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Reflections on the Draft Final U.S. Army Corps of Engineers Interagency Performance Evaluation Task Force (IPET) report titled Performance Evaluation of the New Orleans and Southeast Louisiana Hurricane Protection System

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This is a very important piece of work. It provides extensive insights into the 'engineering mechanics' that lead to the most catastrophic failure of a civil engineered system in the history of the United States. These reflections concentrate on the findings contained in Volume I - Executive Summary and Overview.

Overarching Findings

Yes, the hurricane flood defense 'system' for the greater New Orleans area (NOFDS) was "a system in name only". Even though there had been only one agency in charge of concept development, design, and construction - the Corps of Engineers - it is clear that the NOFDS was not a coherent defense system. It was and continues to be an assembly of disjointed and defective components.

Yes, armoring the back sides and crests of levees and the protected side of floodwalls would have added significant redundancy and reduced breaching. One could wonder why such protection was and has not been provided in the repairs to the levees adjacent to the Mississippi River Gulf Outlet between bayous Dupre and Bienvineu. The original plans for reconstruction of these levees omitted armoring (January 2006). When the plans were revised, only armoring on the front or exposed side was proposed (February 2006). Now, the need for full armoring of the levees is recognized. It would seem that it has been during the course of the IPET study that recognition has developed in the Corps of Engineers that these levees are exposed coastal defense structures that must be able to sustain the combined effects of waves, currents and surge. Coastal engineers around the world have and do understand the need for such defensive measures for earthen levees. Why is the need for such defensive structures such a recent revelation?

Yes, back-up, fail-safe, and defect - damage tolerant system components are needed. However, it is important to recognize that 'redundancy' in itself does not provide such highly desirable performance characteristics. It takes much more than redundancy; it takes proper configuration (which can include redundancy), excess capacity, ductility, and appropriate correlation. The effects of redundancy can be completely erased by a variety of factors. It is obvious that design guidelines are urgently needed for engineers to develop an adequate understanding of what it takes to develop a defect and damage tolerant components for the NOFDS.

Yes, the storm exceeded the design criteria in some parts of the system. The fact that the design criteria in some parts of the system were exceeded and that these parts of the system performed so poorly indicates that the margins of safety were not sufficient. Engineered systems are expected to perform acceptably even though their design criteria are exceeded; that is the reason for margins or factors of safety. It is clear that even the 'design criteria' (referring to the hurricane conditions) as expressed in the Standard Project Hurricane (SPH) also were insufficient and defective. This technology deficiency started in the 1950s and was clearly recognized by the Corps and others in the 1970s; nothing was done to remedy the deficiencies. This same story plays out again and again throughout the history of development of this system: inappropriate use of technology. Another important example is the elevation datum reference developments that resulted in low protection elevations (2 to 3 feet and more); these were recognized by the Corps of Engineers and decisions were made to accept these low protection elevations. The omission of splash pads behind the original concrete I-walls is a similar case. Design engineers were instructed through the Corps of Engineers design guidelines to design only for the authorized water levels; not for overtopping. Such a strategy results in very 'brittle' components that can not tolerate conditions that exceed the authorized conditions. Even the fundamental factors of safety incorporated into the design guidelines for the levees and floodwalls were unreasonably low. Extensive research into the history of these factors of safety could provide no substantial justification for their acceptance in this particular application; defense of a major metropolitan city.

Yes, levee sections were constructed with erodible materials. And, these levee sections were constructed according to the Corps construction specifications. These levee sections were approved based on the Corps quality assurance and control procedures and processes (QA/QC). These construction specifications and QA/QC procedures and processes are documented in current Corps of Engineers design and construction guidelines. These construction specifications and QA/QC procedures are being used (sometimes in forms modified to lessen their requirements) in reconstruction of some of the earth levees (e.g. MR-GO levees).

Yes, the floodwalls and supporting levees within the Inner Harbor Navigation Canal and within the drainage canals (London, Orleans, 17th Street) did not perform acceptably. The failure of these elements contributed the vast majority of flood water that devastated the central New Orleans area. They failed before the design water levels occurred. They failed because of a variety of reasons that can be grouped into what are commonly termed 'engineering failures.' But, these engineering failures were not the causes of the breaches. The failures resulted from inability of the Corps of Engineers to properly apply existing technology. Many of the important parts of this technology were developed by the Corps of Engineers and inexplicably the Corps of Engineers was unable to take advantage of its own developments. There are ample signs of rejection of technology and signs that indicate lethal arrogance.

Yes, the majority of the flooding can be attributed to unanticipated and undesirable breaches in the flood protection system. Our work indicates something in excess of 75 to 80 % while the Corps of Engineers work indicates approximately 67%. In some areas, our work indicates as much as 90% (St Bernard Parish). So, there is general agreement that the majority of flooding, damage, death, and suffering can be attributed to breaching that should not have occurred.

Yes, in most cases it is likely that the repaired sections of the hurricane protection system are the strongest parts of the system. We understand that it takes a coherent and integrated system to provide proper protection. Strong pieces embedded within weak pieces does not translate to a reliable system. All parts or components of the NOFDS are suspect until it can be proven beyond a reasonable doubt that they will perform acceptably. That confirmation has not been provided. A prime example of shifting the problem from one location to others regards the installation of gate closures for the drainage canals. These gate closures when completed will provide protection against hurricane surges entering from Lake Pontachatrain. However, at this time and in the foreseeable future, there is insufficient pumping capacity at the lake front to allow the pump stations located at the heads of the canals to operate at their full capacity to empty the city of rainwater and floodwater. This then shifts the problem to the levees and floodwalls that line these canals and these have already proven marginal or insufficient for significant water levels in the canals. The question then is how much water can be allowed to build-up in the canals? Depending on the factors of safety that would be required, the answers seem to range from 5 feet to 8 or 9 feet. Will the pumps be able to keep up? Will the pumps operate as intended? What will happen if the pumps can not keep up with the water pumped into the canals?

Synopsis of Principal Findings

Geodetic vertical and water level datum

Yes, subsidence was not properly accounted for. Yes, revisions in reference datum were not recognized. Yes, there were errors made in references of datum to water level. Multiple errors accumulated over a very long period of time (40+ years). Corps of Engineers documents do indicate that the potential errors were detected and recognized; however, they were not corrected. The decision was made to construct the works to the elevation datum referenced at the time of the original authorization of the works (1965). The accumulation of these errors lead to walls and levees being constructed 2 to 3 feet or more lower than intended; resulting in substantial compromises in the reliability of the NOFDS.

Hurricane Protection System

The first sentence "There was no evidence of government or contractor negligence or malfeasance" seems to be misplaced in this document. It has not been documented by the Corps of Engineers that such assessments or evaluations were within the scope of this study. No corroboration or substantiation of this statement has been provided. This statement appears to be very self-serving and detracts from the quality and credibility of the engineering forensic studies incorporated into this important study.

Based on the evidence (written, verbal) gathered during the course of the ILIT study, there was and is evidence of government negligence and malfeasance. Negligence is defined as a failure to exercise the care that a prudent person would. Malfeasance is defined as wrongful conduct. The documented background for development of this flood protection system during a period of more than 40 years indicates many instances of both negligence and malfeasance. We received uncorroborated written reports of instances in which inspectors were told to disregard construction specifications and construction quality control reports falsified. Statements included in the IPET report such as "generally built", "consistent with local practice", and "with exceptions noted below" do not relive the Corps of Engineers of allegations of negligence and malfeasance. Such determinations must be left to the courts and our legal processes.

Yes, the original design criteria represented in the Standard Project Hurricane were not and are not appropriate.

Yes, the methods used to evaluate the soil shear strength, factors of safety, and levee - floodwall stability were not and are not appropriate.

Yes, the incomplete sections (e.g. north of the Orleans pump station and south of the 17^{th} Street pump station), missing railway floodgates, trees at levee toes, in-ground construction at levee toes, were all contributors or 'enablers' in the disastrous flooding. The trees required long periods of time to grow to their size (it is noteworthy that trees blown over by the hurricane winds were observed at the centers of each of the drainage canal breaches and were located at the critical toes of the levees). Multiple required inspections of these components in the flood defense system indicated that 'all was well.' How did these infractions in the requirements go unrecognized, unreported, and unresolved by so many people for such a long period of time?

Storm

Yes, the water levels developed in some parts of the NOFDS did exceed the design criteria. But, as noted, it was known since the 1960's that the SPH conditions that defined the criteria were not representative of those that should have been used to design the NOFDS. The degree of exceedance of the conditions varied from place to place in the NOFDS. The degree of exceedance is indicated by results from calibrated analytical models and the results from these models differ. The presence of dynamic forces is also to be expected when surge current velocities and wave forces are present. The contributions of these forces are also uncertain.

Yes, overtopping by surge and waves on the fronts, crests, and backs of the levees all lead to high potential for scour and erosion. These erosive stresses varied from place to place and had varying effects depending on the orientation of the stresses relative to the levees, the soil characteristics, the presence of natural defenses (wetlands, trees, grass) and the presence of engineered defenses (that sometimes had exacerbating effects). Our work indicates that there were many significant cases in which the levees that failed due to erosion were caused by erosion of the front face; this finding contradicts the IPET finding that "the levees that failed due to erosion determined that all were caused by erosion of the crest and back face." Our work is continuing to examine the cases where erosion and other hydrodynamic and hydraulic phenomenon during the surge build-up brought severe wave action and current action against the front faces of the levees, floodwalls, and flood control structures. Evidence in some important cases indicates breaching prior to overtopping.

Yes, the southeast trending leg of the MRGO had little influence on the water levels in the IHNC during Katrina. Our work indicates that it was the confluence of the MR-GO, the ICWW, and the IHNC that resulted in the magnifying effect on the surge heights in IHNC previously identified as the "Funnel Effect". Our work contradicts the IPET finding that the "MRGO was far from the 'hurricane highway' moniker with which it has been branded." Our work indicates that the most important effect of the MRGO was destruction of the wetlands and freshwater swamp growth that had provided natural defenses for this area. This destruction was due directly to the increased salinity introduced by the MRGO and by the widening of the MRGO channel due to ship wave pressure erosion effects. MRGO had additional effects provided by its geometry relative to other waterways and the required dredging associated with maintenance of this channel. So the observation that the MRGO in itself had a small effect on the rise of water levels is correct; however, the conclusions drawn from this observation are not correct.

Our work does not corroborate the statement "Of the 50 major breaches experienced by the hurricane protection system during Katrina, ALL (capital letters added for emphasis) but four were due to overtopping and erosion." Our work indicates that there were many instances in which it is very likely that breaching occurred BEFORE overtopping. This discrimination is important for several reasons; one of the most important reasons regards learning from the failures so that proper corrective measures are introduced into design of repairs and new components. Perhaps the nuance in this IPET statement regards "no evidence of systemic breaching caused by erosion on face or water sides of the levees"; the breaching before overtopping is due to much more than erosion; additional important phemenona such as liquefaction and seepage pressures must be recognized - in addition to the water velocity magnification effects caused by 'hard structures' adjacent to 'soft' earth structures.

The fact that components in the NOFDS were overtopped and this overtopping exceeded the design criteria (SPH) should not lead to the conclusion that failure or poor performance should be expected. Quite to the contrary; good engineering design would incorporate additional defensive measures including armoring, appropriate factors of safety leading to 'excess' capacity, configuration to provide for acceptable performance (e.g. creation of polders or separated defended sections), ductility (ability to maintain capacity even though damaged, defective, or pushed beyond the capacity), and appropriate correlation (high positive for series components achieved through appropriate uniformity in design, construction, operation, and maintenance; low positive for parallel components to achieve independence in performance characteristics).

Yes, the four breaches in the outfall canals and IHNC involving I-walls occurred before water levels reached the top of the floodwalls, and in most cases well before the water levels reached the design conditions. All of the conditions responsible for these breaches were known and foreseeable in advance of these failures. In this sense, these were 'predictable failures.' For a wide variety of apparent reasons, the knowledge was not used appropriately.

Yes, transitions in the NOFDS created a large number of vulnerabilities and reduced the effectiveness of the protection. Yes, some of the transitions are associated with changes in the organization, incompletion of the authorized construction, and others associated with necessary penetrations through the system. None of these factors in themselves provides acceptable explanations for the ineffectiveness of the transitions in a system that was constructed over a period of more than 40 years. It is clear that this system while possibly originally conceived as a coherent and integrated system (1965) the NOFDS was not designed, constructed, nor maintained as such. This system was riddled with major and systemic flaws whose source lies primarily in organizational and institutional dysfunctions. The so-called engineering failures are not the causes of these failures; the causes are firmly rooted in the organizational and institutional dysfunctions.

Yes, some sections of the NOFDS did perform well even though "subjected to design-exceeding conditions and forces." However, this performance was due to many more factors than erosion resistant materials and more conservative designs. In many cases, natural defenses (wetlands, barrier islands, swamp vegetation) and constructed works (roadways, railways, bridges) also provided important defenses. This is an important observation as it regards development of strategies for future development of the NOFDS as well as for a comprehensive understanding of the reasons for successes and failures in the NOFDS.

Yes, "Flooding from Katrina covered approximately 80% of the New Orleans metropolitan area." While the IPET studies indicate "Approximately two-thirds of that flooding can be attributed to water flowing through breaches" our work indicates figures closer to 75% to 80% and in some cases 90%. This difference seems to be founded primarily in the understanding of breaching after or before the peak of the surge conditions in various parts of the NOFDS. Our work indicates that IF everything that we had in the NOFDS had worked properly and as we wanted it to work, then we would have had some minor flooding; some soaked carpets, missing shingles and window glass (and other associated wind damage). We would not have had the single most catastrophic failure of an engineered system in the history of the United States. This catastrophic failure developed because of unanticipated, unintentional, and undesirable breaches in the NOFDS. The catastrophe was compounded by rescue and recovery meldowns.

Yes, pump stations did play a role in the flooding. There were systemic and pervasive flaws in this part of the NOFDS that persist to this point in time. As the future NOFDS is developed, it is essential that the ability to pump water out of the sections or polders that comprise the NOFDS be re-engineered (start over), designed, constructed, maintained, and continually proofed and improved.

Consequences

Yes, the most serious direct impact of the failures of the NOFDS that accompanied Katrina was the high number of deaths (currently estimated at more than 1,700 with more than 500 still missing). Note that the 'blame' for these deaths should not be placed in this statement on 'Katrina'; Katrina severely tested the NOFDS. The NOFDS failed the test. This catastrophe did not result from an act of 'God'. It resulted from acts of 'People.' This represents human failure to deliver appropriate technology to prevent such a catastrophe.

The NOFDS failed the test because of a large number of flaws and defects that had been embedded in the system primarily during the period 1965 - 2005; these have been termed engineering failures. However, the engineering failures are not the causes. The causes are firmly founded in organizational and institutional failures that are primarily focused in the Corps of Engineers.

The background that has been developed during the ILIT study indicates that direct and indirect economic costs of the failure of the NOFDS will approach $400 billions. This cost is about 100 times the cost originally estimated in the Corps of Engineers cost-benefit studies that justified the levels of protection incorporated into the NOFDS. The cost-benefit process that continues to be used by the Corps of Engineers to justify protection expenditures and recommendations to Congress is very seriously flawed. Until these flaws are addressed, decision makers will not have appropriate information to make informed decisions. And, the protected public will not have appropriate information to make decisions on how they want to live their lives in this area.

The ILIT study findings do not provide corroboration of the statement "Overall, any sustained environmental loss from flooding and flood management is indicated to be very small in the context of long-term impacts from development in the region." Many sources have documented that there have been and continue to be substantial environmental losses from flood management as conceived, designed, constructed, and in some cases, operated and maintained (e.g. navigable waterways) by the Corps of Engineers. The legendary environmental insensitivity of the Corps of Engineers is encapsulated in this statement.

Lessons Learned

Resilience

Yes, resilience is clearly needed in all future flood defense systems, and particularly for those that protect large metropolitan areas or resources important to such areas. Resilience has been and continues to be a very important part of engineering many types of important systems. There is a substantial body of knowledge about how resilience, robustness, and fail-safe design can be achieved. This body of knowledge needs to be properly understood by the Corps of Engineers and this knowledge appropriately incorporated into revisions of ALL guidelines involving engineering, construction, operation, maintenance, and continued improvement of future flood defense systems. The Corps of Engineers must have highly qualified and motivated engineers and assisting contractors that can help translate these guidelines to the realities required to achieve and maintain a high quality and reliable NOFDS.

Systems Performance

Yes, detailed attention needs to be given to life-cycle performance of the NOFDS. It must be understood that 'systems' consist of many highly interactive, inter-dependent, and adaptive components that include the 'operators', organizations and institutions, hardware and structures, procedures and processes, environments, and interfaces among the foregoing. Systems design and engineering is another technology that needs to be properly understood by the Corps of Engineers and this knowledge appropriately incorporated into revisions of ALL guidelines involving engineering, construction, operation, maintenance, and continued improvement of future flood defense systems. The Corps of Engineers must have highly qualified and motivated engineers and assisting contractors that can help translate these guidelines to the realities required to achieve and maintain a high quality and reliable NOFDS.

One of the most important parts of the 'system' is the Technology Delivery System (TDS) upon which the physical components in a future NOFDS are founded. This TDS represents the collation of the public, government, and industry / commerce whose goal is provision of adequate and acceptable long term hurricane and other (river, rainfall) flood protection - the NOFDS. These components are embedded in and interact with their natural and cultural environments. Inputs comprise knowledge plus human, natural, and fiscal resources. Outputs include desired goods or services and undesired outcomes or unintended consequences.

While the physical components in the NOFDS clearly need rehabilitation and dramatic improvement, this goal can not be realized unless the TDS is also rehabilitated and improved. Perhaps the most important cause for failure of the NOFDS during and after hurricane Katrina was failure of the TDS that was responsible for its life-cycle (concept development, design, construction, operation, maintenance, improvement). The Corps of Engineers had a primary role in this dysfunctional TDS; but, there were other organizations that contributed to this dysfunctional performance. The TDS must be re-engineered and actually translated to actions and behaviors and coupled with appropriate and sustained resources before a desirable and acceptable NOFDS can be realized.

Risk and Reliability

Yes, modern risk and reliability approaches hold much promise for providing information and insights that can help a parts of the TDS make better decisions. It is important that holistic and realistic proactive, reactive, and interactive approaches be utilized and measures taken to not allow these approaches to become paper chases or numbers games. In implementation of these approaches it must be remembered that the greatest sources of uncertainties are associated with human factors (operator and organizational performance, knowledge acquisition and utilization). Experience with a wide variety of high risk and reliability systems clearly indicates that creation and maintenance of High Reliability Organizations (HROs) is the single most important approach that is needed to develop engineered systems that have desirable and acceptable quality (serviceability, safety, compatibility, durability) over their lifetime. The steps taken and that are being taken by NASA to translate itself to an HRO (the 'One NASA Initiative') are one model that should be studied as one considers a future TDS for the NOFDS.

Knowledge, Technology, and Expertise

Yes, "The history of the planning, design, and performance of the Hurricane protection System in New Orleans points out a dilemma." Yes, the pieces were not put together in a meaningful. Although the 'dots' were clear, they were not connected. And, there are many examples that developed throughout the history of the NOFDS between the disastrous flooding of the system during hurricane Betsy (1965) and the catastrophic flooding of the system during hurricane Katrina (2005). These examples are clearly indicative of a 'non-learning' organization. The ILIT study indicates that there are many reasons for this non-learning characteristic that includes loss of core competencies in the Corps of Engineers ("we have taken engineering out of the Corps of Engineers"). Bureaucratic engineering produced a defective and deficient NOFDS. In many cases, we found evidence of 'lethal arrogance'; information that provided potential early warnings was rejected because "the Corps knows everything." But, there were other important players that include the executive and legislative branches of both the federal, state and local government agencies. The ILIT study choose to focus these breakdowns and malfunctions in the 'dysfunctional TDS'. It is clear that the TDS must be rehabilitated before an adequate long-term NOFDS can be realized.

ILIT Findings: Failure of the NOFDS

Failure of the NOFDS was a predictable, predicted, and preventable catastrophe. Failure of the NOFDS was not caused by an overwhelming extreme natural event. While portions of the NOFDS were overtopped by hurricane Katrina's surge and waves, the majority of the flooding came from unanticipated and unintended breaches in the levees and the floodwalls and water entering through and over low spots in the NOFDS system. The roots of these unanticipated and unintended developments are firmly embedded in malfunctions in the TDS. Eight categories of TDS malfunctions were identified by the ILIT that played primary roles in the failure of the NOFDS. These malfunctions were corroborated with results from other in-depth studies performed and documented by federal agencies (White House, Congress), public groups, and individual investigators.

Failures of foresight: Catastrophic flooding of the greater New Orleans area due to surge from an intense hurricane was predicted for several decades. The consequences observed in the wake of hurricane Katrina were also predicted. The hazards associated with the NOFDS were not recognized, defensive measures identified and prioritized, and effective action was not mobilized to effectively deal with the hazards.

Failures of organization: The roots of the failure of the NOFDS are firmly embedded in flawed organizational - institutional systems. The organizational - institutional systems lacked centralized and focused responsibility and authority for providing adequate flood protection. There were dramatic and pervasive failures in management represented in ineffective and inefficient planning, organizing, leading, and controlling to achieve desirable quality and reliability in the NOFDS. There were extensive and persistent failures to demonstrate initiative, imagination, leadership, cooperation, and management.

Failures of resource allocation: Contributing to the failure of the NOFDS was provision of inadequate resources based primarily on recommendations provided by the Corps of Engineers. This was followed by failure of the federal and state governments to fund badly needed improvements once limitations were recognized. In several instances, State agencies pressured for 'lower cost' solutions not realizing that these solutions would result in lowering the quality and reliability of the NOFDS. There were important deficiencies in the cost - benefit analyses used to justify the levels of protection and their continued improvement as knowledge and technology advanced.

Failures of diligence: Forty years after the devastating flooding caused by hurricane Betsy, the flood protection system authorized in 1965 and founded on the Standard Project Hurricane (SPH) was not completed. The concept and application of the SPH was recognized to be seriously flawed, yet there were no adjustments made to the system before Katrina struck. Early warning signs of deficiencies and flaws persisted throughout development of the different components that comprised the NOFDS and these signs were not adequately evaluated and acted upon.

Failures of decision making: The history of this system was marked by a series of flawed decisions and trade-offs that proved to be fatal to the ability of the system to perform adequately. Compromises in the ability of this system to perform adequately started with the decisions regarding the fundamental design criteria for the development of the system, then were propagated through time as alternatives for the system were evaluated and engineered. Design, construction, operation, and maintenance of the system in a piecemeal fashion allowed the introduction of additional flaws and defects. Efficiency was traded for effectiveness. Superiority in provision of an adequate NOFDS was traded for mediocrity and getting along.

Failures of management: Requirements imposed on the Corps of Engineers by Congress, the White House, State and local agencies, and the general public have changed dramatically during the past three decades. Defense, re-construction, maintenance, waste disposal, recreational, emergency response, ecological restoration have served to divert attention from flood control. Public and Congressional pressures to reduce backlogs of approved projects, improve project and organizational efficiency (down-sizing, out-sourcing), address environmental impacts and develop appropriations for projects have served to divert attention from engineering quality and reliability of flood control. Engineering technology leadership, competency, expertise, research, and development capabilities appear to have been sacrificed for improvements in project planning and controlling.

Failures of synthesis: While individual parts of a complex system can be adequate, when these parts are joined together to form an interactive - interdependent - adaptive system, unforseen failure modes can be expected to develop. These unforseen, but forseeable, failure modes did develop in the NOFDS during hurricane Katrina. It is evident that insufficient attention was given to creation of an integrated series of components to provide a reliable NOFDS. Synthesis was subverted to decomposition. As a result, many failures developed at interfaces or 'joints' in the NOFDS.

Failures of risk assessment and management: The risks (likelihoods and consequences) associated with hurricane surge and wave induced flooding were seriously underestimated. There was inadequate recognition of the primary contributors to the likelihoods and consequences of catastrophic flooding. Sufficient defensive measures to counteract and mitigate these uncertainties were not used. Factors of safety used in design of the primary elements in the NOFDS were not sufficient. Quality assurance and control measures invoked during the life of the system failed to disclose critical flaws in the system. Inappropriate use was made of existing engineering technology available to design, construct, operate, and maintain a NOFDS that would have acceptable quality and reliability. Deficient risk management methods were used to allocate resources and impel action to properly manage risks. Risk management failed to employ continuing improvement, monitoring, assessment, and modifications in means and methods which were discovered to be ineffective.

ILIT Findings: Future NOFDS

Engineering Developments

The technology exists that can be used to develop a NOFDS that will be effective and efficient. A major challenge is timely and proper application of this technology.

Recommendation 1: Develop an integrated and coherent Flood Defense System for the greater New Orleans area (NOFDS) that will provide desirable and acceptable levels of flood protection throughout its life-cycle. Particular attention must be paid to interfaces and interdependencies in this system. The NOFDS should be balanced, complete, cohesive, clear, consistent, and have controls and continuity. The NOFDS should be based on the best available and safest technology and most up-to-date legal standards. Risks should be properly identified, contained and compartmentalized. The system must recognize the unique natural environmental setting including its geology, meteorology, oceanography, the Mississippi River floodplains, deltas and wetlands, subsidence, and the rise in sea level and frequency and intensity of hurricanes. The system must also recognize and accommodate the unique societal and cultural environments of this area.

Recommendation 2: Develop a NOFDS based on enhancing natural defenses supplemented with engineered defenses that incorporate concepts of defenses in depth, robustness or resilience, and fail-safe performance. Selective re-establishment of natural coastal defenses and wetlands and restored floodplains to provide for river floods should be supplemented with engineering works that together will have the capabilities of providing desirable and acceptable levels of flood protection. Coastal management must be focused on providing safety from flooding and environmental protection. Water should be given space. Some areas will have to be returned to nature and judicious and wise decisions reached on which areas will be populated and developed and the levels of protection that will be provided to these areas. Engineering works should include raising and strengthening and defense of levees, provision of floodgates, storm surge barriers, positioning and defense of modern pump stations, compartmentation to limit potential flooding, adequate and effective evacuation measures to help limit effects on people and their possessions. A robust NOFDS will require a combination of appropriate configuration of engineered elements and components, ductility or an ability to deform and stretch and not loose important performance characteristics, excess capacity so that if some elements or components are overloaded or do not perform desirably then desirable protection can be maintained, and appropriate correlation or mutual relationships so that desirable protection is realized. Fail safe characteristics should be provided in all of the important elements of the NOFDS so that when the design and ultimate performance conditions are exceeded, the performance characteristics are not appreciably compromised.

Recommendation 3: Develop a NOFDS founded on advanced Risk Assessment and Management principles for all phases in the life-cycle including concept development, design, construction, operation, and maintenance. These principles should address natural, analytical modeling, human and organizational performance, and knowledge acquisition and utilization uncertainties and be based on proactive, reactive, and interactive risk assessment and management approaches. These approaches should be based on reductions in likelihoods of failure, reduction in the consequences associated with potential failures, and increases in detection and correction of developments that can lead to failures. Advanced Risk Assessment and Management approaches should be used to provide decision makers with information to define what levels of protection should be provided for which areas to be protected and how much can and should be spent for those purposes.

Recommendation 4: Develop updated engineering guidelines and procedures for all elements and components to be incorporated in the FDS for all life-cycle phases based on proven state-of-practice and state-of-art technology. Where technology gaps are identified, then substantial development programs should be implemented to fill these gaps with existing research results. Where technology gaps can not be filled with existing research results, then research should be undertaken or sponsored to enable timely filling of the technology gaps.

Recommendation 5: Develop, implement, and enforce advanced Quality Assurance and Quality Control methods and procedures for all life-cycle phases of the NOFDS. Quality Assurance (proactive) and Quality Control (interactive) measures are of particular importance to help disclose 'predictable surprises' and variances in the desirable quality characteristics of the elements and components in the NOFDS. These methods and procedures should be used in all life-cycle phases of the NOFDS including concept development, design, construction, operation, maintenance, and continued improvement. These procedures and measures need to assure that the best available and safest technology is being used and used properly.

Technology Delivery System Developments

The primary requirement for reconstitution of a Technology Delivery System that can and will provide an adequate and acceptable NOFDS is mobilization of the 'will' to provide such a system. If the United States decides that the catastrophe of Katrina will not be repeated, then the necessary leadership, organization, management, resources, and public support must be mobilized to assure such an outcome. One of the primary challenges is time, the clock is ticking until this area of the United States is again confronted with a severe challenge of flooding.

Recommendation 1: Seriously consider defining risk in the framework of federal, state, and local government responsibilities to protect their citizens.

Recommendation 2: Exploit the major and unprecedented role that exists for citizens who should be considered part of governance in the spirit that those who govern do so at the informed consent of the governed. This is the population exposed to catastrophic risks and the people that will be protected by the NOFDS. Authorities for catastrophic risk management should ensure that those vulnerable have sufficient and timely information regarding their condition and a reciprocal ability to respond to requests for their informed consent especially regarding tradeoffs of safety for cost. The public protected by the NOFDS need to be encouraged to actively and intelligently interact with its development.

Recommendation 3: Intensify, focus, and fund Corps of Engineers modernization efforts increasing in-house engineering capabilities and project performance, increasing in-house research and development capabilities, increasing in-house engineering performance of technically challenging projects, developing an organizational culture of high reliability founded on existing cultural values of Duty, Honor, Country, and developing a leadership role and responsibility for technical and management oversight of all phases in development of a NOFDS. Technical superiority must be re-established. Outsourcing must be balanced with in-sourcing to encourage development and maintenance of superior technical leadership and capabilities. This will require close and continuous collaboration of federal legislative, executive, and judicial agencies. This will require that the Corps of Engineers reconceptualize itself as a pivotal part of a modular organization developing partnerships with other federal agencies, state and local governments, enterprise interests, and private stake holders.

Recommendation 4: Restructure federal/state relationships in flood control. One possible model is what has been called “modularity” -- a concept which involves provisional and functional rearrangement of units in terms of alternative configurations of tools, structures and relationships.

Recommendation 5: Develop a National Flood Defense Authority (NFDA) charged with oversight over the design, construction, operation and maintenance of flood control systems. Each state would have an equivalent organization that could foster cooperation and developments between and within the states. The Corps of Engineers, state flood control authorities, and technical advisory boards would work with the NFDA to foster application of the best available technology and help coordinate development and maintenance efforts and planning. In cooperative developments, federal and state governments would provide reliable and sustainable funding for the life-cycle of specific flood defense systems. This development should be accompanied by development of an integrated and coherent Louisiana Flood Defense Authority representing state, regional, local, city, and public stakeholders that can focus and prioritize stakeholder interests and requirements and collaborate with the Corps of Engineers in development of a NOFDS.

Recommendation 6: Because of the importance of emergency response in the NOFDS, FEMA should be developed as a high reliability organization and returned by the executive branch to Cabinet level status. A new Council for Catastrophic Risk Management should be appointed in the White House and given oversight of disaster preparation and response. A similar body should be appointed to Congress. Incentives must be created to encourage all levels of government to seriously deal with potential national, regional, and local catastrophes.

Summary

This has been the most challenging study of the failure of an engineered system that I have been involved in during my 53 year engineering career. I have been directly involved in investigations of more than 100 high consequence failures and performed detailed studies of more than 500 additional such failures (including work for NASA on the Columbia accident and the shipping industry and USCG on the Exxon Valdez). This failure played out exactly as the majority of these other failures played out. The dominant contributors to the failure were centered in human and organizational malfunctions represented as breakdowns in the TDS. The failure developed during the operations and maintenance phases of the system. The vast majority of the contributors to the failure were firmly rooted in the early concept development and design phases of the system.

I had particularly good qualifications to help perform this study. I started my career in 1954 working for the Corps of Engineers in the south Florida flood control district helping engineer and construct levees, pump stations, and canals around Lake Okeechobe. My father was a career Corps of Engineers officer (started at St. Louis District and retired at Jacksonville District). I was raised Corps of Engineers; 'yes sir and salute.' I left the Corps of Engineers in 1959 and returned to school. I joined Shell Oil Company in 1960 and worked in the coastal areas in Mississippi, Alabama, Louisiana and Texas.

By 1965 I headed Shell Oil Company's Head Office Offshore Civil Engineering Group in New Orleans (registered civil, structural, geotechnical engineer in 8 states). In September 1965 after hurricane Betsy passed over New Orleans, I returned to our home after we (my wife and 6 month old son) had evacuated at the height of the storm to my central New Orleans office (where we lived for the next 2 months). I swam and waded back to the site of our flooded home. Ten feet of water. We lost everything including our home and wedding photographs. There was no help. There was no insurance. Bank account equals zero time of our lives.

But, our lives went on. After having worked in all of the major coastal and offshore areas worldwide (engineering, construction, research, operations, maintenance, management), I left PMB-Bechtel (Vice President) and industry in 1989 and was appointed as a Professor of Engineering at the University of California Berkeley. Since then, my work has focused on risk assessment and management, engineering systems, and engineering and project management.

So, when I returned to New Orleans in September 2005 to help the ILIT with the field studies of the failures of the NOFDS, I was coming home to something I had seen 40 years before. Only this time there was vastly more destruction, devastation, and grief. And this time, I saw the world through a different set of glasses. I returned to the site of our old home in East New Orleans (Pines Village); a new home had been rebuilt on the foundations of our previous home. The owners were dragging wet mattresses out of their home just as I had done 40 years earlier. I broke down and cried. Mine were tears of frustration because by that time I understood that this was a predictable and preventable catastrophe. Flooding of this area had occurred in almost exactly the same ways and from the same places 40 years earlier. This catastrophe involved much more than the physical failures of levees, floodwalls, and pump stations; it had it roots firmly embedded in human and organizational performance malfunctions (errors) - breakdowns in the TDS that we had relied upon to provide adequate flood protection.

Bob Bea