CHAPTER TWELVE: ORGANIZED FOR FAILURE

We reflect on the 9/11 Commission's finding that the most important failure was one of imagination. The Select Committee believes Katrina was primarily a failure of initiative. But there is, of course, a nexus between the two. Both imagination and initiative - in other words, leadership - require good information. And a coordinated process for sharing it. And a willingness to use information - however imperfect or incomplete - to fuel action.

Hundreds of miles of levees were constructed to defend metropolitan New Orleans against storm events. These levees were not designed to protect New Orleans from a category 4 or 5 monster hurricane, and all of the key players knew this. The original specifications of the levees offered protection that was limited to withstanding the forces of a moderate hurricane. Once constructed, the levees were turned over to local control, leaving the USACE to make detailed plans to drain New Orleans should it be flooded.

The Local sponsors - a patchwork quilt of levee and water and sewer boards - were responsible only for their own piece of levee. It seems no federal, state, or local entity watched over the integrity of the whole system, which might have mitigated to some degree the effects of the hurricane. When Hurricane Katrina came, some of the levees breached - as many had predicted they would - and most of New Orleans flooded to create untold misery.

A Failure of Initiative

Final Report of the Select Bipartisan Committee

U.S. House of Representatives, 109th Congress (2006)

12.1 Introduction

This chapter summarizes results of studies performed by members of the Independent Levee Investigation Team (ILIT) into the organizational and institutional factors associated with failure of the Flood Defense System for the greater New Orleans area (NOFDS).

Over a period of eight months following failure of the NOFDS on 29 August 2005, the ILIT examined more than 2,800 documents, conducted more than 220 interviews, and reviewed more than 370 inputs from the general public. During the past 8 months, there have been a large number of extensive investigations into the reasons for the failure of the NOFDS. The ILIT made full use of results from these investigations. These results were combined with results from the ILIT investigations to formulate the primary findings documented in this chapter; organized for failure.

Chapter 13 outlines our thoughts on future organizational developments; *organizing for success*. Chapter 14 summarizes background on engineering a long-term NOFDS and the associated engineering guideline developments; *engineering for success*.

Appendix F presents a synopsis of the history of developments in the NOFDS between 1965 and 2005, summarizes background on understanding failures of engineered systems, and provides key quotations and results from other studies of failure of the NOFDS. Results from studies of the engineering and organizational aspects associated with future developments of a NOFDS are summarized in Appendix G. Appendix H, by Dr. Edward Wenk, Jr., documents a study of *How Safe is Safe? - Coping with Mother Nature, Human Nature and Technology's Unintended Consequences*.

12.2 Purposes

The ILIT studies have two purposes:

- to understand how and why the failure of the NOFDS developed, and
- to understand alternatives to reduce the likelihoods and consequences of such future catastrophes.

If we can adequately understand the mistakes of the past, then perhaps we have a chance to avoid making them in the future.

The ILIT approach in this study was to include 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 NOFDS. One cannot develop an adequate understanding of the failure of the NOFDS without understanding both the engineering and organizational factors that were interwoven in development of this failure.

12.3 Failure of the New Orleans Flood Defense System

Of particular importance in this diagnosis is the organizational - institutional *Technology Delivery System (TDS)* that was used to develop the NOFDS. This TDS is comprised of three major components: (1) Government (federal, state, local), (2) Industry, and (3) the Public. All of these components and elements are interconnected through a complex series of multiple connections that represent information and communication transmission. Inputs to the system include technical information, human and natural resources, capital, manufactured goods and services and values and preferences. Outputs from these components are represented in the NOFDS including its intended and unintended consequences.

The Government component is represented by agencies from all three branches (executive, legislative, judicial) at federal, state, and local levels. There are important multiple connections among federal, state, and local (parish, city) agencies. In the case of the NOFDS, the primary agencies are the Corps of Engineers, the Louisiana Department of Transportation and Development, and the parish levee boards and sewerage and water boards. All of these government agencies are interconnected with a multitude of other federal, state, and local agencies. These parts of the TDS were summarized by the Select Bipartisan Committee to Investigate the Preparation for and Response to Hurricane Katrina (2006):

> *Several organizations are responsible for building, operating, and maintaining the levees surrounding metropolitan New Orleans. USACE generally contracts to design and build the levees. After construction USACE turns the levees over to a local sponsor. USACE regulations state that once a local sponsor has accepted a project, USACE may no longer expend federal funds on construction or improvements. This prohibition does not include repair after a flood. Federally authorized flood control projects, such as the Lake Ponchartrain project, are eligible for 100 percent federal rehabilitation if damaged by a flood.*
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> *The local sponsor has a number of responsibilities. In accepting responsibilities for operations, maintenance, repair, and rehabilitation, the local sponsor signs a contract (called Cooperation Agreement) agreeing to meet specific standards of performance. This agreement makes the local sponsor responsible for liability for that levee. For most of the levees surrounding New Orleans, the Louisiana Department of Transportation and Development was the sate entity that originally sponsored the construction. After construction, the state turned over control to local sponsors. These local sponsors accepted completed units of the project from 1977 to 1987, depending on when the specific units were completed. The local sponsors are responsible for operation, maintenance, repair, and rehabilitation of the levees when the construction of the project, or a project unit, is complete.*

In development of the NOFDS, the Corps of Engineers had the primary responsibilities for development of the concepts, design, and construction (Collins 2005; National Academy of Engineering 2006). Once construction was completed, the operations and maintenance were then turned over to the responsible state and parish agencies. At the federal level, the Corps of Engineers had important interfaces with the executive branch (e.g., Department of Defense and the White House), the legislative branch (Congress), and the judicial branch. Important interfaces also developed with state, parish, and city government agencies, industry, and with the general public. The Industry component is represented by commercial enterprises that are involved throughout the life-cycle of the system including concept development, design, construction, operation, and maintenance. The Public component is represented by national, state, and local individuals and groups that are concerned with and influenced by the NOFDS.

12.4 Extrinsic Factors

Failure of the NOFDS is firmly rooted in *Extrinsic* factors associated with human and organizational performance (Appendix F; Rasmussen 1997; Svedung and Rasmussen 2002; Bea

2006). Causes of the NOFDS failure spanned the full spectrum of organizational failures: cultures, communications, lack of knowledge, use of existing technology, structure and organization, management, leadership, monitoring and control, and mistakes. Mistakes involved breakdowns in perceptions, interpretations, decisions, discrimination, diagnoses, judgments, and actions. In several notable cases, doing things right and doing the right things apparently were surrendered to getting the job done in an expedient way. These observations were summarized by the Select Bipartisan Committee to Investigate the Preparation for and Response to Hurricane Katrina (2006):

> *Both USACE and the local sponsors have ongoing responsibility to inspect the levees. Annual inspections are done both independently by USACE and jointly with the local sponsor. In addition, federal regulations require local sponsors to ensure that flood control structures are operating as intended and to continuously patrol the structure to ensure no conditions exist that might endanger it. Records reflect that both USACE and the local sponsors kept up with their responsibilities to inspect the levees. According to USACE, in June 2005, it conducted an inspection of the levee system jointly with the state and local sponsors. In addition, GAO reviewed USACE's inspection reports from 2001 to 2004 for all completed project units of the Lake Ponchartrain project. These reports indicated the levees were inspected each year and had received 'acceptable' ratings.*
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> *However, both the NSF-funded investigators and USACE officials cited instances where brush and even trees were growing along the 17th Street and London Avenue canals levees, which is not allowed under the established standards for levee protection. Thus, although the records reflect that inspections were conducted and the levees received acceptable ratings, the records appear to be incomplete or inaccurate. In other words, they failed to reflect the tree growth, and of course, neither USACE nor the local sponsor had taken corrective actions to remove the trees.*

Complex formal and informal organizations developed that involved a multiplicity of federal, state, parish, city, commercial - industrial, and public enterprises. These organizations had vastly different means, methods, and resources that evolved in different ways at different times. Executive, legislative, and judicial forms of government provided a primary framework for interactions with commercial, industrial, public, and private enterprises. Malfunctions within and between these organizational elements provided the primary element responsible for the failure of the NOFDS (Government Accountability Office 2005, Members Scholars of the Center for Progressive Reform 2005, Select Bipartisan Committee to Investigate the Preparation for and Response to Hurricane Katrina 2006, Townsend 2006, Houck 2006). Ineffective leadership and management were evident before and after failure of the NOFDS. Leonard and Howitt observed (2006):

> *The leadership failures that contributed to the events we witnessed on the Gulf Coast last August and September began long, long before Katrina came ashore. It literally took centuries to make the mistakes that rolled together to make Katrina such a vast natural and human-made calamity. First, for hundreds of years, people have been constructing and placing large amounts of precious (human lives) and expensive (infrastructure, homes, communities) value in New Orleans and along the Gulf Coast in the known path of severe storms. Second, for decades, we have been living with inadequately designed, built, or maintained*

man-made protections (levees, building codes, pumps, and so on), and have pursued policies and interventions that actively contributed to the destruction of the natural buffers (salt marshes, dunes, and other natural barriers) against the hazards created by placing value in harm's way. Third for years - at least since 9/11, but even before that - we have known that we had systems of preparation and response that would prove inadequate against truly large scale disasters. Fourth, in the days and hours before Katrina's landfall, we failed to mobilize as effectively as we might have those systems that we did have in place. And fifth, the days following the impact, we did not execute even the things that we were prepared to do as quickly and smoothly as we should have. How do we not, in the future, find ourselves again with those same regrets? Our work needs to begin with a judicious and honest assessment of threats, followed by investments in prevention and mitigation and by construction of response systems that will be equal to a larger of class of disturbances than we have previously allowed ourselves to contemplate."

In development of the analysis of Extrinsic factors involved in failure of the NOFDS, it is important to recognize that while the Corps of Engineers was primarily responsible for design and construction of the NOFDS and the local state and parish organizations (e.g., Department of Transportation and Development, Levee Boards, Sewerage and Water Boards) were primarily responsible for operations and maintenance, these organizations were subjected to a wide variety of influences and constraints provided by their executive, legislative, judicial and public constituents. The responses of these multiple organizations to provide an adequate NOFDS was clearly lacking. The Senate Committee on Homeland Security and Governmental Affairs report supports this (Leonard and Howitt 2006).

For many years, the Corps of Engineers was severely criticized for delays and cost increases in the Lake Pontchartrain and Vicinity Hurricane Protection Project (Government Accountability Office 1972, 1982, 2005b, 2005c; Carter 2003, 2005a, Carter and Sheikh 2003, Carter et al 2005). Many of these delays and cost increases were reflections of challenges posed by local cost sharing and participation requirements. Local participation and funding requirements introduced additional problems as did interactions with the general public. Additional complexities were added by federal and state legislative, executive, and judicial participation in the developments (lots of 'managers' with different goals, objectives, means, and methods).

At the federal level a long and complex process is required to identify, define, select, and develop projects and secure funding authorizations (Carter and Hughes 2005, Carter 2005d). Historic problems exist with project backlogs, increases in funding requirements, reprogramming actions to manage project funds, and even the fundamental basis for project selection; cost-benefit analyses (Government Accountability Office 1983, 2003, 2005). In short, the Corps must operate in a world that is not of its own making. Outside pressures on the Corps have been negative as well as positive in terms of their effects on performance.

This study indicates that the historic procedures utilized to develop the cost-benefit analyses employed by the Corps of Engineers were and are seriously flawed. These procedures are apparently responsible for some of the seemingly illogical elements in the NOFDS. All costs and all benefits are not incorporated into these analyses (General Accountability Office 2003, Heinzerling and Ackerman 2002). These analyses fail to recognize many important considerations, uncertainties and projected future developments (Government Accountability Office 2003).

Because of the multitude of recognized deficiencies presently incorporated into traditional Corps cost-benefit analyses, flawed information is provided to policy makers to help them make wise decisions regarding provision of financial resources to develop an adequate NOFDS. Within the executive branch, the Office of Management and Budget has the responsibility to ensure the quality of cost-benefit analyses and resource recommendations, yet the deficiencies were not effectively addressed.

This study indicates that many of the flaws that were introduced into the NOFDS came from flawed decision making regarding provision of financial resources by many organizations at many levels, times, and places. The exceedingly complex and flawed organizational system and its decisions regarding provision of resources that evolved during development of the NOFDS was a primary cause of the failure of the NOFDS. The Corps of Engineers does have and use advanced methods to evaluate costs, benefits, and risks for flood damage reduction studies and dam safety (National Research Council 1983; U.S. Army Corps of Engineers 1996; Powers 2005). Application of these advanced methods was not, however, in evidence in the background available on development of the NOFDS. The substantial body of technology developed to assist risk management decision making (e.g., Fischhoff et al. 1981; Wenk 1989; Shapira 1995; Molak 1997; Kammen and Hassenzahl 1999; Spouge 1999; Moteff 2004; Jordan 2005; see Appendix H) should be further developed, codified and applied by the Corps to assist policy makers in making decisions regarding development and maintenance of levees and flood protection systems.

For many years, the Corps of Engineers has been subjected to extreme pressures at the federal and state levels to do more with less (Government Accountability Office 1997; Office and Management and Budget 2006); to do their projects better, faster, and cheaper; and improve project management (planning, organizing, leading, controlling). The organization's attempts to respond to all of these frequently conflicting pressures has introduced organizational turbulence and diversion of attention and resources that continues the present time. The Corps of Engineers developed a plan to re-engineer itself (U.S. Army Corps of Engineers, 2003b). However, it is clearly struggling with all of its constraints to achieve key elements in this plan (Office of Management and Budget 2006). Our study indicates that as in the case of NASA (Appendix F) technical and engineering superiority and oversight was compromised in attempts to respond to all of these constraints and pressures; especially those pressures for increased efficiency and decreased costs. Adequate quality and reliability in the constructed works has suffered and will continue to suffer until these challenges are successfully addressed.

Evidently the organizations responsible for the various parts of the life-cycle of the NOFDS did not have effective process auditing procedures (Knoll 1986). They did not have incentive systems that discouraged excessive and inordinate risk taking that could lead to less than desirable quality and reliability. Quality standards did not meet or exceed the referent standards required for a high quality and reliable NOFDS. These organizations did not correctly assess the risks associated with given problems or situations; apparently, situational awareness was frequently lost. These organizations lacked strong command and control systems as evidenced with appropriate rules and procedures, effective selection and training of personnel, decisions being made in the right ways at the right times by the right people, effective redundancy (robustness) to create tolerance to organizational defects, and maintenance of situational awareness for appropriate action. In general, these organizations performed as Low

Reliability Organizations (Weick and Sutcliffe 2001). Effective leadership and management was lacking (Townsend 2006; Collins 2005; Government Accountability Office 2006). Such organizational malfunctions were summarized by Irons (2005):

> *The evidence indicates the U.S. Army Corps of Engineers knew about the threat of breaches, as opposed to overtopping, since the early 1980s. Moreover, all concerned agencies, including those at the local, state, and federal levels, knew about the threat of overtopping and consequent flooding in even a Category 3 hurricane.*
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> *Basic flaws in the design of the levee protection system were first recognized over two decades ago, before the wetlands were so diminished. An outside contractor, Eustis engineering, was the first to express concerns about the levee vulnerability to breaching in the early 1980s. In 1981, the New Orleans Sewerage & Water Board developed a plan to improve street drainage by dredging the 17th Street Canal. The Corps of Engineers issued permits to do the dredging in 1984 and 1992, though the Corps was not a partner in the Project. Eustis Engineering contracted to do a design study for Modjeski and Masters, the consulting engineers on the project, and performed soil investigations on a section of the 17th Street Canal from south of the Veterans Memorial Boulevard bridges to just north of those structures. They found that 'the planned improvements to deepen and enlarge the canal may remove the seal that has apparently developed on the bottom and side slopes, thereby allowing a buildup of such pressures in the sand stratum.' Eustis' concerns about a 'blow-out', or breach, of the levee were strong enough that the company recommended test dredging before the final design.*
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> *…The most puzzling point about the dredging project is that the Corps of Engineers planned to follow the project by raising the floodwall from 10 feet to 14.5 feet. It is unclear whether the Corps paid attention to the contractor's concerns since most of the documents related to the work remain unavailable to the public. Although the Corps of Engineers was not a direct partner in the dredging, it was aware of the work and knew it would have an impact on its later project. Indeed, contractors working for the Corps on the later project raised their own concerns about the soil and foundations of the levee.*
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> *Reports indicate that key sections of the levee system's soil and foundation, particularly the floodwall on the 17th Street Canal where much of the serious flooding occurred, posed serious problems for the contractors involved. Court papers from 1998 show that Pittman Construction indicated to the Corps of Engineers as early 1993 that the soil and foundation for the walls were 'not of sufficient strength, rigidity and stability' to build on. The construction company claimed that the Corps of Engineers did not provide it with complete soil data when it developed a bid on the levee project.*
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> *…Engineers now say the difficulties Pittman Construction faced were early warning signs that the Corps of Engineers ignored. The Corps of Engineers officially disputed the points made by Pittman Construction regarding the soil condition, though it now seems clear that the crucial breaches in New Orleans occurred in levees where the floodwall foundations were not as deep as the canals and that the Corps of Engineers was aware of the issue.… Would an organization*

with processes in place to support ongoing learning, and surprise-avoidance, fail to recognize the legitimacy of the contractor's point rather than argue about purely budgetary issues related to the contract?

Principal knowledge related malfunctions centered on inappropriate use of existing technology ("unknown knowables") and inadequate measures to disclose unknowns throughout the life-cycle of the NOFDS. Examples include the subsidence and settlements of critical flood protection elements in the NOFDS including those of the floodwalls along the drainage canals (which are now known to be about two feet below intended elevations), the Industrial Canal floodwalls (about three feet below intended elevations), and the levee elevations along the Mississippi River Gulf Outlet (MR-GO) that front the south side of Lake Borgne (about two to three feet below intended elevations) (Interagency Performance Evaluation Task Force, 2006a, 2006b). Concerns regarding settlements and subsidence were expressed early in the development of the NOFDS, but apparently no effective action was taken to quantify the regional subsidence and settlements and to make appropriate adjustments to the NOFDS. Even though information was developed by the National Geodetic Survey that the reference benchmarks being used as controls in construction of the NOFDS were in excess of one foot low, the decision was made in August 1985 to use the benchmarks "current at the time of construction of the first increment of the project" (1965) (Chatry 1985). The report of the Senate Committee on Homeland Security and Governmental Affairs observed (2006):

In Designing, constructing and maintaining the hurricane-protection system the Corps did not adequately address: (a) the effects of local and regional subsidence of land upon which the protection system was built; and (b) then-current information about the threat posed by storm surges and hurricanes in the region.

Another important example of knowledge development and utilization malfunctions is that of the overtopping and breaching of the levees and flood control structures along the MR-GO. Of particular importance is the stretch of levee that defends St. Bernard Parish between the bayou Bienvenue and bayou Dupre flood control structures. This stretch of levee was badly damaged during hurricane Katrina as were sections where the levee joined the flood control structures (Seed et al., 2005). The current work of the ILIT indicates that the sections adjacent to the flood control structures breached where the construction had covered the original bayou channels. The design of the junctions between the flood control structures and the earth levee were not sufficient to withstand the surge and wave action developed during hurricane Katrina. In a similar manner, the levees between bayous Dupre and Bienvenue were not able to withstand the waves and surge that developed across lake Borgne; they were severely breached and massively eroded. The ILIT indicates that the wave and surge velocities that preceded the arrival of the peak surge likely were initiating breaching before these levees were overtopped so that when the levees were overtopped, the breaches could be readily expanded and allow large volumes of water to enter the protected areas in St. Bernard parish. In contrast, the performance of the levee north of bayou Bienvenue to its intersection with the GIWW was markedly different. Our studies indicate that this performance resulted from a combination of factors that included superior soils used in construction of this stretch of levee (highly erosion resistant) and natural protection (water velocity reduction) afforded by adjacent wetlands on the outboard side of the levee.

The MR-GO is a 76-mile long navigation channel connecting the Gulf of Mexico to the Port of New Orleans Inner Harbor Navigation Canal via the GIWW. The channel bisects the marshes of lower St. Bernard Parish and the shallow waters of Chandeleur Sound. Construction of this shipping channel/canal was authorized by Congress in 1956. Its construction was started in 1958 and completed in 1965. Many people contend that the MR-GO played a prominent role developing the flooding of St. Bernard parish and East New Orleans during hurricane Betsy (1965). Before, during, and after construction of the MR-GO (48 years) many concerns were expressed regarding the effects of this canal on the adjacent wetlands and on its potential focusing effect on storm surge propagation into the IHNC. Originally conceived as a way to get deep draft ships to the Port of New Orleans facilities in the IHNC, it failed to realize its commercial justification because of changes in ships (deeper drafts) and because of the need for almost continuous dredging to keep the channel open. The channel also allowed the highly saline waters from the Gulf of Mexico to intrude into the adjacent fresh and brackish water wetlands and marshes, destroying many in the process (estimated more than 20,000 acres of marsh have been destroyed). In 1988, the St. Bernard Parish Council unanimously adopted a resolution to close MR-GO because it constituted a threat to public health and safety. In October 2004, the Louisiana Legislature passed a resolution urging closure of the MR-GO and immediate implementation of remedial measures to address the risk posed by the MR-GO.

Available information and soil sampling conducted during this study indicates that the levees between bayous Bievenieu and Dupre originally were constructed from dredge spoil deposited during the construction of the MR-GO (A. Theis, personal communication, January 2006) (see Chapters 6 and 9). The USACE’s own design documentation states that the materials used are potentially susceptible to erosion (USACE, DM-___, 19__). Additional construction was proposed to increase the height of the levee at the time of hurricane Katrina. While these materials were highly susceptible to scour and erosion, the ILIT study has failed to discover documentation of plans or proposals for armoring this levee prior to hurricane Katrina.

Given the recognized degradation of the protection afforded by wetlands (Hallowell 2001), recognition of the erodability of the levee soils, the lack of provision of protection for the levee soils, recognized deficiencies in the design criteria, the continued challenges of keeping these levees at their authorized elevations (significant subsidence and compression), and the repeated expressions of concerns for the adequacy of these protective works, the performance of this part of the NOFDS was a “predictable surprise.” The Member Scholars of the Center for Progressive Reform (2005) arrived at similar conclusions.

Rejection and misuse of technology are evident in the history of the NOFDS. Interactive risk assessment and management approaches (e.g., Quality Assurance and Quality Control) (Knoll 1986; Loosemore 2000) to help detect, analyze, and correct knowledge related challenges apparently failed for a wide variety of reasons including excessive authority gradients, low task and situational awareness, excessive professional courtesy, cultural-societal morays, excessive beliefs, deficiencies in communications, and deficiencies in resource and task management. Irons observed (2005):

> *The U.S. Army Corps of Engineers is historically an insular agency, known for doing things its own way. It is not possible to say whether surprise-avoidance processes are in place at the Corps of Engineers, until the public receives more access to internal documents. The failure of Corps' staff to recognize and prioritize the challenges of levee upgrades and receding wetlands to the city of New Orleans, and surrounding areas, strongly suggests that surprise-conducive processes characterize its organization. The Corps' organization has over the past few decades outsourced more work, lost many engineers to private industry, and consequently suffered a diminished capacity to attract top-notch engineers.*

New Orleans had dodged the bullet many times, with the major force of hurricanes skirting around the area. Nevertheless, most people with a reason to know about it were aware that a Category 3 hurricane posed a severe threat to the New Orleans' levee protection system, and a Category 5 hitting land as a Category 4, as with Katrina, posed a catastrophic threat.

The occurrence of a hurricane like Katrina was not unexpected in New Orleans; neither were the complications faced in the aftermath of the storm. Given this understanding, and the neglect in preparing for a hurricane like Katrina, as well as the ineffective response preparations, it seems reasonable to assert that Katrina as well as its aftermath was a predictable surprise. The threats posed by the hurricane, and the likely aftermath, were well known and unsurprising to most who thought about the hurricane threat to New Orleans. Unfortunately, much of the local, state, and federal leadership, especially the U.S. Army Corps of Engineers, appears to have remained complacent about preparing the levees for a catastrophic hurricane.

All of these Extrinsic factors represent corporate failures in making decisions that involved all components of the TDS, including the public. The right things were traded-off for the wrong things at the wrong times and in the wrong ways. The failure of the NOFDS has all of the same ingredients found in previous catastrophic failures and accidents (Appendix F). It involved many different people and organizations developing a wide variety of malfunctions (e.g., decisions) over a long period of time (40 years). While a majority of these malfunctions were embedded during the concept and design phases, early warnings that indicated 'all was not well' as the NOFDS progressively developed were not detected, analyzed, and corrected. When hurricane Katrina finally tested the flawed, defective, and deficient NOFDS, it failed catastrophically producing the single most catastrophic failure of an engineered system in the history of the United States.

12.5 Intrinsic Factors

Intrinsic factors representing natural variability and analytical modeling uncertainties also played roles in the failure of the NOFDS (Vick 2002; Bea 2006). There are fundamental flaws in the basic criteria and guidelines that were used to design the NOFDS. These flaws include engineering elements that address:

- Design *demands* for the elements of the NOFDS; including the Standard Project Hurricane (SPH) conditions (surge heights in the NOFDS, frequency of occurrence, and lack of explicit recognition of the likely effects of more intense hurricanes) (Select Bipartisan Committee to Investigate the Preparation for and Response to Hurricane Katrina 2006, ASCE 2006a). Even though studies after 1972 indicated the need for increases in the design flood protection elevations due to greater surge and wave heights, these were not reflected in revised design guidelines (Brouwer 2003; Carter 2005a, 2005b).
- Design *capacities* for the elements of the NOFDS; including engineering guidelines used to design and construct the levees and floodwalls (e.g., analyses of levee stability, levee stability factors of safety, analyses of floodwall/sheetpile stability, deformation and stresses, floodwall design factors of safety, provision for deformations in the floodwalls during surge loading, provisions for robustness - defect and damage tolerance and fail-safe performance, and provisions for subsidence) (Select Bipartisan Committee to Investigate the Preparation

for and Response to Hurricane Katrina 2006; Vartabedian and Braun 2006; Irons 2005; ASCE 2006b).

- Configuration of the elements that comprise the NOFDS as an *integrated flood defense system* (Seed et al. 2005, ASCE 2006a). Many failures of the NOFDS occurred at a variety of types of interfaces in the physical elements such as interfaces between earth levees and concrete and steel flood protection elements and between the flood control structures and pump station structures (Carter 2005a). Flood discharge pumps were not sufficiently protected from backflow and exacerbated flooding. Many vulnerabilities were found at transitions and interfaces between flood protection elements and/or where other infrastructure elements were involved (Seed et al. 2005). The NOFDS was not an integrated, coherent system; rather "*it is a jointed series of individual pieces conceived and constructed piecemeal*" (ASCE 2006a).

12.5.1 Standard Project Hurricane

The heart of most Corps of Engineers hurricane protection projects since the 1960s has been the Standard project Hurricane, or SPH (Carter 2005a, Government Accountability Office 2005a, 2005b). The SPH was developed by the National Weather Service and the Corps of Engineers at the request of Congress in the 1950s "to provide generalized hurricane specifications that are consistent geographically and meteorologically for use in planning, evaluating and establishing hurricane design criteria for hurricane protection works" (Grahan and Nunn 1959). Attempts to describe the SPH in terms of Categories has lead to confusion because the SPH preceded development of the Saffir-Simpson hurricane scale (Categories). Depending on what characteristic of a hurricane is referenced, the SPH for the NOFDS can vary from a Category 2 to a Category 4 storm.

A primary goal of the SPH was to compare hurricane protection standards from region to region (Perdikis 1967). This standardized approach led to disparities within a particular region. The SPH model excluded storms that were deemed to be inordinately severe. For example, the 1979 revision of the SPH removed two particularly severe storms from the data base; hurricane Camille of 1969 and the Labor Day Hurricane of 1935. Experience shows that excluding outlier data is not appropriate in the context of dealing with extreme hazards. In addition, a higher standard of protection was specified for facilities and areas "where high winds, waves and storm surge could pose a threat to the public health and safety from a hurricane-induced accident at a nuclear power plant" (Schwert et al 1979). This shows that the SPH criteria includes an implicit cost-benefit assessment. This implicit assessment prevents policymakers (and the public they represent) from determining whether an extreme event is worth guarding against by excluding the possibility that such an event will or can occur. The following quotations indicate the interpretations that developed through the history of development of the NOFDS regarding what the system's SPH represented.

- "The Standard Project Hurricane wind field and parameters represent a 'standard' against which the degree of protection finally selected for a hurricane protection project may be judged and compared with protection provided at projects in other localities." (Graham and Nunn 1959).

- "The project is designed to protect against the Standard Project Hurricane moving on the most critical track. Only a combination of hydrologic and meteorological circumstances anomalous to the region could produce higher stages. The probability of such a combination of occurring is, for all practical purposes, nil." (U.S. Army Corps of Engineers 1974).

- "The SPH is a steady state hurricane having a severe combination of values of meteorological parameters that will give high sustained wind speeds reasonably characteristic of a specified coastal location. By reasonably characteristic is meant that only a few hurricanes of record over a large region have had more extreme values of the meteorological parameters." (National Weather Service 1979).

- "The SPH was expected to have a frequency of occurrence of once in about 200 years, and represented the most severe combination of meteorological conditions considered reasonably characteristic for the region." (Government Accountability Office 2005).

As can be seen, over time the SPH went from being a general indicator of threat levels to a guarantee of safety. The methods used to define the SPH were buried, along with their potential flaws and questionable assumptions. Because it became the "gold standard" of flood system performance, the SPH served to prevent up-to-date reanalysis of the true risks of catastrophic flooding of the NOFDS.

Recent work indicates that the probability that a hurricane will pass within 75 miles of New Orleans in any given year is about 12.5 percent, or about once every eight years (URS 2005). The likelihood of a major hurricane (Category 3 and above) are about 3.2 percent per year, or about once every 30 years. These projections do not account for the current period of intensified hurricane activity (Klotzbach and Gray 2006). Thus, the history of development and evolution of the SPH did not provide an adequate basis to understand the risks associated with catastrophic flooding of the NOFDS. The report of the Senate Committee on Homeland Security and Governmental Affairs observed (2006):

> *For several years, the Corps has inaccurately represented to state and local officials and to the public the level of protection that the hurricane system provided. The Corps claimed the system protected against a fast-moving Category 3 storm even though: (a) there was no adequate study or documentation to support this claim; and (b) information known to or provided to the Corps demonstrated that the claim was not accurate.*

Some industries (e.g. offshore engineering) that must deal with hurricane related hazards have developed specific design conditions (e.g., wave or surge height) and associated forces based on specified annual return periods (e.g., 100 years) (Bea 1990, 1998, 2001). These design conditions are chosen based on their potential *effects* (e.g., forces, water surface elevations) *on the structures to be designed*. The design conditions and prescribed forces are supplemented with safety factors (e.g., 2 to 4) that help assure that the resulting system can perform acceptably in much more intense conditions (frequently identified as Ultimate Limit State conditions) (Bea 1990). For important industrial facilities, these Ultimate Limit State conditions have return periods in the range of 1,000 to 10,000 or more years (Vick 2002; Baecher and Christian 2003, U.S. Army Corps of Engineers 1999, Tekie and Ellingwood 2003). For example, typical modern offshore structures in the Gulf of Mexico that are evacuated in advance of hurricanes are designed to be able to resist forces from hurricanes that have return periods of more than 1,000 to 5,000 years (Bea 1996). Structures that cannot be evacuated are designed to be able to resist forces from hurricanes and storms that have return periods in the range of 5,000 to 10,000 years

(Spouge 1999). In a similar vein, the Dutch currently provide protection against flooding of the Netherlands for events that represent the worst storm that could be expected to affect the area with return periods in the range of 1,000 to 10,000 years (Versteeg 1988, Netherlands Water Partnership 2005).

The SPH evolved to represent the most severe storm the government should guard against when designing hurricane protection projects. The SPH came to represent not only a method for comparative assessment of storm risks between geographic areas, but also a design standard that carried its own assurance of adequate reliability. For a variety of reasons, the concept of storms much more intense than the SPH was not allowed to explicitly enter the engineering process, even though the development of the SPH also involved a Probable Maximum Hurricane (PMH) (National Weather Service 1979):

> *The PMH is a hypothetical steady state hurricane having a combination of values of meteorological parameters that will give the highest sustained wind speed that can probably occur at a specified coastal location.* ***One of several possible uses of the values of meteorological parameters is to compute maximum storm surge at coastal points when the hurricane approaches along the most critical track*** [authors' emphasis].

Thus, it was clearly recognized that the SPH did not represent a maximum set of conditions for design against hurricane conditions. It is also clear that general public was not informed about the flooding risks that the selection of the SPH as a basis for design implied. In many cases, even though very inexpensive defenses could have been provided for the potential for hurricane surges exceeding those of the SPH (e.g., splash-pads behind I-walls and other similar floodwalls sensitive to overtopping erosion), these defenses were not provided.

Another important element of the SPH was that it was not revised as knowledge improved after the 1960s. Authorization constraints and engineering restraints were provided to us as an explanation for this (bureaucratic engineering). Tremendous strides in the meteorology and oceanography of hurricanes were made during the 1970's, and these improvements in technology continue to evolve to the present time (Simpson 2003, Interagency Performance Evaluation Task Force 2006a, 2006b). However, the SPH remains essentially the same as it was when it was initially defined in the 1950s and early 1960s. The natural variability in hurricane conditions, and the ability of these conditions to exceed the design norms of the SPH, and how these norms were translated in design resulted in many of the failures observed in the NOFDS in the wake of hurricanes Katrina and Rita.

12.5.2 Failure Modes and Safety Factors

A primary obligation of an engineer is to anticipate failure modes in the element, component, or system being engineered and then provide measures to prevent those failure modes from developing or from developing catastrophic results (Petroski 1985, 1994; Harr 1987; Wenk 1989, 1995, 1998; Appendix H). This obligation requires two primary things: (1) anticipation of possible failure modes, and (2) provision of defenses in depth to prevent and/or mitigate those failure modes.

The design demand for a particular component in the NOFDS, when combined with a prescribed safety factor and associated analytical models and procedures, determines the Ultimate Limit Strength of that element. When combined with an assessment of the intrinsic uncertainties (natural, model, parametric, state), the ratio of the Ultimate Limit Strength to the design demand (factor of safety) reflects the reliability (or probability of failure) associated with that component (Bea 1990; Kulhawy 1996; Duncan 2000; Whitman 2000; Vick 2002; Christian 2004; Lacasse 2004).

For example, a factor of safety of 1.3 was specified by the Corps of Engineers as the minimum acceptable safety factor for drainage canal levee lateral stability for the “transient” loading conditions represented by hurricane-induced storm surge and waves (U.S. Army Corps of Engineers 1988, 1989, 1990, 2000). Our examination of the basis for this factor of safety indicates that it was developed in the 1950s for levees used primarily to defend sparsely populated agricultural areas (Wolff, 2005). This factor of safety is embodied in current Corps of Engineers guidelines for the design of levees and assessment of slope stability (U.S. Army Corps of Engineers 2000, 2003). In the case of the drainage canal levees and those along the IHNC, and the floodwalls constructed on and in these levees, the design demand was determined by the total lateral force represented by the canal water level determined on the basis of the SPH (U.S. Army Corps of Engineers 1994).

In the 1990s the Corps of Engineers developed very advanced analytical methods to assess the reliability of important flood control components such as levees and dams (U.S. Army Corps of Engineers 1996, 1999, National Research Council 1983). These methods were validated with field and laboratory test data and field performance data (U.S. Army Corps of Engineers 1999; Wolff 1999; Duncan 2000). Application of these methods entailed an assessment of the inherent uncertainties for different failure modes and identification of target reliabilities for these modes (Wolff, 1999). Analytical methods were developed for both elements and assemblies of elements that represented flood control components and systems. The issues associated with ‘target’ or acceptable reliabilities were also addressed. These methods were used to define reliability-based design and maintenance factors of safety. Application of these methods for important flood protection facilities defending highly populated areas and the Corps of Engineers levee stability analysis procedures indicated the need for factors of safety that substantially exceeded those actually used for the levees and associated floodwalls that defended the NOFDS drainage canals. A need for “Factors of safety” of 2 to 3 and greater were indicated for very important facilities (annual target Safety Indices in the range of 3 to 4). Similar safety factors were identified by other investigators for similar facilities (Bea 1990, Duncan 2000, Whitman 2000, Vick 2002, Christian 2004, Lacasse 2004). Apparently a *technology lag* (breakdown in technology transfer) or rejection of technology (Sowers 1993) developed and persisted in the design guidelines used for levees and floodwalls in the NOFDS. As a result, standard design Factors of Safety were inadequate, and overall system reliability was compromised as a direct result.

Following Hurricane Katrina a similar technology lag was identified as one of the causes of the failure at the 17th Street canal. Both the ILIT (Seed et al. 2005) and the Corps of Engineers Interagency Performance Evaluation Task Force analyses (Interagency Performance Evaluation Task Force 2006b) of this failure concluded that a failure mode developed that was not recognized by the designers. This finding lead to the official contention that this was a “design failure.” *The information developed by the ILIT clearly indicates that this failure was a result, not a cause.*

This failure mode involved lateral deflection of the concrete floodwall and the sheet piles that supported that floodwall. This deflection resulted in separation between the stiff supporting sheet piling and the soft soil of the levee on the outboard side (flood side) of the wall. Water was then able to enter the gap and exert additional lateral forces against the lower portions of the sheetpiles and thus on the remaining (inboard) 'half' of the levee (and floodwall. Now the levee only had about 'half' of its width and mass able to transmit the lateral forces to the underlying soils. This combination resulted in lowering the lateral resistance with a commensurate lowering of the factor of safety.

This development was incorrectly reported as "unforeseen and unforeseeable" by the Interagency Performance Evaluation Task Force on March 10, 2006 (Marshall 2006; Seed and Bea 2006). In 1985, the New Orleans district of the Corps of Engineers conducted a full scale instrumented lateral load test of a 200-foot long sheet pile / flood wall in the Atachafalaya basin [the E99 sheetpile test] (U.S. Army Corps of Engineers 1988b). This particular location (south of Morgan City, Louisiana) was chosen because of the close correlation of the soil conditions in the New Orleans area with those at the test location. "The foundation soils are relatively poor, consisting of soft, highly plastic clays, and would be representative of near worst case conditions in the NOD (New Orleans District)." (U.S. Army Corps of Engineers 1988b).

Test data from the highly instrumented sheet pile wall and adjacent supporting soils indicated a gapping behavior (separation of the sheet piles from the soils). The test was designed to take an eight foot height of water (above the supporting ground level) with a factor of safety of 1.25. But, the wall was already in a failure condition (increasing lateral displacements with no increase in loading) when the water level reached only 8 feet instead of the calculated 10 feet. Strain gage readings on the sheet piles indicated that they were well below the steel yield point, thus the yielding had to have been developing in the supporting soils. Two very important pieces of information developed by the E-99 sheet pile tests were that there was potential soil separation from the sheet piles (allowing water to penetrate below the ground surface between the piles and the soils) and that the calculated safety factor was not reached (it was over-estimated due to unanticipated deformations in the soils).

Additional reports and professional papers further developed the experimental information and advanced analytical models that could be used to help capture such behavior (U.S. Army Corps of Engineers Waterways Experiment Station 1989b). Later developments in this work confirmed the gapping between the sheetpiles and the outboard side of the levee embankment, and were published in USACE reports and were eventually reported in the open professional engineering literature by Oner, Dawkins and Mosher (1997):

> *As the water level rises, the increased loading may produce separation of the soil from the pile on the flooded side (i.e., a "tension crack" develops behind the wall). Intrusion of free water into the tension crack produces additional hydrostatic pressures on the wall side of the crack and equal and opposite pressures on the soil side of the crack. Thus part of the loading is a function of system deformations.*

These developments in technology inexplicably were *not* reflected in the design guidelines used (U.S. Army Corps of Engineers 1988a, 1989a, 1990). We also found no evidence that questions regarding the adequacy of the design were raised after the design and construction were completed. Loss of corporate memory, breakdowns in technology transfer, and abilities to keep the design guidelines current with existing knowledge seemed to background these developments.

A second suspect element in the development of the failure at the 17Th Sreet Canal regarded characterizations of the soils that supported the earth levee and sheet piling in the vicinity of the 17th Street canal breach. The processes used at the time of design to analyze the soil types and engineering characteristics did not capture the unique characteristics of the soils. Soil strengths based on samples from beneath the crest of the levee, with higher strengths resulting from higher overburden loads and thus compression of these soils to a denser state, were inappropriately used to characterize the strengths of the soils at and beyond the toes of the levees (where lower overburden loads resulted in lower strengths). In addition, the spatial averaging process (vertical and lateral) did not capture the unique soil characteristics in the vicinity. Soils in Southern Louisiana and other parts of the Gulf Coast have very complex histories due to past floods, hurricanes, the rise and fall of sea level, changes in vegetation, and other events. Far from being uniform, they contain complicated and rapidly varying strata of different materials with very different characteristics.

In 1964 - 1965 the Corps ran a full scale levee test in the Atachafalaya basin in which advanced studies were conducted regarding characterizations of the soil strengths and performance – stability characteristics of the levee (U.S. Army Corps of Engineers 1968; Kaufman and Weaver 1967). The levee test sections were thoroughly instrumented and their performance monitored during and after construction. Various analytical methods were used to evaluate the usefulness and reliability of the various methods. These developments clearly indicated the need to understand the geologic soil depositional processes and the associated variations in soil strengths (horizontal and vertical) in order to understand the performance and stability characteristics of levees. The importance of local soil conditions to performance of the levee was clearly pointed out. The tremendous importance of overburden loads on soil strengths was a major focus of this work; and led to award-winning advancement of the Stress History and Normalized Engineering Performance (SHANSEP) framework for evaluation and modeling of the strengths of these types of soils. Additional reports and professional papers were published that resulted in significant advances to the engineering knowledge (Duncan 1970, Ladd et al. 1972; Edgers et al. 1973; Foott and Ladd 1973, 1977). None of these vital principals, however, were subsequently incorporated in the design and analysis of the 17th Street canal levees and floodwalls.

In-depth background and understanding of the geologic and depositional environment and history of vital importance to understanding the characteristics of the Mississippi Basin soils were developed in the 1950s and 1960s (Fisk et al. 1952; Kolb and Van Lopek 1958; Krinitzsky and Smith 1969) and the Corps of Engineers led in the development of this background. Of particular importance was recognition that the marsh and swamp deposits were “treacherous” and highly variable. It was repeatedly pointed out that “careful and detailed characterization of the soil properties was required.” Further, the studies cited above led to the recognition that the methods based on traditional Corps of Engineers soil characterization and stability analyses gave factors of safety that were unconservative (too large); (Foot and Ladd 1977). As in the first instance, these developments in technology inexplicably were not reflected in the design guidelines and practices that were used in the actual design studies.

The safety factors used in design were not sufficient to accommodate the uncertainties inherent in the design procedures and processes and inherent in the environment in which the facility would exist. Important failure modes in the components were not recognized. When the system was tested, it failed because of a confluence of intrinsic and extrinsic uncertainties. *This was not a design failure; this was a failure on the part of the organizations responsible for the design and construction of the flood defense works to effectively use proven technology*.

12.6 Life-Cycle Development of Flaws

Sources of flaws in the NOFDS developed during the life-cycle of the system starting with its concept (e.g., SPH), then during design (e.g., I-wall configurations, strength and stability guidelines, factors of safety), construction (e.g., normalized reports of excavation and forming instabilities and seepage from canals) and operation (e.g., persistent reports of leakage from canals and signs of ground instability), and finally during the maintenance (e.g., in-ground construction, vegetation growth on and adjacent to levee toes) phases (Select Bipartisan Committee to Investigate the Preparation for and Response to Hurricane Katrina 2006, Irons 2005). Similar life-cycle flaws were developed and propagated in the levee and flood protection structures adjacent to the MR-GO. *Important flaws in the NOFDS were embedded in every stage of the life-cycle.* In many cases, these flaws were allowed to propagate and magnify. Early warning signs were ignored or were ineffectively addressed. NOFDS component interface flaws that developed throughout the life-cycle of the NOFDS were particularly evident.

When the NOFDS was challenged by hurricane Katrina, these flaws became evident. Had these flaws not been present, it is likely that hurricane Katrina would not have developed into a major catastrophe.

Design challenges not successfully addressed were traced to fundamental flaws that became embedded in engineering design procedures and how these procedures were used. Tests were performed and the results not properly utilized, and in several key cases, not utilized at all (Seed and Bea 2006). Even though procedures for other similar facilities (e.g., dams, coastal and offshore structures) existed and were highly developed, the design (also construction, operation, inspection, maintenance, and repair) technology was not integrated into the design of the NOFDS (rejection or misuse). In addition to flaws previously discussed, the design procedures focused on individual components, with insufficient treatment given to the concepts of integrated system performance, defenses in depth, and robustness (damage and defect tolerance). The Member Scholars of the Center for Progressive Reform arrived at similar conclusions in their report titled *An Unnatural Disaster: The Aftermath of Hurricane Katrina* (2005).

12.7 Findings - Looking Back

Failure of the NOFD was not caused by an overwhelming extreme natural event (hurricane wind, waves, currents, surge). While portions of the NOFDS were overtopped by hurricane Katrina's surge and waves, our studies indicate that the majority of the flooding came from unanticipated and unintended breaches in the levees (many adjacent to other structures), failures in the floodwalls, and water entering through gaps (floodgates not in place) or low spots in the NOFDS. The roots of these unanticipated and unintended developments were firmly embedded in Technology Delivery System flaws and malfunctions; failures of organizations - institutions and their resource allocation processes.

ILIT identified eight categories of technology delivery system (TDS) malfunctions that played primary roles in the failure of the NOFDS. Additional background on each of these TDS malfunctions is provided in Appendices F and H.

Failures of foresight: Catastrophic flooding of the greater New Orleans area due to surge from an intense hurricane had been predicted for several decades (Townsend 2006). The consequences observed in the wake of hurricane Katrina were also predicted (Members Scholars of the Center for Progressive Reform 2005). The hazards associated with the NOFDS were not adequately recognized, defensive measures were not identified and prioritized, and effective action was not mobilized to effectively deal with these hazards (Irons 2005; Senate Committee on Homeland Security and Governmental Affairs 2006).

Failures of organization: The roots of the failure of the NOFDS are firmly embedded in flawed organizational - institutional systems (Select Bipartisan Committee to Investigate the Preparation for and Response to Hurricane Katrina 2006). The organizational - institutional systems lacked centralized and focused responsibility and authority for providing adequate flood protection (Government Accountability Office 2005a, 2005b; Carter 2005a, 2005b; ASCE 2006a; Senate Committee on Homeland Security and Governmental Affairs 2006). Dramatic and pervasive failures in management existed, exemplified by ineffective and inefficient planning, organizing, leading, and controlling to achieve desirable quality and reliability in the NOFDS (Houck 2006, Braun and Vartabedian 2005). There were extensive and persistent failures to demonstrate initiative, imagination, leadership, cooperation, and management (Leonard and Howitt 2006).

Failures of funding: The failure of the NOFDS resulted in part from inadequate provision of resources based primarily on recommendations provided by the Corps followed by failure of the federal and state governments to fund badly needed improvements once limitations were recognized (Members Scholars of the Center for Progressive Reform 2005; Houck 2006; Braun and Vartabedian 2005). In several instances, State agencies pressured for 'lower cost' solutions not realizing that these solutions would result in lowering the overall quality and reliability of the NOFDS (Members Scholars of the Center for Progressive Reform 2005). Important deficiencies existed in the cost-benefit analyses used to justify the levels of protection and their continued improvement as knowledge and technology advanced (Government Accountability Office 2003, 2005; Heinzerling and Ackerman 2002).

Failures of diligence: Forty years after the devastating flooding caused by hurricane Betsy, the flood protection system authorized in 1965 and based on the Standard Project Hurricane (SPH) was still not completed (Government Accountability Office 2005a, 2005b). The concept and application of the SPH was recognized to be seriously flawed, yet no adjustments were made to the system before Katrina struck (Select Bipartisan Committee to Investigate Preparation for and Response to Hurricane Katrina 2006). 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 (Houck 2006; Carter 2005a, 2005b).

Failures of trade-offs: A history of flawed decisions and trade-offs proved to be fatal to the ability of the system to perform adequately (Carter 2005a, 2005b). 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, and were propagated through time as alternatives for the system were evaluated and engineered (Houck 2006). Design, construction, operation, and maintenance of the system in a piecemeal fashion allowed the introduction of additional flaws and defects (Collins and Lieberman 2005). Efficiency was traded for quality, reliability, and effectiveness. Superiority in provision of an adequate NOFDS was traded for mediocrity and getting along (Collins 2005; Senate Committee on Homeland Security and Governmental Affairs 2006).

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, and ecological restoration have served to divert attention from flood control (Office of Management and Budget 2006, Vartabedian and Braun 2006). Public and Congressional pressures to reduce backlogs of approved projects, improve project and organizational efficiency (downsizing, outsourcing), address environmental impacts and develop appropriations for projects have served to divert attention from engineering quality and flood control reliability (Carter and Sheikh 2003). Engineering technology leadership, competency, expertise, research, and development capabilities appear to have been sacrificed for improvements in project planning and controlling (Office of Management and Budget 2006; Senate Committee on Homeland Security and Governmental Affairs 2006).

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 (Rasmussen 1997; Bea 2000). These unforseen, but forseeable, failure modes developed 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 (ASCE 2006a). Synthesis was subverted to decomposition. As a result, many failures developed at interfaces or 'joints' in the NOFDS (Committee on New Orleans Regional Hurricane Protection Projects 2006; Seed et al. 2005).

Failures of risk assessment and management: The risks (likelihoods and consequences) associated with hurricane surge and wave induced flooding were seriously underestimated (Carter 2005a, 2005b). 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. Safety factors used in design of the primary elements in the NOFDS were insufficient (ASCE 2006a, 2006b). Quality assurance and control measures invoked during the life of the system failed to disclose critical flaws in the system (Vartabedian and Braun 2006). 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 (Moteff 2004). Risk management failed to employ continuing improvement, monitoring, assessment, and modifications in means and methods which were discovered to be ineffective (Senate Committee on Homeland Security and Governmental Affairs 2006).

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