Hauling sandbags,
New Orleans

U.S. Army photo

Why the New Orleans Levees Failed

> What makes the New Orleans levees unusual is the high stakes involved in terms of the population being protected. … In a system with several hundred miles of levees, it is very difficult to do suitable investigation and basically to nail all the details. … If you leave one detail unnailed, you leave a vulnerability which may in the end bring the whole system down.[1]
>
> — Raymond Seed, Ph.D., National Science Foundation-sponsored Independent Levee Inspection Team (ILIT), University of California, Berkeley

The flooding of the metropolitan New Orleans area challenged emergency response at all levels. This flooding was largely caused by failures of the levees and floodwalls in and around New Orleans. An examination of why the levees failed to protect New Orleans is critical,[2] and several teams of scientists of varied affiliation are presently conducting massive studies of the mechanisms responsible for the flooding. Topics of forensic analysis include:

- Levee breaches along the 17th Street, London Avenue, and the Inner Harbor Navigation Canals
- Overtopping of various levees and floodwalls
- Design and construction issues
- Proper levee/floodwall oversight
- Subsidence in the metropolitan New Orleans area
- The impact of the Mississippi River Gulf Outlet (MRGO)

The Levee Breaches Along the 17th Street and London Avenue Canals

Three levee breaches along the major stormwater drainage, or "outfall," canals of central New Orleans – one breach on the east side of the 17th Street Canal and two others along the London Avenue Canal (on the east and west) – caused catastrophic flooding in the heart of the city. These canals are part of the city's drainage system and allow rain and flood waters to be pumped out of the city into Lake Pontchartrain.

Breaches in the floodwalls along these canals caused water from Lake Pontchartrain to flood into, among other areas, the Central Business District, the blocks surrounding the Superdome, Lakeview, Mid City, the area around Tulane University, and Lakewood.[3] It was this flooding that made the humanitarian and rescue efforts at the Superdome and Convention Center so difficult.

Scientists have confirmed that these levee and floodwall breaches were unlike the failures of levees and floodwalls in other areas of the metropolitan New Orleans region, which were overtopped by Katrina's storm surge. There is scientific consensus that the floodwalls along the 17th Street Canal (and the London Avenue Canal) were not, prior to failure, overtopped by the storm surge from Lake Pontchartrain.[4] A report by the U.S. Army Corps of Engineers' Interagency Performance Evaluation Task Force (IPET) – an academically diverse group of scientists examining, among numerous other issues, the type of failure in the 17th Street Canal breach – gave two causes for the breach.

Breached floodwall, New Orleans
Marty Bahamonde photo

First, the concrete floodwall, which stood erect at the crest of the earthen levee and was supported by steel sheetpiles driven into, and below, the earthen levee, was pushed away from the canal by waters rising toward the protected land side. As it was pushed away, a gap was created between the floodwall (along with the sheetpile upon which it was supported) and the adjacent levee embankment soils. This allowed flood waters to rush into the gap, apply pressure against the lower sheetpiles supporting the floodwall underground, and push the embankment section aside. Once the embankment began to be pushed aside, a second failure mechanism combined to produce a catastrophic failure of the wall. This second mechanism was the failure of an unusually weak layer of clay at the foundation or "toe" of the levee. Under pressure from floodwaters pressing on the wall, this layer gave way and allowed the "lateral translation," or movement, of the earthen levee supporting the floodwall along the "failure plain" in the weak clay layer. These combined mechanisms resulted in the violent sideways heave of the entire embankment section.[5]

While the forensic teams generally agree that the 17th Street Canal breach was the result of structural failure, they disagree whether the original design anticipated this problem. The IPET report said that it did not.[6] However, in the National Science Foundation-sponsored Independent Levee Inspection Team's (ILIT) *Initial Comments on Interim (70%) IPET Study Report*, Raymond B. Seed, Ph.D., and Robert G. Bea, Ph.D., took issue with the IPET's assertion – a concern also raised by the American Society of Civil Engineers External Review Panel.[7] The ILIT stated that the Corps of Engineers had a "masterful knowledge and understanding of the complex and challenging geology of this region in the 1950's,"[8] and "should not claim that the weak foundation soil strata at the 17th Street Canal breach site were unexpected, and that no prior publications would have disclosed this possibility."[9]

The ILIT scientists also referenced a test conducted prior to the construction of the 17th Street Canal, which, according to Seed and Bea, foreshadowed the catastrophic failure at the breach site. They say a Corps field test of a levee and sheetpile-supported floodwall in 1985, just south of Morgan City, LA, predicted exactly the sort of failure that occurred at the 17th Street Canal. The model levee embankment and the sheetpile-supported concrete floodwall were sized and built to simulate conditions expected for the 17th Street, Orleans, and London Avenue Canals, as well as major portions of the Inner Harbor Navigational Canal. "Thus," the NSF team concluded, "there would seem to be little justification for the contention that the sheetpile failure mode disclosed by the IPET analyses had not previously been seen, or published, and that it could not have been anticipated."[10]

The two breach sites along the London Avenue Canal appear to have been the result of foundational instability near the fine sand and clay substratum layers at the site.[11]

Overtopping of Various Levees and Floodwalls

As noted, the flooding in the heart of the city was caused by the breaches along the 17th Street and London Avenue Canals. But most of the levee and floodwall failures in the metropolitan New Orleans area – including New Orleans East, the Lower 9th Ward, St. Bernard

Parish, and Plaquemines Parish – "were caused by overtopping, as the storm surge rose over the tops of the levees and/or their floodwalls and produced erosion that subsequently led to failures and breaches."[12] One report described the overtopping as follows:

> Overtopping was most severe on the east side of the flood protection system, as the waters of Lake Borgne were driven west towards New Orleans, and also farther to the south, along the lower reaches of the Mississippi River. Significant overtopping and erosion produced numerous breaches in these areas. The magnitude of overtopping was less severe along the Inner Harbor Navigation Canal (IHNC) and along the western portion of the Mississippi River Gulf Outlet (MRGO) channel, but this overtopping again produced erosion and caused additional levee failures.[13]

Finally, as described more fully in the design and construction subsection below, one report notes that, "it appears that many of the levees and floodwalls that failed due to overtopping might have performed better if relatively inexpensive details had been added and/or altered during their original design and construction."[14]

Design and Construction Issues

Understanding the design and/or construction shortcomings of protective structures is critical as the Corps of Engineers proceeds with the rebuilding of the New Orleans region's hurricane protection system.

As one report observes, the protective system is a "piecemeal" assemblage of elements that "evolved over a long period of time."[15] By contrast, a proper system "would integrate components and … would contain a level of redundancy sufficient that, if a levee failed, all would not be lost."[16]

For the most part, the reports reviewed by the Committee have revealed the following critical design and construction issues: (1) I-wall vs. T-wall design; (2) vulnerable "transition points" within the protective system; (3) accessibility to breach sites; and (4) enhanced protection.

Ripped-out sheetpile with chunks of floodwall attached, New Orleans

Louisiana National Guard photo

I-wall vs. T-wall Design

"I-wall" floodwalls run along the top of earthen levees and are supported by metal sheetpiles driven into, and below, the earthen levees to various depths. As noted above, the erosion of soils on the protected land side of these floodwalls was caused by water cascading over the tops of the structures themselves, reducing the walls' resistance to pressure from the water side.[17] This type of failure was "most dramatic" along the Inner Harbor Navigation Canal next to the Lower Ninth Ward."[18]

This type of failure mechanism was not a problem at most T-wall floodwalls, which look like an inverted "T" and are constructed with concrete bases with more substantial, armored foundations.[19] Their horizontal platforms provide more stability for the vertical wall and give the levee soil some protection from water pouring over the top of the wall.

Transition Points

The Lake Pontchartrain and Vicinity Hurricane Protection Project (Lake Pontchartrain Project) was authorized in the Flood Control Act of 1965 to provide hurricane protection to areas around Lake Pontchartrain in Orleans, Jefferson, St. Bernard, and St. Charles Parishes.[20] The total project called for the design and construction of approximately 125 miles of levees and floodwalls.[21] Parts of the system were built at different times and involved the review and co-operation of different local levee districts. Quite often, this resulted in non-uniform junctions. Scientists examining these "transition points" found inconsistencies in crest heights, types of protective structures, and materials used.[22] In some places, floodwalls stood at a higher elevation than adjoining earthen levees, which concentrated the flow of water to the non-uniform intersection, "causing turbulence that resulted in erosion of the weaker levee soil."[23]

One report noted that the key to the transition-points problem is that "infrastructure elements [were being] designed and maintained by multiple authorities."[24] The report said the result is that "the weakest (or lowest) segment or element controls the overall performance" of the hurricane protection system.[25] One engineering recommendation was that crest heights – the highest elevations of the structure being used, regardless whether it is just a levee or a floodwall standing upon a levee – should be planned to guide overtopping waters "preferentially" toward locations that would minimize damage.[26]

Accessibility to Breach Sites

Scientists also found that the design of the levees and floodwalls along the major outfall canals (the 17th Street and London Avenue Canals) hampered emergency operations at the breach sites, despite a Corps of Engineers regulation[27] about the importance of access roads to levees for inspection, maintenance, and flood-fighting. These narrow access roads usually run along the crown of the earthen levee itself. However, the report noted that adding I-walls to levees in highly built-up areas of New Orleans had sacrificed road access to the tops of the levees. These decisions resulted in very significant increases in time and cost when it became necessary to close breaches along these canals.[28] Emergency roads needed to be constructed to get access to the breached areas so that construction equipment and fill materials could be brought in.

Enhanced Protection

Hurricane Katrina was a catastrophic storm that exceeded the design limits of parts of the levee system. Nevertheless, some portion of the flooding that occurred could have been lessened had the levees themselves not been eroded – and ultimately breached – by overtopping. The scientific community has determined that the hurricane protection system designed to protect the people living within the metropolitan New Orleans area could have (and should have) been constructed with enhanced protective features. As noted in one report:

> A fundamental flaw in the floodwalls and levees is that they include no means of accommodating overtopping that does not inflict major damage or destruction. … Most of the 350 miles of levees in New Orleans are unprotected from devastating damage and potentially total destruction if overtopped.
>
> The question is not whether the levees will again be overtopped but when and by how much they will be overtopped.[29]

Another report found that the performance of many levees and floodwalls could have been greatly improved "and some of the failures likely prevented, with relatively inexpensive modifications" of the system, such as riprap (a loose assemblage of broken stones and concrete), concrete splash slabs, or pavement on the protected side of the levees to guard against anticipated overtopping.[30]

The failure of the system's design to adequately address the impact of significant overtopping likely resulted in a system more prone to failure in a major hurricane and should have raised greater concern about the effects of overtopping.

Proper Hurricane Protection System Oversight

As alluded to in the "transition points" subsection above, scientists have noted that there are design/technical problems with the hurricane protection system that they attribute to numerous "infrastructure elements [being] designed and maintained by multiple authorities."[31]

As Seed testified before the Committee during a public hearing:

> No one is in charge. You have got multiple agencies, multiple organizations, some of whom aren't on speaking terms with each other, sharing responsibilities for public safety. The Corps of Engineers had asked to put flood gates into the three canals [structures that would, upon activation, block the waters of Lake Pontchartrain from entering the drainage canals], which nominally might have mitigated and prevented the three main breaches that did so much destruction downtown. But they weren't able to do that because, unique to New Orleans, the Reclamation Districts who were responsible for maintaining the levees are separate from the Water and Sewage District, which does the pumping. Ordinarily, the Reclamation District does the dewatering pumping, which is separate from the water system. These guys don't get along. The Sewage District was so concerned they wouldn't be able to pump through gates which had to be opened and closed that in the end, the Corps, against its desires, was forced instead to line the canals [with the floodwalls], which they did with some umbrage, and the locals bore a higher than typical fraction of the shared cost as a result of that …
>
> Levees in the New Orleans area are at different heights. You can stand – we have a photograph in our report at one section where you can clearly see five different elevations, all within 100 yards of each other. If you have got five different elevations within 100 yards, the person who built the lowest section wins because they become the public hazard. There is a need to coordinate these things.[32]

As a report by the ASCE's External Review Panel (ERP) notes:

> The ERP sees clearly that organizational complexities and the ways in which decisions are made are among the most important factors that influenced the performance of the hurricane protection system. Organizational effectiveness has been and will continue to be questioned, with justification. It is impossible for the ERP to conceive a mechanism through which the levee system can be rebuilt and operated effectively and efficiently with such organizational discontinuity and chaos.[33]

Subsidence in the Metropolitan New Orleans Area

In addition to design and construction issues, soil subsidence – "the lowering or sinking of [the] earth's surface"[34] – has impaired the protection offered by the New Orleans levee system. In the New Orleans area, subsidence is caused primarily by the cumulative weight of millions of years of soil and silt deposits left by the Mississippi River as it enters the Gulf of Mexico. The sediment literally presses down on the earth's crust, causing the land to sink. As a result, the water level rises, gradually increasing vulnerability to tides and storms. The levees themselves can also subside because of their own weight pressing down on the swampy soils upon which they are built.

As a result, it appears that the level of protection actually provided by the New Orleans region's levee system at the time of Katrina was significantly lower than intended:

> Many sections of the levees and floodwalls were substantially below their original design elevations, an effective loss of protection. For example, the

Plugging a breached floodwall, New Orleans

structures associated with the Inner Harbor Navigation Canal were originally constructed to an elevation of 15 feet (relative to mean sea level) but are now just over 12 feet, a typical loss of approximately 2.7 feet in elevation over the lifetime of the project.[35]

The report noted that "subsidence is occurring at a rate of up to one inch every three years" in the New Orleans region.[36]

Subsidence routinely creates problems for those trying to construct levees and other structures at known heights above sea level. As stated in one IPET report, due to the complex and variable subsidence in southeast Louisiana, "establishing an accurate vertical reference for measurements has been a constant challenge."[37] Unfortunately, until the October 2005 release by the U.S. Department of Commerce's National Geodetic Survey of 85 benchmarks located in southern Louisiana, which showed heights (elevations) accurate to between 2 and 5 centimeters (roughly 1 to 2 inches), surveyors, engineers, and the U.S. Army Corps of Engineers in New Orleans evaluated the levees and structures built and in use against vertical heights that had not been calibrated nor checked for several years.[38]

As a result, it appears that the levees were not built and maintained at the proper level above sea level. Since the level of protection that the levees provide is so closely related to their height above sea level, which affects their ability to block increased water levels driven by hurricanes, the failure to build and maintain the levees at the proper elevation diminished the level of protection they provided.

1 Testimony of Raymond Seed, Ph.D., National Science Foundation, before the U.S. Senate, Committee on Homeland Security and Governmental Affairs, hearing on *Hurricane Katrina: Why Did the Levees Fail?*, Nov. 2, 2005.

2 This section analyzes and summarizes the following scientific reports: The November 2, 2005, American Society of Civil Engineers (ASCE) and National Science Foundation (NSF) *Preliminary Report on the Performance of the New Orleans Levee System in Hurricane Katrina on August 29, 2005*, [hereinafter, "ASCE/NSF *Preliminary Report*"]; The December 5, 2005, *Summary of Field Observations Relevant to Flood Protection in New Orleans, LA: Interim Report to Task Force Guardian* by the Interagency Performance Evaluation Task Force [hereinafter, "IPET *Summary of Field Observations*"]; The January 10, 2006, Interagency Performance Evaluation Task Force *Performance Evaluation Plan and Interim Status, Report 1 of a Series: Performance Evaluation of the New Orleans and Southeast Louisiana Hurricane Protection System* [hereinafter, "IPET *Report 1 of a Series*"]; The February 20, 2006, American Society of Civil Engineers *External Review Panel Progress: Report Number 1* [hereinafter, "ASCE *ERP Progress Report Number 1*"]; The March 10, 2006, Interagency Performance Evaluation Task Force *Performance Evaluation, Status and Interim Results, Report 2 of a Series: Performance Evaluation of the New Orleans and Southeast Louisiana Hurricane Protection System* [hereinafter, "IPET *Report 2 of a Series*"]; and various other ASCE and NSF preliminary evaluations of the IPET *Report 2 of a Series*.

For background, it should be understood that the U.S. Army Corps of Engineers (USACE) responded to Hurricane Katrina with, among other things, the activation of Task Force Guardian (TFG), with the crucial responsibility of repairing the damages to the hurricane protective system by the storm. *Source:* U.S. Army Corps of Engineers, Interagency Performance Evaluation Task Force, *Summary of Field Observations Relevant to Flood Protection in New Orleans, LA,"* Dec. 5, 2005, p. 2 [hereinafter IPET, *Summary of Field Operations*]. In addition, the Interagency Performance Evaluation Task Force (IPET) was established on October 10, 2005, by the Chief of Engineers of the USACE, and sanctioned by the Secretary of Defense in a directive to the Secretary of the Army on October 19, 2005. *Source:* U.S. Army Corps of Engineers, Interagency Performance Evaluation Task Force, Performance Evaluation Plan and Interim Status, *Report 1 of a Series*, Jan. 10, 2006, p. 3 [hereinafter IPET, *Report 1 of a Series*]. The IPET, "comprised of leading experts in a comprehensive array of science and engineering disciplines [is] charged with studying the response of the hurricane protection system during Katrina for lessons learned." *Source:* IPET, *Summary of Field Observations*, p. 2. Moreover, the IPET 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." *Source:* IPET, *Report 1 of a Series*, p. 3. The American Society of Civil Engineers (ASCE) External Review Panel (ERP) then "provide[s] for an external, expert, and constructive technical review of the activities and products of the [IPET]." *Source:* IPET, *Report 1 of a Series*, Appendix D, p. D–7. While this review is to be comprehensive, and done on a periodic basis, it is clear that the "ERP has no approval authority on the findings of the [IPET], nor are the ERP's recommendations to the [IPET] binding, but the [IPET] will give serious consideration to each." *Source:* IPET, *Report 1 of a Series*, Appendix D, p. D–8.

On Nov. 2, 2005, the Committee held a public hearing entitled, "Hurricane Katrina: Why Did the Levees Fail?" [hereinafter, "HSGAC Levee 1 Hearing"]. The witnesses for this hearing were representatives and/or heads of several different forensic data gathering teams investigating why the levees in and around New Orleans failed. Testifying before the Committee were Raymond B. Seed, Ph.D., on behalf of the National Science Foundation (NSF), Peter Nicholson, Ph.D., P.E., on behalf of the ASCE, Ivor van Heerden, Ph.D., of the LSU Hurricane Center and on behalf of the State of Louisiana Forensic Data Gathering Team, and Paul F. Mlakar, Ph.D., P.E., on behalf of the USACE. The bulk of Seed and Nicholson's formal written testimony provided for the HSGAC Levee 1 Hearing summarized the ASCE/NSF *Preliminary Report*.

During the HSGAC Levee 1 Hearing, Mlakar specifically noted the IPET objective: "The final results will include conclusions as to the causes of the failures and recommendations for the future design and construction of such infrastructure nationwide. These results will be independently reviewed by an external panel of the [ASCE]. At the request of the Secretary of Defense, the National Academies will also independently assess the results and report to the Assistant Secretary of the Army for Civil Works." *Source:* Testimony of Paul Mlakar, Senior Research Scientist, Army Engineer Research and Development Center, before the U.S. Senate, Committee on Homeland Security and Governmental Affairs, hearing on *Hurricane Katrina: Why did the Levees Fail?,* Nov. 2, 2005.

On Nov. 2, 2005 – the day of the HSGAC Levee 1 Hearing – the ASCE and NSF teams jointly released the ASCE/NSF *Preliminary Report*. As noted in the report itself, the "ASCE/NSF *Preliminary Report*" present[ed] the results of field investigations performed by collaborating teams of scientists and engineers in the wake of the passage of Hurricane Katrina, to study performance of the regional flood protection systems and the resulting flooding that occurred in the New Orleans area." *Source:* American Society of Civil Engineers and National Science Foundation, *Preliminary Report on the Performance of the New Orleans Levee System in Hurricane Katrina on Aug. 29, 2005*, Nov. 2, 2005, p. 1–1 [hereinafter, ASCE/NSF, *Preliminary Report*]. The initial field investigations conducted in preparation for the report took place from Sept. 28, through Oct. 15, 2005. *Source:* ASCE/NSF, *Preliminary Report*, p. iv. Following the ASCE/NSF *Preliminary Report*, on Dec. 5, 2005, the IPET *Summary of Field Observations* was issued, which consisted of an "IPET review provided [to] Task Force Guardian with a simple statement of concurrence or nonoccurrence from the IPET floodwall and levee sub team and additional relevant discussion for each of the major findings of the ASCE/NSF "*Preliminary Report*." *Source:* IPET, *Report 1 of a Series*, Appendix F, p. F–2.

Consistent with IPET's mission, it produced its first evaluation of the metropolitan New Orleans area hurricane protection system on Jan. 10, 2006. The IPET *Report 1 of a Series* is a massive document. Moreover, as noted in its "Purpose" section, "IPET, *Report 1 of 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 [ASCE ERP], and a status report on the work accomplished to date." *Source:* IPET, *Report 1 of a Series*, p. 4. However, and as noted by the Feb. 20, 2006, ASCE ERP *Progress Report Number 1*, "the IPET [*Report 1 of a Series*] presented no specific findings and conclusions, which is not surprising in view of the many questions that as yet are unanswered." *Source:* American Society of Civil Engineers, letter to Lt. Gen. Carl Strock, "ERP Progress Report Number 1," Feb. 20, 2006, p. 2. Provided to the Committee [hereinafter ASCE, "ERP Progress Report Number 1"]. The IPET Final Report "will include the completed analyses for consequences and risk and reliability," and is scheduled for release on June 1, 2006. *Source:* IPET, *Report 1 of a Series*, viii.

According to the IPET *Report 1 of a Series,* Objectives section, the IPET's overall review is focused on answering the following critical 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? *Source:* IPET, *Report 1 of a Series*, p. 6–7.

While all of these questions are important ones – many of which are addressed throughout the balance of this Committee's Report, the following have a direct bearing upon this section of the Committee's Report: questions (a) and (a)(1)-(4); (b) and (b)(1); and (c) and (c)(1)-(2). In any event, given the state of the IPET's review at the time of this Committee's Report, the IPET *Report 1 of a Series* can best be used to demonstrate what the DOD sanctioned team of scientists is doing (or plans to do), while also taking note of what it is not doing (as referenced in the ASCE *ERP Progress Report Number 1*).

As noted above, the IPET Final Report is scheduled for release on June 1, 2006. Overall, and as largely recognized by the ASCE ERP, the IPET's goal (and its approach to meeting this goal) is a critical and comprehensive one. The IPET Final Report has the makings to be – if conducted as planned, including the duo-layered review process – the definitive work on the lingering scientific/forensic questions related to Hurricane Katrina. However, and as referenced elsewhere in this Committee's Report, the organizational problems referenced in the ASCE ERP *Progress Report Number 1*, and also by the scientists who testified before the Committee at the HSGAC Levee 1 Hearing, are significant issues that must be properly addressed before residents of the greater New Orleans area are to exude confidence in the hurricane protection system charged with protecting their lives and livelihoods.

3 Ivor L. van Heerden, G. Paul Kemp, Wes Shrum, Ezra Boyd and Hassan Mashriqui, Louisiana State University, Center for the Study of Public Health Impacts of Hurricanes, *Initial Assessment of the New Orleans' Flooding Event during the Passage of Hurricane Katrina,* pp. 7-10. [hereinafter LSU, *Initial Assessment of New Orleans Flooding*]. The LSU professors also noted that, "[w]ater poured through the three deep breaches of the drainage canals into the New Orleans Metro bowl for more than 60 hours, until early Thursday morning, when the level inside reached equilibrium with the water in the lake at about 3 feet above sea level, and with the 'average' home in the flooded neighborhoods standing in six to nine feet of water." LSU, *Initial Assessment of New Orleans Flooding*, p. 10.

4 ASCE/NSF *Preliminary Report*, pp. iv-v, 2–3, 8–2; IPET, *Summary of Field Observations*, p. 8; and IPET*, Report 1 of a Series*, pp. 113-114; U.S. Army Corps of Engineers, Interagency Performance Evaluation Task Force, Performance Evaluation Plan and Interim Status, *Report 2 of a Series*, Mar. 10, 2006, p. vi-3 [hereinafter IPET, *Report 2 of a Series]*.

5 IPET, *Report 2 of a Series*, p. I–4. *See also:* Raymond B. Seed and Robert G. Bea, National Science Foundation-Sponsored Independent Levee Inspection Team (ILIT), Univ. of Calif. at Berkeley, *Initial Comments on Interim (70%) IPET Study Report*, Mar. 12, 2006, p. 1 [hereinafter, ILIT, *Initial Comments on Interim (70%) IPET Study Report*]. It should be noted that the ASCE ERP, noted above, seems to be satisfied with the IPET's assessment: "In its initial review of the U.S. Army Corps of Engineers' [IPET] second report, *Status and Interim Results*, the [ASCE] External Review Panel (ERP) members are generally satisfied with the group's analysis and progress. More specifically, we have been impressed with the IPET's investigation of the 17th Street failure mechanism." American Society of Civil Engineers, "Statement attributable to David Daniel, Ph.D., P.E., president of the University of Texas, Dallas, Chair, American Society of Civil Engineers (ASCE) External Review Panel (ERP)," news release, Mar. 10, 2006, p. 1.

6 IPET, *Report 2 of a Series*, p. I–4 (emphasis added).

7 American Society of Civil Engineers, letter to Lt. Gen. Carl Strock, Mar. 23, 2006, pp. 1-2. Provided to the Committee. Wherein the ASCE ERP also noted the Corps' knowledge regarding soil/foundational issues in the area of the major outfall canals, and the floodwall field test demonstrating similar failure mechanisms as that actually realized at the site of the 17th Street Canal and referenced in the IPET *Report 2 of a Series*.

8 ILIT, *Initial Comments on Interim (70%) IPET Study Report*, p. 1.

9 ILIT, *Initial Comments on Interim (70%) IPET Study Report*, p. 1.

10 ILIT, *Initial Comments on Interim (70%) IPET Study Report*, p. 3. *See also:* American Society of Civil Engineers, Letter to Lt. Gen. Carl Strock, Mar. 23, 2006.

11 IPET, *Report 1 of a Series*, p. 106.

12 At this point, it should be noted that the IPET team undertook an analysis to determine the effects of the Mississippi River Gulf Outlet (MRGO) upon the storm surge generated by Hurricane Katrina. The note, which examined "the impact of the MRGO on large scale catastrophic storm surge development and propagation," found as follows:

> The MRGO is a dredged channel that extends southeast to northwest from the Gulf of Mexico to a point where it first merges with the Gulf Intracoastal Waterway (GIWW), and then continues westward until it intersects the Inner Harbor Navigation Canal (IHNC). … The first 9 miles, the bar channel, are in the open Gulf. The next 23 miles of the channel lie in the shallow open waters of Breton Sound. From there, the inland cut extends 14 miles to the northwest with open marsh on the northeast and a 4,000-ft wide dredged material placement bank on the southwest side. At this point the channel cuts across the ridge of a relict distributary of the Mississippi River, Bayou La Loutre. For nearly the next 24 miles, there is a hurricane protection levee atop a dredged material placement bank on the southwest side of the channel and Lake Borgne and open marsh lie to the northeast. A portion of the levee protecting St. Bernard Parish/Chalmette and the portion of the hurricane protection levee along the south side of Orleans East Parish, north of the GIWW, form the "funnel" that is often referenced. The point where the MRGO and GIWW channels merge is just to the east of the Paris Road Bridge. … From this point, the merged GIWW/MRGO channel continues west for about 6 miles to the point where it intersects the IHNC; this portion has hurricane protection levees on both banks. The IHNC extends from Lake Pontchartrain, to the north, to the Mississippi River to the south. The IHNC has levees or floodwalls along both banks. … The MRGO bar channel authorized depth is 38 ft; the authorized bottom width is 600 ft. The remainder of the channel has an authorized depth of 36 ft and an authorized bottom width of 400 or 450 ft, depending on location.
>
> It is important to distinguish between two sections of the MRGO and the role each plays in tide and storm surge propagation. One is the east-west oriented section that runs between the IHNC and the confluence of the GIWW/MRGO near the Paris Road Bridge … and hereinafter referred to as Reach 1. The other is the much longer southeast-northwest section … hereinafter referred to as the Reach 2. IPET, *Report 2 of a Series*, Appendix E, p. E–2.

Citing past studies, and analyses of their own, the IPET report noted the following regarding MRGO/Reach 2:

> The change in storm surge induced by MRGO/Reach 2 (computed as a percentage of the peak surge magnitude) is greatest when the amplitude of the storm surge is low, on the order of a few feet or less. In these situations, changes induced by the MRGO are rather small, 0.5 ft or less, but this amount is as much as 25% of the peak surge amplitude. When the long wave amplitude is very low, the surge is more limited to propagation via the channels. Once the surge amplitude increases to the point where the wetlands become inundated, this section of the MRGO plays a diminished role in influencing the amplitude of storm surge that reaches the vicinity of metropolitan New Orleans. For storm surges of the magnitude produced by Hurricane Betsy and Katrina, which overwhelmed the wetland system, the influence of MRGO/Reach 2 on storm surge propagation is rather small. When the expansive wetland is inundated, the storm surge propagates primarily through the water column over this much larger flooded area, and the channels become a much smaller contributor to water conveyance. *Source:* IPET, *Report 2 of a Series*, Appendix E, p. E–4. … The reasons for the very limited influence of the MRGO/Reach 2 in the vicinity of New Orleans for strong storm events are clear. First, the MRGO does not influence the important preliminary east-west movement of water that drives the significant build up of surge in the early parts of the storm. Second, the northerly propagation of surge during the later stages of the storm are only minimally influenced by the MRGO because the increased hydraulic conveyance associated with the channel is very limited for large storms due to the large surge magnitude and especially due to the very large lateral extent of the high waters on the Mississippi-Alabama shelf that build up early on from the east. In addition, the propagation direction of this surge wave does not typically align with the MRGO and furthermore the southeasterly winds which align with the MRGO occur only very briefly. *Source:* IPET, *Report 2 of a Series*, Appendix E, p. E–6.

Finally, the report said of MRGO/Reach 1:

> While the simulations clearly show that Reach 2 of the MRGO does not significantly influence the development of storm surge in the region for large storm events, Reach 1 (the combined GIWW/MRGO section) and the IHNC, together, provide a hydraulic connection between Lake Borgne and Lake Pontchartrain. As a result of this connection, the storm surge experienced within the IHNC and Reach 1 (GIWW/MRGO) is a function of storm surge in both Lakes; a water level gradient is established within the IHNC and Reach 1 that is dictated by the surge levels in the two lakes. This is true for both low and high storm surge conditions. To prevent storm surge in Lake Borgne from reaching the IHNC or GIWW/MRGO sections of waterway, flow through the Reach 1 channel must be dramatically reduced or eliminated, either by a permanent closure or some type of structure that temporarily serves to eliminate this hydraulic connectivity. The presence of an open channel is the key factor.
>
> The hurricane protection levees along the south side of Orleans Parish [Orleans East] and the eastern side of St. Bernard Parish along the MRGO, which together are referred to as a funnel, can locally collect and focus storm surge in this vicinity depending on wind speed and direction. This localized focusing effect can lead to a small local increase in surge amplitude. Strong winds from the east tend to maximize the local funneling effect. *Source:* IPET, *Report 2 of a Series*, Appendix E, p. E–7.

A team of scientists from LSU, however, seem to take a different position on the MRGO channel. In a report entitled, LSU, *Initial Assessment of New Orleans Flooding*, Ivor L. van Heerden, G. Paul Kemp, Wes Shrum, Ezra Boyd and Hassan Mashriqui state the following:

> As the eye of the storm approached the latitude of New Orleans, a 14-17 foot surge was pushed into the western apex of a triangle known as the "Funnel", so called because the hurricane protection levees that form the south bank of the MRGO and the north bank of the GIWW converge from being about 10 miles apart to a few hundred yards at the banks of the GIWW where it separates the East Orleans and St. Bernard basins. The Funnel is a 6-mile long section of the GIWW where the cross-section was enlarged by a factor of three when the MRGO was built to expand it from a barge channel to accommodate ocean-going vessels. At the western end, the Funnel focused a jet into the IHNC. The US Army Corps of Engineers had inadvertently designed an excellent storm surge delivery system – nothing less – to bring this mass of water with simply tremendous "load" – potential energy – right into the middle of New Orleans. *Source*: LSU, Initial Assessment of New Orleans Flooding, p. 4.

13 ASCE/NSF, *Preliminary Report*, pp. iv-v.

14 ASCE/NSF, *Preliminary Report*, pp. iv-v.

15 ASCE, "ERP Progress Report Number 1," p. 3.

16 ASCE, "ERP Progress Report Number 1," p. 3.

17 ASCE/NSF, *Preliminary Report*, p. 8–1. See also: IPET, *Summary of Field Observations*, p. 6.

18 IPET, *Summary of Field Observations*, p. 6.

19 ASCE/NSF, *Preliminary Report*, p. 8–1. However, it should be noted that while the IPET report concurred with the ASCE/NSF *Preliminary Report* finding regarding the T-walls, noting that, "if overtopping of T-walls did occur, it did not lead to extensive scour and erosion," the IPET team also stated that there were some T-wall structures "that had significant scour, but none showed evidence of distress or movement" IPET, *Summary of Field Observations*, p. 6.

20 Written Statement of Anu Mittal, Director, Natural Resources and Environment, U.S. General Accountability Office, for the U.S. Senate on Environment and Public Works, hearing on *Comprehensive and Integrated Approach to Meet the Water Resources Needs in the Wake of Hurricanes Katrina and Rita*, Nov. 9, 2005, p. 2.

21 Written Statement of Mittal, Senate Committee on Environment and Public Works hearing, Nov. 9, 2005, p. i.

22 ASCE/NSF, *Preliminary Report*, pp. 8–1 through 8–2; *see also* IPET, *Summary of Field Observations*, pp. 6-7; IPET, *Report 1 of a Series*, p. 114.

23 IPET, *Summary of Field Observations*, pp. 6-7.

24 ASCE/NSF, *Preliminary Report*, pp. 8–1 through 8–2.

25 ASCE/NSF *Preliminary Report*, pp. 8–1 through 8–2.

26 ASCE/NSF *Preliminary Report*, p. 8–3. It should be noted that the IPET team generally agreed with these ASCE/NSF comments, however, while the IPET recognized that planning for overtopping by adjusting crest heights "should be considered," the team stated that there are a number of uncertainties regarding the location and size of these planned "spillways." IPET, *Summary of Field Observations*, p. 11.

27 U.S. Army Corps of Engineers, *Engineering and Design, Design and Construction of Levees,* Apr. 30, 2000, Section 8–9.

28 ASCE/NSF, *Preliminary Report*, pp. 8–3 through 8–4. It should also be noted that the IPET team concurred, specifically noting that, "Given the logistical difficulties in accessing and sealing the breaches to unwater flooded areas, [TFG] should carefully reconsider the guidance of EM 1110-2-1913, Section 8-9 [the Army Corps regulation on point]." IPET, *Summary of Field Observations*, p. 11.

29 ASCE, "ERP Progress Report Number 1," p. 3.

30 ASCE/NSF, *Preliminary Report*, p. 8–3. *See also*: IPET, *Summary of Field Observations*, p. 10.

31 ASCE/NSF, *Preliminary Report*, pp. 8–1 through 8–2. The IPET team, however, has left "the issues of organizational and jurisdictional complexities that can impact the effectiveness of the physical system" to be treated separately. IPET, *Report 2 of a Series*, p. I–1.

32 Testimony of Raymond Seed, Ph.D., Team Leader, National Science Foundation, before the U.S. Senate, Committee on Homeland Security and Governmental Affairs, hearing on *Hurricane Katrina: Why Did the Levees Fail?*, Nov. 2, 2005.

33 ASCE, "ERP Progress Report Number 1," p. 2.

34 IPET, *Report 2 of a Series*, p. III–6.

35 IPET, *Report 2 of a Series*, p. I–2.

36 IPET, *Report 2 of a Series*, p. III–6.

37 IPET, *Report 2 of a Series*, p. I–2.

38 IPET, Report 2 of a Series, p. III-6. Significantly, the report found that geodetic elevations are very time-dependant in the New Orleans area "and must be periodically adjusted to account for apparent sea level changes." It also recommended annual reviews to measure subsidence. IPET, Report 2 of a Series, p. III–53.