

CHAPTER FIFTEEN: FINDINGS AND RECOMMENDATIONS

15.1 Overview

This report presents the results of an investigation of the performance of the New Orleans regional flood protection system during and after Hurricane Katrina, which struck the New Orleans region on August 29, 2005. This event resulted in the single most costly catastrophic failure of an engineered system in history. Current damage estimates at the time of this writing are on the order of \$100 to \$150 billion in the greater New Orleans area, and the official death count in New Orleans and southern Louisiana at the time of this writing stands at 1,293, with an additional 306 deaths in nearby southern Mississippi. An additional Approximately 400 additional people are currently still listed as “missing”, and the death toll is expected to continue to rise a bit further. More than 450,000 people were initially displaced by this catastrophe, and at the time of this writing more than 200,000 residents of the greater New Orleans metropolitan area continue to be displaced from their homes by the floodwater damages from this storm event.

This investigation has targeted three main questions as follow: (1) What happened?, (2) Why?, and (3) What types of changes are necessary to prevent recurrence of a disaster of this scale again in the future?

In the end, it is concluded that many things went wrong with the New Orleans flood protection system during Hurricane Katrina, and that the resulting catastrophe had its roots in three main causes: (1) a major natural disaster (the Hurricane itself), (2) the poor performance of the flood protection system, due to localized engineering failures, questionable judgments, errors, etc. involved in the detailed design, construction, operation and maintenance of the system, and (3) more global “organizational” and institutional problems associated with the governmental and local organizations responsible for the design, construction, operation, maintenance and funding of the overall flood protection system.

15.2 Performance of the Regional Flood Defense System During Hurricane Katrina

As Hurricane Katrina initially approached the coast, the resulting storm surge and waves rose over the levees protecting much of a narrow strip of land on both sides of the lower Mississippi River extending from the southern edge of New Orleans to the Gulf of Mexico. Most of this narrow protected zone, Plaquemines Parish, was massively inundated by the waters of the Gulf.

The eye of the storm next proceeded to the north, on a path that would take it just slightly to the east of New Orleans.

Hurricane Katrina has been widely reported to have overwhelmed the eastern side of the New Orleans flood protection system with storm surge and wave loading that exceeded the levels used for design of the system in that area. That is a true statement, but it is also an incomplete view. The storm surge and wave loading at the eastern flank of the New Orleans flood protection system was not vastly greater than design levels, and the carnage that resulted

owed much to the inadequacies of the system as it existed at the time of Katrina's arrival. Some overtopping of levees along the eastern flank of the system (along the northeastern frontage of the St. Bernard and Ninth Ward protected basin, and at the southeast corner of the New Orleans East protected basin), and also in central areas (along the GIWW channel and the IHNC channel) was inevitable given the design levels authorized by Congress and the surge levels produced in these areas by the actual storm. It does not follow, however, that this overtopping had to result in catastrophic failures and breaching of major portions of the levees protecting these areas, nor the ensuing catastrophic flooding of these populous areas.

The northeast flank of the St. Bernard/Ninth Ward basin's protecting "ring" of levees and floodwalls was incomplete at the time of Katrina's arrival. The critical 11 mile long levee section fronting "Lake" Borgne (which is actually a Bay, connected directly to the Gulf of Mexico) was being constructed in stages, and funding appropriation for the final stage had long been requested by the U.S. Army Corps of Engineers (USACE), but this did not arrive before Katrina struck. As a result, large portions of this critical levee frontage were several feet below final design grade. In addition, an unfortunate decision had been made to use local dredge spoils from the excavation of the adjacent MRGO channel for construction of major portions of the levees along this frontage. The result was that major portions of these levees were comprised of highly erodible sand and lightweight shell sand fill.

When the storm surge arrived, massive portions of these levees eroded catastrophically and the storm surge passed through this frontage while still on the rise, crossed an open swamp area that should have safely absorbed most of the overtopping flow from the outer levees (if they had not catastrophically eroded), and it then crossed easily over a secondary levee of lesser height that had not been intended to face a storm surge largely undiminished by the minimal interference of the too rapidly eroded outer levees fronting Lake Borgne. The resulting carnage in St. Bernard Parish was devastating, as the storm surge rapidly filled the protected basin to an elevation of approximately +12 feet above sea level; deeply inundating even neighborhoods with ground elevations well above sea level in this area.

The storm surge swelled waters of Lake Borgne also passed over and then through a length of levees at the southeast corner of the New Orleans East protected basin. Here too, the levees fronting Lake Borgne had been constructed primarily using materials dredged from the excavation of an adjacent channel (the GIWW channel), and these levees also contained major volumes of highly erodible sands and lightweight shell sands. These levees also massively eroded, and produced the principal source of flooding that eventually inundated the New Orleans East protected area. Here again, there was an area of undeveloped swampland behind the outer levees that might have absorbed the brunt of any overtopping flow, and a secondary levee of lesser height was in place behind this swampland that might then have prevented catastrophic flooding of the populous areas of New Orleans East. This secondary levee was not able to resist the massive flows resulting from the catastrophic erosion of the highly erodible section of the Lake Borgne frontage levee, however, and the floodwaters passed over the secondary levee and began the filling of the New Orleans East protected basin.

The catastrophic erosion of these two critical levee frontages need not have occurred. These frontages could instead have been constructed using well compacted clay fill with good resistance to erosion, and they could have been further armored in anticipation of the storm surge and wave loading from Lake Borgne. The levee at the northeast edge of St. Bernard Parish could have been completed in a more timely manner. The result would have been some overtopping, but not catastrophic erosion and uncontrolled breaching of these critical frontages. Some flooding and damage would have been expected, but it need not have been catastrophic.

The storm surge swollen waters of Lake Borgne next passed laterally along the east-west trending GIWW/MRGO channel to its intersection at a “T” with the north-south oriented IHNC channel, overtopping levees along both banks to a limited degree. This produced an additional breach of a composite earthen levee and concrete floodwall section along the southern edge of New Orleans East, adding additional uncontrolled inflow to this protected basin. This failure could have been prevented at little incremental cost if erosion protection (e.g. a concrete splash pad, or similar) had been emplaced along the back side of the concrete floodwall at the levee crest, but the USACE felt that this was precluded by Federal rules and regulations regarding authorized levels of protection.

The surge next raised the water levels within the IHNC channel, and produced a number of failures on both the east and west banks. Two major failures occurred on the east side of the IHNC, at the west edge of the Ninth Ward. Overtopping occurred at both of these locations, but this was not the principal cause of either of these failures. Both failures were principally due to underseepage flows that passed beneath the sheetpile curtains supporting the concrete floodwalls at the crests of the levees. Like many sections of the flood protection system, these sheetpiles were too shallow to adequately cut off, and thus reduce, these underseepage flows. The result was two massive breaches that devastated the adjacent Ninth Ward neighborhood, and then pushed east to meet with the floodwaters already rapidly approaching from the east from St. Bernard Parish as a result of the earlier catastrophic erosion of the Lake Borgne frontage levees.

Several additional breaches also occurred farther north on the east side of the IHNC fronting the west side of New Orleans East, but these were relatively small features and they just added further to the uncontrolled flows that were now progressively filling this protected basin. These breaches occurred mainly at junctures between adjoining, dissimilar levee and floodwall sections, and represented good examples of widespread failure to adequately engineer these “transitions” between sections of the regional flood protection system.

Several breaches occurred on the west side of the IHNC, and these represented the first failures to admit uncontrolled floodwaters into the main metropolitan (downtown) protected area of New Orleans. These features did not scour and erode a path below sea level, however, so they admitted floodwaters for a number of hours and then these inflows ceased as the storm surge in the IHNC eventually subsided. Only 10% to 20% of the floodwaters that eventually inundated a majority of the main (downtown) New Orleans protected basin entered through these features.

These failures and breaches on the west side of the IHNC all appear to have been preventable. One failure was the result of overtopping of an I-wall, with the overtopping flow then eroding a trench in the earthen levee crest at the inboard side of the floodwall. This removal of lateral support unbraced the floodwall, and it was pushed over laterally by the water pressures from the storm surge on the outboard side. Here again the installation of erosional protection (e.g. concrete splash pads or similar) might have prevented the failure.

The other failures in this area occurred at “transitions” between disparate levee and floodwall sections, and/or at sections where unsuitable and highly erodible lightweight shell sand fills had been used to construct levee embankments. Here, again, these failures were as much the result of design choices and/or engineering and oversight issues as the storm surge itself.

As the eye of the hurricane next passed to the northeast of New Orleans, the counterclockwise swirl of the storm winds produced a storm surge against the southern edge of Lake Pontchartrain. This produced additional temporary overtopping of a long section of levee and floodwall at the west end of the lakefront levees of New Orleans east, behind the old airport, adding further to the flows that were progressively filling this protected basin.

The surge against the southern edge of Lake Pontchartrain also elevated the water levels within three drainage canals at the northern edge of the main metropolitan (downtown) New Orleans protected basin, and this would produce the final, and most damaging, failures and flooding of the overall event.

The three drainage canals should not have been accessible to the storm surge. The USACE had tried for many years to obtain authorization to install floodgates at the north ends of the three drainage canals that could be closed to prevent storm surges from raising the water levels within the canals. That would have been the superior technical solution. Dysfunctional interaction between the local Levee Board (who were responsible for levees and floodwalls, etc.) and the local Water and Sewerage Board (who were responsible for pumping water from the city via the drainage canals) prevented the installation of these gates, however, and as a result many miles of the sides of these three canals had instead to be lined with levees and floodwalls.

The lining of these canals with levees topped with concrete floodwalls was rendered very challenging due to (a) the difficult local geology of the foundation soils, and (b) the narrow right of way (or available “footprint”) for these levees. As a result of the decision not to install the floodgates, the three canals represented potentially vulnerable “daggers” pointed at the heart of the main metropolitan New Orleans protected basin. Three major breaches would occur on these canals; two on the London Avenue Canal and one on the 17th Street Canal. All three of these breaches eroded and scoured rapidly to well below sea level, and these three major breaches were the source of approximately 80% of the floodwaters that then flowed into the main (downtown) protected basin over the next three days, finally equilibrating with the still slightly elevated waters of Lake Pontchartrain on Thursday, September 1.

The central canal of the three, the Orleans Canal, did not suffer breaching, but a section of floodwall topping the earthen levee approximately 200 feet in length near the south

end of the canal had been left incomplete, again as a result of dysfunctional interaction between the local levee board and the water and sewerage board. This effectively reduced the level of protection for this canal from about +12 to +13 feet above sea level (the height of the tops of the floodwalls lining the many miles of the canal) to an elevation of about +6 to +7 feet above sea level (the height of the earthen levee crest along the 200 foot length where the floodwall that should have topped this levee was omitted). As a result of the missing floodwall section, flow passed through this “hole” and began flowing into the heart of the main New Orleans protected basin. This flow eventually ceased as the storm surge subsided, and so was locally damaging but not catastrophic.

The three breaches on the 17th Street and London Avenue canals were catastrophic. None of these failures were the result of overtopping; surge levels in all three drainage canals were well below the design levels, and well below the tops of the floodwalls. Two of these breaches were the result of stability failures of the foundation soils underlying the earthen levees and their floodwalls, and the third was the result of underseepage passing beneath the sheetpile curtain and resultant catastrophic erosion near the inboard toe of the levee that eventually undermined the levee and floodwall.

A large number of engineering errors and poor judgments contributed to these three catastrophic design failures, as detailed in Chapter 8. In addition, a number of these same problems appear to be somewhat pervasive, and call into question the integrity and reliability of other sections of the flood protection system that did not fail during this event. Indeed, additional levee and floodwall sections appear to have been potentially heading towards failure when they were “saved” by the occurrence of the three large breaches (which rapidly drew down the canal water levels and thus reduced the loading on nearby levee and floodwall sections.)

15.3 Engineering Issues

The New Orleans regional flood protection system failed at many locations during Hurricane Katrina, and by many different modes and mechanisms. This unacceptable performance can in many cases be traced to engineering lapses, poor judgments, and efforts to reduce costs at the expense of system reliability. These, in turn, was to a large degree the result of more global underlying “organizational” and institutional problems associated with the governmental and local organizations jointly responsible for the design, construction, operation, and maintenance of the flood protection system, including provision of timely funding and other critical resources.

Our findings to date indicate that no one group or organization had a monopoly on responsibility for the catastrophic failure of this regional flood protection system. Many groups, organizations and even individuals had a hand in the numerous failures and shortcomings that proved so catastrophic on August 29th. It is a complex situation, without simple answers.

It is not without answers and potential solutions, however, just not simple ones. There is a need to change the process by which these types of large and critical protective systems are created and maintained. It will not be feasible to provide an assured level of protection for

this large metropolitan region without first making significant changes in the organizational structure and interactions of the national and more local governmental bodies and agencies jointly responsible for this effort. Significant changes are also needed in the engineering approaches and procedures used for many aspects of this work, for the standards used in such design, in the conceptual approaches considered, and in the conceptualization and treatment of potential modes of failure and poor performance during design and operation. There is also a need for interactive and independent expert technical oversight and review as well. In numerous cases, it appears that such review would have likely caught and challenged errors and poor judgments (both in engineering and in policy and funding) that led to failures during Hurricane Katrina.

There are many detailed engineering lessons developed within this report, but a number of overarching engineering issues have been identified, and a number of the most important of these are presented below. These are a somewhat urgent set of issues, as the USACE and the IPET investigation are currently working to assess the level of risk associated with the now largely reconstructed system, and these issues impact that assessment.

1. Overall levels of safety and reliability targeted during engineering design and analysis were inappropriately low for a critical system protecting a major metropolitan area. Factors of safety and analysis methods and procedures used in design calculations for the “transient” loading conditions associated with hurricane-induced storm surge, coupled with the design surge elevations employed, provided levels of risk that were on the order two to three orders of magnitude higher than the standards generally used in U.S. dam practice where similarly large populations are at potential risk. This left little room for error, uncertainties, or surprises.

2. The difficult and complex geology of the region posed design challenges that were not adequately addressed. Insufficient site investigation and characterization of foundation soil conditions at many sites produced minor short-term project savings, but these pale against the massive losses that ensued. More attention needs to be paid to the geology, and more detailed site investigation and site characterization is clearly warranted given the potential consequences of failures.

3. There was a persistent pattern of attempts to reduce costs of constructed works, at the price of corollary reduction in safety and reliability. This represented a policy that has now been shown to be “penny wise and pound foolish”.

4. A pattern of optimistic assessment with regard to a number of potential sources of risk and of potential modes of failure was endemic to the detailed design of a number of major system elements. This included:

- (a) The risks associated with underseepage flows during “transient” storm surges were systematically underestimated. This led to the use of sheetpile curtains that were extended to inadequate depths at a number of locations, and it led directly to a number of the major failures and breaches during hurricane Katrina. Appropriate consideration and analysis of underseepage issues (including potential embankment instability due to pore pressure induced strength reduction, and potential erosion and

pipings) for transient storm surge conditions was routinely missing, and the overall system should now be re-evaluated with regard to these potential modes of failure.

(b) The use of highly erodible sand and even lightweight shell sand fills in levee sections also figured prominently at numerous locations of breaching and catastrophic erosion. Use of such materials should henceforth be disallowed in this system that protects a major metropolitan region. Here again, the overall system should be re-evaluated for their presence, and the levels of risk posed by the presence of these unsuitable materials, both in levee embankments and at shallow depths within the underlying foundation soils. This risk should be mitigated.

(c) Similarly, design procedures did not include consideration of the potential failure mode that involves formation of a ‘gap’ at the outboard side of the floodwalls, between the outboard section of the earthen levee embankment and the sheetpile curtains supporting the floodwalls. Formation of such gaps occurred at a number of sites as pressure increased on the outboard sides of the floodwalls, and water then intruded into the gaps and greatly increased the lateral “push” of the storm surge (water) against the sheetpile/floodwalls. A number of failures occurred as a result. In the future, such gapping should be “assumed” during analysis and design. Many of the “I-wall” type concrete floodwalls are currently being removed and replaced by the more robust “T-wall” type floodwalls (which have additional battered piles to help them resist overturning and lateral displacement.) These T-wall systems will have somewhat increased capacity, but they too will need to be analyzed with regard to this potential failure mode. It cannot simply be assumed that “T-walls” are intrinsically completely safe.

5. Design review was generally inadequate, and there was an institutional failure to catch and challenge unconservative design assumptions and interpretations of data. Instigation of interactive consultation and review by consulting panels of leading outside experts is common practice in dam engineering. It should be common practice in levee engineering as well, when the levee systems protect significant populations. In addition, it would be wise for local interests (e.g. the State and/or the City) to mount an additional unbiased expert review panel (again including leading experts) to provide a second check and opinion. At many failure sites it appears likely that suitable expert review would have caught and challenged errors and questionable judgments that contributed to the failures observed.

6. Improved advantage needs to be taken of ongoing technical advances related to the engineering, design and construction of these types of regional flood defense systems. Engineering design concepts and analysis approaches employed at many locations were sorely “dated” at the time of their use, and there was a lack of movement towards embracing new and improved methods and tools. “This is how we have always done it” is a potentially dangerous concept here, and inertia in terms of embracing technical advances was a troubling issue. Failure to embrace their own full-scale field testing and research led the Corps to neglect the “water-filled gap” as a potential failure mode to be addressed during design. And it is time to relegate the “Method of Planes” to its place in history and to adopt more modern and more flexible stability analysis methods capable of addressing a wider range of potential failure modes.

7. The USACE is the lead oversight agency with regard to engineering and construction of the regional flood defense system. The Corps needs to be allocated adequate funding and support, given the ability to perform research, and granted adequate freedom to facilitate the continuing professional development of highly qualified engineers within the Corps in order to ensure an adequate in-house supply of engineering expertise for their critical role.

15.4 Looking Back - Organized for Failure

The ILIT mandate at the outset of this investigation study was to include study of historical and organizational - institutional issues, political and budgetary considerations, decision making, utilization of technology, and the evolving societal, governmental, and organizational priorities over the life of the Flood Defense System for the Greater New Orleans Area (NOFDS). One cannot understand the failure of the NOFDS without understanding both the underlying engineering and organizational mechanics that were interwoven in the evolution of this failure.

ILIT's view of the importance of these *organizational, institutional, resource and technology delivery* factors increased during the course of this study. These factors are grouped into what is termed a *Technology Delivery System (TDS)*. A TDS can be represented as system that has organizational components, inputs, outputs, and information linkages that are interactive, inter-dependent, and adaptive. Three primary organizational components comprise a TDS for a system such as the NOFDS. These are: (1) society (the public), (2) government (federal, state, local), and (3) enterprise (commercial, industrial, private). 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.

Eight principal categories of TDS malfunctions were identified that played major roles in the catastrophic failure of the NOFDS, and these are as follow:

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 reliability) provided, and also the continued improvement in these levels of protection (and reliability) 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 when hurricane Katrina arrived. 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, lower expenditures, 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 development, emergency response, and ecological restoration have served to divert attention from flood control. Public and Congressional pressures to (1) reduce backlogs of approved projects, (2) improve project and organizational efficiency (e.g.: down-sizing, out-sourcing, etc.), (3) address environmental impacts, and (4) 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, unforeseen failure modes can be expected to develop. These unforeseen, but foreseeable, 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 overall NOFDS. Synthesis was subverted to decomposition, as projects were engineered and

constructed in piecemeal fashion to conform to incremental appropriations. As a result, many failures developed at interfaces or 'transitions' 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 employed. Factors of safety used in design of the primary elements in the NOFDS were not sufficient; and represented implicit levels of system reliability that were inappropriately low for a system protecting a major metropolitan region. 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.

15.5 Looking Forward - Organizing for Success

The following recommendations are offered for consideration in developing a NOFDS that will have desirable and acceptable quality and reliability. These recommendations are divided into two categories: engineering developments and organizational developments. It will take both working together to realize the desired goals of an NOFDS. The primary challenge is timely mobilization of inspired and inspiring leadership, adequate resources, existing technology, and high reliability organizations.

15.5.1 Strategic and Engineering System Issues:

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: (1) raising, strengthening and improvement of the erosion resistance of levees, (2) provision of floodgates, and storm surge barriers, (3) improved positioning and defense of modern pump stations, (4) compartmentation to limit potential flooding consequences, and (5) 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 lose important performance characteristics (e.g. the ability to overtop for some limited period of time without catastrophic breaching), and provision of excess capacity so that if some elements or components are overloaded or do not perform desirably then desirable protection can be maintained. 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 excessively 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 improvements 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, 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 cannot be filled with existing research results, then research should be undertaken or sponsored to enable timely filling of the technology gaps. Upgrading the technical capabilities of the engineers responsible for oversight and design, and the use of interactive boards of consultants as well as expert external review boards, would likely greatly improve the ability to deliver reliable flood protection.

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.

15.5.2 Technology Delivery System Developments - Organizing for Success

It will not be feasible to create an adequately reliable regional Flood Defense System without addressing the organizational, institutional, political and resources issues that adversely affect the current process. Simply changing engineering procedures, design manuals, and the review process will not suffice.

The primary requirement for reconstitution of a Technology Delivery System that can and will provide an adequate and acceptably reliable 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 reorganization and modernization efforts directed toward (1) increasing and maintaining in-house engineering capabilities and project performance, (2) increasing in-house research and development capabilities, (3) increasing in-house engineering performance on technically challenging projects, (4) developing an organizational culture of high reliability founded on existing cultural values of Duty, Honor, Country, and (5) 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 within the USACE. This will require close and continuous collaboration of federal legislative, executive, and judicial agencies. This will require that the USACE 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. This will require additional funding; in the end the nation will get only what it is willing to invest and pay for.

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 responsibly deal with potential national, regional, and local catastrophes.

15.6 Conclusion

The performance of the New Orleans regional flood protection system during hurricane Katrina was unacceptable. Detailed study has now led to understanding of the physical causes and mechanisms of most of the many failures and breaches, and this in turn provides a basis for development of improved conceptual and engineering design methods, as well as improved review and overview paradigms.

Simply addressing engineering design methods, standards and procedures is unlikely to be sufficient to provide a suitably reliable level of protection, however. There is also a need to resolve difficult issues intrinsic in the operations and relationships between (1) Federal and more local government as they serve as decision-making, policy and funding sources, (2) the Federal and local agencies responsible for the actual design, construction and maintenance of such flood protection systems, and (3) private enterprise that must assist in construction. Some of these groups need to enhance their technical capabilities; a long-term expense that would clearly represent a prudent investment at both the national and local level, given the stakes as demonstrated by the losses in this recent event. Steady commitment and reliable and sustainable funding, shorter design and construction timeframes, clear lines of authority and responsibility, and improved overall coordination of disparate system elements and functions are all needed as well.

The overall philosophy and basis for design of these types of expensive and vital systems warrants reconsideration. Improvements such as (1) conceptual design strategies that involve working in conjunction with natural barriers and other favorable

features, (2) system-based risk assessment, analysis and design, (3) allocation of appropriate resources, (4) embracing research and appropriate technological advances, and (5) maintenance of a deliberate culture of diligence in seeking overall system reliability would all represent significant steps forward.

And there is some urgency to all of this. The greater New Orleans regional flood protection system was significantly upgraded in response to flooding produced by Hurricane Betsy in 1965. The improved flood protection system was intended to be completed in 2017, fully 52 years after Betsy's calamitous passage. The system was incomplete when Katrina arrived. As a nation, we must manage to dedicate the resources necessary to complete projects with such clear and obvious ramifications for public safety in a more timely manner.

New Orleans has now been flooded by hurricanes six times over the past century; in 1915, 1940, 1947, 1965, 1969 and 2005. It should not be allowed to happen again.