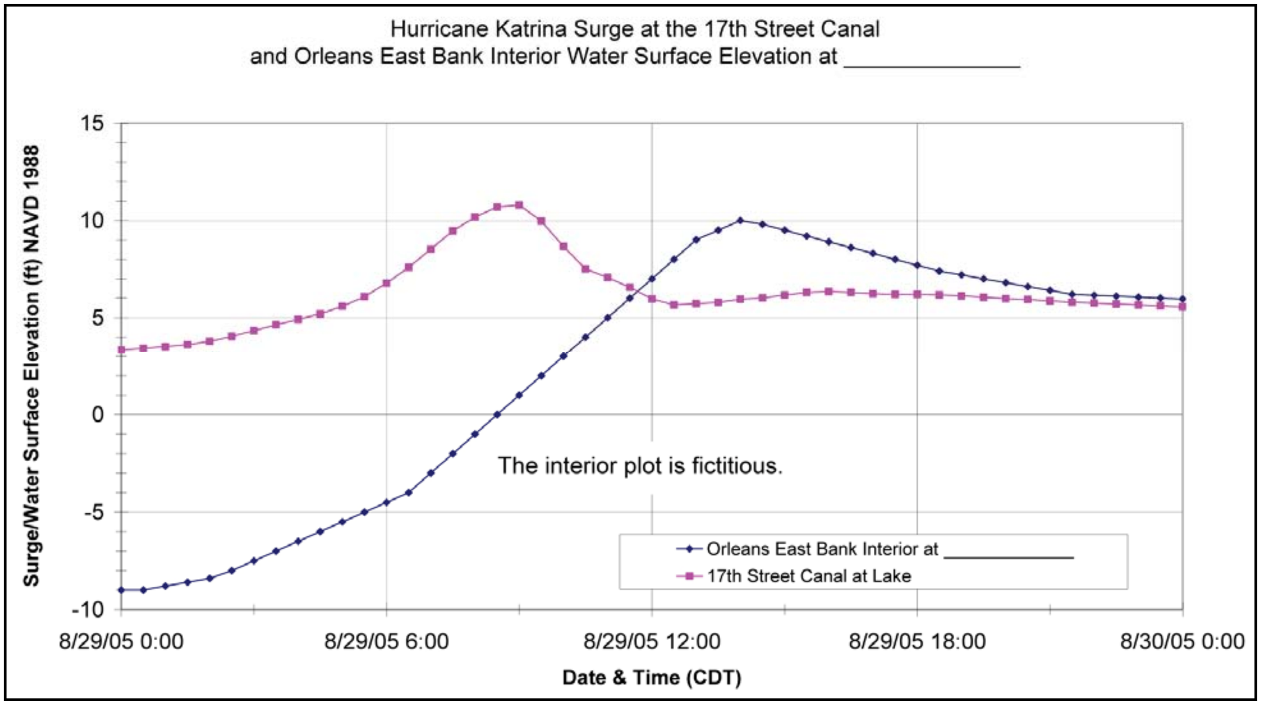



Figure 63. Sample water elevation (stage) versus time plot

## Objective

**Interior Drainage Model:** Develop interior drainage models that simulate water elevations in areas that flooded based on flow into and out of specified hurricane protection systems. Hurricane protection systems in the New Orleans area typically include facilities such as pump stations, levees, floodwalls, and levee closure structures. Water can enter areas protected by the hurricane protection system from precipitation, levee and floodwall overtopping, levee and floodwall breaches or flanking, pump backflow, and pump station basin overflow. Water flows out of the interior through breaches or pump stations.

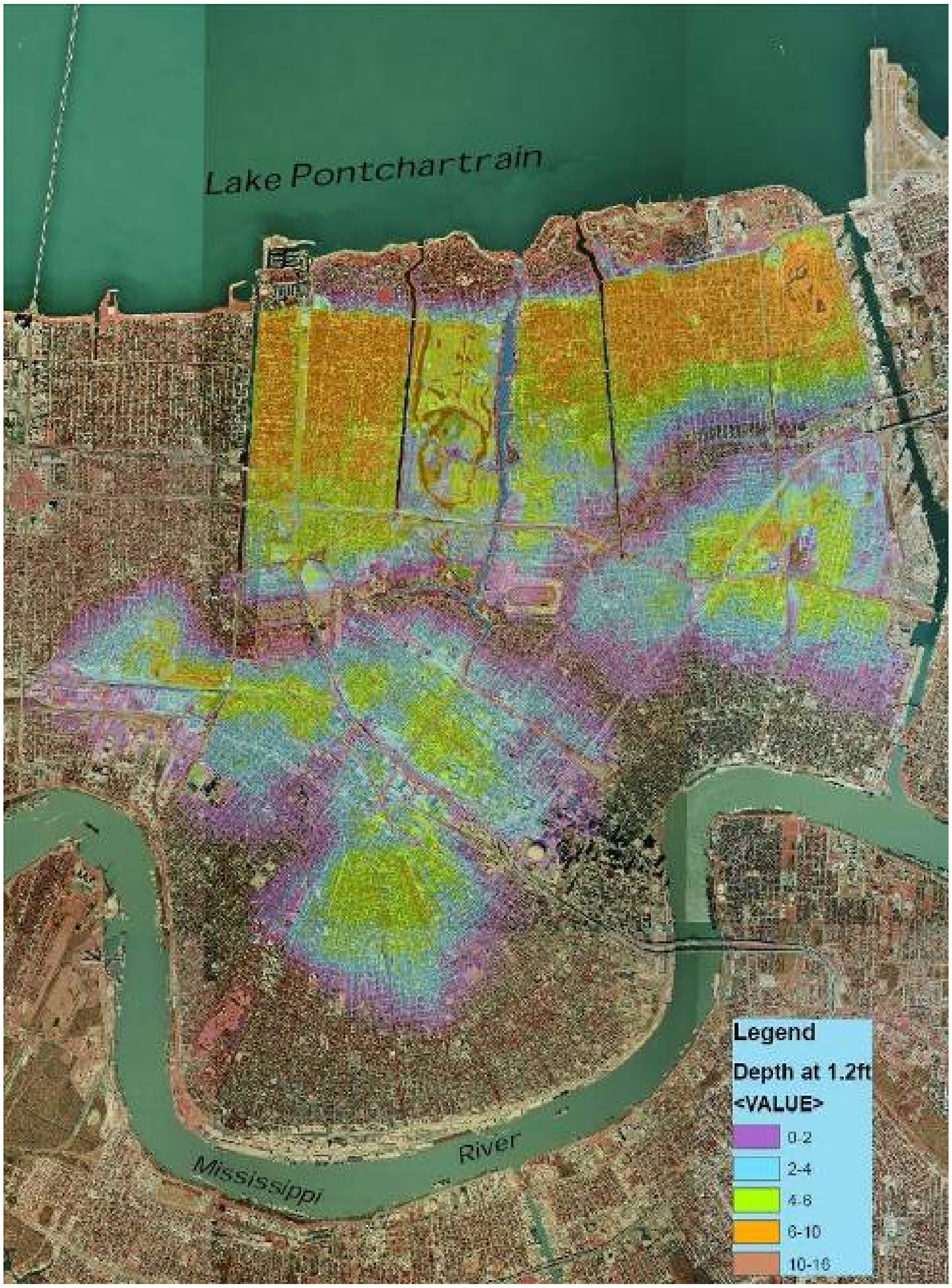



Figure 64. Sample flooded area mapping

**Pre-Katrina or As-Designed Scenario:** Using the interior drainage models, simulate what would have happened during the Katrina event had all hurricane protection facilities remained intact, functioned as designed, and operated as planned. No levees will be failed for this scenario even where overtopping occurs. All water will be removed by the pumping stations.

**Katrina or Actual Performance Scenario:** Using the interior drainage models, simulate what happened during the Katrina with the hurricane protection facilities performing as actually occurred. All water will exit flooded areas through original breaches, man-made breaches, temporary pump stations and operating pumping stations.

## Scope

### Team

Corps Co-Lead: Jeff Harris, Hydrologic Engineering Center
Non-Corps Co-Lead: Steve Fitzgerald, Harris County Flood Control District

Interagency Review
Jayantha Obeysekera – South Florida Water Management District
Dr. Arthur Miller – Penn State University

Modeling Resources:
Hydrologic Engineering Center (HEC): Gary Brunner, Dr. Michael Gee, Matt Fleming, Cameron Ackerman
New Orleans District (MVN): Clyde Barre, Robert Bass, Heath Jones, David Ramirez
Vicksburg District (MVK): Ron Goldman, John Smith, Ronald Copeland, Malcolm Dove, Mike Trawle
CTE Consultants (CTE): Nick Textor, John Morgan

ASCE External Review Panel (ERP) Members:
Bill Espey, Espey Consultants Inc.
Robert Traver, Associate Professor, Villanova University

### Approach

**Study Area:** The Interior Drainage/Flooding Analysis Team will develop models for the specific leveed areas listed below and shown on Figure 65 *(Note: Figure 65 not completed for 30% draft. It will be added later).* Modeling team assignments are listed on the table and shown on the exhibit, as well. The Mississippi River Flood Control Levee System is not part of this study.

The goal of this study is to evaluate the performance and operation of the hurricane protection systems in the New Orleans metropolitan area whether the leveed areas flooded significantly or not. Due to the short time frame for the study, the leveed areas have been prioritized as indicated in the table to insure results are obtained for the areas that experienced significant flooding.

Figure 65. To follow.

| Leveed Area | Priority | Team | |
|---|---|---|---|
| | | RAS | HMS |
| Jefferson East Bank | 1 | CTE | CTE |
| Jefferson West Bank | 2 | CTE | CTE |
| Orleans East Bank | 1 | MVK | MVK |
| East New Orleans | 1 | MVN | MVN |
| Orleans West Bank | 2 | MVN | MVN |
| St. Bernard | 1 | MVN | HEC |
| St Charles East Bank | 3 | MVN | HEC |
| Plaquemines | 1 | HEC | HEC |
| CTE – CTE Consultants, Chicago, IL<br>MVK – Corps of Engineers, Vicksburg District<br>MVN – Corps of Engineers, New Orleans District<br>HEC – Corps of Engineers, Hydrologic Engineering Center, Davis, CA | | | |

**Study Area Sequence:** Due to the short time frame for the study, the areas to be modeled have been prioritized to insure results are obtained for the areas that experienced significant flooding. Priorities are listed below and shown in the table above.

- **Priority 1**
  Jefferson Parish – East Bank (Kenner to Metairie)
  Orleans East Bank (17th Street Canal to Industrial Canal)
  East New Orleans (Citrus)
  St. Bernard Parish (Chalmette, including the Lower 9th in Orleans Parish)
  Plaquemines Parish (New Orleans to Mile 0)

- **Priority 2**
  Jefferson Parish – West Bank (Waggaman to Harvey)
  Orleans Parish (Algiers)

- **Priority 3**
  St. Charles Parish – East Bank (Destrehan)

*Note: Verify names above are consistent with IPET naming convention.*

**Models:** HEC-RAS and HEC-HMS models will be used for this study. All models developed will be geo-referenced in accordance with specifications developed from the IPET Data and Vertical Datum Teams. The initial vertical datum to be used will be NAVD88, with more refined information provided through the IPET Vertical Datum Team as it becomes available.

In order to focus on adequately estimating flood depths and not the detailed interior drainage systems, only primary internal drainage canals, underground conduits, and lift stations will be included in the models.

**Scenarios:** Two scenarios are described in detail in the Objectives above:

- As-Designed (Pre-Katrina) Scenario

- Actual Performance (Katrina) Scenario

**Assumptions:** Assumptions are necessary to complete the analysis with satisfactory results in the timeframe required. The list below will be modified and updated through the course of the analysis.

- Sources known to contribute relatively small volumes of water within the leveed areas will not be modeled
- It will be assumed canals, underground conduits, and pumps that were known to be operational were not blocked by debris.

**Model Development Sequence:**

- Develop HEC-RAS models using existing models, if available. Otherwise, construct new RAS models using current LIDAR data.
- Develop HEC-HMS models using existing models, if available.
- Calibrate the models using flood insurance model results and readily available historic flood events.
- Conduct a sensitivity evaluation of critical model parameters.
- Compute the Actual Performance Scenario (Task 3) results using Katrina data for the Priority 1 areas. Adjust model parameters, as appropriate.
- Compute the As-Designed Scenario results for the Priority 1 areas.
- If time allows, compute the As-Designed Scenario results for the Priority 2 and 3 areas.
- If time permits, compute the Supplemental Scenario results for Priority 1 areas.

**Data Needs:** The attached table titled “Interior Drainage/Flooding Data Needs” summarizes the data needed, expected source, and date received.

**Results:** The following output will be produced for each scenario, as applicable.

*Modeling Output*

- Effective rainfall and runoff volume and distribution
- Flow hydrographs at breaches, overtopped areas, pump stations, and other entry and exit points
- Interior leveed area stage and volume hydrographs
- Filling and unwatering timeline

*Visual Displays*

- Cross-sections, alignments and storage basins
- Hydrologic basin delineations
- Radar and hyetographs
- Breach locations, volumes, and flow hydrographs
- Overtopping locations, volumes, and flow hydrographs
- Pump station locations, volumes, and flow hydrographs

- Computed and observed stage and volume hydrographs for interior leveed areas
- Inundation area maps
- Time lapse animation of water flowing into and out of interior leveed areas

*Tables*

- Event timeline
- Summary of volume of flood water from each source
- Comparison of scenario results

**Final Report:** Prepare a final report for this Task in accordance with the IPET Report guidelines to be developed. The report will contain an executive summary, explanation of how the models were developed, the results, maps, tables, and exhibits.

**Dependencies:**

- Incoming – This Task is dependent on data from IPET Data, Storm Surge and Wave Analysis, Vertical Datum, Structural Performance Analysis and Pumping Station Analysis Teams. (See attached "Interior Drainage/Flooding Data Needs Table")
- Outgoing – This Task will provide input to the Consequence Analysis and Risk and Reliability Analysis Teams.

**Team Interaction:** When issues arise or direction is needed concerning the scope, schedule, data input, model development, output interpretation, or presentation of results; the co-leads will collaborate with the modeling teams, HEC staff, and/or interagency advisors as necessary. After a consensus is reached within the team, the decision or issue will be presented to the appropriate ASCE ERP members for review and comment.

**Touch points with ASCE ERP members:** Ongoing updates and discussions occur every two weeks. Major reviews will occur as follows:

- Initial scope of work (10%)
- Data collection and early model development (30%)
- Early results from Priority 1 areas and first draft of report and visual displays (60%)
- Final results from Priority 1 areas; initial results from Priority 2 and 3 areas; and final report and visual displays (90%)

| Interior Drainage/Flooding Task Schedule | | |
|---|---|---|
| **Date** | **Percent Complete** | **Milestone** |
| 11-10-2005 | 10 | Initial scope of work |
| 01-05-2006 | 30 | Data collection and early model development |
| 02-01-2006 | 60 | Early results from Priority 1 areas and first draft of report and visual displays |
| 05-01-2006 | 90 | Final results from Priority 1 areas; initial results from Priority 2 and 3 areas; and final report and visual displays |
| 06-01-2006 | 100 | Complete any loose ends |

# Status

**Data Collection:** NWS Hurricane Katrina rainfall radar information and LIDAR data obtained. Breach and overtopping data, surge and wave elevations, high water marks, and pump station data were requested by 19 December. Data has not been received. Work is proceeding without this data.

**Model Development:**

| Leveed Area | Priority | Est. % Complete | |
|---|---|---|---|
| | | RAS | HMS |
| Jefferson East Bank | 1 | 0 | 0 |
| Jefferson West Bank | 2 | 0 | 0 |
| Orleans East Bank | 1 | 15 | 15 |
| East New Orleans | 1 | 15 | 10 |
| Orleans West Bank | 2 | 0 | 0 |
| St. Bernard | 1 | 33 | 33 |
| St Charles East Bank | 3 | 0 | 0 |
| Plaquemines | 1 | 10 | 10 |

**Calibration:** Started

**Actual Performance Scenario:** Not started

**As-Designed Scenario:** Not started

**Report:** Not started

**Visual displays:** Not started

# The Way Ahead

By the 60% progress point, the Task objectives are to have

- Priority 1 area RAS and HMS models 75% complete using non-Katrina events for calibration
- Early results for Priority 1 areas for the Actual Performance (Katrina) Scenario
- Priority 2 area RAS models 25% complete
- A first draft report and first draft visual displays ready for review

| **Interior Drainage/Flooding Data Needs** | | |
|---|---|---|
| **Data Description** | **Source** | **Date Received** |
| **General** | | |
| Digital background maps and GIS layers (USGS digital quads, orthophotos, parcel data, streets and roads, etc…) | MVN/CRREL/IPET Data Team | Partial 5 Dec |
| Time history of observed hurricane system response - surge, flooding, wave heights, pump operation, levee damage, levee repairs, water level rise & fall within leveed areas, debris in canals (quantity, composition), barges, boats, etc. | IPET field team | |
| Previous H&H studies | MVN | |
| Available H&H models | MVN | 19 Dec |
| Aerial photos before and during flood – location and date/time | | |
| **Geometry** | | |
| DEM of all 5 parishes (LIDAR) | MVN/CRREL | Partial 5 Dec |
| Levee and flood wall alignments, profiles, and crest elevations - pre-storm and post-storm | MVN or TF Guardian | |
| Surveys and/or as builts for all culverts & bridges | MVN | |
| Interior area drainage network data – sizes, locations, profiles | MVN | 22 Dec |
| Canal centerlines and cross sections | MVN | |
| **Hydrologic Data** | | |
| Historic and Katrina precipitation data – point and radar | NOAA NCDC | 15 Dec |
| High water elevations within leveed areas | ERDC-CHL | |
| Flood inundation maps of Katrina – boundaries and elevations over time | MVK | |
| Land use data | USGS | |
| Soils data | USDA NRCS | |
| **Hydraulic Data** | | |
| Historic stream gage data, high water marks, and pump station data. Stream gage rating curves. | USGS, TFG, CHL | |
| Katrina surge height hydrographs | IPET Surge & Wave Team | |
| Breaches - locations, depth, width, descriptions, photos, and dates and times started, fully developed, and repaired. | IPET Field Team | |
| Land side scour locations | MVN-CHL | |
| Photos of levee/flood wall breaches, flanking, and overtopping – georeferenced and with date/time | MVN, IPET field team | |
| Pump station data - location, number of pumps, pump capacity and efficiency curve for each pump, operation plans, Katrina operation timelines | Consequence Team | |

# Consequences Analysis

## Overview

The objective of this task is a full assessment of all consequences resulting from hurricane Katrina and estimates of consequences from several "what-if" events. These events will include post-Katrina events and therefore must account for the post-Katrina land use, population, economic activity and other changes due to Katrina and the ongoing recovery. Consequences fall in the categories of economics, human heath and safety, social and cultural, and environment consequences. The goal is to estimate consequences in each category for the hazard scenarios developed by the IPET Risk and Reliability Assessment Team in contrast to the pre-Katrina economic, demographic, social and environmental attributes or resources. Additionally, this same consequence assessment will be applied to at least two post-Katrina alternative futures described by levels of these same attributes. This task will attempt to estimate the increment in consequences due to interior flooding from the levee and floodwall performance modes considered in the risk and reliability assessment. The assessment will be by the type of event and geographic scale sufficient for the needs of the risk assessment work. To the extent practical, the consequence assessment will be automated to quickly assess multiple scenarios. However, time constraints will limit the number of consequence / risk scenarios analyzed.

While the risk and reliability work is placing emphasis on economic and fatality consequences, the Consequence Analysis Team will go beyond this to examine a broader spectrum of consequences. Risk analysis typically focuses on the direct local consequences of hazard. However, this can omit indirect impacts on the rest of the region and the nation. The interior drainage/flooding analysis will provide timelines, depths and areas for different levee, floodwall and pumps performance scenarios. These quantities in spatial detail will be the primary drivers for estimating the direct local consequences.

The Risk and Reliability Team will be developing multiple risk scenarios based on alternative initiating events and hurricane and flood protection system responses. The Risk and Reliability Assessment Team will need consequences for two primary scenarios and several others. The primary scenarios are as planned system performance and actual performance. The as-planned scenario will result in estimates of flooding if the levees and floodwalls had performed as designed or planned. For the actual scenario, quantitative measures of what occurred will be gathered or estimated as appropriate. Alternative probabilistic initiating event and system performance scenarios are developed by IPET Risk and Reliability Assessment Team and applied to the pre- and post-Katrina database.

### Objective

The overall objective of this task is to examine comprehensively the consequences of Hurricane Katrina. An understanding of the consequences provides a framework for examining the implications of rebuilding the former hurricane protection system or alternative approaches for protection. It also enables the use of risk and reliability analysis in the formulation of future decisions concerning hurricane protection for individuals as well as local, state and national government authorities.

Because of the different natures of the consequences, this effort is divided into 4 subtasks with a subtask leader for each. The subtasks are:

- Economic consequences
- Social consequences and consequences to cultural and historical aspects
- Environmental consequences
- Human health, including psychological, and safety consequences

## Framework of Analysis

### Introduction

The basic approach is to first estimate direct local consequences; then, to estimate regional and national consequences based on the direct local consequence. The analytical framework for estimating local direct consequences is outlined below. Consequences will be estimated by applying event information to the underlying data by applying computational algorithms and models. Each event will be described by combinations of wind and water at spatial resolution consistent with the underlying data. The underlying data used for computations will be based on secondary geospatial data. Databases used include

- 2000 Census of Population and Housing
- 2002 Economic Census
- 2002 Census of Governments
- 2002 Census of Agriculture
- 2003 Census of Manufacturing
- 2005 Census of Employment (COE)
- Commercial fishing data form the Fish and Wildlife Service
- 2003 County Business Patterns
- 2004 American Housing Survey for the New Orleans Metropolitan Area

The smallest geographical reporting unit of these data is census block, while other data are available down to the census block group, census track or zip code levels. The spatial extent and elevation of water surface and the ground elevation DEM can be used to compute the depth of water at each damage centroid. The damage centroid is the geographic center of the GIS theme element linked to the demographic and economic database. For instance, one event is hurricane Katrina with the flood walls and levees performing as actually happened. The result is direct wind speeds and water depths at all locations within the IPET study area. Using the wind information, estimates of direct wind damage to structures, utilities, etc., can be made by applying algorithms relating damage as a function of wind speed. Using the median residential structure value (with adjustments for price level changes and perhaps other adjustments) and Corps depth-damage relationships, direct economic damage to residential structures can be computed. Similarly, other direct consequence metrics can be computed.

### Scenarios

Event scenario is the term used to describe the combination of initiating events and engineering system response. For instance, one scenario of this type is hurricane Katrina and the actual levee and floodwall performance. Another scenario is hurricane Katrina and the as-planned levee and floodwall performance. Each of these results in wind, rainfall, and flooding at different locations within the study area.

Condition scenarios are necessary to describe the underlying data that reflect both the pre-Katrina and alternative future land uses. These alternative futures will be described in terms of housing, population, business activity, infrastructure and other measures at two or more points in time. The first point is June 2006, while a second point might be June 2007. These futures, especially past the next six months, are very uncertain and are tied to such factors as whether hurricanes strike New Orleans in 2006 and combined with the performance of the protection system. Developing very many of these conditional future land use scenarios will quickly cause the analytical requirements to be intractable. The underlying base data for these futures will be quantified by adjustments to the pre-Katrina levels. These are “what-if” scenarios and not forecasts.

### Spatial Resolution for Consequence Assessment

Risk analysis will be conducted at the polder aggregation scale. Although this has not been finalized, the consequence assessment is defining the polder as one of the 13 separate ringed levee subsystems. There are 7 on the east bank and 6 on the west bank in greater New Orleans. The following is the list of levee subsystems:

- **East Bank**
  1. New Orleans Metro
  2. New Orleans East-Citris
  3. New Orleans East- Bayou Sauvage Refuge
  4. St. Bernard Parish-Chalmette

5. St. Bernard Parish-Sump
6. Jefferson parish-East Bank
7. St. Charles Parish-East Bank

- **West Bank**
  1. Cataouache
  2. Westwego to Harvey Canal
  3. Harvey Canal to Algiers Canal A
  4. Harvey Canal to Algiers Canal B
  5. Algiers Canal to Hero Canal A
  6. Algiers Canal to Hero Canal B

One problem in relating the secondary data level of spatial detail to the polder is that some parishes have multiple polders. For instance, Orleans Parish has 5 polders (New Orleans Metro, New Orleans East-Citris, New Orleans East-Bayou Sauvage Refuge, Harvey Canal to Algiers Canal B, and Algiers Canal to Hero Canal B). In addition, some polders only have part of the parish. For instance, Jefferson parish extends from Lake Ponchartrain to Grand Isle but it is not all protected by levees. It contains the subsystems Jefferson parish-East Bank, Cataouache, Westwego to Harvey Canal, and Harvey Canal to Algiers Canal A.

The intention of this task is to estimate consequences at the lowest data unit as possible and then provide the data to the Risk and Reliability Assessment Team, aggregated to the polder level. Figure 66 shows census the parishes, zip codes and census block groups, shaded by population density, within the study area. This is an example of the hierarchy to aggregate to the polder level.

## Analytical Framework

The steps below outline the basic analytical framework that will be followed to develop consequence estimate for events and inputs for the risk analysis.

1. **Background initial data elements for pre-Katrina and alternative post-Katrina future land uses.** Each consequence subtask has its own set of data elements for which consequences will be estimated. Demographic and economic data will be that available for the 2000 census of population and housing and other economic and demographic databases including more timely, but less detailed, sample survey data. Environmental data will be that available from a variety of government and university sources over a period of about 5 years preceding Hurricane Katrina. For alternative post-Katrina futures, these data will be adjusted to reflect potential redevelopment. The population from the background initial data elements will be the estimate of the population at risk for the scenarios using the pre-Katrina base data. The alternative post-Katrina populations at risk will be based on the alternative land use forecasts. These data will be aggregated up to the resolution for the risk analysis, which at this time is the polder or drainage basin. This level is primarily at the parish level although some parishes contain more than one polder (Orleans and Orleans East)

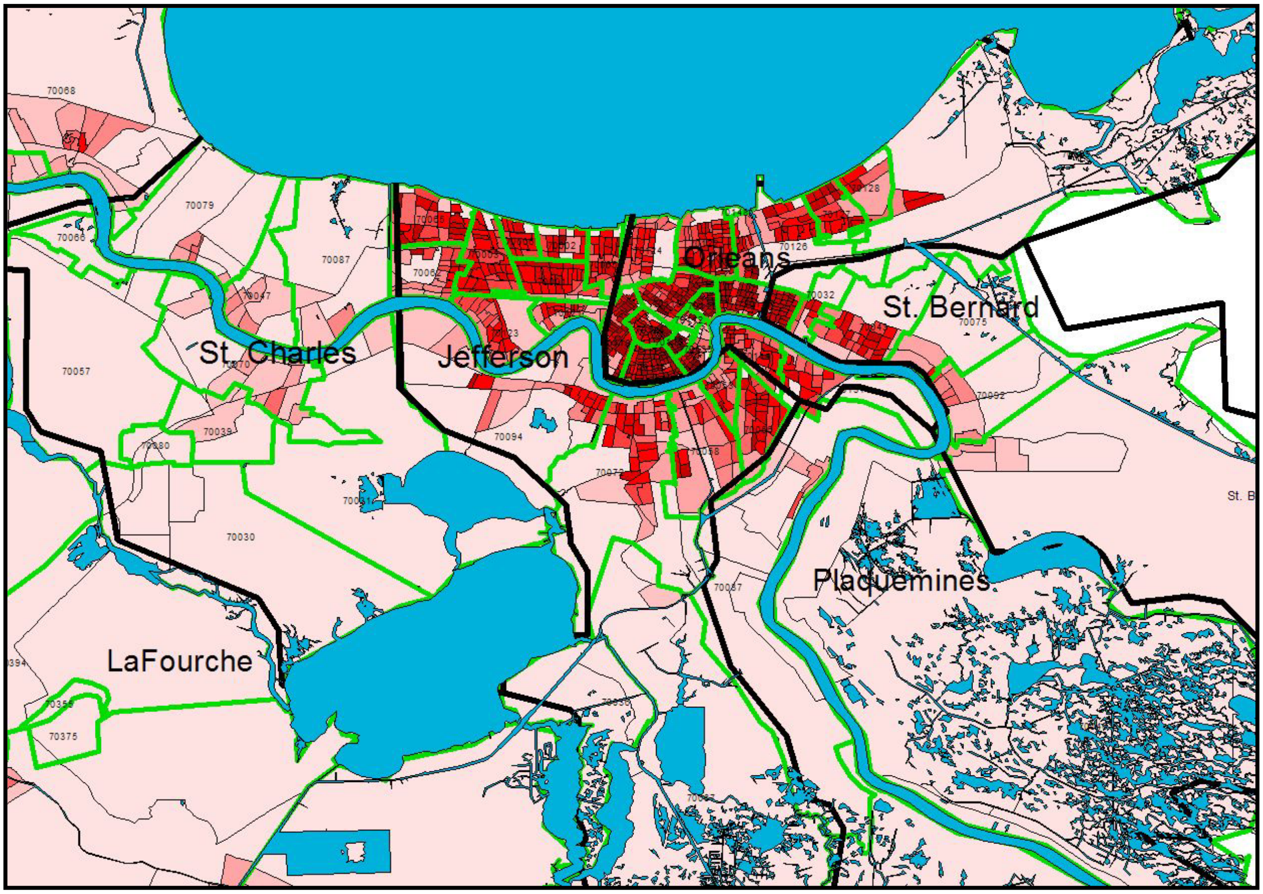



Figure 66. Example data hierarchy and aggregation

2. **Forecast of initiating events.** Initiating events are hurricanes requested to be evaluated by Risk and Reliability Assessment Team. Forecast of each initiating event needs to be described in terms of time of warning, time of evacuation notice. This time needs to be compared to time of occurrence of the event.

3. **Human response to event forecast and warning initiation.** People responded to the hurricane Katrina forecast and evacuation orders. This response adjusts the base date on population and perhaps other items such as automobiles. The population that evacuates incurs costs associated with the evacuation. They also incur nonmonetary effects such as anxiety and trauma. The population that remains is the threatened population that is subjected to high winds and flooding. Post-Katrina response to evacuation notice may be different than actually occurred. Alternative response scenarios will be considered and their significance to the number in the threatened population will be at least cursorily assessed.

4. **Occurrence of event.** The hurricane occurs at a point in time. For further analysis, the important quantity is the time lag between when threatened population, houses and other consequence bearing variables are exposed to the event and the start of warning and evacuation.

5. **Direct wind and water from the event.** Each event produces a rain, wind field, surge and waves at each point in the study area. Each event wind speed, forward speed and track combination will result in different levels of wind, surge and wave at different levee and floodwall reaches. Task 4 is responsible for providing data on both of these for all events. This represents the initial exposure to the hazard.

6. **Direct effects on adjusted background.** Wind and water from the event can have direct consequences. Wind can cause structural damage to buildings. Damage to buildings, trees, utility lines, ecological resources, etc. can also result in injuries and fatalities. Rain can pond, causing localized flooding. Storm surge and waves can similarly cause building damage and injuries in those areas outside protective structures. However, at this point in the analysis there is no interior flooding due to levee and floodwall overtopping or breaching.

7. **Protective system response to event.** Where hurricane protection systems exist, the modeled event subjects the structures to loads due to surge and waves. These forces will be different for each reach of the system. The Levee and Floodwall performance analysis will develop probabilities of system responses by reach for each combination of event forces as modeled by the storm surge and wave analysis, including a failure modes assessment. The physical response of the structures to loads may result in no overtopping, breaching, overtopping induced breaches, or overtopping with no breach. Each of these will result in different amount of water and interior flooding.

8. **Risk exposure (dose) process on adjusted background descriptors.** Each combination of event forces and failure mode will generate flooding within protected areas in addition to any caused by rainfall. The interior drainage/ flooding analysis will then estimate the time line and water surface elevation by location for the surge/wave/performance combination. The time line and water surface elevation is the primary variable input for estimating incremental direct local consequences depending on the protective system performance.

9. **Response of each adjusted background data element to risk exposure (dose).** Each polder will have experience the direct effects of wind and rainfall from the hurricane event. The mode of performance of the protective system will result in a level interior flooding within each of the polders. The response of each quantity of interest in each polder will be estimated. For instance, for a given threatened population, depth of flooding, duration of flooding, and perhaps other characteristics of the flood or the population, fatalities will be estimated for each event and each alternative future land use considered. Dollar values of damage to buildings, vehicles, and public utilities will be estimated. Flooding has direct effects on environmental resources due to exposure to salt water and, possibly, to other contaminants transported from sources within the interior flooding to ecological resources within and outside each polder. Each subtask has specific metrics for measuring impacts do to interior flooding from an event.

10. **Secondary effects from direct effects.** For each direct effect of interior flooding, there may be secondary effects locally, regionally or nationally. Local economies are linked financially to the rest of the region and the nation so that economic consequences can be transmitted outside the immediate area. Similarly,

local impacts on people can be transmitted, causing economic effects to the rest of the nation through evacuation. Draining flood waters can transmit toxic or contaminated water and sediment into lakes and estuaries impacting aquatic resources including economically valuable fisheries and endangered species.

### Matrix of Subtask Analyses, Event Scenarios and Base Data

The matrix below attempts to clarify that the event and system response scenarios impacts multiple consequence metrics. In addition, it acknowledges the difference between consequences applied to the pre-Katrina greater New Orleans and the alternative future post-Katrina greater New Orleans. Each cell in the event/system performance/consequence/conditions matrix represents multiple outcome measures within each of the major consequence categories.

**Matrix of Analysis**

| | | | Conditions | | |
|---|---|---|---|---|---|
| **Event** | **System Performance** | **Consequences** | **Pre-Katrina New Orleans** | **Post-Katrina 1 New Orleans** | **Post-Katrina 2 New Orleans** |
| Katrina | Actual[1] | Economic | *Econ-0* | *NA* | *NA* |
| | | Social-Cultural | *Soc-0* | *NA* | *NA* |
| | | Human Health | *Hum-0* | *NA* | *NA* |
| | | Environmental | *Env-0* | *NA* | *NA* |
| Katrina | Floodwalls as planned[2] | Economic | *Econ-1* | *NA* | *NA* |
| | | Social-Cultural | *Soc-1* | *NA* | *NA* |
| | | Human Health | *Hum-1* | *NA* | *NA* |
| | | Environmental | *Env-1* | *NA* | *NA* |
| Other* | Probabilistic[3]** | Economic | *NA* | *Econ-2* | *Econ-3* |
| | | Social-Cultural | *NA* | *Soc-2* | *Soc-3* |
| | | Human Health | *NA* | *Hum-2* | *Hum-3* |
| | | Environmental | *NA* | *Env-2* | *Env-3* |

Post-Katrina New Orleans conditions are alternative future recovery scenarios (e.g., Econ-3, Econ-5).
* Katrina with different track and other storm events request to be analyzed by Risk and Reliability Assessment Team.
** Multiple levee reach performance mode scenarios defined by Risk and Reliability Assessment Team.
[1] The Actual System performance leads to the actual consequences (Econ-0, Soc-0, Env-0, Hum-0) estimated using the pre-Katrina data on economics, demographics, etc.
[2] The Flood walls working as planned leads to new consequence values (Econ-1, Soc1, Env-1, Hum-1). The increment in consequences due to the actual floodwall performance is the differences between Econ-0, Soc-0, Env-0, Hum-0 and Econ-1, Soc1, Env-1, Hum-1.
[3] Each probabilistic system performance scenario is applied to each of the future post-Katrina conditions resulting in consequences Econ-2, Soc-2, Env-2, Hum-2 for post-Katrina 1 New Orleans conditions. Similarly, Econ-3, Soc-3, Env-3, Hum-3 are consequences for Post-Katrina 2 New Orleans.

### Hierarchical Data Structure of Matrix of Analysis

The matrix of analysis can be represented in the form of a hierarchical data base with the following form.

ScenarioID
Init_EventID
System_PerfID
    Conditions_ScenID

ParishName
PolderName
Zip_Code
Census_Tract
Census_BG
Census_Block
MaxWaterDepth
FloodDuration
Economic Consequences(multiple metrics)
Social-Cultural (multiple metrics)
Human Health (multiple metrics)
Environmental (multiple metrics)

Each record in the database would have a unique scenario name or ID. Each scenario is a combination of initiating event, system performance and condition scenario. All consequences will be identified by parish, polder, zip code, census tract, census block group, and census block as data is available. The water depth and duration of flooding at the smallest geographic scale will be used to estimate the direct consequences for the scenario.

### Leadership

The Consequence Analysis Team is being led by Dr. David Moser, IWR and Chief Economist, USACE, and Dr. Patrick Canning, Economic Research Service, Department of Agriculture.

## Overview and Status of Each Subtask

### Economic Consequences

**Introduction.** As generally defined for the IPET mission, the economic consequence analysis is being developed to investigate various scenarios associated with hurricane Katrina and the possible future occurrence of similar or more severe storms. Specific to occurrence of Katrina, two scenarios involve the assessment of flooding and inundation with subsequent physical and economic consequence for storm conditions as they transpired on 29 August with one scenario allowing for physical levee or floodwall failure (as it actually happened) and another scenario assuming performance of the levee and floodwall system commensurate with its intended level of protection. Additional scenarios involve assessment and evaluation of what will be at risk as of 1 June at the beginning of next hurricane season in relation to varying sets of conditions for possible future storms and potential for levee or floodwall failure in different reaches of the levee\floodwall system.

**Approach.** Requirements for consequence analysis involve estimation of direct, indirect, and induced economic impacts of storm effects with regard to flooding and inundation and related costs or damages associated with varying scenarios. By default, investigations will require investigation and estimation of procedures concerning wind-driven damages so that the marginal economic costs or value of the levee\floodwall system can be determined.

**Team**
Ian Mathis- CEIWR, Subtask Leader
Stuart Davis-CEIWR
Keven Lovetro-CEMVN-Economist
Brian Maestri-CEMVN-Economist
Dennis Robinson- University of Missouri
Jeffrey J.D. Hewings-University of Illinois
Thomas Arnold—Economic Consultant

ITR
Karen Polenske—Regional Economist—MIT
Nick Rockler—Economic Consultant
Other--TBD

**Status.** Draft scopes of work and a government cost estimate have been prepared for estimation of the indirect and induced costs of storm damages. Documentation for sole-source acquisition of services has also been completed based on unique knowledge and skill set and justification for urgent and compelling need in association with studies for Hurricane Katrina is in process. Primary data compilation for two of the five parishes has been largely completed. In addition, research concerning available datasets and desired GIS mapping coverage for the five parish area is pending (subject to provision of funding) and is tentatively scheduled for completion by the middle to end of January.

Potential reviewers for studies and analysis have also been contacted concerning their capacity or experience and their availability to provide advisory or review support. Draft scopes of work and government cost estimates have been prepared for each of these with remaining products required for contracting involving justification and authorization (J&A) for other than full and open competition (primarily based on urgent and compelling need related to studies for Hurricane Katrina) and endorsement of management decision documentation. Figure 67 shows some preliminary estimates of residential structure losses by zip code and represents the type of graphical display of consequences to be produced by this task. Table 13 shows the impact of flooding and wind damage impact on local employment and businesses.

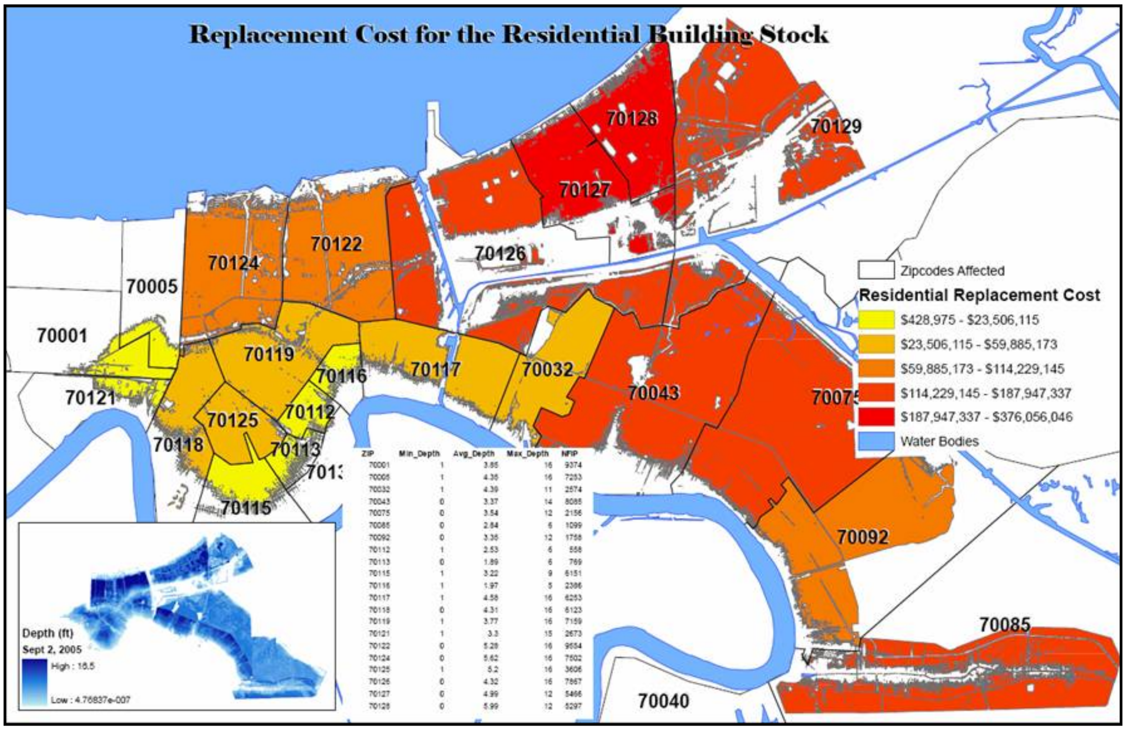



Figure 67. Replacement cost for the Residential Building Stock - Jefferson, Orleans, St. Bernard Parishes. SOURCE: LSU Hurricane Katrina and Rita Information Clearinghouse, *https://katrina.lsu.edu/downloads/Picayune/Zip_ResLoss2.pdf*.

**Table 13: Establishments, Employment, and Quarterly Wages within Katrina-Damaged Areas as Defined by FEMA**

| Damage Type | LOUISIANA (Q:IV 2004) | | |
|---|---|---|---|
| | Establish-ments | Employ-ment | Quarterly Wages |
| **Flooded Area** | 18,078 | 305,340 | $2,966,338,291 |
| **Non-flooded area:** | | | |
| **Limited Damage** | 681 | 7,731 | $59,505,161 |
| **Moderate Damage** | 140 | 2,055 | $12,701,137 |
| **Extensive Damage** | 45 | 577 | $3,717,779 |
| **Catastrophic Damage** | 53 | 360 | $4,880,302 |
| **TOTAL** | 18,997 | 316,063 | $3,047,142,670 |
| **TOTAL** | 3,352 | 55,081 | $419,139,867 |

**Explanation of FEMA Storm Damage Categories**

Limited Damage: Generally superficial damage to solid structures (e.g. loss of tiles or roof shingles); some mobile homes and light structures are damaged or displaced.

Moderate Damage: Solid structures sustain exterior damage (e.g. missing roofs or roof segments); some mobile homes and light structures are destroyed, many are damaged or displaced.

Extensive Damage: Some solid structures are destroyed; most sustain exterior and interior damage (e.g. roofs are missing, interior walls exposed), most mobile homes and light structures are destroyed.

Catastrophic Damage: Most solid and all light or mobile structures are destroyed.

Source: U.S. Department of Labor, Bureau of Labor Statistics, *http://www.bls.gov/katrina/data.htm#5*

### Human Health & Safety Subtask

**Introduction.** The human health and safety consequences assessment addresses the following IPET question included in the December 6, 2005 ASCE comments on the IPET detailed scope of work:

> *What were the societal-related consequences of the flooding and hurricane damage, and what are the future societal-related risks that will be faced in New Orleans following reconstruction?*

The primary objective of this subtask is to estimate potential flood-related mortality risks in greater New Orleans under different pre- and post Hurricane Katrina risk scenarios as developed by the Risk and Reliability Analysis Team. For each risk scenario, the Interior Drainage/Flooding Analysis Team will supply information on spatially-distributed flood levels and velocities that will be used in this subtask to estimate potential loss of life in the five parishes that make up the greater New Orleans metropolitan area. The product will be maps of potential life loss under each risk scenario that will be provided to and reported by the Risk and Reliability Analysis Team. A secondary objective of this subtask is to characterize--but not quantify-- human impacts on New Orleans residents resulting of the Hurricane Katrina event, and to identify external studies to quantify those impacts. This is necessary because the human health consequences of Katrina and its aftermath include various potential morbidity impacts in addition to loss of life, some of which may be widespread and long-lasting.

**Team.**
Paul Scodari, CEIWR, subtask leader
Private contractor, loss of life modeling and health impacts characterization
New Orleans (MVN) District, GIS data layers

Independent Technical Reviewers (not yet under contract)
Dr. David Bowles, RAC Engineers and Economists (loss of life modeling)
Dr. Thomas Burke (public health impacts)

**Approach.** Potential loss of life due to flooding will be estimated for several risk scenarios as determined by IPET Risk and Reliability Analysis Team, potentially including pre-Katrina, the Katrina event assuming no failure of the hurricane and flood protection system, and residual risks following repair and reconstitution of the protection system. Spatially-distributed data on flood elevations and velocities for the different risk scenarios provided by the IPET risk and reliability team will be used to estimate potential loss of life in each risk scenario. This estimation will use an appropriate model for estimating potential loss of life due to flooding together GIS profiles of demographic and related data for the five parishes of greater New Orleans for both pre-Katrina and post-Katrina base cases. The "LIFEsim" model has been tentatively selected for loss of life modeling because of its modular nature, accounting for complex warning and evacuation processes, ability to simulate within uncertainty mode, and familiarity to the Corps. The GIS data layers are relying on census block data and other sources of data on demographic and related conditions in New Orleans. Mapping of estimated loss of life under each risk scenario will be provided to the Risk and Reliability Analysis Team for IPET reporting. The characterization of

Hurricane Katrina health impacts and studies will be documented in a summary report provided to the Risk and Reliability Analysis Team. The work will utilize expert opinion and review by an Independent Review Team consisting of one expert in flood-related loss of life modeling and another expert in human health and safety. They will be consulted immediately following development of detailed analytical framework, and prior to and following model runs (for loss of life modeling) and report drafting (for Katrina health impacts).

**Status.** Completed tasks include analytical framework development and selection of loss of life model. Work is underway to develop GIS data layers for human health as well as other subtasks within the Task 9 consequences assessment. Due to delay in funding, the preferred contractor, who has extensive experience in public health and safety impact assessment and modeling, is still being secured. The private contractor and ITR members should be under contract by mid January 2006. Figure 68 shows the location of fatalities in the Greater New Orleans area by zip code.

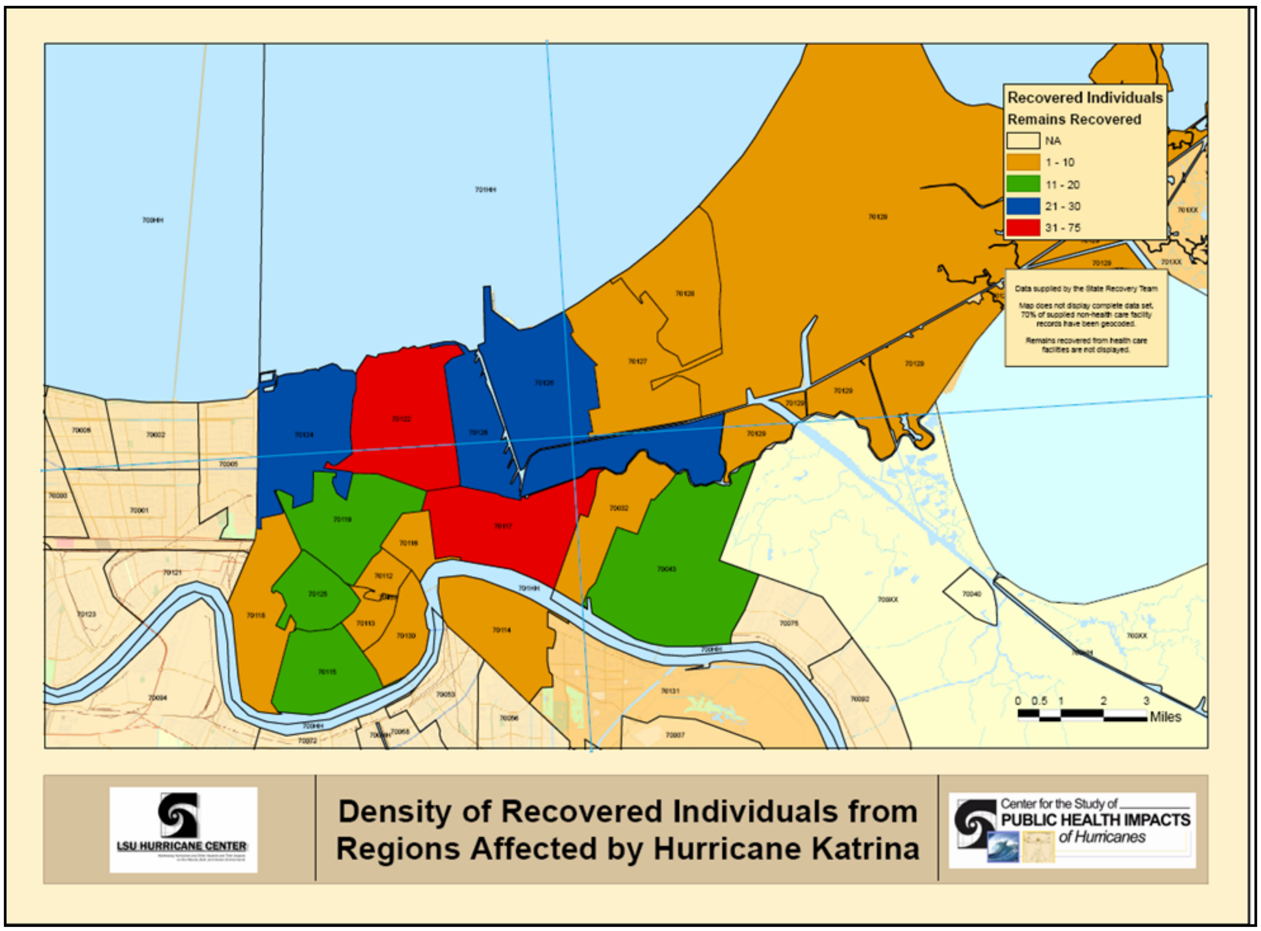



Figure 68. Fatalities from Hurricane Katrina by Zip Code. SOURCE: Louisiana Department of Health and Hospitals, *http://www.dhh.louisiana.gov/offices/publications/pubs-145/DHH_102605_1200_Revisions.pdf*

**The Way Ahead.** The next steps involve adaptation and calibration of the loss of life model to greater New Orleans. By the 60% report we expect to have the model and GIS data layers fully developed for application.

## Environmental Subtask

**Summary.** This subtask addresses the environmental consequences of hurricane protection system performance at New Orleans and four adjacent parishes. The following are activities included:

- Identify indicators of performance to include changes in health status and level of metals, petrochemicals, selected pathogens and other contaminants in sedimentary habitat, endangered sturgeon, shell fish and fin fish community; changes in wetland acreage and composition, and changes in debris disposal amounts and contamination.
- Consolidate all existing data on indicators and environmental factors influencing changes in performance indicators and, when insufficient, gather original data on performance indicators and pathways (e.g., water contaminant concentration and salinity) between hurricane system performance and indicator condition.
- Use a contaminants fate model to sort out wind, surge and other sources of environmental impact and to estimate the transport and fate of contaminants within the hurricane protection system and in the environment outside the hurricane protection system affected by any failure in the hurricane protection system to perform as expected under scenario conditions provided by the Risk and Reliability Analysis Team.
- Determine contaminant sources and mechanisms for contaminants release within the flood zones indicated by scenarios supplied by the Risk and Reliability Analysis Team.
- Use background data gathered just before and after Hurricane Katrina to verify model predictions of performance indicators to the extent data allows for the Katrina event.

**Background.** Environmental consequences could extend to further degradation of endangered species, scarce wetland ecosystems, and habitats and ecological resources supporting valued fisheries and recreational opportunities.

**Objective.** Forecast changes in ecological resource condition resulting from various hurricane and hurricane protection system scenarios provided by Risk and Reliability Assessment Team, and their anticipated impact on environmental benefits.

**Team.**
Richard Cole—CEIWR—Environmental Scientist—Subtask Leader
Barbara Kleiss—CEERDC—Ecologist
Burton Suedel—CEERDC—Biologist
Other ERDC scientists

ITR
TBD

**Approach.**

- Domain for work: New Orleans and four adjacent parishes and potentially influenced environments in the vicinity of the parishes.
- Models or tools to be used: Spatially explicit contaminants fate model and hydrologic model outputs from Tasks 2 and 3 as indicated by the Risk and Reliability Assessment Team.
- Data requirements and principal sources: Data on all performance indicators summarized above gathered from all existing sources for pre and post-Katrina, and original data, some of which were recently gathered for habitat contamination analysis.
- Analysis methodologies: Contaminant fates model calibration with existing data and model outputs, statistical analysis of existing data where appropriate.
- Expected products and their nature: ecological resource summary of existing data; contamination status after Katrina, if possible to determine; performance indicator health status, to extent determined; hurricane system performance impact on ecological resources/performance indicators; hurricane system performance impact on environmental benefits.
- Major interdependencies: Data from other agencies/universities, contaminants model and other analysis requires inputs from The Risk and Reliability Analysis, Interior Drainage/Flooding Analysis Teams. Figure 69 shows sediment sampling sites conducted by US EPA and Louisiana Department of Environmental Quality.
- Major touch points with ERP:
- Product schedules/milestones: Finalize scope in early January 2006 and Final document drafted by April 2006.

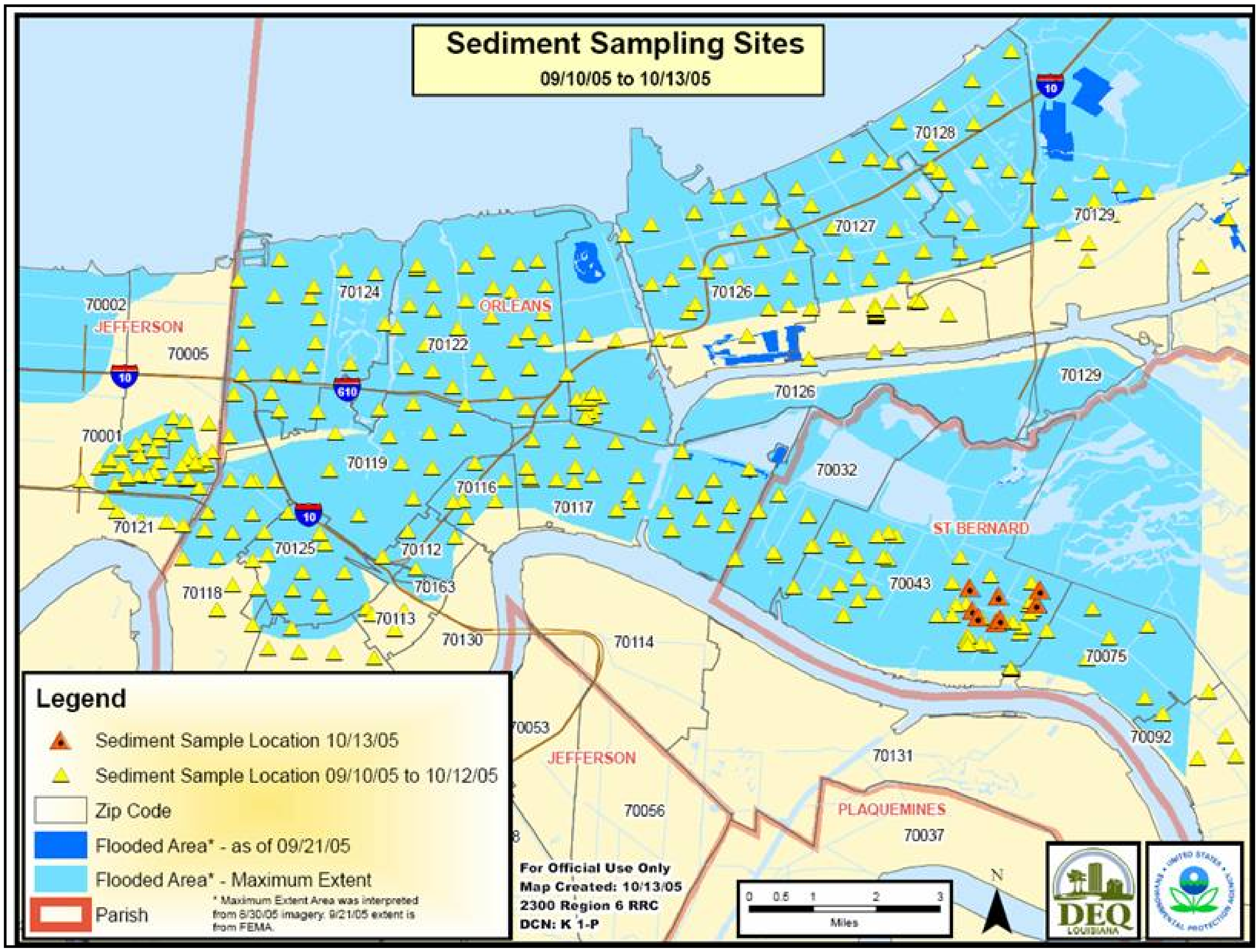



Figure 69. Sediment sampling sites. Source: US EPA Region 6, *http://epa.gov/region6/katrina/pdfs/SedimentSamples_110805all.pdf*

**Status.**

- Refined draft of scope developed in mid-December
- Initial consolidation of existing data from agency and university sources
- Preliminary sampling of perishable data in sediments and wetlands in early December
- Preliminary analysis of sediment contamination underway

**The Way Ahead (60-percent report).**

- Completion of scope
- Existing data collected with preliminary analysis and summation
- Original data collected and much of it analyzed
- Possible partial completion of contaminants model analyses.

### Social, Cultural and Historic Consequences

**Background.** This part of the Consequence Analysis Team work effort focuses upon the social, cultural and historic consequences of the levee system performance in New Orleans metropolitan area during Hurricane Katrina. The levees in the New Orleans metropolitan area were designed to provide hurricane and flood protection for physical properties and safety. The levees also protected the overall social well-being of the area's population and the places in which that population lived. Such protection fosters conditions that allow the social organization that makes population sustainable, and preserves that population cultural heritage. The levee failures had a dramatic impact on the population beyond economic losses. These impacts are unprecedented in their social consequences. The social, cultural and historic aspects of New Orleans are unique. In order to understand what those impacts were, the study team will quantify key parameters reflecting the social conditions immediately prior to the hurricane. Included in that will be characteristics of the population living in the neighborhoods in the metropolitan area, including parameters that make populations especially vulnerable, such as age, income, and ethnicity. Also included in the analysis are measures of the key institutions in the community such as churches, schools, health care, and voluntary organization. The analysis will address the effects of the hurricane upon the population in these neighborhood and the institutions. Additional the analysis will identify cultural and historic consequences of social areas of the neighborhoods and culturally significant locations.

The overall purpose of the analysis is to give the decision maker an understanding of the social conditions in the metropolitan area, the impact of hurricane events, and the social, cultural and historic relevance of hurricane protection. The objective is to provide a qualitative and quantitative analysis.

**Team.**
John Singley—CEIWR—sociologist—Subtask leader
Ed Rossman—CESWT—sociologist
New Orleans District staff
URS Corporation

Advisory Team and ITR from these Institutions
Louisiana State University
University of New Orleans
University of South Carolina
Oklahoma State University
Disaster Research Center at the University of Delaware

**Status.** A draft work plan has been developed providing a general direction for the study. That plan call for using US Census tract data and other existing data sources for existing and impact information on the neighborhoods. The data will be organized within a Geographic Information System format. Data on institutions will also be collected from a variety of existing sources. These data will also be organized in a GIS framework, based on the institutional "footprint" of the institutions. Qualitative data on historic and cultural significant areas of the metropolitan area will be used, drawn from community leaders and those experts in the cultural history of the area. The draft work plan will be reviewed and fine tuned by the panel of experts, scheduled to convene at the end of January 2006.

**The Way Ahead.** The final report will be completed by June of 2006 with key parameters and summaries being made available in April 2006. The final report will be organized on a neighbor by neighbor basis, providing both pre- and post- conditions with a discussion of social conditions in the one- to five-year time frame.

Currently the expert panel is being recruited. A draft work plan is being developed. Key parameters are being identified, and contracting capabilities are being established. By the next report, the work plan should have been finalized. By this time much of the data collection will be completed and the analysis initiated.

# Engineering and Operational Risk and Reliability Analysis

## Introduction

### Summary

This task will examine the reliability of the hurricane protection system (HPS) and quantify the risk to life and property from hurricanes in the New Orleans region. The analysis will consider three HPS configurations

- the system as it existed prior to Katrina
- the system as it is projected to exist at the start of the 2006 hurricane season
- the system with component strengthening and improvements that are within the project authorization.

Long-term solutions that might include substantial changes to the current HPS that are not within the current project authorization are not part of this effort.

Risk analysis requires consideration of the full spectrum of possible hurricane events that might affect the New Orleans region; the associated wave, surge and wind conditions; the performance of the protective system under such actions; and the resulting state of flooding and consequences. The team assembled to perform this task will develop a unified risk analysis framework to assess the risks associated with the performance of the various features of the New Orleans hurricane protection working together as an integrated system. The products from this work will provide information that will assist the IPET leadership to answer the four questions that the IPET has been tasked to respond to. In particular, Task 10 will develop input to the IPET response to questions 2 and 4:

- 2) How did the floodwalls, levees and drainage canals, acting as an integral system, perform during and after Hurricane Katrina?
- 4) What was and what is the condition of the hurricane protection system before and after Hurricane Katrina and, as a result, is the New Orleans protection system more susceptible to flooding from future hurricanes and tropical storms.

To accomplish this task, the Risk and Reliability Team has met with other IPET teams, in particular the Storm Surge and Wave Analysis Team, the Physical Modeling of Structural Performance Team, the Floodwall and Levee Performance Analysis Team, the Pumping Station Performance Assessment Team and the Consequence Analysis Team. This Team has identified information and data needs from these teams and is working to bridge the gap between what is needed for the risk analysis and what the other teams are expected to produce under their current scopes of work. The Risk and Reliability Team will also be contracting with hurricane modeling experts to provide data required to develop probabilistic surge and wave models. This effort will occur in parallel, and in coordination, with the numerical modeling of Katrina that IPET is conducting and the New Orleans District efforts defining the SPH for the feasibility study of increased protection.

## Background

Decisions about natural hazards are best made by explicitly and quantitatively considering risks. Implementation of risk analysis to the New Orleans HPS is difficult because the system serves a large geographical region and our capability to accurately model hurricanes in regions as complex as the Mississippi delta is limited. Nonetheless, modeling capabilities have improved enough in recent years to make risk analysis an important tool for decision making as the New Orleans HPS is restored.

It is important to note that detailed knowledge of the New Orleans HPS and the engineering parameters that influence its performance or of the hurricane characteristics is limited. For example, we do not know with certainty the properties of foundation soils underlying the extensive levee system, or even the frequency with which hurricanes occur. Hurricane models can predict winds, waves and surges only with limited precision, and reliability models of levee performance when subjected to hurricane forces are similarly limited. Hence, the risks of hurricane-induced flooding cannot be established with certainty. Therefore modern risk analysis practice involves not just a best estimate of risk, but also an estimate of the uncertainty in that best estimate.

Several other issues are important to assure the validity of the risk analysis and the usefulness of the results to decision makers:

- Defining the physical features of the system will require an accurate inventory of all components that provide protection against storm surge and waves. It is important to model not only the cross sections and strength parameters of these components but also transitions between elements, differences in the top elevation along a reach of similar components and varying foundation conditions. The characterization of the physical features of the protection system will be limited by the available information and the resources available to process that information under IPET. It will be essential that the resulting uncertainties are characterized and communicated effectively so that they can be accounted for in decisions making.

- At some locations, the hurricane protection system has been degraded by Hurricane Katrina. Levees and floodwalls may have been overtopped or otherwise damaged and the impacts of these events upon the condition of the features are not necessarily apparent from visual inspection. The possibility of such weakening must be recognized. Therefore, the current condition of features of the system that survived Katrina but may have sustained damage must be modeled to estimate the risk for the 2006 hurricane season.

- Emergency repairs of breached elements have been accomplished since Hurricane Katrina, but many repairs are temporary and may have significantly different strength than permanent repairs.

- The pumping system, while not part of the HPS, is an important element that controls flooding during and after a storm. Pumping plant reliability and capacity have to be considered.

- The consequences of pre- and post-Katrina flooding are different due to changes in population and economic activity. The Risk and Reliability Team will rely on the Consequence Analysis Team to define post-Katrina exposure scenarios and to quantify the consequences of HPS failures. The Risk and Reliability Team will not duplicate these consequence estimates.

- The effectiveness of the protection system depends on human factors as well as engineered systems (e.g., timely road and railroad closures, gate operations, functioning of pumping stations, and so on). Lessons learned from Katrina and other natural disasters will be used in modeling human performance.

## Objective

The reliability and risk analyses will relate the performance of individual features (floodwalls, levees, pumps, levee closures, etc.) located throughout the hurricane protection system to the overall performance of the integrated system and the impact of that performance on economics and public safety. The reliability of all structural features will also consider the varying foundation conditions that exist throughout the hurricane protection system. This will require risk analyses of three states that represent the condition of the hurricane protection system:

- The system as it existed before the arrival of Hurricane Katrina. This state is the baseline for estimating risk.

- After Hurricane Katrina with repairs made prior to the 2006 hurricane season.

- During the interim recovery period after the hurricane protection system has been strengthened and improved, but prior to longer-term increases in the authorized level of protection.

# Scope of Work

## Team Members

**Leadership:**
Jerry Foster, HQUSACE – Co-Leader, Engineering risk and reliability
Bruce Muller, USBR – Co-Leader, Dam safety risk management

**USACE Employees**:
Wayne Jones, USACE-ERDC-ITL, Engineering risk and reliability
Bob Patev, USACE CENAE- Engineering risk and reliability
David Schaaf, USACE CELRL- Engineering risk and reliability
Vance Stutts, USACE - CEMVN Rep.

**Consultants**:
Dr. Bilal Ayyub, University of Maryland, College Park – Risk and reliability analysis
Dr. Greg Baecher, University of Maryland, College Park – Geotechnical
Dr. Mark Kaminskiy, University of Maryland, College Park – Reliability and risk model development
Dr. Fred Krimgold, Va. Tech – Disaster risk management
Dr. Daniele Veneziano, MIT – Risk and reliability analysis
Dr. Peter Vickery, Applied Research Assoc. – Hurricane modeling

**ITR Team**
Dr. Bruce Ellingwood, Georgia Tech – Engineering risk and reliability
Dr. Marty McCann, Stanford – Dam and levee risk analysis.
Dr. David Bowles, Utah State and RAC Engineers & Economists - Dam safety risk management
Dr. Therese McAllister, NIST – Reliability

## Approach

**Basic Methodology** – The reliability and risk analysis will relate the performance of individual features (floodwalls, levees, pumps, etc.) located throughout the hurricane protection system to the overall performance of the integrated system. Experience gained in determining and managing risks for natural disasters (seismic events, floods, etc.) will be utilized to develop a probabilistic framework for quantifying risks.

Hazard analyses will produce a set of hurricane loading events that will be examined to estimate system responses. This analysis will then be followed by estimation of the probabilities and consequences for each scenario identified in the hazard analysis. This estimation will be performed quantitatively based on available resources and data, and subjectively assessed parameters in case of data non-availability. Resulting estimates of risk to life and property will then be evaluated to provide some perspectives on the significance of the estimated risks and the strength of justification for further risk reduction.

The basic elements of the risk analysis methodology are illustrated in Figure 70. The analysis is represented in terms of a series of modules which interface to provide a risk model for the New Orleans HPS.

Risk associated with the hurricane protection system is quantified through the hurricane rate ($\lambda$) and the probability $P(C > c)$ with which a consequence measure $C$ exceeds different levels $c$. The loss exceedance probability per event is evaluated as

$$P(C > c) = \sum_i \sum_j P(H_i) \times P\left[S_j \mid H_i\right] \times P\left[C > c \mid H_i, S_j\right] \tag{38}$$

An annual loss exceedance rate can be estimated as follows:

$$\lambda(C > c) = \sum_i \sum_j \lambda P(H_i) \times P\left[S_j \mid H_i\right] \times P\left[C > c \mid H_i, S_j\right] \tag{39}$$

where $P(H_i)$ is the probability of hurricane events of type $i$, $P[S_j \mid H_i]$ is the probability that the system is left in state $j$ from the occurrence of $H_i$, and $P[C > c \mid H_i, S_j]$ is the probability that the consequence $C$ exceeds level $c$ under $(H_i, S_j)$. Summation is over all hurricane types $i$ and all system states $j$ in a suitable discretization. Simulation studies of hurricanes for risk analysis require the use of representative combinations of hurricane parameters. This requirement can be achieved by developing ranges of these parameters and their combinations so that the combinations are of equal probabilities; therefore permitting the use of stratified sampling. The outcome of this process is a set of hurricane simulation cases and their respective conditional probabilities $P(H_i)$.

Evaluation of the hurricane rate $\lambda$ and the probability $P(H_i)$, the conditional probabilities $P\left[S_j \mid H_i\right]$, and the conditional probabilities $P\left[C > c \mid H_i, S_j\right]$ is the main objective of the hurricane model, the system model, and the consequence model, respectively. The probability $P\left[S_j \mid H_i\right]$ should cover the states of the components of the HPS, such as closure structure and operations, precipitation levels, electric power availability, failures modes of levees and floodwalls, and pumping station reliability. To assess the state of the HPS given a hurricane event requires an evaluation of the reliability of individual structures, systems and components (e.g., levees, floodwalls, pump systems) when they are exposed to the loads and effects of the hurricane (e.g., the peak surge, wave action) and the relationship of these elements to the overall function of the system to prevent flooding in protected areas.

If point estimates of consequences (i.e., $\left[c \mid H_i, S_j\right]$) are available instead of $P\left[C > c \mid H_i, S_j\right]$, order statistics can be used to construct the exceedance probability $P\left[C > c \mid H_i, S_j\right]$.

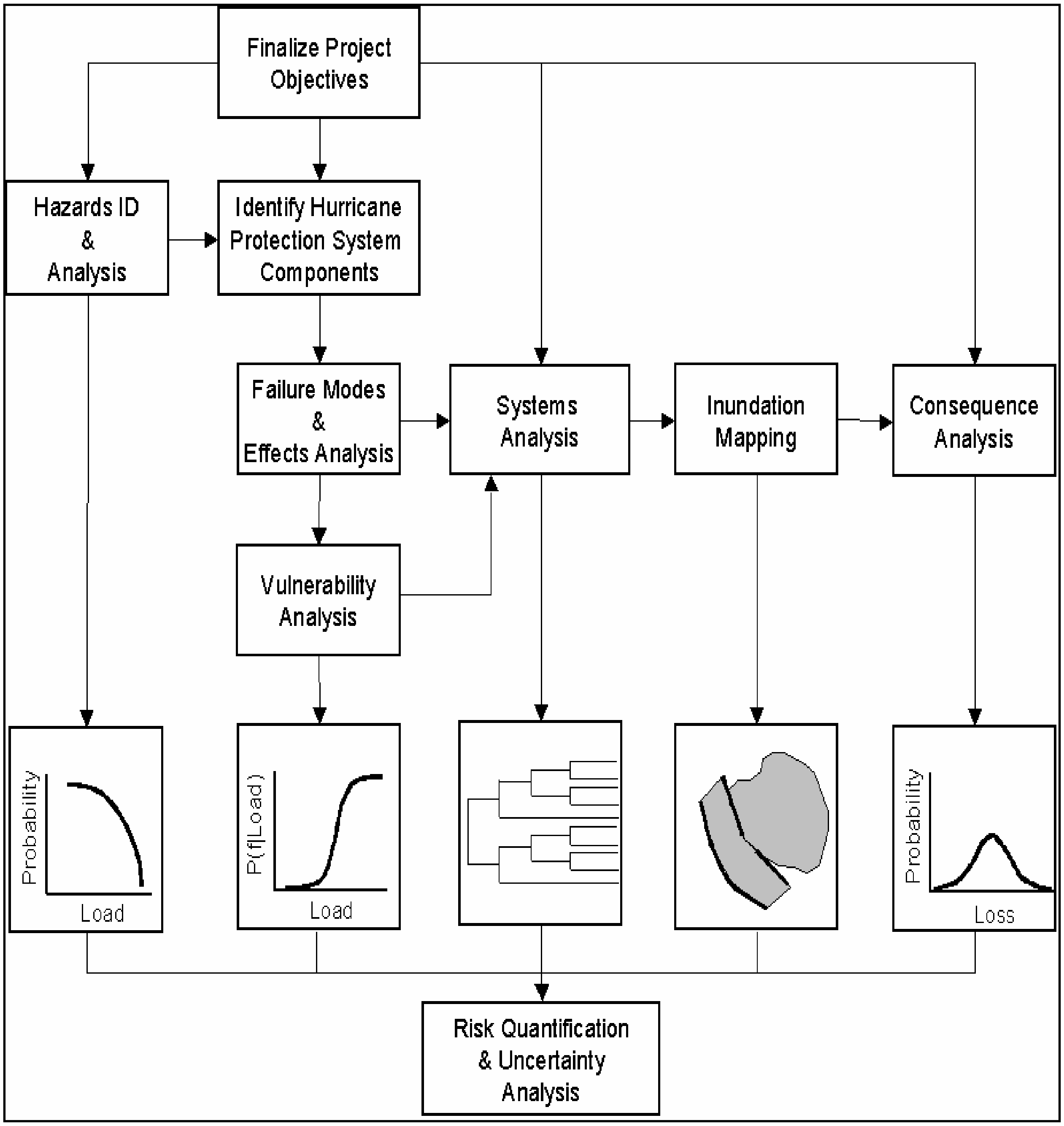



Figure 70. Risk analysis logic diagram

The hurricane loss provided by Eq. 38 can be used to compute a cumulative distribution function (CDF) $F_S(s)$ as 1-$P(C > c)$. The CDF of the accumulated damage (loss) during a non-random time interval [0, $t$] is given by

$$F(s;\ \ t,\lambda) = \sum_{n=0}^{\infty} e^{-\lambda t} \frac{(\lambda t)^n}{n!} F_S^{(n)}(s) \qquad (40)$$

where $F_S^{(n)}(s)$ is the $n$-fold convolution of $F_S(s)$.

As part of the of risk calculation (quantification of equation 39 above), a deaggregation of the results can be made to provide a measure of the contribution of different factors or events to the potential for system failure (i.e., flooding as a result of HPS failures) and consequences. This deaggregation can be made for individual polders to assess their risk and their relative contribution to the total consequences that New Orleans may experience (i.e., does one parish experience a large fraction of the consequences that could occur). Further, the deaggregation can be made to assess the relative contribution that different size hurricanes and various modes of failure (i.e., floodwall foundation failure, levee overtopping, etc.) make to the frequency of HPS failure and to the various consequence types. The various forms of deaggregation which provide insight to HPS failure and to consequences are considered important products of the Risk and Reliability Team analysis (see also the discussion of Expected Products).

At a more detailed level, Figure 71 shows through an influence diagram the interdependencies among different components/events and how such components relate to the final risk.

**The hurricane model -** The objective of hurricane hazard analysis is to describe in probabilistic terms the spectrum of possible future hurricane scenarios and the physical conditions they induce at critical locations along the defense perimeters of the polders. Hurricane-induced conditions must be expressed through quantities (such as peak water level, significant wave height and duration of near-critical conditions) that are needed to analyze the performance of the protection system and the consequences of system failures.

Various methodologies have been used in the past to characterize hurricane hazard (mainly for wind). These include empirical approaches based on the catalog of historic events, the so-called joint probability approach, and the Monte Carlo approach with simulation over time of hurricane tracks and intensities.

The Risk and Reliability Team has chosen the joint probability approach. This method parameterizes hurricanes using a vector $\underline{\theta}$ of characteristics at landfall (central pressure drop, radius of maximum wind, etc.). From the values of $\underline{\theta}$ of historic events, one estimates the recurrence rate density $\lambda(\underline{\theta}) = \lambda f(\underline{\theta})$ where $\lambda$ is the rate of hurricane events in a neighborhood of New Orleans and $f(\underline{\theta})$ is the joint probability density function of $\underline{\theta}$ in that neighborhood.

The discretization $\{\underline{\theta}_i\}$ and the associated effects along the hurricane protection system can be obtained in different ways. A critical consideration is that accurate assessment of the effects requires sophisticated wind/surge/wave models $M$ that are computationally demanding. To reduce the number of runs of $M$, we will use a response surface approach. In this approach one selects a relatively small number $m$ of vectors $\underline{\theta}_i$ and uses $M$ to calculate the corresponding surge and wave levels at the sites of interest. Then one fits a response surface model $M'$ to each response variable (surge or wave level at a specific site) in terms of $\underline{\theta}$. Finally, one uses a refined discretization $\{\underline{\theta}_i\}$ of parameter space with $M'$ as a proxy of $M$ to represent hurricane hazard.

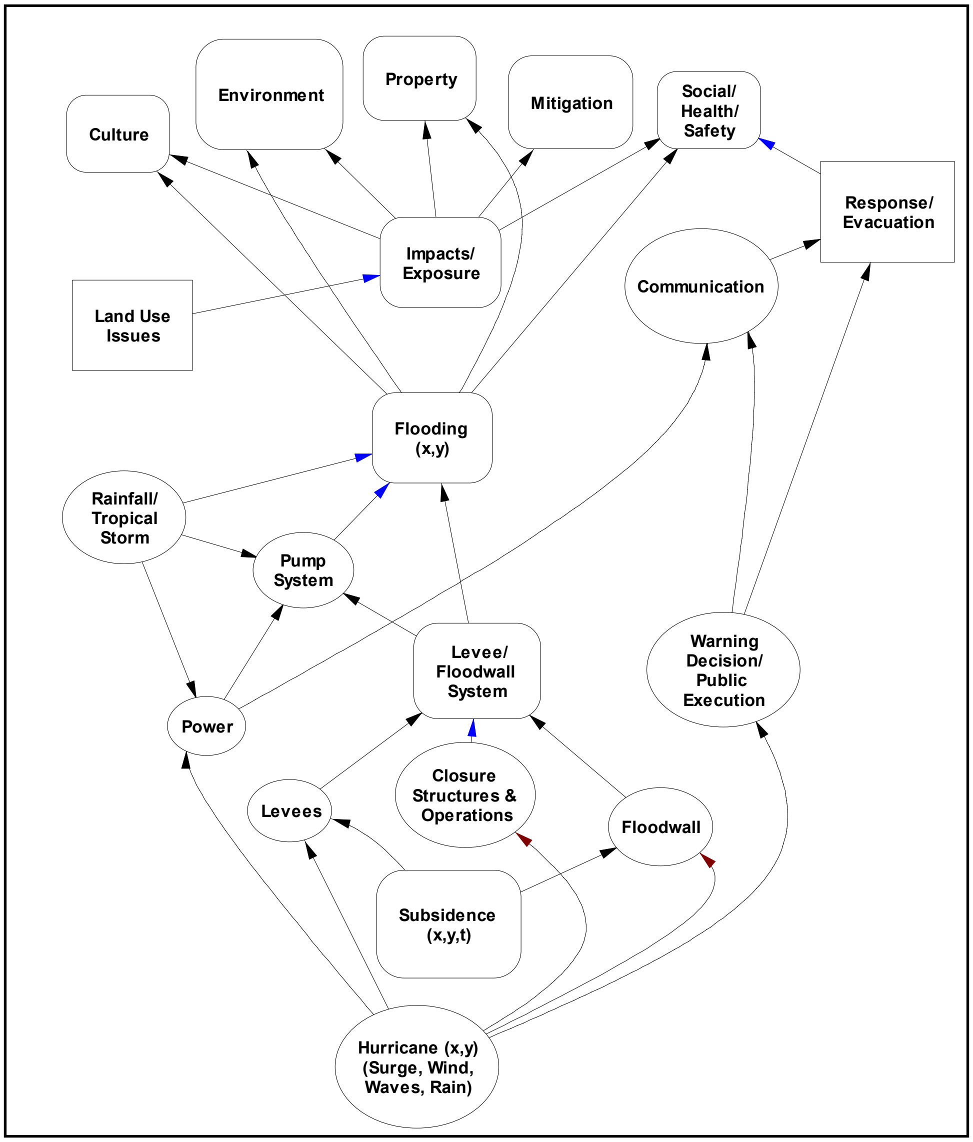



Figure 71. *Influence diagram* suggesting the interactions among components in the natural environment (*e.g.,* hurricane occurrence) and components in the HPS and protected land areas (*polders*).

We are currently interfacing with Team 4 to obtain historic catalogs of $\underline{\theta}$ from which to estimate recurrence rates and Team 5 to run wind/surge/wave models $M$ to use for response surface analysis.

**The system model -** The hurricane protection system of New Orleans includes many components such as floodwalls, levees, road closures, pumping stations and canals. The system is also a combination of several sub-systems (or polders), which are independently maintained and operated by local parishes and levee boards. Data collected by the IPET Data and Vertical Datum Teams and by the Risk and Reliability Team during site visits will be used to define characteristics of each polder sub-system. A schematic example of the HPS is shown in Figure 72.

The role of the system modeling part of the risk analysis is to construct a logic model of the HPS that represents its performance during a hurricane and models the potential sequence of events that result in flooding of protected areas and the subsequent consequence that occur. Event trees (or probability trees) will be constructed to model the performance of the HPS. Figure 73 shows an example of an event tree that was based in part on the influence diagram of Figure 71.

**Reliability Models for System Components -** Reliability analysis methods will be used to relate the performance of the individual elements (floodwalls, levees, pumps, etc.) to the overall performance of the integrated system. Reliability models for the system components will be developed based on design and construction information, maintenance records, a failure modes identification process and on results of IPET structural performance analysis and pumping station performance analysis. These reliability models will include both structural and geotechnical response of the walls, levees, and subsurface geotechnical conditions. The reliability of the various elements of the protection system will be estimated using analytical and expert elicitation methods.

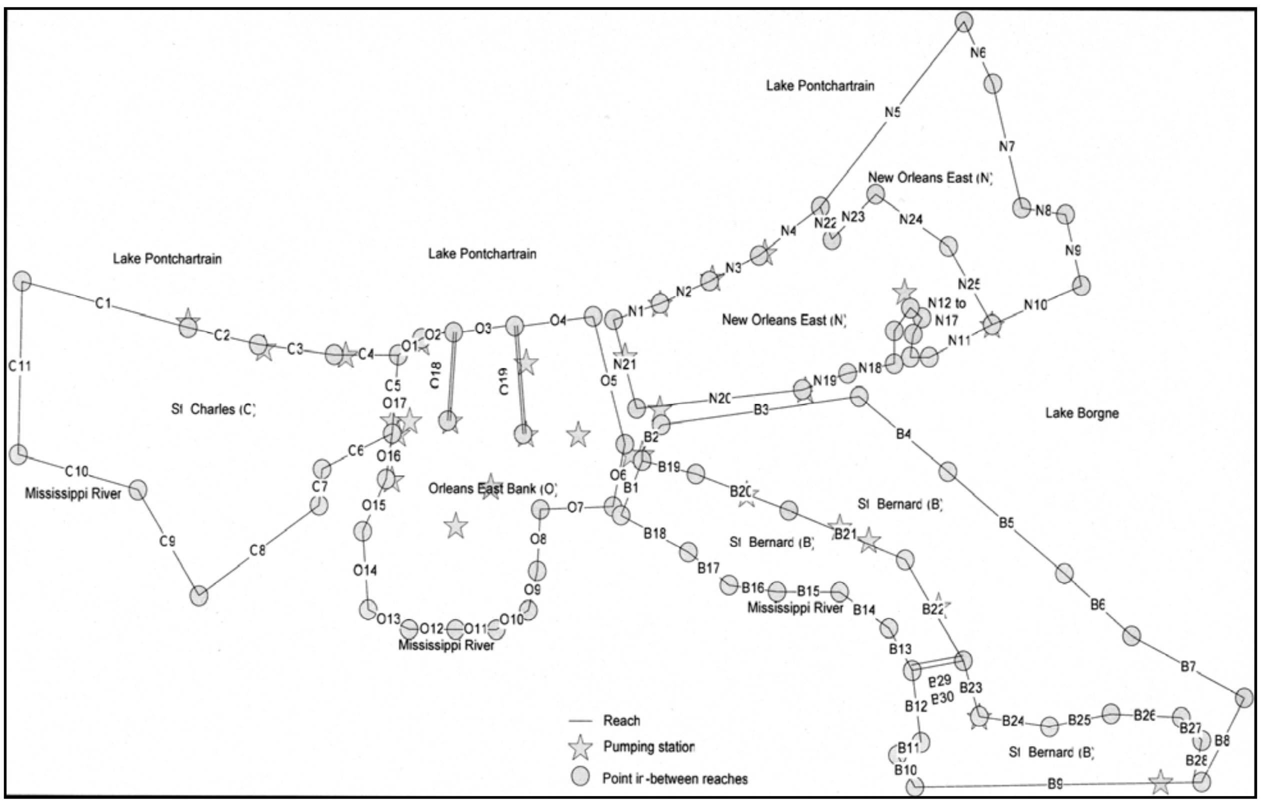



Figure 72. An Illustration of the Definition of the Hurricane Protection System Defined by Polders and Reaches

**Determine Consequences of Component Performance -** Like other natural disasters, hurricanes produce a wide range of consequences including economic and life losses, homelessness, business interruption, environmental changes, and cultural losses. In our analysis we will focus on economic losses and the number of fatalities. Both categories of losses depend on flooding conditions (water depth and duration of flooding) as well as exposure (inventory of infrastructure at risk and population). In addition, loss of life is sensitive to emergency evacuation plans and their implementation.

Task 9 is studying in detail the losses caused by Hurricane Katrina and will provide us with estimates of economic losses and fatalities given flooding parameters. The Risk and Reliability Team will not duplicate the work of the Consequence Analysis Team, but will rely on the work products of that team. To emphasize the level of safety afforded by different pre- and post-Katrina hurricane protection systems, we will evaluate losses assuming in all cases that exposure rates are the same as in the pre-Katrina scenario. Regarding the effectiveness of evacuation, we will make a parametric analysis, assuming different degrees of implementation effectiveness.

The pre-Katrina risk will be calculated based on the evacuation plan that was in place before the hurricane struck. The impacts of the effectiveness of evacuation plans will be examined as shown in Figure 73. The residual risks associated with the post-Katrina protection system will based on loss factors such as warning time, historical effectiveness of evacuation and population or property exposed to flooding.

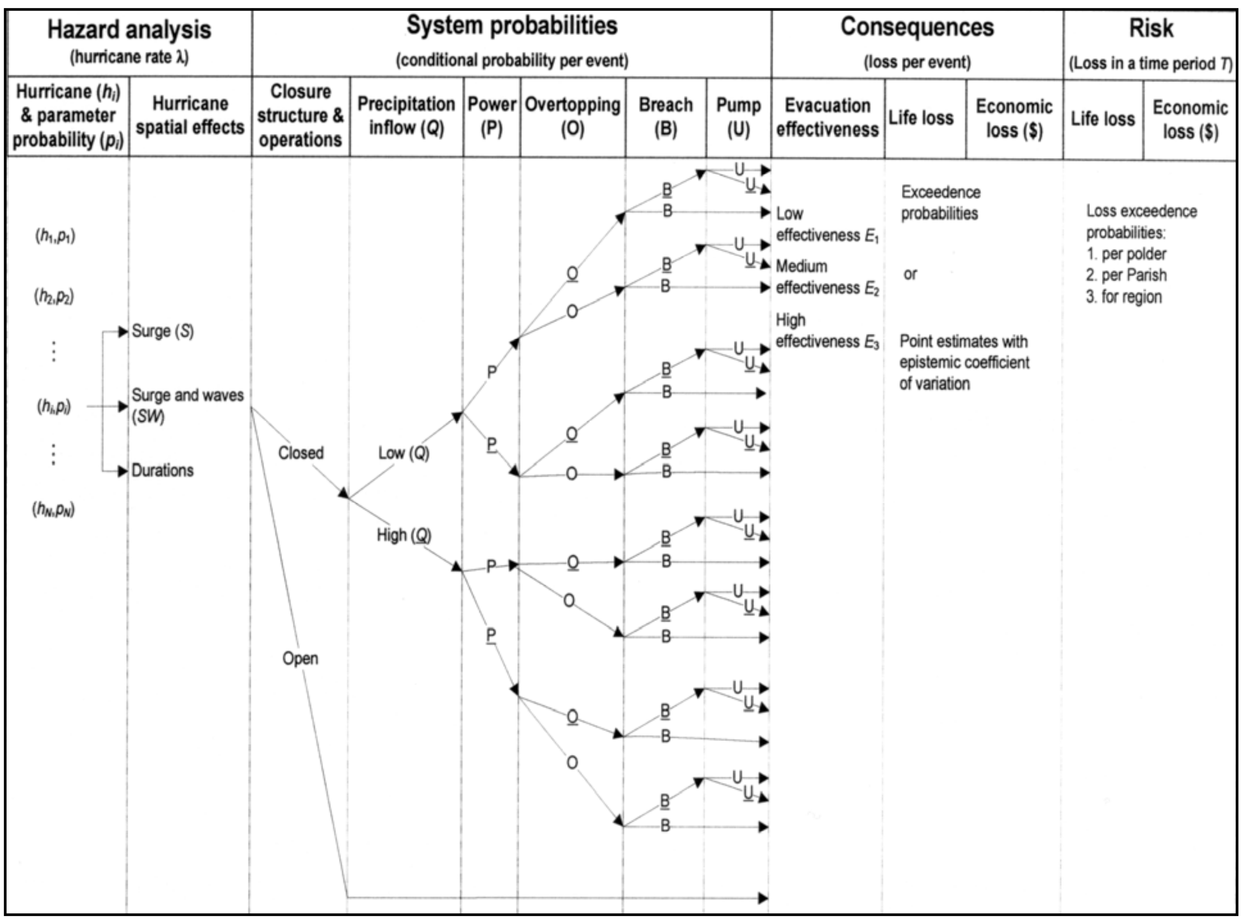



Figure 73. An example of an event tree model for the HPS risk analysis. Underlined events (i.e., Q, P, O, B, and U) are the complements of the respective events (i.e., Q, P, O, B, and U).

**Expected products –** The results of the risk and reliability analyses will be portrayed in various ways in order to facilitate an understanding of the significance of the estimated risk and to effectively communicate those risks to decision makers and public audiences. These will include narratives describing hurricane and system performance scenarios, inundation mapping based on the scenarios studied and graphic displays (as shown in Figure 74 and as used by the USBR to display dam safety risks) to portray the contributions to overall risks of critical components and significant failure modes.

As described above, the fundamental way to express risk is through the risk functions, one for each consequence category of interest. Joint risk functions that simultaneously consider all consequence categories can be defined and provide additional information, but are seldom used in practice. Due to uncertainty on the parameters that enter the risk calculation, the function is not known with certainty. Therefore, a more complete representation of risk should include an expression of uncertainty about the risk curves, for example in the form of a confidence band (Figure 74 shows a schematic example).

Due to the distributed responsibilities in the management of the polders and the fact that polders are, for the most part, physically distinct entities, it is of interest to decompose the total risk functions into polder-specific functions. It is also possible to make other decompositions, e.g. to distinguish the risk for different sub-regions of a polder, for example characterized by different ranges of topographic elevation, by failure mode, and hurricane level (e.g., relative contribution of different peak surge levels that contribute to the frequency of flooding).

In addition to the risk functions that will be developed, other products will be generated that provide a measure of the integrity of the HPS as an engineered system. These include an estimate of the reliability of the HPS as a whole and for individual polders for given hurricane levels, the frequency of HPS failure (again as a whole and for individual polders), and a breakdown of the failure modes that are the primary contributors to risk. An example of this type result is shown in Figure 75 (which also includes the uncertainty in the fragility of the HPS).

**Major touch points with ERP –** The Team has initiated discussions with the ERP risk representative and has briefed him on team makeup, basic methodology, scope of work and on the progress to date. We have also responded to and resolved formal ERP comments. It is expected that several informal touch points with the ERP will occur and that the following formal touch points will occur during IPET status meetings.

- 30% Review - Summary of Team Meeting 1 and Workshop – Risk and reliability models architecture, format of data required from other teams. Expert opinions received. Availability of natural disaster risk models, software selections.

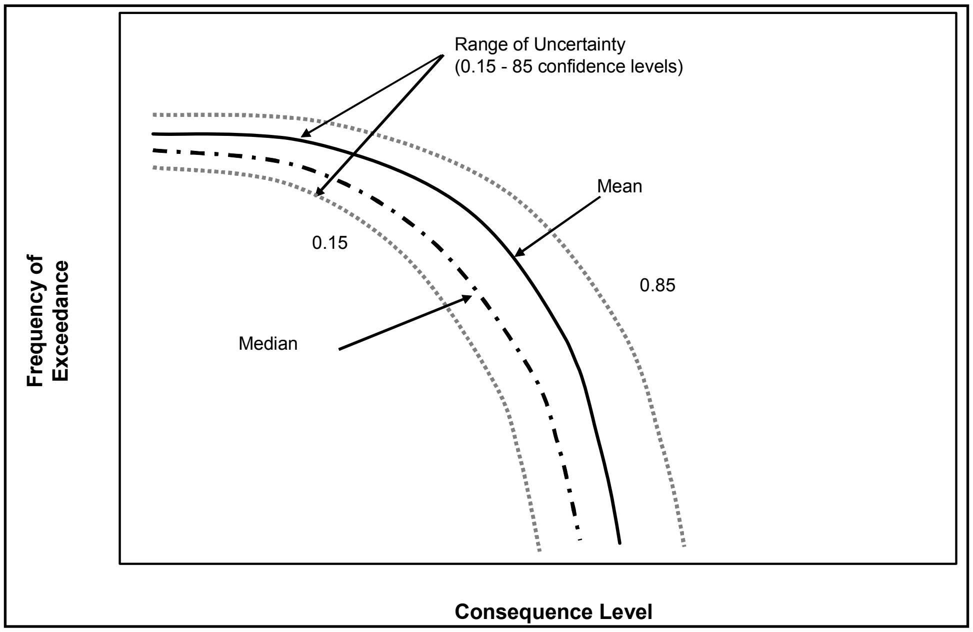



Figure 74. Exceedance probability graph showing the best-estimate risk curves (mean and median) from the risk analysis modeling along with confidence bounds. The horizontal axis is the level of adverse consequence; the vertical axis is the corresponding frequency with which a consequence level is exceeded. The best-estimate curves reflect aleatory uncertainties due to spatial and temporal frequencies of events; the confidence bounds reflect epistemic uncertainties due to limited knowledge.

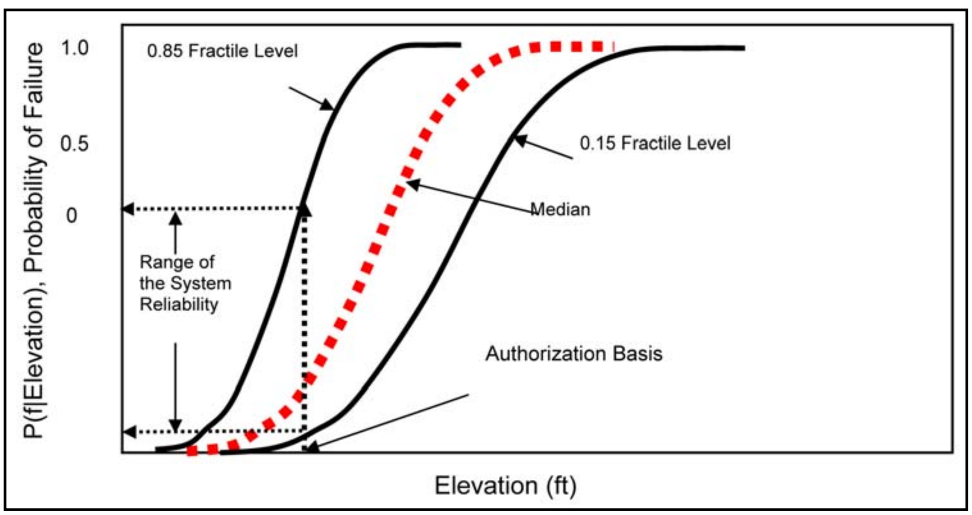



Figure 75. Illustration of the fragility for the HPS including the uncertainty in the analysis and the assessment of the system reliability

- 60% Review - Summary of Meetings 2 and 3 – Scenarios to be considered, refinements made to risk model based on initial model runs, IPET team comments and on physical model observations. Sources of uncertainty, data needed to reduce uncertainties, and initial sensitivity analyses. Data input from other teams. Results of draft model runs.

- 90% Review - Draft report submittal, summary of Team 10 efforts, risk and reliability models, input data and results of final model runs. Summary of ITR and Leader comments, and resolution of issues.

- Final Report

## Status

Completed tasks include a work plan, a workshop with other IPET teams to coordinate data needs for the risk and reliability analysis, site visits to collect data and to meet with CEMVN, attendance at a hurricane modeling workshop sponsored by the Surge and Wave Analysis Team and development of the basic analytical framework. We are still in the process of securing contracts for non-federal team members and a hurricane modeling expert. We expect team and ITR members, and the contractor to be under contract by mid-January 2006.

During this first reporting period, the Team has focused on methodology issues: development of an overall risk analysis approach, modeling and representation of the hurricane hazard, selection of physical variables to be considered for system response (water level, waves, etc.), formulation of a general HPS model (levees, floodwalls, pumping stations, etc.) with the identification of dominant failure modes, a reliability analysis procedure for the HPS, a procedure to evaluate flooding conditions under different HPS failures, and the assessment of consequences (economic and human losses at different spatial resolutions). Each of the above issues corresponds to a module in the overall risk methodology, with inputs consistent with the outputs of the preceding module. In developing the methodology, we have sought to balance the requirement of high spatial resolution and accuracy with the practical constraints of limited time and finite computational resources. Having laid out the general architecture of the risk approach, we are now developing each module in detail while collecting relevant data.

## The Way Ahead

The next steps for the risk and Reliability Task involve: Finalizing development of risk model inputs and system definition information, development of a draft working model for the system risk analysis, preliminary hurricane loading characterization input, coordination of preliminary consequence inputs with the Consequence Analysis Team, identification of the audiences for Risk and Reliability outcomes, formulation of proposed approaches to risk evaluation (including a potential comparison with the past and evolving practices in The Netherlands) and formats for presentation of results. It should be noted that all the models and figures provided in this report are work-in-progress products and might change as the work progresses.

# Part IV: Appendices

# Appendix A Historical Perspective of Hurricane Protection in New Orleans and Vicinity

Historically, the greatest natural threat posed to residents and property in the New Orleans, Louisiana area, has been from hurricane-induced storm surges, waves, and rainfall, including especially those associated with Hurricane Betsy in 1965, Camille in 1969, and Lilli in 2002. Although some hurricane protection had been provided to a few areas of New Orleans, it was not until Hurricane Betsy struck the city, killing 75 people and causing substantial damage and loss of property, that a comprehensive hurricane protection plan was initiated. Over time, three hurricane protection projects have been designed and partially constructed in New Orleans and the South Louisiana region: Lake Pontchartrain and vicinity, the West Bank project, the New Orleans to Venice project. This study will focus on the Lake Pontchartrain and vicinity hurricane protection system.

Congress first authorized the Lake Pontchartrain and vicinity hurricane protection under the Flood Control Act of 1965. The project was designed to protect areas around the lake (in the parishes of Orleans, Jefferson, St. Bernard, and St. Charles) from flooding caused by a storm surge or rainfall associated with a hurricane that would be roughly the same as what is today classified as a fast-moving category 3 hurricane. Although federally authorized, the project was to be a joint federal, state, and local effort, with the federal government paying 70 percent of the costs and the state and local interests paying 30 percent of the costs. The U.S. Army Corps of Engineers was assigned responsibility for project design and construction and the local interests were responsible for maintenance of the levees and flood controls.

During the first 17 years of construction of what has become known as the barrier plan, project delays and cost increases occurred as a result of technical issues, environmental concerns, legal challenges, and local opposition to various aspects of the project. This opposition culminated in a December 1977 court decision that enjoined the Corps from constructing the barrier complexes and certain other parts of the project until a revised environmental impact statement was prepared and accepted. After the court order, the Corps changed course and recommended abandoning the barrier plan and shifting to a higher-level plan originally considered in the early 1960s. Local sponsors executed new agreements to assure their share of the non-federal contribution to the revised project.

As of May 2005, the Lake Pontchartrain and vicinity project included about 125 miles of levees, major floodwalls, flood-proofed bridges, and a mitigation dike on the lake's west shore. Progress on the project varied by area: 90 percent complete in Orleans Parish; 70 percent complete in Jefferson Parish; 90 percent complete in the Chalmette area; and 60 percent complete in St. Charles Parish. The estimated completion date for the entire project was 2015.

On August 29, 2005, Hurricane Katrina struck the coasts of Louisiana, Mississippi, and Alabama, causing the greatest loss of life and property damage to portions of the Gulf Coast in recorded history. During this event, integral parts of the Lake Pontchartrain hurricane protection system failed, allowing the inundation of large urban areas in the New Orleans metropolitan area. Breaches were created in the floodwalls along several drainage canals. Water flowed from Lake Pontchartrain through the breaches and inundated large urban areas in New Orleans to depths of about 20 feet. The system of pumping stations integral to the system were overwhelmed and eventually shut down. The levees in St. Bernard Parish and Plaquemines Parish failed and other large urban areas were inundated. The impact of this event will likely be felt for decades.

Located in the low-lying Mississippi River delta in Louisiana, large portions of the city of New Orleans lie near or below sea level, which has posed complex flood management problems since the city's founding in 1718. The location of the greater New Orleans metropolitan area makes it vulnerable to occasional severe hurricanes that cross the Gulf of Mexico. An extensive levee and drainage system has been installed by the U.S. Army Corps of Engineers and others to keep high water out of the city resulting from both storm surges and flooding of the Mississippi River.

The original project design for the Lake Pontchartrain and vicinity hurricane protection project, known as the barrier plan, included a series of levees along the lakefront, concrete floodwalls along the Inner Harbor Navigation Canal, and control structures, including barriers and flood control gates located at the Rigolets and Chef Menteur Pass areas. These structures were intended to prevent storm surges from entering Lake Pontchartrain and overflowing the levees along the lakefront. A paradox of these massive levees is that in keeping water from the city, they also prevent Mississippi River sediment--which has historically been important in replenishing deltaic land surfaces--from spreading across the region. As a result, many areas of the city have been slowly subsiding, which has further exacerbated flood risks.

This design was developed to combat a hurricane that might strike the coastal Louisiana region once in 200-300 years. The basis for this was the standard project hurricane developed by the Corps with the assistance of the U.S. Weather Bureau (now the National Weather Service). The model was intended to represent the most severe meteorological conditions considered reasonably characteristic for that region: winds up to 111-113 miles per hour and can be expected to cause some structural damage from winds and flooding near the coast from the storm surge and inland from rains.

Even before construction began on the barrier plan, design changes to raise the levees along the three main drainage canals that drain water from New Orleans into Lake Pontchartrain were incorporated to protect against storm surges from the lake. The construction of higher levees has long been an option for reducing risks; but they are expensive to build, require the acquisition of additional lands, and may entail negative aesthetic and environmental consequences. Over the years planning guidance for levee construction has become more sophisticated, especially since the 1990s when the Corps of Engineers introduced risk-based calculations into their levee planning studies. The Corps has made strong efforts in balancing the need to construct levees high enough to protect against most floods, with a desire to restrain spending and to not build levees higher than necessary.

In recent years, questions were raised about the ability of the project to withstand more intense hurricanes than it was designed for. In 2002, a pre-feasibility study on whether to strengthen hurricane protection along the Louisiana coast was completed. A full feasibility study was estimated to take 5 years to complete. As of March 2005, some funding had been allocated to complete a management plan for the feasibility study.

When Hurricane Katrina slammed into the U.S. Gulf Coast region on August 29, 2005, the hydraulic and/or structural capacity of several levees protecting New Orleans apparently was exceeded the following day, exacerbating what has come to be the largest natural disaster in U.S. history. These massive floods entail many technical implications for consideration in studies of the levee system and future flood risk management.

The most immediate technical question centers on the geotechnical structure and performance of the levee system during the hurricane and the accompanying flood conditions. Although the modes of levee failures are not understood perfectly, it is now commonly hypothesized that most of the failures resulted not from water overtopping the levees, but rather from breaches (collapses) of the levees. If levees were breached, it may not be clear exactly how those breaches occurred (e.g., water pressure, seepage under a levee, damage from floating debris or projectiles).

Other technical questions relate to levee heights and materials, engineering models and projections, storm surges and storm surge models, as well as hurricane strength, frequency, and forecasting. For example, while the Corps of Engineers stated that the New Orleans levees had been designed to withstand a "200 year" flood (a flood with a probability of occurrence of .005), it is not clear how this hydrologic calculation translates to the strength of hurricanes, which are ranked in their intensity on a 1-5 Saffir-Simpson scale. In retrospect, was this the best height for constructing a levee system for New Orleans? How was the residual risk of floods for New Orleans described? Did the levees surrounding New Orleans sink or become compacted over time, thereby affecting the level of flood protection they provided?

Soon after the onset of flooding in New Orleans and while still in a "disaster response" mode, the Corps of Engineers began to assess the extent and causes of problems to and resulting from the various structures and facilities. One team currently studying the failure of levees is the Interagency Performance Evaluation Task Force, which is being led by engineers from the Army Corps of Engineers and other agencies to include the National Oceanic and Atmospheric Agency, the Bureau of Reclamation, the U.S. Geological Survey, the Federal Emergency Management Agency, and the Department of Agriculture. This interagency effort is being assisted by an External Review Panel, a group of experts convened by the American Society of Civil Engineers, which will provide continuous oversight and review of the technical work of the Task Force and present information to the NRC/NAE committee, the New Orleans Regional Hurricane Protection Committee, that has been formed through the request of the Secretary of Defense and Secretary of the Army to provide strategic oversight to these activities.

# Appendix B
# ASCE External Review Panel

| ERP Member | Title | Organization |
|---|---|---|
| Dr. David A. Daniel, P.E. (Chair) | President | University of Texas at Dallas |
| Ms. Christine F. Andersen, P.E. | Director of Public Works | City of Long Beach, CA |
| Dr. Jurjen Battjes | Professor Emeritus | Delft University of Technology |
| Dr. Billy Edge, P.E. | Professor | Texas A&M University |
| Dr. William H. Espey, Jr., P.E. | President | Espey Consultants, Inc. |
| Mr. Thomas L. Jackson, P.E. | Sr. Vice President | DMJM Harris |
| Mr. David Kennedy | Director (Retired) | California Department of Water Resources |
| Dr. Dennis S. Miletti | Professor Emeritus (Retired) | University of Colorado at Boulder |
| Dr. James K. Mitchell, P.E. | Professor Emeritus | Virginia Tech |
| Dr. Peter Nicholson, P.E. | Associate Professor | University of Hawaii |
| Mr. Clifford A. Pugh, P.E. | Director | U.S. Bureau of Reclamation |
| Mr. George Tamaro, Jr., P.E. | Partner | Mueser Rutledge Consulting Engineers |
| Dr. Robert Traver, P.E. | Associate Professor | Villanova University |
| Mr. Lawrence H. Roth, P.E., G.E. | Deputy Executive Director | American Society of Civil Engineers |
| Mr. Steven G. Vick, P.E. | Consulting Engineer | Independent Consultant |
| Mr. John E. Durrant, P.E. | Managing Director, Engineering Programs | American Society of Civil Engineers |

# Appendix C
# NRC New Orleans Regional Hurricane Protection Committee

| NRC Committee Member | Title | Organization |
|---|---|---|
| Dr. G. Wayne Clough | President | Georgia Institute of Technology |
| Dr. Rafael L. Bras | Edward A. Abdun-Nur Professor | Massachusetts Institute of Technology |
| Dr. John T. Christian | Consulting Engineer | Consulting Engineer |
| Mr. Jos Dijkman | Flood Management Engineer | WL/Delft Hydraulics |
| Dr. Robin L. Dillon-Merrill | Assistant Professor | Georgetown University |
| Dr. Delon Hampton | Chairman of the Board | Delon Hampton & Associates |
| Dr. Richard A. Luettich | Director | Institute of Marine Sciences at University of North Carolina at Chapel Hill |
| Mr. Peter Marshall | Vice President of Operations | Burns & Roe Services Corporation |
| Dr. David H. Moreau | Professor | University of North Carolina at Chapel Hill |
| Dr. Thomas D. O'Rourke | Thomas R. Briggs Professor | Cornell University |
| Dr. Risa I. Palm | Executive Vice Chancellor Provost | Louisiana State University |
| Dr. Kenneth W. Potter | Professor | University of Wisconsin |
| Dr. Frederic Raichlen | Professor Emeritus | California Institute of Technology |
| Dr. Y. Peter Sheng | Professor | University of Florida |
| Dr. Robert H. Weisburg | Professor | University of South Florida |
| Dr. Andrew J. Whittle | Professor | Massachusetts Institute of Technology |

# Appendix D
# Interagency Performance Evaluation Task Force Communications Plan

## Table of Contents



## Part 1: Background and Purpose

**Background:** The Interagency Performance Evaluation Task Force (IPET) was established by the Chief of Engineers. Hurricane Katrina caused the nation considerable concern with regard to our approaches and capabilities to protect Americans from land falling hurricanes, as well as our general emergency response readiness. This concern is shared by the professionals involved with planning, designing, constructing, sustaining and operating many of the flood protection and damage reduction measures. The Katrina Interagency Performance Evaluation Task Force was established by the Chief of Engineers to learn what happened with regard to flood protection and damage reduction capabilities in New Orleans during hurricane Katrina and to use that knowledge to shape the reconstitution of flood protection for the New Orleans area.

The mission of the task force is to provide credible and objective scientific and engineering answers to fundamental questions about the performance of the hurricane protection and damage reduction system in the New Orleans metropolitan area. These facts will be used to assist in the reconstitution of hurricane protection in New Orleans.

The Task Force is comprised of experts from government (federal, state and local), industry and academia, working together as teams to accomplish a comprehensive analysis before the start of the next hurricane season. It will be modeled after the practice of the National Academy of Engineering with an independent review component as well as broad participation by experts from across government and academia. They will use the most appropriate tools and available data to better understand what forces the storm placed on the New Orleans flood protection structures and why the performed as they did. It is not enough to know that a structure or measure failed, it is essential to examine the observed evidence of performance in the context of the forces applied and the resulting response to build back the desired capability without inherent vulnerabilities that may have previously existed.

The Task Force will partner with other organizations conducting related studies and analyses to maximize their effectiveness within the short time frame of the study. While specific attention will be given to the components of the system that experienced failure, understanding where and why other components may have been degraded in their ability to provide protection and where they performed successfully is equally important to providing more reliable protection in the future. An external panel of experts under the leadership of the American Society of Civil Engineers will provide constant review of the Task Force assumptions, analyses and findings. A National Research Council Panel will provide independent strategic oversight and synthesize the results of this work, particularly with regard to the physical performance of the flood control structures. As such, there will be a two-tier review of the quality and applicability of the findings of the Task Force.

**Purpose:** This document provides a single assembly of the communications protocols and plans for the Interagency Performance Evaluation Task Force. It is intended to cover all aspects of communications from the assurance of data and information, interaction with external and independent review groups, interfaces with the media and external organizations as well as communications internal to the Corps of Engineers. A special section is provided on the interface with Task Force Guardian because of the high priority placed on providing insights and findings to them as they are developed to influence as much as possible the reconstitution of hurricane protection in the New Orleans area.

# Part 2: Data and Information Assurance

**Objective:** To provide an information repository that can be used as an effective and efficient source of information for the work of the IPET, Task Force Guardian, the ASCE External Review Team and to provide effective information transfer in response to external requests. It is essential for all of these purposes that the information within the IPET repository is examined and validated for authenticity, accuracy and sensitivity (legal and security). The metadata is also an essential part of entering the data and information into the repository to allow efficient management, access and distribution of the information as it is needed.

**Process:** IPET data residing within the data repository will be used in many different forms and for many different purposes. It will be essential to the IPET that an effective QA/QC procedure be developed to ensure that all IPET teams and members operate within a consistent operating framework and that all data residing within the repository undergo QA/QC before it is sanctioned for use in applications. It is recommended that for every major data type (elevations, high water marks, time series information, soil/substrate characteristics, etc), a team of experts, working in conjunction with Denise Martin, be designated to review data used in applications to establish appropriate standards for these data. It would also be the responsibility of this team to provide the "final" information to the appropriate application groups within a pre-defined schedule.

## Data QA/QC

The concept as it might be applied to data used to form the Digital Elevation Model (DEM) is described below.

1. Data collected from many sources would come into the data repository after some level of screening and computer-based QA/QC is applied. These data would need to have the metadata necessary to link them back to time of survey and benchmarks referenced.

2. The proper treatment of different classes/sets of elevation data would be established. For example, some of the LIDAR elevations may be contaminated by vegetation, or some of the surveys may not yet be linked appropriately to established benchmarks.

3. Data would be extracted from the database and used to generate information for the DEM. The DEM grid would be reviewed by a team of experts (QA/QC group), ensuring that "line" features such levees are properly resolved and that the grid appropriately meets the need of the intended application(s). This team should consist of people who are recognized as being able to speak authoritatively in this field with regard to the data itself (someone with a surveying background), the data storage/retrieval (presumably Denise Martin), the intended data application (someone with modeling experience), and others as needed to perform required work.

4. This group would be responsible for providing the common DEM to be used by all applications for the IPET study.

5. All elements within the DEM would be linked back to source information in a fashion that would allow subsequent adjustments in the vertical to be applied to the grid.

6. The DEM would be stored within the data repository with appropriate annotations stating the purpose of the grid and any notes relative to limits of applicability.

The general concept in this QA/QC procedure is that data within a data repository may be of various levels of validity and/or accuracy. Given the multiple sources and types of data being collected or acquired for this study, computers can only provide a cursory level of QA/QC. Consequently, at least in important areas of common interest over several groups (DEM, high-water marks, soil characteristics, levee structures, etc.). A subject matter expert team will be required to ensure that the data is appropriate and consistent before it is be used in final applications. Initial runs may have to proceed before this team has completed its product; however, this effort should be given sufficient funds and priority to make sure that these QA/QC efforts provide their products within a time frame that is consistent with the needs for these products. Point of Contact for information QA/QC is Denise Martin, ERDC/ITL, 601-634-4574, *denise.b.martin@erdc.usace.army.mil*.

## Legal and Security QA/QC

The evaluation of information for legal or security sensitivity is an important step in the process of proving information to requestors in a reasonable time frame. The IPET mechanism chosen for provision of information is setting up a web site on which all releasable information is placed and can be accessed by the public. That web site, *http://ipet.wes.army.mil*, became active on 29 Oct 2005 and will have increasing amounts of information available as it is screened and deemed releasable. While the ultimate release authority remains at this time the DoD HKTF, the USACE process for screening and releasing information for inclusion on the IPET web site is as follows:

1. If information has been widely available or released in the past, it can be immediately placed on the IPET Web site, making it available to the public.

2. If information has not been released or in the public domain previously it will be first checked for prior legal or security designations. If designated as protected information, that designation will evaluated for current appropriateness by legal council and a subject matter expert. If no longer considered sensitive, it will be reevaluated for release using current privacy and security criteria.

3. If information is not previously designated as sensitive from a legal or security perspective, it will be evaluated by a subject matter expert and legal council to determine if it can be released. If deemed non-sensitive, it will be

presented to the DoD HKTF for consideration for release. Given approval from the HKTF, it the information will be immediately placed on the IPET Web Site.

If a request for information relevant to Hurricane Katrina is received by the IPET, the requestor will be directed to the IPET Web Site, the repository for all released information. If they cannot find what they want, they will be instructed to submit a more focused request, which will be examined for potential response based on the near term availability of the information. Point of Contact for legal/security release is Mr. John Treadwell, ERDC Office of Council, 601-634-4203.

## Part 3: IPET and Task Force Guardian Plan

**Objective:** The primary purpose of this plan is to facilitate timely support to Task Force Guardian (TFG) from the Interagency Performance Evaluation Team (IPET). Incorporation of lessons learned by the IPET is critical to TFG's design and construction to restore the Federal hurricane protection system in New Orleans and southeast Louisiana to withstand the Standard Project Hurricane. This level of protection, which was authorized by Congress, is equivalent to a fast moving Category 3 hurricane. TFG has been tasked to complete restoration of the hurricane protection system to this level by June 1, 2006, the start of hurricane season along the Gulf coast.

This plan establishes roles and responsibilities to:

- Efficiently transfer and coordinate the flow of information from the New Orleans District (MVN) to the IPET;
- Coordinate and expedite the flow of information between the IPET and TFG during design; and
- Document IPET input to TFG during the design and construction processes.

**Process:** Three people from MVN (Walter Baumy, John Grieshaber and Ken Klaus) are assigned to the IPET to participate at varying levels of engagement on the surge and wave, geodetic assessment, flood wall and levee performance, consequence, and risk and reliability task teams. Due to their comprehensive understanding of the MVN organization, the hurricane protection system and the performance evaluation project objectives, they have a primary responsibility for facilitating the prompt transfer of information from the MVN to the IPET. Ken Klaus has the leadership responsibility, with John Grieshaber and Walter Baumy providing backup assistance as needed.

All formal input from the IPET to TFG shall be documented in an email correspondence to provide a prompt means of conveyance and a record to substantiate the input. The email shall be addressed to the relevant TFG Technical Manager with a receipt confirmation request. It shall include Lynn Tinto as a cc addressee to the message, and she shall maintain a comprehensive electronic record of these correspondences. If receipt confirmation by the TFG technical lead is not received within 48 hours, the IPET originator shall contact Lynn Tinto to follow up.

In the cases where there is a disagreement between the respective technical leaders on the IPET and TFG teams, the TFG Project Manager is responsible for coordinating and documenting the resolution. The TFG shall not be bound to implement IPET input or recommendations; however, the TFG Project Manager shall document the rationale for not concurring with the comment in a brief memorandum for the record.

Whenever the IPET, or subsets of the IPET, plan to be on site they are required to contact Lynn Tinto a minimum of three days in advance, so that their TFG counterparts have the opportunity to participate in the on-site observations and data collection efforts. Additionally, the IPET shall provide an outbrief to discuss all notable observations at existing infrastructure sites and at reconstruction sites with the TFG Project Managers. The TFG Project Managers are responsible for assembling the appropriate members of their Project Delivery Teams (PDTs) to participate in the outbriefs. In addition to the outbrief, the IPET will provide a trip report that documents significant observations that should be considered in the designs for restoring the hurricane protection project. The trip report will be furnished to Lynn Tinto for dissemination to the TFG Project Managers.

Walter Baumy and John Jaeger (co-IPET leader) have the lead responsibilities for communicating IPET and TFG progress and for maintaining situational awareness among the corresponding disciplines on each team. The IPET conducts a weekly conference call to coordinate their internal activities. The final topic of discussion at each weekly teleconference is, "What have we learned that would benefit the reconstruction effort currently underway in New Orleans?" Jeremy Stevenson will provide minutes of these meetings to Lynn Tinto as another way to share information. Lynn will be responsible for disseminating these minutes to the TFG Project Managers.

To assure the hurricane protection system performance evaluation is initiated as quickly as possible, the entire IPET has scheduled a site visit for November 7-8, 2005. The leaders of the IPET will meet with the Commanders of the Mississippi Valley Division, the New Orleans District, Task Force Guardian and their senior leaders on November 6, 2005 to assure that project needs and priorities are clearly understood. Upon completion of the IPET site visit, the IPET will provide an out brief to the TFG Project Managers and Technical Managers. The TFG Project Managers will provide a layout of the Project Management Plan for restoration of the hurricane protection system with special emphasis on key milestones and dates. The IPET will submit the trip report to Lynn Tinto by November 15, 2005.

The IPET shall be offered the opportunity to participate in the Independent Technical Review (ITR) process for construction plans and specifications. The TFG Project Manager shall contact the IPET Project Manager a minimum of 7 days prior to completion of the draft documents. The IPET Project Manager shall determine the appropriate reviewers within the IPET and provide the TFG project Manager with the list of persons to forward the documents. The respective IPET members shall have 5 days to submit comments. The TFG shall not be bound to implement IPET recommendations; however, the appropriate

TFG Technical Manager shall document the rationale for not concurring with the comment in a brief response to comment record.

Due to the critical schedule constraints, the design process must be completed on a very fast track. This will require the TFG design team to make reasonable assumptions regarding such critical design parameters as soil shear strength and permeability. When a substantial difference between expected and actual conditions is observed during construction, it is critical that the best technical experts participate in any decisions to modify the plans or specifications during construction. Therefore, IPET participation in the Engineering During Construction (EDC) process is critical to project success. The IPET shall plan for prompt response to all EDC requests. The IPET and TFG Project Managers shall promptly arrange for the most appropriate technical experts to respond to these requests, and the results shall be documented within the contract modification documents.

## Part 4: IPET and ASCE External Review Panel Terms of Reference

**Objective:** The Objective of the ASCE External Review Panel is to provide for an external, expert, and constructive technical review of the activities and products of the Interagency Performance Evaluation Task Force to provide:

a. Validated and credible answers to fundamental questions concerning the performance of the flood protection system in New Orleans during Hurricane Katrina, and

b. Insights for the reconstitution of authorized flood protection for New Orleans.

**Process:** The primary point of contact for the ASCE in this relationship will be Mr. Larry Roth, Deputy Executive Director, ASCE. The IPET points of contact will be Dr. Lewis E. Link, IPET Project Director, University of Maryland, or Dr. John Jaeger, IPET Technical Director, Chief of Engineering and Construction, Huntington District, USACE.

The external review panel will operate in accordance with three overarching principles:

a. Independence

- The External Review Panel will comprise experts with limited or no current ties to the Corps of Engineers or major stakeholders in the New Orleans flood protection process.
- The activities of the ERP will be separate and independent from the activities of the Task Force.

b. Periodic

– The ERP will provide review and feedback throughout the conduct of the schedule of activities of the task force to expedite completion of the task force efforts, as well as providing a final overall review.

c. Comprehensive

– The ERP will have membership with recognized expertise in the major technical areas in which the Task Force will be conducting analysis.

The scope of the ERP activities will provide balanced, objective, expert technical review that includes:

a. At the start of the Task Force - The overall scope of work and composition of efforts planned by the IPET.

b. At specified points and as required during the IPET work effort - The key assumptions, technical analysis and products generated by each of 10 major technical teams.

c. At the end of the IPET effort – The overall findings and conclusions of the teams and the task force, specifically whether the interpretations of analysis and the conclusions based on the analysis are reasonable.

The ERP has no approval authority on the findings of the Task Force, nor are ERP's recommendations to the Task Force binding, but the Task Force will give serious consideration to each and respond in writing to the ERP with a summary of actions taken and the rationale for such actions. Given any significant disagreement between the IPET and ERP, a dispute resolution process will be used to reach consensus.

The following Rules of Engagement will govern the interaction of the IPET and ERP:

**The IPET:**

a. Will provide information requested by ERP in timely manner to facilitate expedient review.

b. Will assign Team Leaders as primary POC to ERP for specific topical areas.

c. Will provide ERP actions to be taken in response to specific feedback / recommendations provided to the Task Force.

d. Leadership will meet monthly (or more frequently as needed) with ASCE leadership to assess effectiveness of independent review process.

e. Will participate with ASCE leadership to provide an efficient issue resolution process for the effort.

f. Will handle release and dissemination of all information concerning the activities, analyses and products of the IPET using the communications protocols included herein and by the USACE.

g. Will handle all media inquiries concerning the activities, analyses and products of the IPET using the communications protocols included herein and by the USACE.

h. Will refer all media inquiries concerning the ERP activities, analyses and products to the ERP.

**The ERP:**

a. Will provide a principle point of contact to the Task Force and to each Task Force Team.

b. Principle Points of Contact will not participate in Task Force Team activities or discussions.

c. Will provide expedient review to facilitate the continued progress by the Task Force.

d. ASCE leadership will meet monthly (or more frequently as needed) with Task Force leadership to assess effectiveness of Independent review process.

e. Will participate with Task Force leadership to provide an efficient issue resolution process for the effort.

f. Will refer to the task Force all inquiries and requests for data, information, analyses or products generated by the Task Force.

g. Will handle information dissemination and disclosure for all analyses and products generated by the ERP using ASCE communications protocols.

h. Will handle all media inquiries concerning the activities, analysis and products of the ERP using accepted ASCE communications protocols.

i. Will refer all media inquiries and requests concerning the Task Force activities, analyses or products to the Task Force.

## Part 5: National Research Council Independent Review Panel Terms of Reference

TO BE DEVELOPED with OASA(CW) and NRC.

## Part 6: IPET External Communications Plan

**Objective:** IPET information and analysis is intended to be distributed as widely as possible. While the first priority will be to assist Task Force Guardian and officials involved in the New Orleans flood protection reconstruction, validated information and validated analyses will also be provide to the public as appropriate. This protocol is to provide clear guidelines for the preparation and release of information concerning IPET activities and findings.

**Process:**

**DOD Hurricane Katrina Task Force:** The Department of Defense (DoD) has created a Hurricane Katrina Task Force (HCTF) that will act as a clearing-house and denial authority for all information released pursuant to requests for information relating to Hurricane Katrina from inside and outside the DoD. The HKTF is lead by COL Rhodes. They are the ultimate release authority for Katrina related information requests. The Current guidance from the HCTF is as follows:

a. The Corps can post previously released information – such as general design memoranda – on its websites even when the purpose of posting such information was to respond to numerous public information requests relating to Hurricane Katrina. The Corps does not need to clear such information or documents to be posted with the HCTF prior to posting. The HCTF is only interested in reviewing the release of previously unreleased information pursuant to a Hurricane Katrina related request. The HKTF will accept packages for review by Action Officers. Those action officers identified below will separately provide documents to the Task Force for review prior to release, based on the following procedures.

b. Packages sent electronically will be sent to *McHale-Mauldin.tf.osd-policy@osd.mil*.

c. We will attempt to send information in the most expeditious manner. Paper packages will be coordinated through the same e-mail address. Small amounts of information should be sent via e-mail. For large amounts provide the HKTF with access to an .ftp or internal website, or send CD/DVDs or coordinate with the HKTF on other methods.

d. Only completed packages will be sent to the Task Force for review. Packages will not be sent to the Task Force until they have gone through the normal Corps coordination procedures.

E-mail messages transmitting Packages to the HKTF by the Corps representatives should be copied to the other members of the Corps Team to ensure that we are not duplicating efforts. Additional procedures will be provided by the HKTF as their processes become more refined and the IPET interface is more comprehensively defined.

The U.S. Army Corps of Engineers on Oct. 29, 2005 began publicly releasing available data relevant to the performance of the hurricane and storm protection system around New Orleans during Hurricane Katrina. The current releasable data will be posted on a publicly accessible web site, *https://ipet.wes.army.mil*. Additional data will be added to the web site as it becomes available. See Part 2, Data and Information Assurance for the process used to screen and release information.

**Media Interaction:** All media requests for information will be forwarded to the USACE Public Affairs person assigned to support IPET. Reponses will be coordinated with the appropriate Team leaders and team members as well as the Project Director and/or the Technical Director.

a. Releases will be based on validated and factual information.

b. Releases on new, previously unpublished or distributed information will be cleared as appropriate through the DoD HKTF.

c. Releases will be coordinated with the Office of Public Affairs, HQ USACE and where appropriate with the Public Affairs offices in MVD and MVN.

d. The Project Director or Technical Director or a designated individual will provide verbal public feedback on specific questions.

e. The IPET will conduct frequent media updates on its work and specific releases to announce findings considered significant to the study and the reconstitution of flood protection in New Orleans.

f. The IPET will coordinate any releases or responses that involve or mention the ERP with the ASCE Communications staff.

## Part 7: IPET Internal Communications Plan

**IPET Virtual Office:** IPET internal communications will be supported by Groove Virtual Office. Groove Virtual Office is a product that effectively facilitates file sharing, meetings and project management, data and process tracking for groups of geographically distributed co-workers, such as our IPET teams. Groove makes it easier for teams to bring relevant information together in one place – data, files, messages, edits, forms, meetings, calendars, etc. Instead of using email to transfer files among team members, files can be transferred to a folder within a Groove Workspace and immediately available to the entire membership of the workspace. A Groove workspace has been created for the IPET team with separate folders for each Task. In order to participate within this workspace, the Groove software must be installed on each participant's desktop computer. The USACE Knowledge Management Environment (KME) manages the Groove software licenses. The following protocol has been established to manage internal communications via Groove for the IPET study.

### Acquiring and Installing Groove Software

USACE users: USACE employees may request a Groove license by completing the request form at *http://kme.usace.army.mil/groove*. Within 24-48 hours an email will be sent with the license keys and installation instructions. Once Groove is installed on a user's computer, an invitation must be sent by the IPET workspace manager to participate in the workspace. Upon acceptance of the invitation, the workspace will be loaded on the user's computer and available for opening from the Groove Launchbar.

Non-USACE users: Non-USACE users may request a Groove license as an external partner through a USACE sponsor. The USACE sponsor provides the external partner's Full name, Company Name, Company address, and email address to the USACE KME Groove manager (Hortense Frank). The instructions for installing Groove and the activation key are then sent via email to the external partner. Once Groove is installed on a user's computer, the user must send their VCard to the workspace manager.

To send your VCard (External Partner):

1) On your Launchbar, click Options —>Preferences

2) Under the Identities tab, click on the link that says “email this contact”

3) Enter the workspace manager’s email address in the To: field and click send

The workspace manager will then send an invitation to the external partner to participate in the workspace. Upon acceptance of the invitation, the workspace will be loaded on the user’s computer and available for opening from the Groove Launchbar.

Foreign National users: Foreign Nationals may not participate in the Groove workspace.

## IPET Workspaces

To facilitate internal communications for the large team involved in this study, several Groove workspaces have been created:

IPET Study – Management
IPET Study – Task 1 Data Collection and Mgmt
IPET Study – Task 2 Baseline Hydro Response
IPET Study – Task 3 Actual Hydro Response
IPET Study – Task 4 Numerical Model for Storm Surge and Wave
IPET Study – Task 5 Storm Surge Wave Breaching Physical Model
IPET Study – Task 6 Geodetic Vertical Survey Datum Assessment
IPET Study – Task 7 Analysis of Floodwall and Levee Performance
IPET Study – Task 8 Pumping Station Performance Assessment
IPET Study – Task 9 Consequence Analysis
IPET Study – Task 10 Eng and Operational Risk and Reliability Analysis

Task Leads will manage their respective workspace. With the exception of Task 1, members of the workspaces for individual Tasks will include only those involved in that specific task. Members of the Task 1 workspace will include individuals from all the tasks, since Data activities apply to all of the IPET team. Members of the IPET Study – Management workspace include Don Basham, Ed Link, John Jaeger, Jeremy Stevenson, and the Task Leads, with Jeremy Stevenson as the manager.

## IPET Data Repository

In addition to the Groove workspace, a data repository will support IPET internal communications. The data repository will provide the hardware and software framework required to store, organize, manage, and deliver the data associated with this study to both USACE users and non-USACE partners. A USACE enterprise approach based on existing corporate frameworks and standards will be employed to manage the heterogeneous data required for this study. Data sets will be stored and managed according to the component that best fits the type of data. For example, scanned documents will be stored and managed within the corporate framework for unstructured data, while GIS layers will be stored and managed within the corporate framework for geospatial data, and model data will be stored and managed within the appropriate corporate framework. An overall data manager will manage the metadata for all datasets. A web-based interface will be developed to support user access to the data. A QA/QC Group of subject matter experts will be established to authorize each data set that is stored in the repository. The base data will reside in a common repository in a format suitable for archival and active use.

### Weekly Virtual Conferences

IPET will hold at least weekly virtual conferences to facilitate communications within the Task Force. The conference will be arranged through the Jeremy Stevenson, IPET Project Manager, who will provide information concerning call in phone numbers and access codes to the IPET participants. The agenda for the conference will be set by the Technical Director in consultation with the Project Director and posted to the participants at least 2 hours prior to the call. All information or documents needed for the conference will be placed in the Virtual Office space prior to the conference. The conferences will be held, unless circumstances cause a change, at 1000 to 1200 hours Eastern Time. Each conference will include a strategic overview by the Project Director, a status of key activities by the Team Leaders, a discussion of major issues and summary of actions. One fixed item on the agenda will be to summarize contacts with Task Force Guardian and identify what has been generated or learned during the week that can assist Task Force Guardian in their efforts to rebuild hurricane protection in New Orleans. The Project Manager will be responsible for preparing and distributing minutes for the conference, placing them in the Virtual Office space.

## Part 8: Appendices

### Appendix 1: ASCE Media Communications Protocol

**Issue:** Uncoordinated contact with the media often results in incomplete, inappropriate or inaccurate information being disseminated to important audiences. It also can result in missed opportunities to effectively achieve communication goals, and hinder efforts to develop and nurture effective relationships with key media. This policy ensures that team members and staff are properly informed on the best way to meet the needs of both media and the team; enables the communications staff to track media contacts; and ensures media receive quick response to requests.

**Communications Objectives**: Our communications goals are to reassure the public that qualified and credible engineers are studying the levee performance to determine whether there are lessons for the future, to support the panel's work by minimizing disruptions and distractions, and to establish the role of ASCE and panel members as independent, highly credible, and authoritative technical experts.

**Policy:** ERP members must coordinate all contact with the media through the ASCE Communications Department. If a staff member of the Communications Department asks you to respond to a media request for information or comment, you should attempt to do so promptly and within the reporter's deadline.

Media are defined as: newspapers, radio and TV stations, magazines, on-line publications or media sites, and trade magazines (like *ENR* or *Professional Builder*), including those published by universities, government agencies and private corporations or organizations.

**Procedure:** All media calls/e-mails/or personal requests must be forwarded promptly to the communications staff *prior* to responding to any questions, sending information or referring calls to another panel member. Do not provide background material, answer questions, or refer them to another panel member, staff person, or outside expert until asked to do so by a member of the communications staff. All news releases, advisories, letters and pitch calls to the media must be coordinated *first* through the Communications Department. This department is the only Society entity authorized to issue news releases on behalf of the panel.

**Speaking Invitations:** You may be asked to speak before professional organizations. Keep in mind that these presentations, especially when open to the public or media, are covered by the same limitations as media interviews. Please ask that the individuals handling promotion or publicity for these speaking engagements contact communications staff to coordinate. We will also be happy to facilitate review of any part of your presentation that you may have questions about in order to allow you to have, as much as possible, an open exchange of information with your professional colleagues.

**Communications Department Hours:** Communications staff has staggered schedules so there is generally someone available in the office between 8:00 a.m. and 6:30 p.m. The senior manager, external relations and the director of communications are on-call on evenings and weekends.

**Media calls should be referred in the following order:**

| | | |
|---|---|---|
| Sr. Manager, External Relations: | Joan Buhrman | 703-295-6406 |
| Director of Communications: | Jane Howell | 703-295-6403 |

**ASCE Central**: 1-800-548-2723

## Appendix 2: IPET and ERP Issue Resolution Process

The intent for resolving technical issues is at the lowest level possible. When a technical issue develops at the working level, those involved should seek to resolve the issue at there level within 2 days keeping the appropriate IPET Task Co-Leaders (see below) and ERP Task Reviewers (see below) informed of the situation. When the technical issue cannot be resolved within 2 days, those involved at the working level should engage the support of the appropriate IPET Task Co-Leaders and ERP Task Reviewers to resolve the technical issue. The appropriate IPET Task Co-Leaders and ERP Task Reviewers involved seek to resolve the issue at there level within 1 day keeping the IPET and ERP Final Issue Resolution Team (see below) informed of the situation. If the appropriate IPET Task Co-Leaders and ERP Task Reviewers are unable to resolve the technical issue in 1 day, they should engage the IPET and ERP Final Issue Resolution Team where the technical issue will be resolved in 1 day. All discussions and resolutions on technical issues shall be documented through the level in which resolution was made and the documentation shall be maintain in the Groove IPET All-Task workspace and ERP workspace.

All nontechnical issues should be brought to the appropriate IPET and ERP Final Issue Resolution Team Members where the nontechnical issue will be resolved.

**IPET Task Co-Leaders**

Task 1 – Data Collection and Management – Denise Martin and Reed Mosher

Task 2 and 3 – Interior Drainage Interior Models – Jeff Harris and Steve Fitzgerald

Task 4 – Numerical Model of Hurricane Katrina Surge and Wave environment – Bruce Ebersole and Joannes Westerkink

Task 5a – Storm Surge and Wave Physical and Numerical Models Hydrodynamic Forces – Don Resio and Bob Dean

Task 5b – Storm Surge and Wave Physical Model – Centrifuge Breaching – Mike Sharp and Scott Steedman

Task 6 – Geodetic Vertical Survey Assessment – Jim Garster and Dave Zilkowski

Task 7 – Analysis of Floodwall and Levee Performance – Reed Mosher and Mike Duncan

Task 8 – Pumping Station Performance – Brian Moentenich and Bob Howard

Task 9 – Consequence Analysis of Hurricane Katrina – Dave Moser and Pat Canning

Task 10 – Engineering and Operation Risk and Reliability Analysis – Jerry Foster and Bruce Muller

**ERP Task Reviewers**

David E. Daniel - Task 7 – Analysis of Floodwall and Levee Performance

Christine F. Andersen - Task 6 – Geodetic Vertical Survey Assessment

Billy Edge - Task 5a - Storm surge & wave Physical model - Hydrodynamic Forces
Task 5b - Storm surge & wave Physical model - Centrifuge Breaching
Task 4 - Numerical model of Hurricane Katrina surge and wave environment

William H. Espey - Task 2 and 3 - Interior Drainage Numerical Models

Thomas L. Jackson - Task 8 - Pumping Station Performance

David F. Kennedy - Task 1 - Data Collection and Management - Perishable, system data

Dennis S. Mileti - Task 9 - Consequence Analysis of Hurricane Katrina

James K. Mitchell - Task 7 - Analysis of Floodwall and Levee Performance

Clifford A. Pugh - Task 5a - Storm surge & wave Physical model - Hydrodynamic Forces
Task 5b - Storm surge & wave Physical model - Centrifuge Breaching
Task 4 - Numerical model of Hurricane Katrina surge and wave environment

George Tamaro - Task 7 - Analysis of Floodwall and Levee Performance

Robert Traver - Task 2 and 3 - Interior Drainage Numerical Models

Steve Vick – Task 10 - Engineering and Operation Risk and Reliability Analysis

Jurjen Battjes - Task 4 - Numerical Model of Hurricane Katrina Surge and Wave Environment
Task 5a - Storm Surge & Wave Physical Model - Hydrodynamic Forces
Task 5b - Storm Surge & Wave Physical Model - Centrifuge Breaching
Task 7 - Analysis of Floodwall and Levee Performance

Peter Nicholson - Task 7 - Analysis of Floodwall and Levee Performance

**IPET and ERP Final Issue Resolution Team**
David Daniel – Chairman ERP
Larry Roth – Technical Director ERP
Ed Link – Project Director IPET
John Jaeger – Technical Director IPET

# Appendix E
# IPET Public Website

The New Orleans Hurricane Protection Projects Data public website provides access to data associated with the U.S. Army Corps of Engineers Hurricane Protection Projects in the New Orleans, LA area (see Figures E-1 and E-2). The data is organized according to Hurricane Protection Project names, as shown in the left column of the site. Users may view categories of data for a specific Hurricane Protection Project by clicking on the name of the project. Users may view a list of the available documents, view a selected document in the website's view window or in a separate window, and download a specific file to their computer. Since all the files posted on the site are in .pdf format, a link to install the Adobe Acrobat Reader is provided. Also, a link to the New Orleans District Advertised Solicitations website is provided.

Users may view the date that a specific document was posted on the website by simply placing their mouse over the name of the document.

Metrics are collected daily on the number of hits to this website.

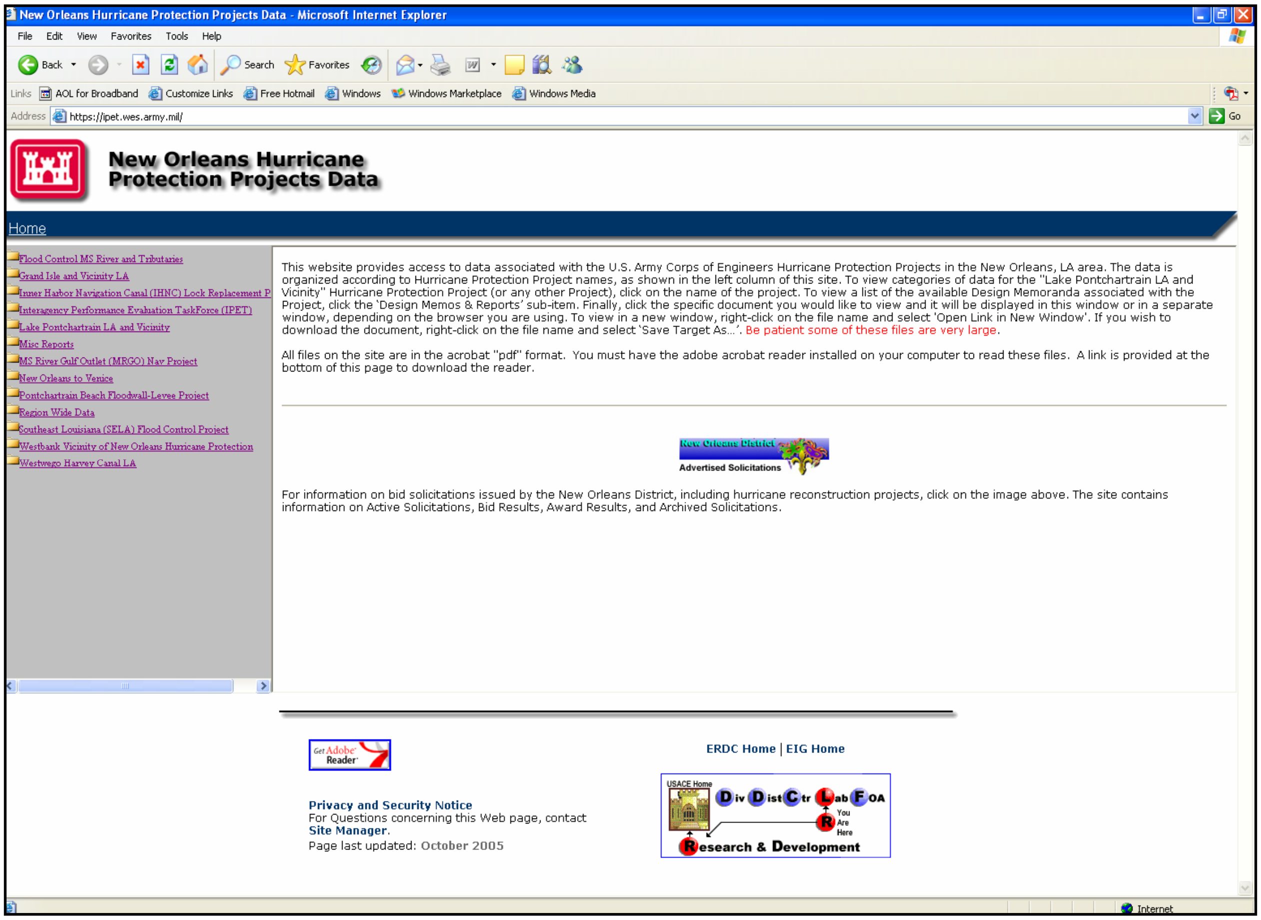



Figure E-1. Screen capture of the frontpage of the New Orleans Hurricane Protection Projects Data website.

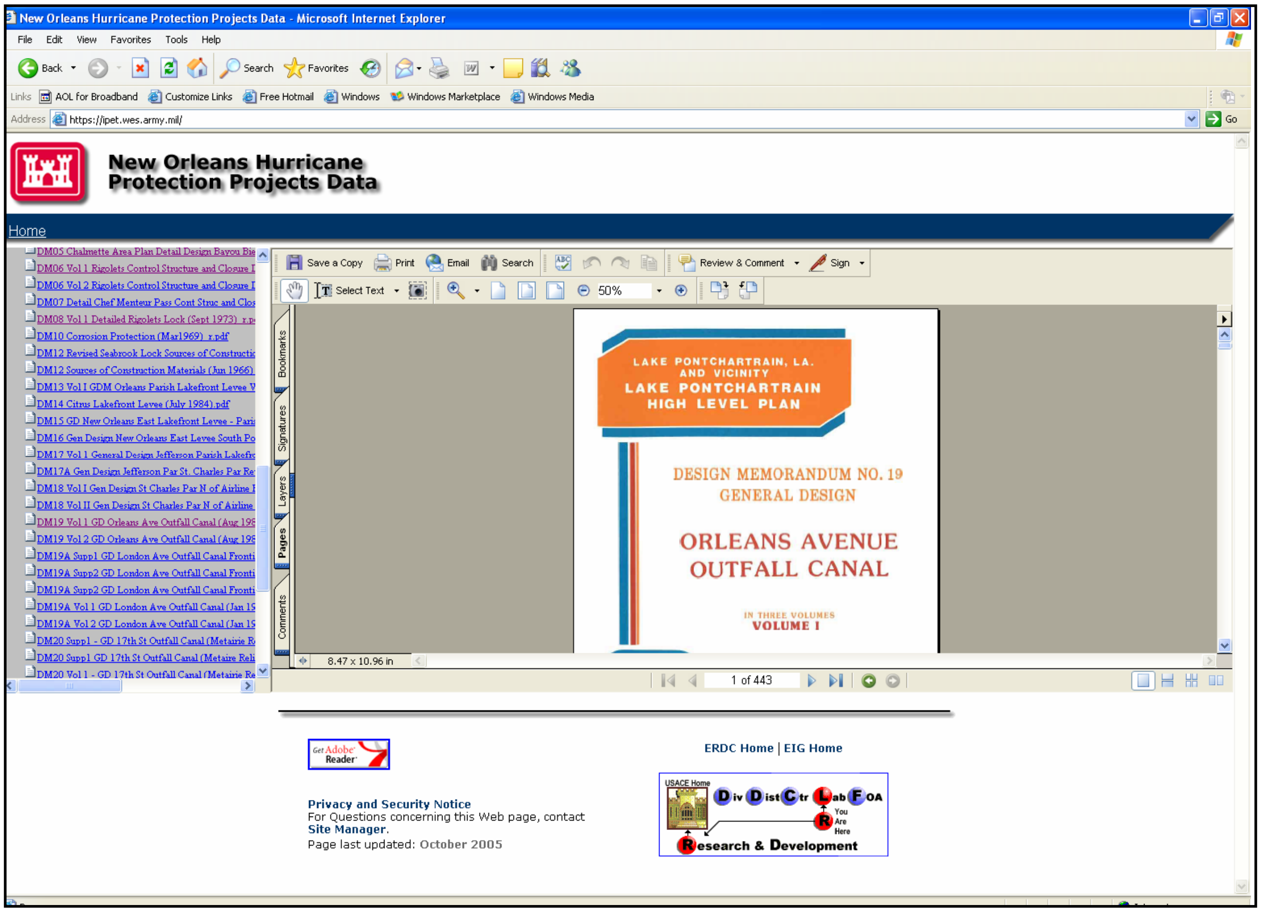



Figure E-2. Screen capture of a document displayed in the view window of the New Orleans Hurricane Protection Projects Data website.

# Appendix F
# Task Force Guardian Inputs

## IPET Products Provided to Task Force Guardian and Task Force Hope as of 31 December 05

a. **Data Repository – 25 October 05.** The IPET Data Repository was established as an entry point for collecting information pertaining to the New Orleans and Southeast Louisiana Hurricane Protection Projects that needs to be validated as factual. This repository supports both the IPET and TFH/TFG efforts by providing a database where information can be reviewed for accuracy and quality prior to posting the information on the IPET public website.

b. **Establishment of the IPET Public Website – 2 November 2005**. The IPET public website was established as a way to be fully transparent in effectively sharing factual information pertaining to the New Orleans and Southeast Louisiana Hurricane Protection Projects. The website provides a way to proactively communicate information that might otherwise require the public and TFG to process Freedom of Information Acts.

c. **Establishment of On-Line Team Workspace using Groove – 22 September 05.** To enable IPET, ERP, and members of TFH/TFG with on-line workspaces to communicate and share information virtually, Groove software and technical support was provided by IPET. Through these virtual workspaces information can be effectively and efficiently shared. Groove is a primary tool used to bring the IPET, ERP, and TFH/TFG teams together in sharing knowledge and information required to accomplish their missions.

d. **Integration of the IPET Public Website and the TFH/TFG Electronic Bid Solicitation Websites – 15 November 05.** As a way to more effectively enable public benefit from the historic and performance-related information on the IPET public website and the reconstruction plans and specifications on the TFH/TFG electronic bid solicitation website, electronic linkage was provided to facilitate integration of the two sites.

e. **"Summary of Field Observations Relevant to Flood Protection in New Orleans, LA" – 5 December 2005.** This IPET review provided Task Force Guardian with a simple statement of concurrence or nonconcurrence from the IPET floodwall and levee sub team and additional relevant discussion for each of the major findings in the ASCE/NSF report's chapter eight, "Summary of Observations and Findings." The additional discussion relates to the analysis being conducted by the IPET or others that would assist in applying the ASCE/NSF findings to the reconstruction of hurricane protection in New Orleans.

f. **"Preliminary Wave and Water Level Results for Hurricane Katrina" – 23 November 2005.** This IPET report to TFH/TFG included observations from the IPET surge and wave sub team from a field trip and overflight of New Orleans and Southeast Louisiana.

g. **"Summary of IPET Numerical Model of Hurricane Katrina Surge and Wave Plans, Approach and Methods" – 19 December 2005.** This PowerPoint presentation by the IPET surge and wave sub team provided TFH/TFG with an update on wave and water level results for Hurricane Katrina. Wave and water level results from fast-track simulations of upper Category 3 type storms on various storm tracks and a Standard Project Hurricane event were also provided.

h. **Review of Proposal to Float In and Sink a Barge to Close Canals by June 2006 – 28 December 2005.** The proposal included the use of existing large ship tunnel thrusters mounted on a barge with huge pumping capacities. Review determined that the closure plan does not have enough pumping capacity to match existing pumps during a hurricane.

i. **Technical Support to TFG on the Analysis and Design of the Reconstruction Plans and Specifications for the Breaches – Continuous Support as Needed.** Technical support continues to be provided to TFG on an as-needed basis. As a minimum, monthly face-to-face meetings take place in New Orleans. This support includes geotechnical and structural consultations. These discussions also include reviews of plans and specifications for reconstruction features such as T-walls, L-walls, I-walls, levees, and foundation investigations.

j. **Evaluation of Existing and As-Built Conditions at Canals – On-going.** This evaluation includes concrete and steel material properties for reinforcement and sheet piles on the I-walls, as-built length of sheet piles, surveys, and foundation material properties and boring logs.

k. **Life-cycle Documentation of the Hurricane Protection System – On-going.** This documentation includes a review of the design, construction, and operation and maintenance of the hurricane system.

l. **Verification of Current and Reconstructed Floodwall Elevations – November 2005.** Established a tidal gage in November 2005 at the 17th Street Canal to monitor current sea level relationships to the newest NAVD88 datum epoch (2004.65). Verified floodwall elevations on Lakefront outfall canals and IHNC relative to this latest tidal and vertical epoch.

m. **LIDAR Ground Truthing – On-going.** Currently performing ground-truthing surveys throughout the region to calibrate various LIDAR-based elevation models used by Task Force Guardian.

n. **Densification of Control Benchmarks – 31 December 2005.** IPET has established approximately 75 vertical benchmarks throughout the region. These control points are being used for Task Force Guardian construction activities.

# Appendix G
# Data Repository – Organization and Content

The IPET Data Repository is organized primarily according to New Orleans Hurricane Protection Projects and the type of data stored. The top-level of data organization is as follows:

- Flood Control Mississippi River and Tributaries
- Grand Isle and Vicinity
- Inner Harbor Navigation Canal (IHNC) Lock Replacement Project
- Lake Pontchartrain LA and Vicinity
- Mississippi River Outlets Vicinity of Venice LA
- Mississippi River Gulf Outlet (MRGO) Navigation Project
- New Orleans to Venice
- Pontchartrain Beach Floodwall-Levee Project
- Southeastern Louisiana (SELA) Flood Control Project
- Westbank in the Vicinity of New Orleans
- Westwego to Harvey Canal
- Region Wide Data
- Misc Reports
- Interagency Performance Evaluation Taskforce (IPET)

For each top-level folder listed above, the following folders further categorize the type of data stored:

- Basemap – *GIS layers, Lidar data, Digital Elevation Models*
- Climate – *Precipitation and Wind data*
- Contracts – *all official contract actions*
- Design Memorandums (DM) – *existing Design memoranda*
- Field Investigations - *breach and repair records, scour locations, timelines, high water marks, damage reports, wall deflection gauges, and slope inclinometer data*
- Geology – *profiles, cross-sections, and vertical control data*

- Hydrology – *stream gauge readings, stage height readings, surge height readings, hydrographs, piezometer readings, tidal gauge records, and historical river gauge readings*
- Laboratory Test Data – *sheet pile test data, concrete test data, and steel reinforcement test data*
- Modeling and Assessment – *drainage numerical models, storm surge and wave numerical models, storm surge, wave and breaching physical models, geodetic vertical survey datum assessment, centrifuge modeling of floodwall, analysis of floodwall and levee performance, pumping station performance, stability analysis, engineering and operations risk & reliability analysis*
- Periodic Inspection Reports – *scanned inspection reports*
- Plans and Specifications – *as-built drawings, construction drawings*
- Reports – *reports from detailed studies, technical reports, etc.*
- Soils – *soil profiles, soil boring logs, stability analysis, soil surveys, cone penetrometer readings*
- Structures – *designs/drawings/cross-sections of bridges, pump stations, floodwalls, levees, canals*
- Transmissions – *presentations, photographs, videos, public meeting minutes, etc.*

The following metadata is collected for each file stored in the Repository, as applicable:

- Document handler: *Person creating, checking or saving files*
- Handler contact: *Handler contact information including phone & email*
- Quality checked: *Contact information of person performing quality check*
- Document title: *Title of document, map, image, etc.*
- Document type: *Type of document such as photo, newspaper, video, TV Broadcast, etc.*
- Document date: *Date of document*
- Project name: *Official project name*
- Plan name: *Official project plan name*
- Plan feature: *Official plan structure or feature*
- Project location: *Parish the project is located in*
- Project status: *Status of project document identifies, such as preliminary, 30%, etc.*
- Key words: *Any key words that describe the file such as location, subject covered, etc.*
- Data source: Source values: *Collected, Derived, Corrected, Scanned*
- Number of items: *Total number of drawings, pages, photos, minutes of broadcast*
- Drawing number: *Drawing number identified in document*

- Sheet number: *Sheet number identified in document*
- Plate number: *Plate number identified in document*
- Document author: *Who authored the original document or who is identified in the signature block*
- Contractor name: *Any contractor identified in the document as designer/author or awarded the contract or performing work as part of this effort*
- Contract number: *Any official contract number identified on the document such as P2 number*
- Approval date: *When was the document approved for construction or bid, etc.*
- Project Work Index: *PWI number in the project*
- Horizontal datum: *Horizontal reference of mapping files such as NAD27, UTM, etc.*
- Vertical datum: *Vertical reference of mapping files such as NGVD27, NGVD88, etc.*
- Map projection: *Projection of mapping files such as Lambert, Gauss Kruger, etc.*
- Map source: *Source of data such as USGS, GDT, local, in-house, etc.*
- Transmit date: *When video/audio/news item was aired or printed*
- Transmit conduit: *What broadcast network or newspaper disclosed the segment*
- Reporter: *Lead reporter in video/audio/print segment*

# Appendix H
# Data Requirements for the IPET Study

Table H-1 below provides a listing of the data requirements based on input from the IPET Task Co-leaders. Each item is categorized as perishable, background, or new data, and the expected source of each item is identified. Additionally, a date by which each item is expected to be available in the Data Repository is assigned. Finally, the Data Repository component responsible for storing each data item is identified. The color-coding in the table represents the data that has been posted to the Repository, where yellow represents partial data and green represents complete data. Task numbers used to describe requestors refer to specific IPET teams as follows: 1 = Data Collection and Management, 2/3 = Interior Drainage and Flooding, 4 = Storm Surge and Wave Analysis, 5 = Hydrodynamic Forces and Overtopping and Geotechnical Structure Performance, 6 = Vertical Datum, 7 = Levee and Floodwall Performance, 8 = Pump Station Performance, 9 = Consequence Assessment, and 10 = Risk and Reliability Analysis.

| Item # | Item Description | Requested by | Perishable/Background/New | Source/Collected by | Date Available | Repository Component |
|---|---|---|---|---|---|---|
| 1 | Post hurricane levee heights, profiles and alignments. | Task 2,3 | Perishable | MVN or TF Guardian/ERDC (Lillycrop) | 1/31/2006 | LDS |
| 2 | Breach locations, depth, width, descriptions, photos, erosion extents, date and time started and date and time fully developed. | Task 2,3,9,10 | Perishable | ERDC-CHL (Steve Maynord, David Biedenharn), ERDC-GSL | locations available 12/22/05 | GIS |
| 3 | Land side scour locations | Task 2,3 | Perishable | MVN-CHL | 1/20/2006 | GIS |
| 4 | Flooded area hi water data located on structures scheduled for razing | Task 2,3,9 | Perishable | CHL (Steve Maynord) | locations of high water marks available 12/15/05 | GIS |

| Item # | Item Description | Requested by | Perishable/Background/New | Source/Collected by | Date Available | Repository Component |
|---|---|---|---|---|---|---|
| 5 | Time history of events; Timeline of Katrina and Observed System Response - temporal hurricane track, observations: surge, flooding, wave heights, currents (direction, magnitude), pump operation, levee damage, debris in canals (quantity, composition), barges, boats, etc. | Task 2,3,5,9,10 | Perishable | CHL | preliminary available 1/15/2006 | PW |
| 6 | Geo-referenced photos of failure sites (x,y,z, project/site, description, measurement of erosion depth and breadth, date, time) | Task 2,3,5, 7 | Perishable | MVN, ERDC field team (Mlakar) | 1/20/2006 | PW |
| 7 | Ground Surveys and Profiles of Ground and Structures(project/site, location, x,y,z, description, date, time, reference point for survey) | Task 5, 7,9,10 | Perishable | MVN, ERDC field team (Mlakar) | 1/20/2006 | PW |
| 8 | Bottom Profile of Canals, Bathymetric surveys, Scour Surveys (project/site, location, x,y,z, description, date, time, reference point for survey) | Task 5, 7,9,10 | Perishable | MVN, ERDC-CHL (Mlakar) | 1/20/2006 | PW |
| 9 | Hydrographic Surveys (project/site, location, x,y,z, description, date, time, reference point for survey) | Task 5, 7,9 | Perishable | MVN-CHL | 1/20/2006 | LDS |
| 10 | Sequential Water Level (project/site, location, x,y,z, description, date, time, reference point for survey) | Task 5, 7,9 | Perishable | MVN-CHL | 1/20/2006 | PW |
| 11 | Eyewitness Accounts of the failures (project/site, location, x,y,z, description, date, time, reference point for survey); Interviews with USACE operators and emergency ops personnel concerning system performance | Task 2, 3, 5, 7,10 | Perishable | CHL-GSL | 1/20/2006 | PW |

| Item # | Item Description | Requested by | Perishable/Background/New | Source/Collected by | Date Available | Repository Component |
|---|---|---|---|---|---|---|
| 12 | Ground-based LIDAR (project/site, location, x,y,z, description, photos, date, time, reference point for survey) | Task 5, 7 | Perishable | NSF-GSL | 1/31/2006 | LDS |
| 13 | Damage Survey Reports (project/site, location, x,y,z, description, photos, date, time, reference point for survey) | Task 5, 7,10 | Perishable | MVN (Mlakar) | 1/20/2006 | PW |
| 14 | Pump Flow rates and location of Discharge as a function of time | Task 5,9 | Perishable | Nancy Blyler, Parishes (Brian Moentenich), MVN (Jay Ratcliff) | 1/31/2006 | PW/GIS |
| 15 | Evidence of structural failure mechanisms (sheet pile depths, sheet pile embedment in concrete, concrete conditions) | Task 10 | Perishable | GSL (Mlakar) | 1/20/2006 | PW |
| 16 | Repair records of emergency breach closures, photos of features buried during repairs | Task 10 | Perishable | MVN/TF-Dewater (Mlakar) | 1/20/2006 | PW |
| 17 | High water marks | Task 10, 4,9 | Perishable | MVN - CHL (Steve Maynord) | locations of high water marks available 12/15/05 | GIS |
| 18 | combined TIN of land surface and detailed canals for each parish | Task 2,3,9 | New | David Stuart to create from baseline DEMs | pre-storm 1/17/2006; post-storm 2/17/2006 | LDS |
| 19 | DEM of all 5 parishes, pre-storm and post-storm DEM and structure/levee crest elevations | Task 2,3,4,9 | New | Rob Wallace creating pre-storm and post-storm baseline DEMs | pre-storm 1/17/2006; post-storm 2/17/2006 | LDS |
| 20 | Top of floodwall and crest of levee surveys (project/site, location, x,y,z, description, date, time, reference point for survey) | Task 5, 7 | Background | some surveys (dgn) received from MVN | 12/30/2005 | LDS |
| 21 | Actual top and bottom of wall elevations (project/site, location, x,y,z, description, date, time) | Task 5, 7 | Background | some surveys (dgn) received from MVN | 12/30/2005 | PW |
| 22 | LIDAR (project/site, location, x,y,z, description, date, time) | Task 5, 7,9 | New | 2000 LIDAR collected by John Chance; 2005 LIDAR collected by John Chance; Lillycrop to provide additional LIDAR by 1/31/2006 | 1/31/2006 | LDS |

| Item # | Item Description | Requested by | Perishable/Background/New | Source/Collected by | Date Available | Repository Component |
|---|---|---|---|---|---|---|
| 23 | Survey of levee 'crest' elevations (perhaps DGPS on a 4-wheeler plus local surveys of tops of flood walls) | Task 5 | New | some surveys (dgn) received from MVN | 12/30/2005 | PW |
| 24 | Multi-beam sonar survey of bathymetry, sub-bottom characteristics (converted to x,y,z geo-referenced data and geo-referenced locations of scour and soil failures | Task 5 | New | MVN – Dave Wurtzel, Fred Young | 1/15/2006 | LDS |
| 25 | Levee elevation surveys before and after Katrina | Task 2, 3, 10 | Background/New | 2000 LIDAR collected by John Chance; 2005 LIDAR collected by John Chance; Lillycrop to provide additional LIDAR by 1/31/2006; some CADD surveys received from MVN | 12/30/2005 | LDS, PW |
| 26 | post-storm levee elevations at highest possible spatial resolution (with indication of which areas were repaired prior to post-storm survey) | Task 4 | New | 2000 LIDAR collected by John Chance; 2005 LIDAR collected by John Chance; Lillycrop to provide additional LIDAR by 1/31/2006 | 1/31/2005 | LDS |
| 27 | As-built cross-sections of levees (project/site, location, x,y,z, description, date, time, reference point for survey | Task 5 | Background | some surveys (dgn) received from MVN | 12/30/2005 | PW |
| 28 | pre- and post-storm canal cross-sections | Task 4 | Background/New | some surveys (dgn) received from MVN; GSL also has some | 12/30/2005 | PW |
| 29 | Detailed surveys and/or as built plans for all Culverts (location, size, invert elevations of all culverts that bring flow into the canals from the land surface side) | Task 2,3 | Background | requested from MVN | 1/31/2006 | PW |
| 30 | Detailed surveys and/or as built plans for all bridges in the study area | Task 2,3 | Background | requested from MVN | 1/31/2006 | PW |
| 31 | Land use data (GIS layer) | Task 2,3 | Background | USGS Multi Resolution Land Cover | 12/1/2005 | GIS |
| 32 | Soils data (STATSGO data) | Task 2,3,9 | Background | USDA NRCS STATSGO and SSURGO | 12/1/2005 | GIS |

| Item # | Item Description | Requested by | Perishable/Background/New | Source/Collected by | Date Available | Repository Component |
|---|---|---|---|---|---|---|
| 33 | Drainage network GIS layer | Task 2,3 | Background | USGS National Hydrologic Dataset | 12/1/2005 | GIS |
| 34 | Levee and Flood Wall alignments and elevations (preferable in GIS) | Task 2,3 | Background/New | MVN .shp files, .dgn files | footprints available12/30/2005 | GIS |
| 35 | GIS layer of canal centerlines and invert elevations | Task 2,3 | Background | MVN | 1/31/2006 | GIS |
| 36 | Digital Background maps and GIS layers (USGS digital quads, orthophotos, parcel data, streets and roads, etc…) | Task 2,3,9 | Background | | 01/15/2006 | GIS |
| 37 | Flood inundation maps resulting from hurricane Katrina (GIS layers showing flood boundaries of the event, with water surface elevations if possible) | Task 2,3,9 | New | MVK (Jack Smith) | 12/30/2005 | GIS |
| 38 | Detailed project maps of the pre-Katrina system | Task 10 | Background | some project maps provided by MVN | 12/30/2005 | PW |
| 39 | Historic precipitation data | Task 2,3 | Background | NOAA NCDC | 12/30/2005 | PW |
| 40 | Historic stream gage data, high water marks, and pump station data for use in calibration of models | Task 2,3 | Background | stream gage data - USGS; HWM - CHL; pump stations - TFG | 12/30/2005 | GIS/PW |
| 41 | Tidal gage records and related analysis | Task 6,9 | Background | NOAA CO-OPS | 1/30/2006 | PW |
| 42 | Geodetic Survey Archive Data (1960 to date) | Task 6 | Background | NOAA-NGS | 1/30/2006 | PW |
| 43 | MVN Historical River Gage Records and associated benchmark reference data | Task 6 | Background | MVN | 1/30/2006 | PW |
| 44 | Storm surge histories | Task 10 | Background | scanned documents | 12/1/2005 | PW |
| 45 | System performance during past storm events | Task 10 | Background | scanned documents | 12/1/2005 | PW |
| 46 | Design Memos | Task 5, 7, 10 | Background | scanned documents | 12/1/2005 | PW |
| 47 | Plans and Specifications | Task 5, 6, 7, 10 | Background | scanned documents | 12/1/2005 | PW |
| 48 | As Built Drawings | Task 5, 6, 7, 10 | Background | scanned documents | 12/10/2005 | PW |
| 49 | Support Computations | Task 5, 7 | Background | scanned documents | 12/1/2005 | PW |
| 50 | Construction QA Records | Task 5, 7 | Background | scanned documents | 12/1/2005 | PW |

| Item # | Item Description | Requested by | Perishable/Background/New | Source/Collected by | Date Available | Repository Component |
|---|---|---|---|---|---|---|
| 51 | Field Investigations | Task 5, 7 | Background | scanned documents | 12/1/2005 | PW |
| 52 | Periodic Inspections | Task 5, 6, 7, 10 | Background | scanned documents | 12/1/2005 | PW |
| 53 | A&E Reports | Task 5, 7 | Background | scanned documents | 12/1/2005 | PW |
| 54 | Project modifications | Task 10 | Background | scanned documents | 12/1/2005 | PW |
| 55 | Construction reports | Task 10 | Background | scanned documents | 12/1/2005 | PW |
| 56 | Conference and Journal Articles | Task 5 | Background | scanned documents | 12/1/2005 | PW |
| 57 | Court records for Cases involving Levee Constructions | Task 5 | Background | scanned documents | 12/1/2005 | PW |
| 58 | Pump station data (location, number of pumps, pump capacity and efficiency curve for each pump, normal water surface elevation at which pump is turned on and off | Task 2,3 | New | USGS (Clint Padget) provided .shp file and .xls file of pumps; requested additional documents listed in .xls file from MVN | 12/30/2005 | GIS |
| 59 | Pump station operation timeline, detailed | Task 2,3,9 | New | | 1/31/2006 | |
| 60 | Pump stations performance | Task 10 | New | Task 8 | 1/31/2006 | GIS |
| 61 | Stream gage information (time series of stages and flows at all possible locations) | Task 2,3 | New | | 1/30/2006 | PW |
| 62 | High water marks (stages of maximum flooding wherever available) | Task 2,3 | New | MVN - CHL (Steve Maynord) | locations of high water marks available 12/15/05 | GIS |
| 63 | Hurricane Katrina Precipitation data (point data and NexRad radar data) | Task 2,3 | New | NOAA NCDC | 12/30/2005 | PW |
| 64 | Lake Pontchartrain stage data | Task 2,3,9 | New | ask Harley Winer, George Brown, MVN | 1/31/2006 | PW |
| 65 | Models and Studies that have been performed by the District office and others | Task 2,3,9 | Background | scanned documents | 12/15/2005 | PW |
| 66 | Surge heights and hydrographs | Task 2,3,9 | New | | 1/30/2006 | PW |
| 67 | Time sequence of hydrologic (surges, waves) events during Katrina (surge timing and directions, wave heights) | Task 10 | New | Task 4 | 1/30/2006 | PW |
| 68 | measured water level hydrographs | Task 4 | New | MVK | 1/30/2006 | PW |

| Item # | Item Description | Requested by | Perishable/Background/New | Source/Collected by | Date Available | Repository Component |
|---|---|---|---|---|---|---|
| 69 | bridge designs and clearances | Task 4 | Background | MVN as-builts | 1/15/2006 | PW |
| 70 | breach configurations | Task 4 | New | location of breaches provided by TFG | 2/01/2006 | GIS |
| 71 | Levee and floodwall failure modes (input data used to analyze floodwalls and levees, material strength distributions, uncertainty in sheet pile depth) | Task 10 | New | Task 7 | 1/30/2006 | PW |
| 72 | Soil Boring (project/site, location, x,y,z, description, graphs, date) | Task 7 | New | GSL (Noah Vroman) | 1/31/2006 | PW |
| 73 | CPT Data (project/site, location, x,y,z, description, graphs, date) | Task 7 | New | GSL (Noah Vroman) | 1/31/2006 | PW |
| 74 | Laboratory Logs (project/site, location, x,y,z, boring number, description, graphs, date) | Task 7 | New | GSL (Noah Vroman) | 1/31/2006 | PW |
| 75 | Soil Test Data (project/site, location, x,y,z, boring number, description, graphs, date) | Task 7 | New | GSL (Noah Vroman) | 1/31/2006 | PW |
| 76 | Soil Material Properties (project/site, location, x,y,z, description) | Task 7,9 | New | GSL (Noah Vroman) | 1/31/2006 | PW |
| 77 | Sheet Pile Test Data (project/site, location, x,y,z, description, graphs, photos) | Task 7 | New | GSL | 12/30/2005-3/30/2006 | PW |
| 78 | Concrete Test Data (project/site, location, x,y,z, description, graphs, photos) | Task 7 | New | GSL | 12/30/2005-3/30/2006 | PW |
| 79 | Steel Reinforcement Test Data (project/site, location, x,y,z, description, graphs, photos) | Task 7 | New | GSL (Noah Vroman) | 12/30/2005-3/30/2006 | PW |
| 80 | Instrumentation (piezometer, slope inclinometers, wall deflection gages, etc.) (project/site, location, x,y,z, description, graphs, photos, date, time) | Task 7 | New | GSL | 1/31/2006 | PW |

| Item # | Item Description | Requested by | Perishable/Background/New | Source/Collected by | Date Available | Repository Component |
|---|---|---|---|---|---|---|
| 81 | Reference Elevation/Datum (reference controlling benchmarks) for all LIDAR/DEM/Aerial mapping recently flown. Ensure all topographic DEM data is referenced to the same SE Louisiana Vertical Time-Dependent Reference framework and related water surface references | Task 6 | New | Task 6 | 1/31/2006 | PW |
| 82 | MVN Vertical Control/Topographic Surveys of Levees | Task 6 | New | Task 6 will collect from MVN | 1/15/2006 | PW |
| 83 | vertical data survey of pump house monuments | Task 8 | New | Task 6 | 1/15/2006 | PW |
| 84 | Timeline of baseline water level data at station inlet and outlet | Task 8 | New | Task 2 | 2/28/2006 | PW |
| 85 | Timeline of actual water level data at station inlet and outlet | Task 8 | New | Task 3 | 2/28/2006 | PW |
| 86 | interpretation of pre-storm ground cover throughout the domain, or imagery to assess ground cover | Task 4,9 | New | MVN/LSU | 2/28/2006 | GIS/LDS |
| 87 | Photos from historical hurricanes affecting these areas | Task 5 | Background | scanned documents | 1/31/2006 | PW |
| 88 | Aerial and Satellite Image (project/site, location, x,y,z, description, date, time) | Task 5, 7, 9,10 | New | GE-Harden Imagery received from MVN | 1/15/2006 | GIS/LDS |
| 89 | Aerial videos (date, time, project/site, location, description) | Task 5, 7 | New | various | 1/30/2006 | PW |
| 90 | Aerial photography of before flood and during flood | Task 2,3,9 | Background/New | various | 1/30/2006 | PW |
| 91 | Photos of damage | | New | CHL (Steve Maynord) | 1/30/2006 | PW |
| 92 | Prioritization List of Structures | Task 6 | New | | 1/31/2006 | PW |
| 93 | Tasks 2, 3, 9 results | Task 10 | New | Tasks 2, 3, 9 | 4/30/2006 | PW |
| 94 | System models used by Task 5 | Task 10 | New | Task 5 | 4/30/2006 | PW |
| 95 | Task 4 Wave/Water heights | Task 7 | New | Task 4 | 4/30/2006 | PW |
| 96 | Task 5b Physical Model Data | Task 7 | New | Task 5b | 4/30/2006 | PW |
| 97 | Task 5a Physical Model Data | Task 7 | New | Task 5a | 4/30/2006 | PW |

| Item # | Item Description | Requested by | Perishable/Background/New | Source/Collected by | Date Available | Repository Component |
|---|---|---|---|---|---|---|
| 98 | Surficial sediment concentration of contaminants in the canals and lake - value, location, time | Task 9 | Perishable | ERDC-EL | 1/30/2006 | PW |
| 99 | Total organic carbon concentration of bottom sediments in canals and lake - value, location, and time | Task 9 | Perishable | EL | 1/30/2006 | PW |
| 100 | Analysis of benthos in sediments near pumps | Task 9 | Perishable | EL, VIMS | 1/30/2006 | PW |
| 101 | Wetland assessment and ground truthing in St. Bernard Parish | Task 4, 9 | Perishable | EL, USGS | 1/30/2006 | PW |
| 102 | Fish contaminant assessment | Task 9 | Perishable | EL, LADNR | 4/30/2006 | PW |
| 103 | Fish Health Assessment | Task 9 | Perishable | EL, LADNR | 4/30/2006 | PW |
| 104 | Endangered and Threatened fish assessment | Task 9 | Perishable | EL, LADNR | 4/30/2006 | PW |

# Appendix I
# NOS Preliminary Local Mean Sea Level (LMSL) – NAVD88 2004.65, Difference for Southern Lake Pontchartrain

In support of the IPET Geodetic Vertical and Water Level Datum Assessment Requirement Plan, the Center for Operational Oceanographic Products and Services (CO-OPS) has been requested by the U.S. Army Corps of Engineers (USACE) to provide a statement on the PRELIMINARY elevation relationship between Local Mean Sea Level (LMSL) and the recently established NAVD88 2004.65 in the New Orleans vicinity. The elevation relationship provided here should be considered PRELIMINARY and applicable only to the region outlined in Figure I-1 North of the Mississippi River. Any application of this value beyond the outlined region is not recommended. A more accurate elevation relationship will be supplied as ongoing tidal and geodetic surveys in the region are completed.

Based on a PRELIMINARY analysis of NAVD88 2004.65 elevations at benchmarks associated with NOS Tide Stations at 8761402, 8761927, and 8762372 it was determined that a **LMSL - NAVD88 2004.65 difference of 0.077 m (0.25 ft)** computed at the newly re-established NOS tide station at New Canal USCG (8761927) is most representative of the LMSL – NAVD88 2004.65 difference for the outlined region**.** For more information contact Jerry Hovis at 301-713-2890 x 109, *gerald.hovis@noaa.gov*.

**Table I-1. NGS NAVD88 2004.65 Benchmarks Associated with NOS Tide Stations**

| NOAA Stations Associated with NAVD88 2004.65 Bench Marks | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Desig** | **PID** | **Lat** | **Long** | **Ortho_New** | **Sta_Num** | **Sta_Nam** | **EPOCH** | **Op** |
| 876 1724 TIDAL 11 | AT0685 | 29.264440 | -89.957500 | **0.950000** | 8761724 | Grand Isle | 83-01 | Y |
| PIKE RESET | BH1164 | 30.166110 | -89.737220 | **2.480000** | 8761402 | Rigolets | 83-01 | N |
| ALCO | BJ1342 | 30.026390 | -90.112500 | **1.870000** | 8761927 | USCG | 83-01 | Y |
| 2372 F 2003 | | 30.050000 | -90.366600 | **0.540000** | 8762372 | E Bank, Labranche | 83-01 | Y |

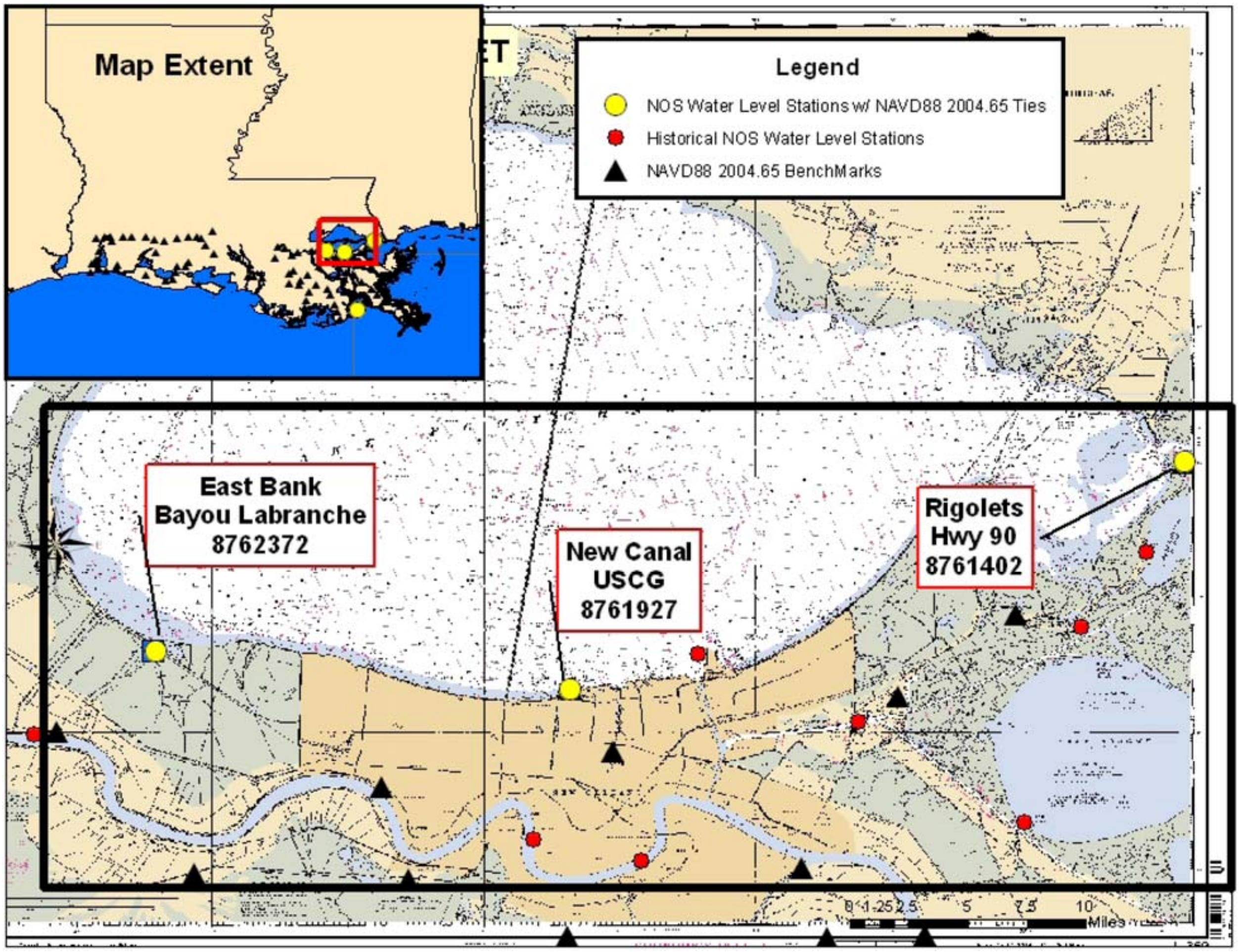



Figure I-1. Locations of NOS Tide Stations associated with NAVD 88 2004.65 benchmarks used to compute LMSL – NAVD88 2004.65 differences.