IPET's Mission: Find Answers

Summary of the IPET June 1 Draft Final Report

ON OCTOBER 10, 2005, THE U.S. ARMY CORPS OF ENGINEERS established the Interagency Performance Evaluation Taskforce (IPET) to provide scientific and engineering answers to questions about the performance of the New Orleans and Southeast Louisiana Hurricane Protection System (HPS) during Hurricane Katrina.

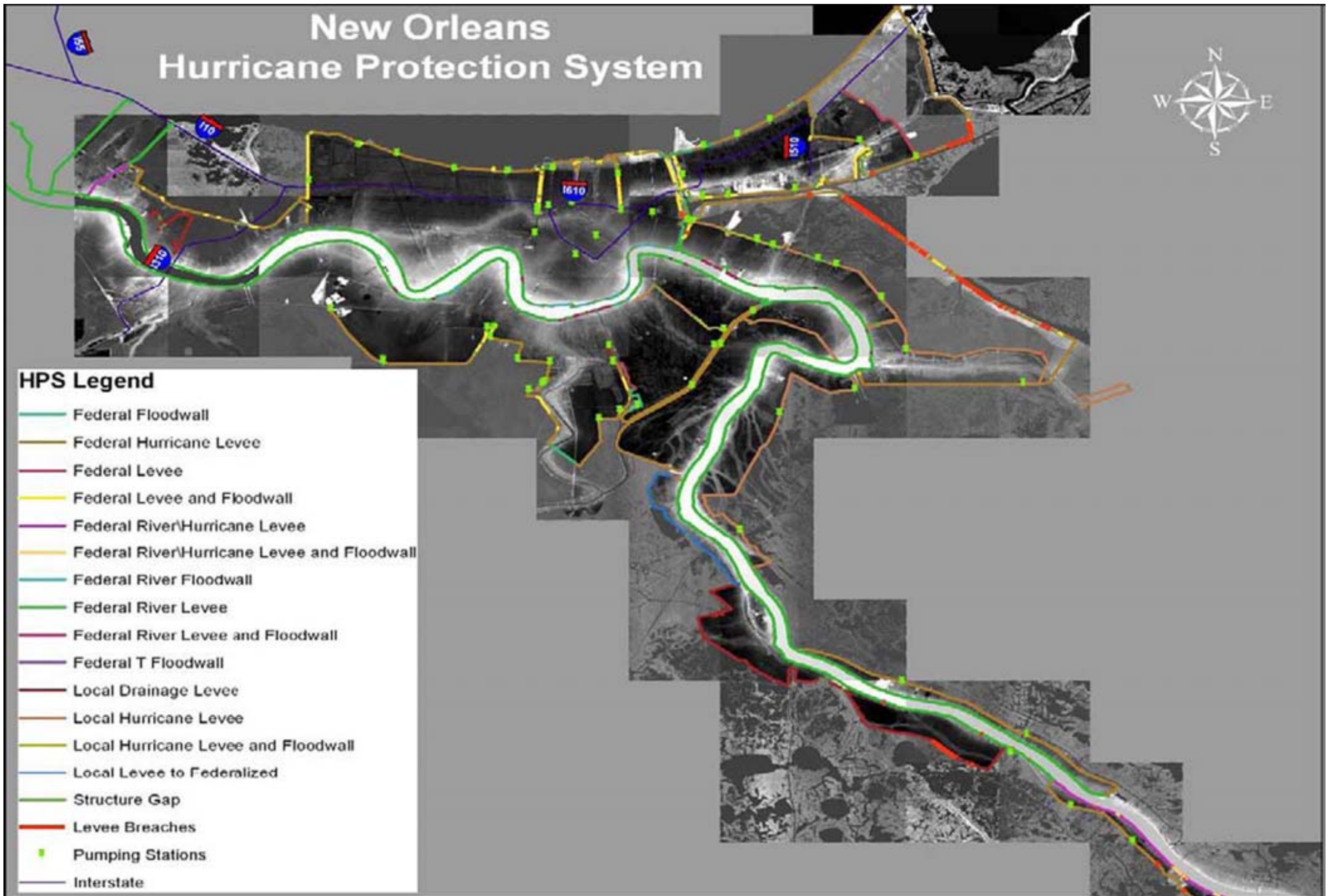
Composed of 150 experts from governmental agencies, academia and private industry, IPET assembled eyewitness accounts; consulted design, construction and maintenance records; examined physical evidence; and performed sophisticated analyses using some of the most advanced scientific and engineering methods and tools available to

- understand the performance of the HPS during Katrina
- assist in the application of that knowledge to
  - reconstruct the damaged portions of the system
  - improve the protection system, identifying deficiencies in existing design and construction and establishing a risk-based framework for recommending changes

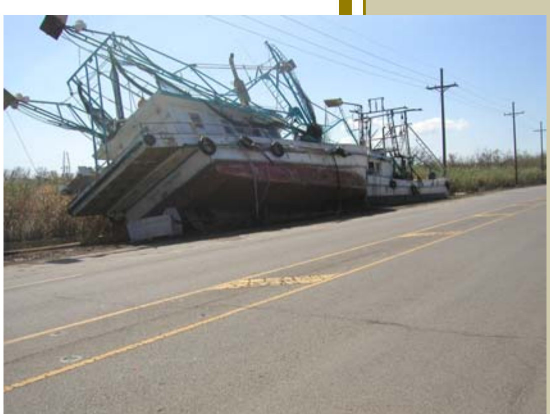
The IPET report addresses five major questions:

- What were the characteristics of the HPS before Katrina and how did they compare to the system's original design?
- What were the storm forces — waves and storm surge — generated by Katrina?

"To provide credible and objective scientific and engineering answers to the fundamental questions about the performance of the hurricane protection and flood damage reduction system in the New Orleans metropolitan area."



- How and why did the floodwalls, levees, pumping stations and drainage canals, individually and acting as an integrated system, perform in response to Hurricane Katrina?
    - What have been the societal consequences of Katrina-related damage?
    - What was the quantifiable risk to the New Orleans area before Katrina, and what will it be after repairs are completed?



This document presents the key findings published in the IPET report and summarizes the lessons applicable to rebuilding the New Orleans Hurricane Protection System and improving future hurricane protection design.

For all IPET reports and information, visit https://ipet.wes.army.mil

Hurricane Katrina

Although Katrina, with wind speeds of 127 m.p.h., was classified as a Category 3 hurricane at the time of landfall, the storm had built up levels of surge and waves exceeding those of any previous storm striking the North American continent.

Katrina-generated surge and waves

- caused 50 major breaches in the HPS
- significantly damaged
  - 34 of 71 pumping stations designed to move water out of the city
  - 168 of the system's 350 miles of protective structures, such as levees and floodwalls
- severely damaged 41 miles of protective structures

Katrina also brought record rainfall of over 14 inches in a 24-hour period. The rainfall, combined with overtopping, contributed about 30 percent of the floodwater in the New Orleans area. Sixty-five of 73 neighborhoods in the city flooded; 34 were completely inundated.

Hurricane Events Relevant to the Performance of the New Orleans Hurricane Protection System

AUGUST 23–28

Katrina gathers strength as it moves slowly over the Gulf of Mexico, pushing storm surge toward the coast.

AUGUST 29

Approximate times CDT

Predawn hours
Plaquemines Parish experiences devastating flooding as Katrina's storm surge overtops, erodes and breaches levees.

4:30 – 5:30 a.m.
Eyewitnesses report flooding in low-lying areas of the Lower 9th Ward, caused by failure of a portion of the IHNC floodwall (east side, north breach).

5:30 – 6:00 a.m.
The low, earthen levee on the west side of the IHNC overtops, initiating flooding in adjacent New Orleans neighborhoods.

6:00 – 7:00 a.m.
Eyewitnesses report a partial failure of 17th Street Canal floodwall (Orleans Parish side).

In East New Orleans, levees along the GIWW/MRGO were overtopping.

Eyewitnesses report rapid flooding in areas west of the IHNC and in East New Orleans.

6:10 a.m.
Hurricane Katrina makes landfall near Buras, La.

7:00 – 8:00 a.m.
Floodwalls on both sides of London Avenue Canal fail.

7:30 a.m.
IHNC floodwalls begin overtopping, water flows into the Lower 9th Ward. Low embankments at the south end of Orleans Canal overtop.

8:20 a.m.
Rapid flooding in Chalmette from Lake Borgne storm surge.

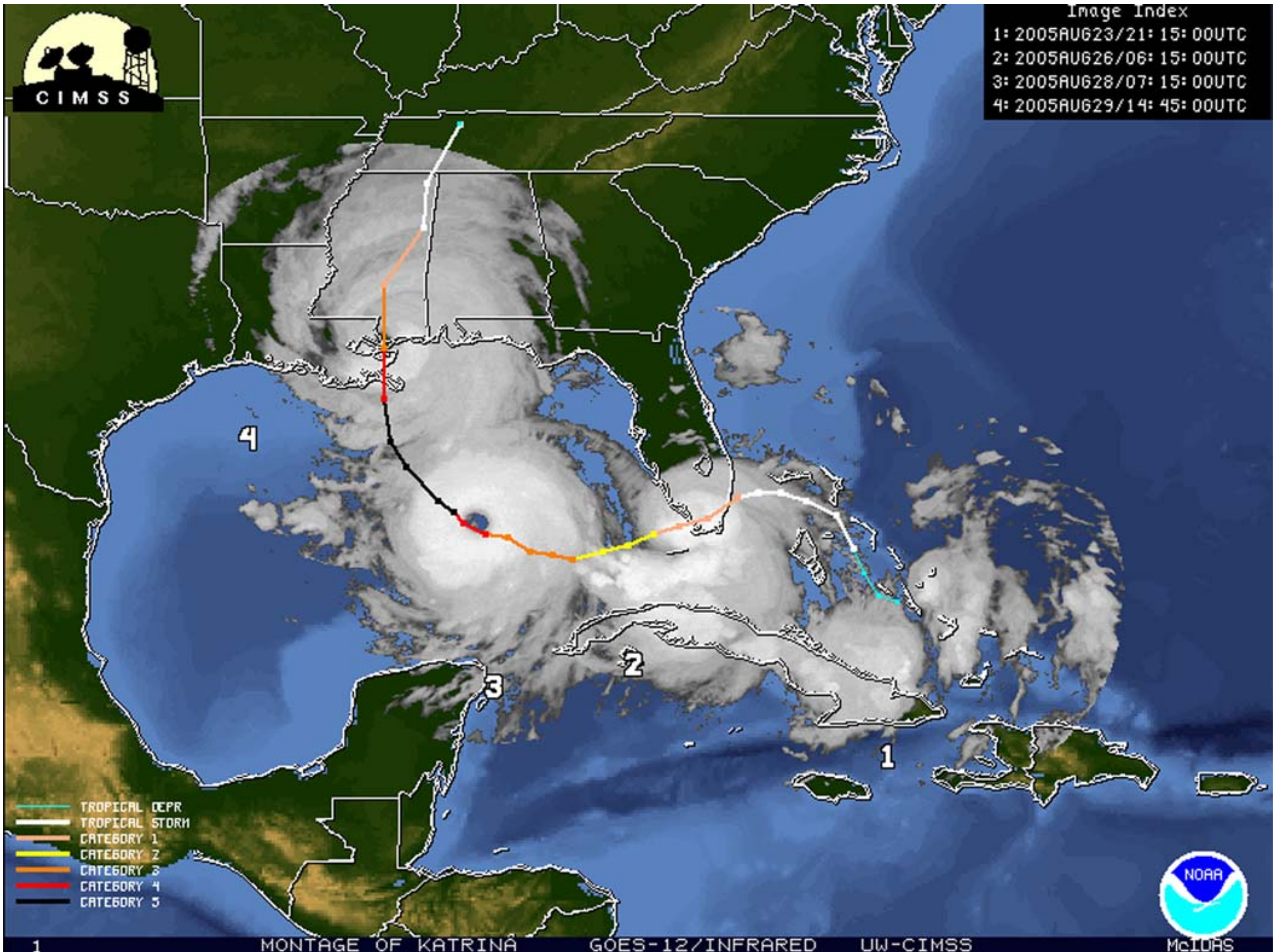
9:00 – 9:30 a.m.
17th Street Canal floodwall breach apparently fully developed; eyewitnesses report rapid flooding in Lakeview neighborhood.

August 30

Floodwaters from breaches spread into metro New Orleans neighborhoods.

August 31

Floodwaters in metro New Orleans neighborhoods stabilize and begin to recede as Lake Pontchartrain water levels slowly fall.



Katrina Storm Track Map

As Katrina progressed slowly across the Gulf of Mexico, the storm gathered enormous quantities of water into its system. A Category 5 hurricane with 175 mph winds 170 miles from landfall, Katrina had dropped to a Category 3 hurricane, with wind speeds of 127 mph, when it came ashore at Buras. But the storm brought with it record levels of surge, waves and rainfall, hydrodynamic aspects of storm strength not factored in the Saffir-Simpson hurricane scale (Category 1–5).

Standard Project Hurricane (SPH): a severe storm considered reasonably characteristic of the region; used to design the protection in New Orleans.

"Subsidence, changing population demographics, and the changing patterns of hurricane intensity and frequency are obvious examples of time-dependent challenges."

Summary of Findings

A network of levees, floodwalls, reinforced bridges and dikes spanning five parishes, the New Orleans Hurricane Protection System was designed to protect southeastern Louisiana from catastrophic flooding in the event of a Standard Project Hurricane. Hurricane Katrina, which made landfall on August 29, 2005, was in several key respects a more powerful storm than the system was designed to handle. Several factors compromised the system's performance:

- **Incompleteness:** The HPS was scheduled for completion in 2015. Some sections of the system were not finished, and transitions between complete and incomplete sections or different types of protection created weak spots in the system.

- **Inconsistency in levels of protection:** Because of differences in the quality of materials used in levees, differences in floodwall designs and variations in elevations of protective structures, protection system-wide was not uniform.

- **Lack of redundancy:** Redundancy — components of the system backing each other up so that failure of one component does not cause the whole system to fail — was not included in the system's design.

While overtopping and significant flooding were inevitable with a large, powerful storm like Katrina, a complete system providing consistent levels of protection and incorporating redundancy would have reduced loss of life and curtailed damage to property.

Summary of Lessons Learned

- While a resilient protection system might not offer full protection under conditions exceeding its design criteria, such a system would not fail catastrophically. In the case of Katrina, two-thirds of flooding in the East Bank in Orleans Parish and in St. Bernard Parish was the result of breaching; a resilient system would have withstood overtopping and water levels exceeding design expectations, resulting in far less flooding.

- Planning and design need to be based on system-wide performance. All components must be examined and treated as integral parts of the system.

- The HPS was designed using a traditional standards-based approach that focused on the performance of individual components. This approach should be replaced by risk analysis, which provides greater capability for assessing system-wide performance and results in better-informed decisions.

- The design/construction and research communities must collaborate to develop new knowledge and fresh approaches to solving problems.

- Guidelines adaptable to new knowledge are preferable to inflexible standards.

Risk Analysis

As its name suggests, risk analysis is concerned with uncertainty — a wide range of possible events, conditions and consequences. Compared to a traditional, standards-based approach, risk analysis offers a more comprehensive picture of the hazards confronting a hurricane protection system as well as a clearer assessment of the strengths and weaknesses of the system itself.

- Because risk analysis is systems-based, it relates component performance to system performance rather than examining each component in isolation.

- Risks assessment allows factors such as loss of life, environmental losses and cultural consequences to be included in decision making without reducing these factors to a single measure such as dollars.

- Most importantly, a risk-based approach allows decision makers to understand the levels of vulnerability specific areas face, the source of the vulnerability and the nature of the consequences. This provides a framework for examining alternative approaches to reducing risk.

Figuring Elevation in Louisiana's Landscape

Land in southeast Louisiana naturally compacts and sinks, affecting the performance of the hurricane protection system.

Some levees were originally built at the heights specified in design, but as the land beneath them subsided, the levees sank in concert with the land. Measured from the ground, these levees remain at design elevation, but relative to sea level, the levees are lower than designers specified. Indeed, the relative height of the levees is further skewed by the fact that while the ground is sinking, the overall level of the sea is rising.

Different methods of measuring also contributed to construction errors. Designers used mean sea level to specify elevation of protection components in contrast to some builders who used a land-based measure. These builders mistakenly assumed the land-based measure to be the same as mean sea level, which led to some construction falling short of design specifications.

Lessons Learned

Factors such as subsidence and sea level rise significantly affect the capability of an HPS. Hurricane protection and flood control structures must be not only designed but also built using a local, up-to-date, sea-level reference. The structures must then be maintained to preserve their correct elevation.

New Orleans Hurricane Protection System, August 2005

After Hurricane Betsy struck New Orleans in 1965, a comprehensive plan for hurricane protection in southeastern Louisiana was initiated. The plan consisted of four separate projects that, when combined, would protect the entire region.

By 2005, portions of each project had been built, but construction delays, design revisions, environmental challenges, funding shortfalls and other factors had hampered completion.

When Katrina struck, the HPS was generally built as designed, and the design was consistent with local practices. The IPET study found no evidence of negligence or malfeasance in its design or construction. However, several factors diminished the system's performance:

- Some sections of the HPS were built lower than intended due to the use of an incorrect and out-of-date survey benchmark system to determine the elevation of the project area.

- In places, the shear strength of soils — their ability to withstand compressive force — was overestimated.

- The system was designed using the original definition of a standard project hurricane (SPH) from 1965, though the SPH definition had been updated in 1979 to more accurately calculate hurricane hazard.

"For any given drainage basin, the protection is only as robust as the weakest component of the system protecting that area."

- The HPS was designed and developed in a piecemeal fashion, resulting in levels of protection that varied from area to area and from structure to structure.

- While not directly causing breaches, the presence of trees and structures on levees, indicative of lax maintenance, may have enabled the breaching process.

Lessons Learned

- Designs and design methods must be reviewed frequently to determine that they represent current best practices and to respond to changes in system requirements or hazard conditions over the life of the project.

- To accommodate unanticipated storm conditions or unexpected system performance, the HPS should be designed for resiliency, adaptive capability and redundancy.

- The system's design should be based on an understanding of how system components depend on and affect other components and the system as a whole.

Katrina Exceeded Design Expectations

The HPS was designed to protect against severe storm conditions the region typically experiences. But Hurricane Katrina's surge and waves significantly exceeded those of the typical severe storm striking the Gulf coast.

In nearly all areas, Katrina's surge was higher than the system was designed to handle, and in many areas the wave periods were approximately three times longer than anticipated. Long-period waves cause much more runup and overtopping of levees than do shorter-period waves, leading to increased scour and erosion.

Lessons Learned

The experience of the 2005 hurricane season indicates the necessity of incorporating additional criteria into protection design:

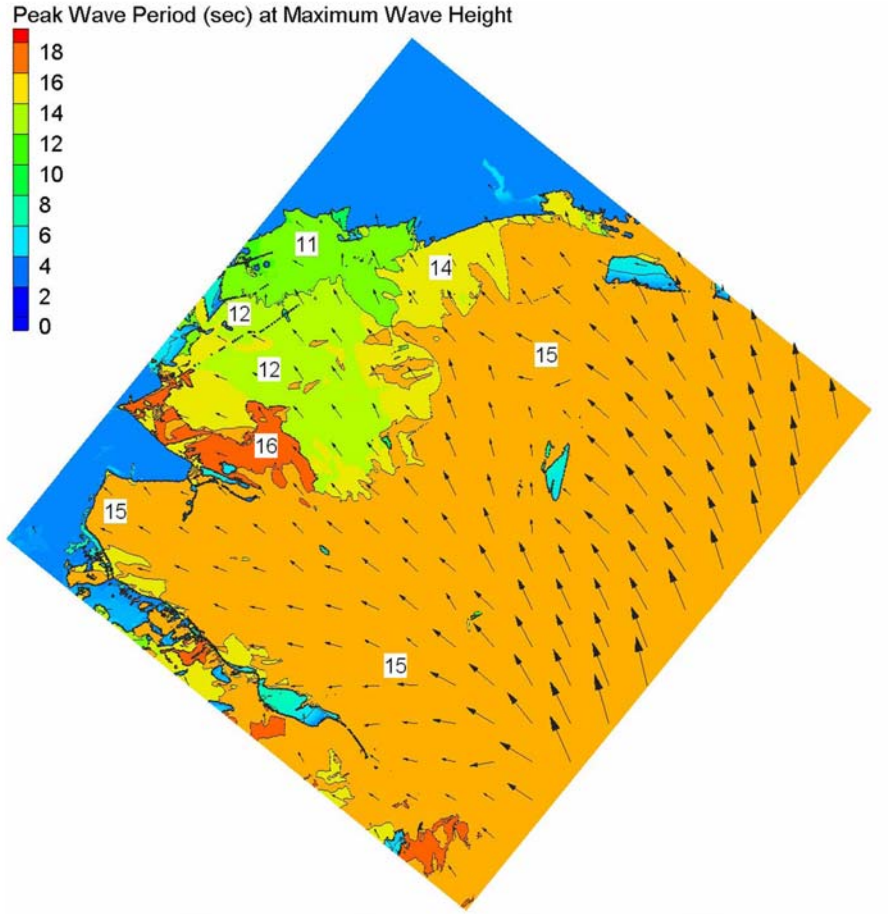
- Hurricane preparedness must account for surge and wave characteristics as well as other meteorological conditions.
- In addition to historical data, assessments of hurricane hazard must take into account storm intensity and track patterns.
- Sophisticated modeling may be used to depict the hydrodynamic conditions — such as surge levels, wave heights and wave periods — created by large storms.

Wave period: the time between waves, usually measured in seconds between two successive wave crests passing a fixed point

Wave runup: occurrence of a cresting, incoming wave running up the slope of a shore or levee; runup height may exceed original wave crest

Limitations of Describing a Hurricane by Category

By assigning a category number to hurricanes, the Saffir-Simpson Hurricane Scale provides a quick indication of a storm's strength. But the scale's 1–5 rating is based on wind speed and barometric pressure, which means the scale doesn't address the surge and wave conditions that pose the greatest threat to coastal regions such as the New Orleans area. While wind speed is an important factor in surge and wave generation, the size, diameter and path of the storm in relationship to structures is equally important and must be considered to estimate surge and wave levels accurately.



Hurricane Katrina damaged or destroyed almost all gauging instruments for measuring its water conditions. Using computer modeling to pattern storm conditions, IPET generated this illustration of wave heights and wave periods to demonstrate the severity of Katrina's wave environment. Ocean-generated waves pounded levees in the Gulf Intracoastal Waterway, St. Bernard and Plaquemines Parishes. Wave periods reached the 16-second range, increasing the potential for wave runup and the overtopping of protective structures.

System Performance, System Failures

Hurricane Katrina's immense storm surge and powerful waves exceeded the conditions that many sections of the New Orleans Hurricane Protection System (HPS) were designed to handle. Although many sections of the HPS performed well, other sections — particularly in St. Bernard and Plaquemines Parishes and along the Gulf Intracoastal Waterway — were overwhelmed. As a result, the system suffered 50 breaches, causing approximately two-thirds of Katrina-related flooding. The remaining one-third was caused by overtopping and rainfall.

- Forty-six breaches were caused by water levels overtopping — exceeding the elevations of — floodwalls or levees.

Where floodwalls were overtopped, water scoured away the soil behind them, leading to instability and wall failure.

As water rushed over levees, it scoured away soil from the levee tops and back sides. Scour atop and behind levees built of erosion-susceptible soil led to breaching. Levees constructed from higher-quality materials such as clay withstood scouring

The I-wall design of floodwalls (above) proved vulnerable in the severe water conditions of Katrina. Sections of repaired floodwalls were rebuilt using the T-wall design (below), giving the wall a more secure footing.

and performed well despite water conditions exceeding design criteria.

Had all structures been built to design elevations, there would have been less overtopping.

- Four breaches occurred before water levels reached design elevations because of I-wall foundation failures. In each case, water flowed into a gap formed along the water side of the floodwall, weakening the soil holding the wall in place and leading to instability and failure.

The duration of flooding could have been reduced if the drainage pumps had been able to operate, but the pumping stations, which are not formally part of the HPS, were not designed to function in severe hurricane conditions.

Lessons Learned

- The design of the HPS should consider a broader spectrum of possible circumstances. For example, floodwall designs need to consider conditions such as overtopping that could weaken the walls' foundations.

- Resiliency — the ability to withstand conditions exceeding design specifications — should be built into the system, and research should determine the full performance limits of structures and offer new approaches for creating designs that will allow adaptation as new technology emerges. Resiliency in pumping capacity is especially important because pumps can shorten the duration of flooding.

- Design methods should be reviewed periodically to ensure they represent the latest knowledge, practice and technology. Periodic review of the entire system should ensure that changing hazards or a changing knowledge base have not undermined existing projects' design.

- Protection should be designed and built as an integrated system to enhance reliability and consistency in performance. For example, incorporating interior drainage and pumping would limit both the amount and duration of flooding.

Katrina's Consequences

Katrina has been cited as the greatest natural disaster the United States has ever suffered. In addition to possibly 2,000 lives lost, the storm disrupted the social fabric of the entire region — employment, trade, travel, education, health care, worship and community.

Quantifiable consequences include direct property losses of over $20 billion in the New Orleans area:

- $16 billion in residential losses
- $2.4 billion in commercial losses
- $4.4 billion to $5.6 billion in infrastructure losses, excluding the hurricane protection system

Total losses were more than triple those from any previous disaster in the New Orleans area.

Recovery, measured by the return of the population and resumption of business activities, is hampered by damage to infrastructure and affiliated public welfare and services. The mass exodus of the region's inhabitants, combined with structural devastation and the demands of rebuilding, has fundamentally changed all aspects of the population's social organization.

Lessons Learned

- A highly resilient protection system can reduce potential losses, direct and indirect, from hurricanes that exceed protection design criteria.
- Loss of life and property from Katrina correlated directly to elevation. Areas at lower elevations experienced the most severe losses and will continue to bear the highest risk of future flooding.
- A risk-based approach can contribute to planning for and management of hurricane protection, including evacuation, recovery and reconstruction.

Assessing Vulnerability in the Path of Hurricanes

IPET's risk analysis establishes a framework for evaluating the threat to life and property from future hurricanes. Its purpose is to identify areas within the HPS that are more vulnerable to flooding than others and to identify the causes of that vulnerability. Assessing risk gives planners and decision makers the tools to decide where it is practical to reduce risk and where the reduction will provide the greatest benefit.

In fall 2005, using field investigations, computer modeling and eye-witness accounts, the analysis team began to evaluate the level of risk under three distinct states of the HPS:

- as it existed prior to Katrina
- as it exists at the beginning of the 2006 hurricane season, with some repair and improvement projects continuing after June 1, 2006
- with all repair and improvement projects complete, but prior to longer-term increases in the authorized level of protection

At the time of this summary report's release, the risk model and its products had not been validated. They will be released in mid-summer. The final risk analysis will consider the expected performance of each system component and the likely consequences of that performance. The analysis will also assess the relative vulnerability of drainage basins, drainage sub-basins, parishes and census blocks that the system protects.

Lessons Learned

Prior to Katrina, the risk of flooding and loss of life and property was significant for several reasons:

- Much of New Orleans lies below sea level. Given any large storm or heavy rainfall, areas farthest below sea level will flood first and flood the most deeply.

- Scheduled for completion in 2015, the HPS was not finished when Hurricane Katrina struck.

- The HPS as it existed had not been tested; many sections had not yet experienced the water levels they were designed to handle.

- A large population and extensive residential and commercial property depended on the system for protection.

Permanent repairs of system components damaged by Katrina have been completed. As of June 1, 2006, repaired sections of the system, comprising 60 percent of the HPS, will be the strongest. Risk will be greatest along the remaining 40 percent of the system until levees and floodwalls are raised and strengthened.

Areas of the HPS located farthest below sea level or most directly exposed to a storm's surge and waves will continue to bear greater risk of flooding and loss than other areas.

About The Task Force and Its Report

To determine the facts of the New Orleans Hurricane Protection System's performance during Hurricane Katrina, Lt. Gen. Carl A. Strock, Commander, U.S. Army Corps of Engineers, formed IPET soon after Katrina hit. More than 150 experts representing over 50 federal, state and local government agencies, universities and private firms comprised the IPET.

The American Society of Civil Engineers set up an External Review Panel to provide continuous review of IPET's work. The National Research Council established a committee to provide strategic oversight of IPET and to make recommendations concerning hurricane protection in New Orleans.

The nine-volume final report will be issued in September 2006. Following is a summary of the contents of each volume:

Volume I: Executive Summary and Overview. Summary of IPET's principal findings and lessons learned.

Volume II: Geodetic Vertical and Water Level Datum. Discussion of methodology used to measure elevation and the necessity for design and construction to use the same benchmarks.

Volume III: The Hurricane Protection System. Description of the system, its design criteria, the as-built construction, and the maintained condition of its various components.

Volume IV: The Storm. Hurricane Katrina's character and the hydrodynamic environment resulting from it. Timeline of events.

Images in this publication courtesy of NOAA, Louisiana Department of Tourism and USACE.

Volume V: Levee and Floodwall Performance. Analysis of the structural performance of levees and floodwalls.

Volume VI: Interior Drainage and Pump Station Performance. Analysis of this major component and its role in building a totally resilient system.

Volume VII: Consequences. Evaluation of economic, health and safety, societal and cultural, and environmental losses from Katrina and of potential losses from future hurricanes.

Volume VIII: Risk and Reliability. Examination of past vulnerability and expected risk reduction upon completion of repairs.

Volume IX: General Appendices. Appendices for IPET analysis and results; summary of contributions to Task Force Guardian; administrative documents.

Further information and the current draft report are available at
https://ipet.wes.army.mil

Address questions to Wayne Stroupe, (601) 634-2404
wayne.a.stroupe@usace.army.mil