APPENDIX F: LOOKING BACK

We must expect more catastrophes like Hurricane Katrina - and possibly even worse. In fact, we will have compounded the tragedy if we fail to learn the lessons - good and bad - it has taught us and strengthen our system of preparedness and response. We cannot undo the mistakes of the past, but there is much we can do to learn from them and to be better prepared for the future. This is our duty.

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The Federal Response to Hurricane Katrina, Lessons Learned
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F.1 Synopsis of History of the New Orleans Flood Defense System 1965 - 2005

This synopsis of the history of the New Orleans Flood Defense System (NOFDS) starts in 1965 in the period following hurricane Betsy. This is only the most recent phase in a history of the NOFDS that dates back 300 hundred years.

September 1965: Hurricane Betsy sweeps over New Orleans with winds exceeding 100 miles per hour and tides up to 16 feet above mean sea level. Betsy was the most destructive hurricane on record to strike the Louisiana coast. It inundated an area of some 4,800 square miles, killed 81 persons within the state, caused about 250,000 people to be evacuated and disrupted transportation, communication, and utility service throughout the eastern coastal area of Louisiana for many months. East New Orleans, St. Bernard Parish, and the Lower Ninth Ward were particularly hard hit. Residents blamed flooding on the Mississippi River Gulf Outlet (MR-GO, completed 1961) and its connection to the Gulf Inter-Coastal Water Way (GIWW) and the Industrial Canal (Inner Harbor Navigation Canal, IHNC). Earlier in the year, the Orleans Levee Board began driving sheet pilings on the 17th Street canal and other drainage canal levees that had been raised following flooding caused by a hurricane in 1947. Maintenance dredging was initiated by the Corps of Engineers on the MR-GO.

October 1965: Congress authorized the Corps of Engineers plan to strengthen the NOFDS to protect from flooding caused by a storm surge or rainfall associated with a Standard Project Hurricane (SPH, estimated to have a 200 to 300 year return period), which is roughly the same as what is now classified as a fast moving Category 3 hurricane. The Corps proposed massive floodgates and barriers on the far end of Lake Pontchartrain to stop hurricane surges from the Gulf of Mexico (Barrier Plan). Also included were additional protection to areas around the lake in the parishes of Orleans, Jefferson, St. Bernard, and St.

Charles. This protection included a series of levees along the lakefront and concrete floodwalls along the Inner Harbor Navigation Canal. This plan was selected over another alternative, known as the High Level Plan which excluded the barriers and flood gates and instead employed higher levees. The Barrier Plan was favored because it was believed to be much less expensive and quicker to construct. Although federally authorized, it was a joint federal, state, and local effort with the federal government paying 70 percent of the costs and the state and local agencies paying 30 percent. *The Corps was responsible for project design and construction. State and local interests were responsible for operations and maintenance of the flood controls.* The project was forecast to take about 13 years to complete (1978) and cost about $85 million.

October 1968: The Corps of Engineers performed field tests of levee construction in the Atchafalaya Basin. These test sections were built in 1964 and 1965 to investigate the performance of new levee designs. The sections were instrumented and their performance monitored during and after construction. Important information was developed regarding characterizations of the soil properties and how these should be used in analyzing levee stability factors of safety. Definitive differences were found between soil strengths near the centers and at the toes of the levee test sections. Differences in factors of safety due to different analysis methods were analyzed and it was noted that the method used at that point in time by the Corps of Engineers tended to over-predict the overall factors of safety.

August 1969: Construction of floodwalls along the Inner Harbor Navigation Canal, started in 1966, was almost completed as was an earthen levee elevated to 12 feet along Lakeshore Drive from West End Boulevard to the Inner Harbor Navigation Canal when hurricane Camille surge conditions produced similar surge conditions to those of hurricane Betsy. Temporary sheet piling had been driven by the Orleans Levee Board to increase their effective height. *Only minor flooding occurred in the project area.* Hurricane Camille (Category 5 hurricane) crossed the Mississippi coast at Pass Christian and devastated the coastal communities along the Mississippi coast to Biloxi Alabama.

November 1969: Corps of Engineers issues report on Standard Project Hurricane surge and wave conditions for St. Bernard Parish. Effects of MR-GO and its adjacent levee are incorporated into these conditions.

December 1973: In order to accelerate construction, the Orleans Levee board financed and constructed portions of the floodwalls along the Inner Harbor Navigation Canal and these were virtually completed at this time.

August 1976: Corps of Engineers estimate that he cost of the improved NOFDS had risen to $352 million, and its completion delayed to 1991. In a review of progress, the Comptroller General's Report to the Congress (1976) observed: "…its (Corps of Engineers) own belated completion of design, plans, and specifications, has contributed to the delays." The Citrus Back Levee, Michoud Slip Levee, New Orleans East Back Levee, New Orleans East South Point to Gulf Intercoastal Water Way were substantially completed as was the flood protection structure at Bayou Bienvenue.

December 1977: In reaction to a suit brought by a coalition of local fishermen and the Save Our Wetlands environmental group in 1976, the Fifth Federal District Court ruled the Environmental Impact Statement for the Corp's Barrier Plan was inadequate and enjoined construction of the entire project. The Court ordered the Corps of Engineers to produce an environmental impact report on the proposed Barrier Plan. The injunction was subsequently modified to permit construction of the levee and floodwall elements of the hurricane protection plan.

September 1979: NOAA issues official revisions to Standard Project Hurricane guidelines first issued during 1959 and used as a basis for the authorization of the Lake Pontchartrain and Vicinity congressional authorization. These revised SPH guidelines increased the sustained and maximum wind speeds, and modified the hurricane radius to the maximum winds and forward speeds. These changes resulted in increases in the surge and wave heights over those in the original SPH. *These changes were not reflected in later design guidelines for the flood protection system.*

April 1980: Flooding overtops east side of the London Avenue canal south of Robert E Lee, where 200 feet of sheet piling had been removed at a point where the levee was eroding.

January 1981: Stability analysis performed by consulting engineers Modjeski and Masters shows that proposed higher levees for the 17th Street canal would fail in high water. Factors of safety less than 1.3 and as low as 0.8 were found for substantial portions of the canal. Additional studies were recommended.

September 1981: Corps of Engineers issues a design memorandum and revised environmental impact statement in which it is observed: "There is an unresolved issue with regards to the three main outfall canals in New Orleans which empty into Lake Pontchartrain along the reach known as the New Orleans Lakefront. Return levees flank these gravity drainage canals for a considerable distance inland from the lake, tying into lift pump stations at the head of the canals. *Since the time of project authorization, it has been determined that the return levees are inadequate in terms of both grade and stability*." Work was underway to raise the lakefront levees to a height of 16 feet.

August 1982: At this time, only about half of the improved NOFDS project had been completed. Costs were estimated to have grown to $757 million, not including any work along the drainage canals, and project completion had slipped to 2008. The General Accounting Office (1982) observed: "We believe that improved planning is needed by the Corps to resolve certain environmental, technical, and financial issues. Environmental concerns have remained unresolved for almost 5 years after a court injunction prohibited the Corps from constructing certain parts of the projects. The Corps is considering a change in its solution of providing protection from constructing barrier structures at the entrance to the lake and the raising of some levee heights (Barrier Plan) to constructing much higher levees with no barriers (High Level Plan)." The report observed: "Costly project work at the drainage canals has not been reported to the Congress, and technical and financial concerns which may impede project completion remain unresolved." Further this report observed: "*Subsequent to project authorization and based on the Weather Bureau's new data pertaining to hurricane severity (NOAA 1979), the Corps determined that the levees along the three main drainage canals, which drain major portions of New Orleans and empty into Lake Pontchartrain, were not high enough since they are subject to overflow by hurricane surges.*"

A report issued to Modjeski and Masters by Eustis Engineering notes following installation of piezometers to determine water pressures on both sides of the canal (17th Street) "*..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 (under the levee)."* Further, it was noted "*computations indicate the possibility of a blow-out during extreme high water in the canal. Unless more definitive information can be developed regarding the potential hydrostatic uplift pressure at the levee toe through this reach, measures should be taken to prevent a blow-out during extreme high water conditions*." Additional correspondence addressed preventative measures including a 65-foot long (deep) sheet pile cutoff wall and a concrete lining for the canal.

November 1984: The Corps of Engineers encounter project delays and cost increases due to design changes caused by technical issues, environmental concerns, legal challenges, and local opposition to various aspects of the project. Foundation problems were encountered during construction of levees and floodwalls which increased construction time; delays were also encountered in obtaining rights-of-ways. The Corps of Engineers presents an alternative to the Barrier Plan identified as the High Level Plan. The Corps of Engineers propose to build floodgates on the canals, but local officials want to construct floodwalls on the levees.

December 1984: Report issued to St. Bernard Parish, NOAA and the Louisiana Department of Natural Resources on the MR-GO bank stabilization. The history of construction, ship traffic, channel dredging, and erosion were documented together with recommendations for protective measures to help prevent further erosion and destruction of wetlands.

July 1985: The Corps of Engineers reach agreements with state and local agencies to proceed with the High Level Plan based on construction of floodwalls on the levees. The Corps of Engineers make a decision to continue use of 1983 benchmark elevations even though National Geodetic Survey information indicates that these elevations are one or more feet low: "Hurricane protection projects which are partially complete will use the NGS benchmarks current at the time of construction of the first increment of the project" (1965).

July 1987: Construction was virtually completed on the lakefront levees and floodwalls raising these defenses to an elevation of approximately 18 feet in accordance with the Corps of Engineers' High Level Plan.

June 1988: The Corps of Engineers issues a technical report documenting results from a full-scale field load test performed on a PZ-27 sheet pile wall located in the Atchafalaya Basin south of Morgan City. Flood loading was simulated by ponding water against the wall which was founded in soft clays similar to those underlying the New Orleans area. *The wall was designed to carry an 8 foot head of water with a factor of safety of 1.25. The wall 'failed' (rapidly increasing wall displacements) when the water head reached 8 feet. A gap developed between the loaded sheet pile and the supporting soil on the water side (indicated by slope indicators located in the soils and on the piles).* The Corps of Engineers Waterways Experiment Station (WES) was contracted to perform additional analyses of the data.

August 1988: The Corps of Engineers issues Design Memorandum 19 for the Orleans Avenue outfall canal work. *Issues were raised regarding the factors of safety for use in design of the flood walls and evaluation of the levee stability (specified to be a minimum of 1.3), quality control problems with reporting the soil characteristics, how soil shear strengths are averaged and selected for the foundation layers, the presence of very low shear strength layers, challenges associated with dredging the canal so that the embankment stability would not be threatened, and concerns for seepage from the canal to the protected sides. Changes in* *the SPH developed in 1979 were not reflected in changes in the flood protection design elevations*.

December 1988: The Corps of Engineers Waterways Experiment Station issues a report that proposes a new method for soil-structure interaction analysis of floodwalls. The report shows that during loading of a floodwall the deformations and strains in the sheet piling are controlled by the movements of the soil supporting the sheet piling. *It was noted that as the water level rises, the increased loading may produce separation of the soil from the pile on the flood side (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. This part of the loading was noted to be a function of the levee soil - sheet pile system deformations.*

January 1989: The Corps of Engineers issues Design Memorandum 19A for the London Avenue outfall canal work. *Issues are raised concerning how the levee stability analyses are performed (including the shapes of the failure surfaces) and how the soil shear strengths are treated in the analyses. Concerns for differences in soil shear strengths along and at the toes of the levees are raised.*

September 1989: The Waterways Experiment Station issues a report on analyses of sheet pile walls based on the E99 tests performed in 1985. The work indicates that deep-seated movements in the levee foundation control the magnitude of the sheet-pile deflection with the result that the height of water loading that can be sustained by a particular I wall is controlled by the stability of foundation as determined by a slope stability analysis. *It was concluded that conventionally determined deflections of the sheet piling were a poor criterion for design because movements were caused by deformations in the foundation and not the cantilever action of the sheet piles.*

March 1990: The Corps of Engineers issues Design Memorandum 20 for the 17th Street outfall canal work. *There are discussions concerning analysis of the soil shear strengths, the shapes of the failure surfaces for stability analyses and factors of safety for evaluation of the levees and sheet pile walls.*

August 1990: The Orleans Levee Board initiates work on the 17th Street canal levee. The levee board elected to take the lead to achieve savings because the New Orleans Sewerage and Water Board planned to deepen and widen the canal to meet their drainage needs. The Corps of Engineers issued permits to the New Orleans Sewerage and Water Board in 1984 and 1992. The work required modifications to the existing levees and floodwalls. After the dredging, the bottom was 18.5 feet below sea level (below the bottom of the sheet piling), and the canal side levee on the Orleans side had been shaved so narrow, water now touched the wall. Concerns were again raised on details associated with how the levee stability analyses were being performed including concerns about factors of safety, analysis of soil shear strengths, and shape of the slope stability analyses geometries.

October 1990: Congress orders the Corps of Engineers to begin raising the levees on the London and Orleans avenues drainage canals.

September 1997: Two technical papers published in the Electronic Journal of Geotechnical Engineering (www.ejge.com) summarize results from the E99 sheet pile load tests performed in 1985 and the subsequent research conducted at the Corps of Engineers Waterways Experiment Station. Advanced analytical methods developed during the period

1982 - 1989 for determining the deformations developed in levees and the interaction of sheet pile floodwalls with the levees were summarized. In the first paper (Oner et al, 1997a) in the section on Incremental Loading (p.10) it was noted "*The rising water produces several loading effects on a flood wall system. Most apparent is the hydrostatic pressure on the exposed wall above the ground surface. This part of the loading is independent of system deformations. …As the water level rises, the increased loading may produce separation of the sol from the pile on the flood side (i.e., a "tension crack" develops behind the wall). Intrusion of free water into the tension crack produces additional hydrostatic pressure on the wall side of the crack and equal and opposite pressures on the soil side of the crack. This part of the loading is a function of system deformations*."

February 1998: Decision reached by administrative judge, member, Corps of Engineers Board of Contract Appeals regarding a construction claim filed by the Pittman Construction Company for difficulties encountered while constructing a section of the floodwall on the 17th Street canal (in vicinity of breach). It was Pittman's contention that the lack of structural integrity of the existing sheet pile around which the concrete was poured and the weakness of the soils resulted in difficulties in pouring the concrete walls to the required tolerances. Pittman's expert witness, *Dr. Herbert Roussel, concluded that the soils is so weak and may have been further weakened by the additional driving of the sheet pile that increasing the penetration ca not get the deflection within tolerance*. Questions were also raised concerning the reasonableness of the specified tolerances for the concrete flood walls (0.25 inches in 10 feet). The claim was rejected by the Corps of Engineers Board of Contract Appeals.

September 1998: Hurricane Georges was headed directly for New Orleans but turned and made landfall instead at Biloxi, Mississippi. Storm tides reached 2 to 3 feet in Lake Pontchartrain and flooded the New Orleans Lakefront Airport. Only minor flooding occurred in the greater New Orleans area.

May 2005: The estimated cost of construction for the completed enhanced NOFDS was estimated to be $738 million with an estimated completion date of 2015. A Corps of Engineers report on the High Level Plan indicated that construction work on the project was 60 - 90 percent complete in different areas. Work on bridge replacement and floodproofing was underway along Orleans Avenue and London Avenue canals and on the Hammond Highway bridge over the 17th Street canal. During the last 10 years (1996-2005), federal appropriations generally declined from about $15-20 million annually in the earlier years to about $5-$7 million in the last three years. The Corps of Engineers noted that the appropriated amount for 2005 was insufficient to fund new construction contracts. The Corps of Engineers also noted it could spend $20 million in 2006 on raising levees that had settled and needed to be raised to provide the design-level of protection.

August 2005: Hurricane Katrina strikes the NOFDS with winds that exceeded 140 miles per hour and a surge that ranged from approximately 10 to 11 feet (Lake Pontchartrain) to 14 to 18 feet (Lake Borgne) flooding more than 85% of the city. The NOFDS failed catastrophically. More than 1,500 people died as a result of the flooding (about 400 more are currently missing). Failure of the NOFDS constitutes the single most catastrophic and costly failure of a civil engineered system in the history of the United States.

F.2 Learning from Failures

Detailed studies have been made of more than 600 well documented major failures and accidents involving engineered systems (Turner 1978; Whittow 1979; Petroski 1985; 1994; Allison 1993; Roberts 1993; Sowers 1993; Groeneweg 1994; Lancaster 1996; Dorner 1996; Dumas 1999; Perrow 1999; Bea 2000; Chiles 2002). These studies include recent accidents including the Challenger and Columbia space shuttles (Vaughn 1996, 1997; Columbia Accident Investigation Board 2003), the collapse of the World Trade Center towers, the failures of the Three Mile Island and Chernobyl nuclear power plants , the Teton dam collapse, the Union Carbide Bhopal chemical plant catastrophe, failures of the offshore platforms Occidental Piper Alpha and Petrobras P36 and the groundings of the oil tankers Torry Canyon, Amoco Cadiz, Exxon Valdez and Braer. Sufficient reliable documentation is available about these failures and accidents to understand the roles of the various components that comprised the systems during their life-cycle phases leading to the accident or failure. In many cases, personnel who participated in the events were interviewed to gain additional insights about how and why the accidents and failures developed. Extensive care was exercised to neutralize biases in this work (e.g., triangulation of multiple reliable sources, use of different assessors with different backgrounds) (Hale et al. 1997; Center for Chemical Process Safety 1994; Rasmussen et al. 1987).

Background from these detailed studies (conducted over a 15-year period) provided important analysis templates that helped development of understanding of the failure of the NOFDS. Results from these studies are summarized in this Chapter. In addition, because it has particular relevance to this investigation, a summary will be presented of results from the investigation of the NASA Columbia accident. This summary will be preceded by introduction of the primary concepts associated with high and low reliability organizations.

F.2.1 Engineered Systems

The studies indicated that the *system* involved in development of failures needed to be carefully defined and evaluated (Bea 2006). Seven primary interactive, inter-related, and highly adaptive components were defined to help characterize engineered systems: 1) structure (provides support for facilities and operations), 2) hardware (facilities, control systems, life support), 3) procedures (formal, informal, written, computer software), 4) environments (external, internal, social), 5) operators (those who interface directly with the system), 6) organizations (institutional - organizational frameworks in which operations are conducted), and 7) interfaces among the foregoing.

The studies clearly identified the importance of system interfaces in the development of failures. Breakdowns in communications and other actions frequently developed at the interfaces between the operators and the organizations that controlled resources, means, and methods. Communication malfunctions at organization-to-organization interfaces, information filtering, distortion, and 'stove-piping' communication barriers in large bureaucratic organizations were even more prevalent.

An important part of this system is the Technology Delivery System (TDS) involved in development, operation, and maintenance of the engineered system. Technology is a social process by which specialized knowledge from science and experience is employed to deliver a system to meet specific needs of a society. The TDS is an ensemble of institutions involving the public, government, and enterprise (industry) which are linked by webs of information channels. Inputs to the TDS consist of technical knowledge, natural resources, capital, human talents, and value preferences. Outputs are the intended goods and services to provided by the engineered system, including unintended and unwelcome consequences. The basic elements of a TDS are further developed in Appendix H.

The studies showed it was essential to identify how the system developed throughout its life-cycle to the point of failure including development of concepts, design, construction, operation, and maintenance. The history (heritage) of a system generally had much to do with development of failures. The studies indicated that in a very large number of cases, the seeds for failure were sown very early in the life of a system; preceding and during the concept development and design phases. These seeds were allowed to flourish during the construction, operation and maintenance phases, and with the system in a weakened flawed and defective condition, when severely challenged, it failed.

F.2.2 Causes of Failures

Uncertainties that were primary contributors to the accidents and failures were organized into four major categories: 1) natural variability (information insensitive), 2) analytical modeling uncertainties (information sensitive), 3) human and organizational performance uncertainties, and 4) knowledge related uncertainties. This organization of uncertainties was developed to permit definition of means and measures that could be used to help manage the causes and effects of the uncertainties.

The studies showed that the causative factors most often (80 % or more) involved human, organizational and knowledge related uncertainties (Reason 1990, 1997; Perrow 1999; Bea 2000, 2006). These were identified as *Extrinsic Factors (not belonging to the essential nature of the system).* Frequently, these factors are identified as *human errors.* The remaining 20% of the factors involved natural and analytical model related uncertainties. These were identified as *Intrinsic Factors (belonging to the essential nature of the system)* (Vick 2002).

Of the Extrinsic Factors, about 80% of these developed and became evident during operations and maintenance activities; frequently, the maintenance activities interacted with the operations activities in an undesirable way. Of the failures that occurred during operations and maintenance, more than half were traced to seriously flawed engineering concept development and design. The physical system may have been designed according to accepted standards and yet was seriously flawed due to limitations and imperfections embedded in the standards and/or in how they were used. Frequently, engineered systems were designed that could not be built, operated, and maintained as originally intended. Changes (work-arounds) were made during the construction process to allow the construction to proceed; flaws were introduced by these changes or flaws were introduced by the construction process itself. After the structure was placed in operation, modifications were made in an attempt to make it workable or to facilitate operations, and in the process additional flaws were introduced. Thus, during operations and maintenance phases, operations personnel were faced with a seriously deficient or defective system that could not be operated and maintained as intended.

A useful analogy to describe the Extrinsic Factors was that of a ‘spear’ (Reason 1997) The *pointed end* of the spear represented the operators (operating teams) who are responsible for performing the activities during the life-cycle development of the system. The *blunt end* or shaft of the spear represented the organizations that controlled means, methods, and resources. The activity at the pointed end of the spear was largely determined by what happened along the shaft of the spear; the TDS.

The 20% of the causation factors that involved natural and model related uncertainties represented residual risks that developed from exceedances of the criteria and conditions used to design, construct, operate, and maintain the system. These could identified as *'acts of god'* (Bernstein 1996; Molak 1996; Prigogine 1997).

F.2.3 Magnitudes of Failures

An important discriminating difference between major (catastrophic) and not-so-major failures involved the *magnitude of consequences* developed during and after the failures. Not-so-major failures generally involved only a few people, a few malfunctions or breakdowns, and small magnitude consequences. Major or catastrophic failures involved of many people and their organizations, a multitude of malfunctions or breakdowns developed over long periods of time, and very large magnitudes of consequences (direct, indirect, on-site, off-site, short-term, long-term). Frequently, organizations construct barriers to prevent failure causation to be traced in this direction. In addition, until recently, the legal process focused on the proximate causes of failures (*human errors*). There have been some recent major exceptions to this focus; the important roles of organizational and institutional malfunctions in accident causation have been recognized in court and in public. Not-so-major accidents, if repeated very frequently, can lead to major losses and it is obvious that it is important to develop approaches and strategies to address both categories of accidents.

F.2.4 Breaching Defenses

Most failures involved never to be exactly repeated sequences of events and multiple breakdowns or malfunctions in the components that comprise a system. Failures resulted from breaching multiple defenses that were put in place to prevent them. These events are frequently dubbed incredible or impossible. After many of these failures, it was observed that if only one of the barriers had not been breached, the accident or failure would not have occurred. Experience adequately showed that it was extremely difficult, if not impossible, to recreate accurately the time sequence of the event that actually took place during the period leading to failure. Unknowable complexities generally pervade this process because detailed information on failure development is not available, is withheld, or is distorted by memory. Hindsight and confirmational biases are common as are distorted recollections. Stories told from a variety of viewpoints involved in the development of a failure are the best way to capture the richness of the factors, elements, and processes that unfold in the development of a failure.

Defenses against breaching could be organized into *proactive, interactive, and reactive* categories (Bea 2000). These categories represented the timeframes in which activities were conducted to defend the system against failure. Reason (1997) suggested the analogy of Swiss Cheeze; failures could develop when 'holes' in these three defenses aligned. The larger the number and sizes of the holes, then the more likely they were to align and allow a failure to develop. While generally a lot of attention was given to proactive measures, insufficient attention was given to interactive and reactive defenses.

Development of effective reactive defenses often degraded because of an unwillingness or inability to recognize the 'truth', measures employed to depress development of accurate facts, and deficiencies introduced because of a wide variety of unrecognized biases (e.g., recall, hindsight, rational, control, wishful thinking, small samples, knowledge, correlation, perception, belief, confirmational, reductive). Searches were often conducted to assign blame and distribute pain. Often, once the facts and truth were known, there were efforts to restrain communications or put a 'spin' on the information so it would not appear as unfavorable as it was. In general, there were very numerous and large holes in reactive defenses.

Development of ineffective interactive defenses often developed because their importance was not recognized (Klein 1999). A key example of interactive defenses was quality control (quality assurance is a proactive measure). Often the wrong things were inspected by the wrong people at the wrong times using the wrong things and for the wrong reasons. Proper detection, analysis and correction of potential flaws was inhibited by a variety of problems (Sasou and Reason 1997). In many cases, even though very thorough proactive quality assurance procedures and processes were developed, they were not followed (violations). Often insufficient resources were allocated to implementation of interactive defenses. In general, there were very numerous and large holes in the reactive defenses (Weick and Sutcliffe 2001).

F.2.5 Knowledge Challenges

One sobering observation concerning many accidents and failures is that their occurrence is directly related to knowledge (information) access and development. Information access and development challenges were organized into two general categories: *unknown knowables*, and *unknown unknowables*. The first category represents information access and understanding challenges (Weick 1995; Klein 1999). The information exists but is either ignored, not used, not accessed, or improperly used. This category is identified as rejection - misuse of technology. Others identify this category as *'predictable surprises'* (Bazerman and Watkins 2004).

The second category - *unknown unknowables* - represents limitations in knowability or knowledge. There are significant limitations in abilities to project system developments or characteristics very far in space or time. Human abilities to know all the things that are potentially important to the future success of systems is limited. Often, there are major limitations in knowledge concerning new or innovative systems and the environments in which these systems will be developed and exist. There is ample history of accidents and failures due to both of these categories of challenges to knowledge. They appear to be most important during the early phases of constructing and operating engineered systems; *burn-in failures*. Things develop that one did not know or could not know in advance. They also appear to be most important during the late life-cycle phases; *wear-out failures*. In this case, the quality characteristics of the system have degraded due to the effects of time and operations (frequently exacerbated by improper or ignored maintenance) and the hazards posed by unknown knowables and unknown unknowables interact in undesirable ways. This recognition poses a particularly important limitation on proactive risk analyses that are conducted before systems are constructed and put in service; in a predictive sense, one can only analyze what one understands or knows. The most effective approach identified during these studies is *interactive* risk *assessment and management* (National Academy of Engineering 2004; Klein 1998; Weick and Sutcliffe 2001). Interactive risk assessment and management can be facilitated through a variety of people and system enhancements which promote abilities to detect, analyze, and correct challenges to quality and reliability before they are allowed to propagate to failures (Loosemore 2000).

F.2.6 Organizational Malfunctions

Analysis of the history of failures of engineered systems provides many examples in which organizational and institutional malfunctions were primarily responsible for the failures (Wenk 1986, 1998; Dorner 1997; Hopkins 1999, 2000; Reason 1997; Vaughn 1996; Columbia Accident Investigation Board 2003). Organization malfunction is defined as a departure from acceptable or desirable practice on the part of a group or groups of individuals that results in unacceptable or undesirable results (Roberts and Bea 2001a, 2001b). Frequently, the organization develops high incentives for maintaining and increasing production; meanwhile hoping for quality and reliability (*rewarding 'A' while hoping for 'B')* (Roberts 1993; Roberts and Libuster 1993). The formal and informal rewards and incentives provided by an organization have a major influence on the performance of operators and on the quality and reliability of engineered systems. In a very major way, the performance of people is influenced by the incentives, rewards, resources, and disincentives provided by the organization. Many of these aspects are embodied in the organization's culture (shared beliefs, artifacts). This culture largely results from the organization's history (development and evolution). For many successful organizations, success breeds arrogance that can lead to failure (lethal arrogance). Cultures are extremely resistant to change.

Several major organizational malfunctions developed because of down-sizing and out-sourcing practices adopted in response to pressures to increase organizational efficiency. Loss of corporate memories (leading to repetition of errors), inadequate core competencies in the organization, creation of more difficult and intricate communications and organization interfaces, degradation in morale, unwarranted reliance on the expertise of outside contractors, cut-backs in quality assurance and control, and provision of conflicting incentives (e.g. cut costs, yet maintain quality) are examples of activities that lead to substantial compromises in the intended quality of systems. Much of the down-sizing ('right-sizing'), outsourcing ('hopeful thinking'), and repeated cost-cutting ('remove the fat until there is no muscle or bone') seems to have its source in modern 'business consulting.' While some of this thinking can help promote 'increased efficiency' and maybe even lower CapEx (Capital Expenditures), the robustness (damage and defect tolerance) of the organization and the systems it creates are greatly reduced. Higher OpEX (Operating Expenditures), more 'accidents', and unexpected compromises in desired quality and reliability can be expected; particularly over the long-run.

Experience indicates that one of the major factors in malfunctions is the organization's culture (Reason 1997; Merry 1998; Meshkati 1995). Organizational culture is reflected in how action, change, and innovation are viewed; the degree of external focus as contrasted with internal focus; incentives provided for risk taking; the degree of lateral and vertical integration of the organization; the effectiveness and honesty of communications; attention to the potentials for failures; diligence in the use of information; particularly bad or unwelcome news (lethal arrogance); autonomy, responsibility, authority and decision making; rewards and incentives; and orientation toward the quality of performance contrasted with the quantity of production. One of the major culture elements is how managers in the organization react to suggestions for change in management and the organization. Given the extreme importance of quality and reliability, it is essential that these managers see suggestions for change (criticism?) in a positive manner. This is extremely difficult for some managers because they do not want to relinquish or change the strategies and processes that helped make them managers.

F.2.7 Engineering Challenges

New technologies compound problems of latent system flaws (structural pathogens) (Reason 1997). Excessively complex design, close coupling (failure of one component leads to failure of other components) and severe performance demands on systems increase the difficulty in controlling the impact of human malfunctions even in well operated systems. The field of ergonomics (people-hardware interfacing) has much to offer in helping create ‘people friendly’ engineered systems. Such systems are designed for what people will and can do, not what they should do. Such systems facilitate construction (constructability), operations (operability), and maintenance (maintainability, reparability).

It is becoming painfully clear that the majority of engineering design codes and guidelines do not provide sufficient direction for creating robust, damage/defect tolerant systems. Thinking about sufficient damage tolerance and inherent stability needs rethinking. Thinking about designing for the ‘maximum incredible’ events needs more development. While two engineered systems can both be designed to ‘resist the 100-year conditions’ with exactly the same probabilities of failure, the two structures can have very different robustness characteristics. The minimum CapEx system will not have a configuration, excess capacity, ductility , or appropriate correlation to allow it to weather the inevitable defects and damage that should be expected to develop during its life. Sufficient damage tolerance almost invariably results in increases in CapEx; the expectation and the frequent reality is that OpEx will be lowered. But one must have a long-term view for this to be realized.

Robustness (defect and damage tolerance) can be developed through a combination of four key elements. The first is appropriate configuration of the elements that comprise the system. The second is excess capacity built into the system elements that will allow ‘overloads’ to be carried without compromising the basic quality and reliability characteristics of the system. The third is ductility or an ability to stretch without breaking so that overloads can be shifted to other under-loaded elements. The fourth is appropriate correlation of the elements; for series (weak link) type systems, high degrees of correlation are needed to reduce the likelihood of weak links; for parallel (redundant) type systems, low degrees of correlation are needed to help insure independence in performance.

Other strategies to achieve robust systems include those of fail-safe and inherently-safe design. In fail-safe design the system is configured and proportioned so that when its ‘capacities’ are exceeded the system fails in a way that does not compromise basic safety requirements. In design of intrinsically safe systems, the system is configured so that there are fewer inherent hazards, there is a reduced probability of unwanted events, there is reduced inventory and damage potential (reduced severity), there are fewer people exposed, there is reduced scope for smaller incidents to escalate and overwhelm the facilities, and there is a clear focus on simplicity, reliability and longevity to reduce exposure.

This work has clearly shown that the foregoing statements about structure and hardware robustness apply equally well to organizations and operating teams; frequently, this is termed organizational redundancy. Proper configuration, excess capacity, ductility, and appropriate correlation play out in organizations and teams in the same way they do in a structure and hardware. When the organization or operating team encounters defects and damage – and is under serious stress, the benefits of robustness become evident. A robust organization or operating team is not a repeatedly downsized (lean and mean), out-sourced, and financially strangled organization. A robust organization is a *High Reliability Organization (HR0)* (Roberts 1989, 1990, 1993; Weick and Sutcliffe 2001; Columbia Accident Investigation Board 2003).

Software and engineering guideline errors in which incorrect and inaccurate algorithms were coded into computer programs or written into engineering guidelines have been at the root cause of several recent failures of engineered systems. Extensive software and guidelines testing and validation is required to assure that the desired performance and results are realized. Of particular importance is the provision of qualified independent checking processes and people using those process who can be used to validate the results from analyses and engineering work. High quality procedures need to be verifiable based on first principles, results from testing, and field experience.

Given the rapid pace at which significant industrial and technical developments are taking place, there is a tendency to make design guidelines, construction specifications, and operating manuals more and more complex. Such a tendency is apparent in many current guidelines used for designing engineered systems. In many cases, poor organization and documentation of software and procedures has exacerbated the tendencies for humans to make errors. Simplicity, clarity, completeness, accuracy, and good organization are desirable attributes in procedures developed for the design, construction, maintenance, and operation of engineered systems.

F.2.8 Initiating, Contributing, Compounding Events

These studies illustrate the failure development process as organized into three categories of events or stages: *1) initiating, 2) contributing, and 3) propagating*. The dominant initiating events were developed by operators (e.g. design engineers, construction, maintenance personnel) performing erroneous acts of commission; what is carried out has unanticipated and undesirable outcomes. The other initiating events are acts or developments involving omissions (something important left out, often intentional short-cuts and violations). Communications breakdowns (withheld, incomplete, untrue, not timely) were a dominant category of the initiating events. Various categories of violations (intentional, unintentional) were also very prevalent and were highly correlated with organizational and social cultures.

The dominant contributing events were organizational malfunctions (about 80%); these contributors acted directly to encourage or trigger the initiating events. Communication malfunctions, interface failures (organization to operations), culture malfunctions (excessive cost cutting, down-sizing, outsourcing, and production pressures), unrealistic planning and preparations, and violations (intentional departures from acceptable practices) were dominant categories of these organizational malfunctions.

The dominant propagating events also were found to be organizational malfunctions (about 80%); these propagators were responsible for allowing the initiating events to unfold into a failure or accident. With some important additions, the dominant types of malfunctions were the same as the contributing events. The important additions concerned inappropriate selection and training of operating personnel, failures in quality assurance and quality control (QA/QC), brittle structures and hardware (damage and defect intolerant), and ineffective planning and preparations.

F.2.9 High and Low Reliability Organizations: The NASA Columbia Accident Investigation

> ***The organizational causes of this accident are rooted in the Space Shuttle Program's history and culture, including the original compromises that were required to gain approval for the Shuttle Program, subsequent years of resource constraints, fluctuating priorities, schedule pressures, mischaracterizations of the Shuttle as operational rather than developmental, and lack of an agreed national vision. Cultural traits and organizational practices detrimental to safety and reliability were allowed to develop, including: reliance on past success as a substitute for sound engineering practices (such as testing to understand why systems were not performing in accordance with requirements/specifications); organizational barriers which prevented effective communication of critical safety information and stifled professional differences of opinion; lack of integrated management across program elements; and the evolution of an informal chain of command and decision-making processes that operated outside the organization's rules.***
>
> **Columbia Accident Investigation Board (2003)**

The findings documented in the Columbia Accident Investigation Board (CAIB) Report (2003) have particular relevance to development of insights about how technology can have *unintended consequences* or *revenge effects* when an organizational - institutional culture of low reliability is allowed to develop. After introducing the concepts of High and Low Reliability Organizations, findings of the CAIB regarding the organizational - institutional issues will be summarized .

F.2.10 High Reliability Organizations

Studies of HRO (High Reliability Organizations) has shed some light on the factors that contribute to errors made by organizations and risk mitigation in HRO. HRO are those organizations that have operated relatively error free over long periods of time making consistently good decisions resulting in high quality and reliability operations. A variety of HRO ranging from the U. S. Navy nuclear aircraft carriers to the Federal Aviation Administration Air Traffic Control System have been studied.

The HRO research has been directed to define what these organizations do to reduce the probabilities of serious errors (Roberts, 1989). Reduction in error occurrence is accomplished by the following:

- Command by exception or negation,
- Redundancy,
- Procedures and rules,
- Training,
- Appropriate rewards and punishment
- Ability of management to "see the big picture".

Command by exception (management by exception) refers to management activity in which authority is pushed to the lower levels of the organization by managers who constantly monitor the behavior of their subordinates. Decision making responsibility is allowed to migrate to the persons with the most expertise to make the decision when unfamiliar situations arise (employee empowerment).

Redundancy involves people, procedures, and hardware. It involves numerous individuals who serve as redundant decision makers. There are multiple hardware components that will permit the system to function when one of the components fails.

Procedures that are correct, accurate, complete, well organized, well documented, and are not excessively complex are an important part of HRO. Adherence to the rules is emphasized as a way to prevent errors, unless the rules themselves contribute to error.

HRO develop constant and high quality programs of training. Training in the conduct of normal and abnormal activities is mandatory to avoid errors. Establishment of appropriate rewards and punishment that are consistent with the organizational goals is critical.

Lastly, Roberts defines an HRO organizational structure as one that allows key decision makers to understand the big picture. These decision makers with the big picture perceive the important developing situations, properly integrate them, and then develop high reliability responses.

In recent organizational research reported by Roberts and Libuser (1993), they analyzed five prominent failures including the Chernobyl nuclear power plant, the grounding of the Exxon Valdez, the Bhopal chemical plant gas leak, the mis-grinding of the Hubble Telescope mirror, and the explosion of the space shuttle Challenger. These failures were evaluated in the context of five hypotheses that defined "risk mitigating" organizations. The failures provided support for the following five hypotheses.

- Risk mitigating organizations will have extensive process auditing procedures. Process auditing is an established system for ongoing checks designed to spot expected as well as unexpected safety problems. Safety drills would be included in this category as would be equipment testing. Follow ups on problems revealed in prior audits are a critical part of this function.
- Risk mitigating organizations will have reward systems that encourage risk mitigating behavior on the part of the organization, its members, and constituents. The reward system

is the payoff that an individual or organization gets for behaving one way or another. It is concerned with reducing risky behavior.

- Risk mitigating organizations will have quality standards that meet or exceed the referent standard of quality in the industry.
- Risk mitigating organizations will correctly assess the risk associated with the given problem or situation. Two elements of risk perception are involved. One is whether or not there was any knowledge that risk existed at all. The second is if there was knowledge that risk existed, the extent to which it was acknowledged appropriately or minimized.
- Risk mitigating organizations will have a strong command and control system consisting of five elements: a) migrating decision making, b) redundancy, c) rules and procedures, d) training, and e) senior management has the big picture.

Weick, Sutcliffe, and Obstfeld (1998) have extended these concepts to characterize *how* organizations can organize for high reliability. Their extensive review of the literature and studies of HRO indicate that organizing in effective HRO's is characterized by:

- Preoccupation with failure – any and all failures are regarded as insights on the health of a system, thorough analyses of near-failures, generalize (not localize) failures, encourage self-reporting of errors, and understand the liabilities of successes.
- Reluctance to simplify interpretations – regard simplifications as potentially dangerous because they limit both the precautions people take and the number of undesired consequences they envision, respect what they do not know, match external complexities with internal complexities (requisite variety), diverse checks and balances, encourage a divergence in analytical perspectives among members of an organization (it is the divergence, not the commonalties, that hold the key to detecting anomalies).
- Sensitivity to operations – construct and maintain a cognitive map that allows them to integrate diverse inputs into a single picture of the overall situation and status (situational awareness, 'having the bubble'), people act thinkingly and with heed, redundancy involving cross checks, doubts that precautions are sufficient, and wariness about claimed levels of competence, exhibit extraordinary sensitivity to the incipient overloading of any one of it members, sensemaking.
- Commitment to resilience – capacity to cope with unanticipated dangers after they have become manifest, continuous management of fluctuations, prepare for inevitable surprises by expanding the general knowledge, technical facility, and command over resources, formal support for improvisation (capability to recombine actions in repertoire into novel successful combinations), and simultaneously believe and doubt their past experience.
- Under-specification of structures – avoid the adoption of orderly procedures to reduce error that often spreads them around, avoid higher level errors that tend to pick up and combine with lower level errors that make them harder to comprehend and more interactively complex, gain flexibility by enacting moments of organized anarchy, loosen specification of who is the important decision maker in order to allow decision making to migrate along with problems (migrating decision making), move in the direction of a garbage can structure in which problems, solutions, decision makers, and choice opportunities are independent streams flowing through a system that become linked by

their arrival and departure times and by any structural constraints that affect which problems, solutions and decision makers have access to which opportunities.

F.2.11 Low Reliability Organizations

Weick, Sutcliffe, and Obstfeld (1998) observe that low reliability organizations (LROs) are characterized by a focus on success rather than failure, and efficiency rather than reliability. In these organizations the cognitive infrastructure is underdeveloped, failures are localized rather than generalized, and highly specified structures and processes are put in place that develop inertial blind spots that allow failures to cumulate and produce catastrophic outcomes. Efficient organizations practice stable activity patterns and when they encounter unusual cognitive processes these often result in errors. They do the same things in the face of changing events, these changes go undetected because people are rushed, distracted, careless, or ignorant.

LROs are characterized by expensive and inefficient learning. Diversity in problem solving is not welcomed. Information, particularly 'bad' or 'useless' information is not actively sought, failures are not taken as learning lessons, and new ideas are rejected; lethal arrogance. Communications are regarded as wasteful and hence the sharing of information and interpretations between individuals is stymied. Divergent views are discouraged, so that there is a narrow set of assumptions that sensitize it to a narrow variety of inputs.

Success breeds confidence and fantasy, managers attribute success to themselves, rather than to luck, and they trust procedures to keep them appraised of developing problems. Under the assumption that success demonstrates competence, LROs drift into complacency, inattention, and habituated routines which they often justify with the argument that they are eliminating unnecessary effort and redundancy. Down-sizing and out-sourcing are used to further the drives of efficiency. Insensitivity is developed to overloading and its effects on judgement and performance. Redundancy (robustness) is eliminated or reduced in the same drive resulting in elimination of cross checks, assumption that precautions and existing levels of training and experience are sufficient, and dependence on claimed levels of competence. With outsourcing, it is now the supplier, not the buyer, that must become preoccupied with failure. But, the supplier is preoccupied with success, not failure, and because of low-bid contracting, often is concerned with the lowest possible cost success. The buyer now becomes more mindless and if novel forms of failure are possible, the loss of a preoccupation with failure makes the buyer more vulnerable to failure. LROs tend to lean toward anticipation of expected surprises, risk aversion, and planned defenses against foreseeable accidents and risks; unforeseeable accidents and risks are not recognized or believed.

F.2.12 Columbia Accident Investigation Board Findings

The following quotations from the Columbia Accident Investigation Board (CAIB) Report provide important insights into how NASA in the span of three decades developed into a LRO.

> ***Accident Theories****: To develop a thorough understanding of accident causes and risk, and to better interpret the chain of events that led to the Columbia accident, the Board turned to the contemporary social science literature on accidents and risk and sought insight from experts in High*

Reliability, Normal Accident and Organizational Theory. High Reliability Theory argues that organizations operating high-risk technologies, if properly designed and managed, can compensate for inevitable human shortcomings, and therefore avoid mistakes that under other circumstances would head to catastrophic failures. Normal Accident Theory, on the other hand, has a more pessimistic view of the ability of organizations and their members to manage high-risk technology. Normal Accident Theory holds that organizational and technological complexity contributes to failures. Organizations that aspire to failure-free performance are inevitably doomed to fail because of the inherent risks in the technology they operate. Normal Accident models also emphasize systems approaches and systems thinking, while the High Reliability model works from the bottom up: if each component is highly reliable, then the system will be highly reliable and safe.

Though neither High Reliability Theory nor Normal Accident Theory is entire appropriate for understanding this accident, insights from each figured prominently in the Board's deliberation. Fundamental to each theory is the importance of strong organizational culture and commitment to building successful safety strategies.

***What Went Wrong**: The Board believes the following considerations are critical to understand what went wrong during STS-107.*

1) *Commitment to a Safety Culture: NASA's safety culture has become reactive, complacent, and dominated by unjustified optimism. Over time, slowly and unintentionally, independent checks and balances intended to increase safety have been eroded in favor of detailed processes that produce massive amounts of data and unwarranted consensus, but little effective communication. Organizations that successfully deal with high-risk technologies create and sustain a disciplined safety system capable of identifying, analyzing, and controlling hazards throughout a technology's life cycle.*
2) *Ability to Operate in Both a centralized and Decentralized Manner: The ability to operate in a centralized manner when appropriate, and to operate in a decentralized manner when appropriate, is the hallmark of a high-reliability organization.*
3) *Importance of Communication: At every juncture of STS-107, the Shuttle Program's structure and processes, and therefore the managers in charge, resisted new information.*
4) *Avoiding Oversimplification: The Columbia accident is an unfortunate illustration of how NASA's strong cultural bias and its optimistic organizational thinking undermined effective decision-making.*
5) *Conditioned by Success: Even when it was clear from the launch videos that foam had struck the Orbiter in a manner never before seen, the Space Shuttle Program managers were not unduly alarmed. They could not imagine why anyone would want a photo of something that could be fixed after landing. More importantly, learned attitudes about foam strikes diminished*

management's wariness of their danger. The Shuttle Program turned the experience of failure into the memory of success.

6) *Significance of Redundancy: The Human Space Flight Program has compromised the many redundant processes, checks, and balances that should identify and correct small errors. Redundant systems essential to every high-risk enterprise have fallen victim to bureaucratic efficiency. Years of workforce reductions and outsourcing have culled from NASA's workforce the layers of experience and hands-on systems knowledge that once provided a capacity for safety oversight. Safety and Mission Assurance personnel have been eliminated, careers in safety have lost organizational prestige, and the Program now decides on its own how much safety and engineering oversight it needs.*

Organizational Development: *The Board's investigation into the Columbia accident revealed two major causes with which NASA has to contend: one technical, the other organizational. The Board studied the two dominant theories on complex organizations and accidents involving high-risk technologies. These schools of thought were influential in shaping the Board's organizational recommendations, primarily because each takes a different approach to understanding accidents and risk.*

The Board determined that high-reliability theory is extremely useful in describing the culture that should exist in the human space flight organization. NASA and the Space Shuttle Program must be committed to a strong safety culture, a view that serious accidents can be prevented, a willingness to learn from mistakes, from technology and from others, and a realistic training program that empowers employees to know when to decentralize or centralize problem-solving.

The Board believes normal accident theory has a key role in human space flight as well. Complex organizations need specific mechanisms to maintain their commitment to safety and assist their understanding of how complex interactions can make organizations accident-prone. Organizations can not put blind faith into redundant warning systems because they inherently create more complexity, and this complexity in turn often produces unintended system interactions that can lead to failure.

The Shuttle Program's complex structure erected barriers to effective communication and its safety culture no longer asks enough hard questions about risk. Safety culture refers to an organization's characteristics and attitudes - promoted by its leaders and internalized by its members - that serve to make safety the top priority.

By their very nature, high-risk technologies are exceptionally difficult to manage. Complex and intricate, they consist of numerous interrelated parts. Standing alone, components may function adequately, and failure modes may be anticipated. Yet when components are integrated into a total system and work in concert, unanticipated interactions can occur that can lead to catastrophic outcomes. the risks inherent in these technical systems are *heightened when they are produced and operated by complex organizations that can also break down in unanticipated ways.*

Despite periodic attempts to emphasize safety, NASA's frequent reorganizations in the drive to become more efficient reduced the budget for safety, sending employees conflicting messages and creating conditions more conducive to the development of a conventional bureaucracy than to the maintenance of a safety-conscious research-and-development organization. Over time, a pattern of ineffective communication has resulted, leaving risks improperly defined, problems unreported, and concerns unexpressed. The question, is why?

The Shuttle Independent Assessment Team's report documented these changes, noting that the size and complexity of the Shuttle system and of the NASA / contractor relationships place extreme importance on understanding, communication, and information handling. among other findings, the Shuttle Independent Assessment Team observed that: The current Shuttle program culture is too insular. There is a potential for conflicts between contractual and programmatic goals; There are deficiencies in problem and waiver-tracking systems; the exchange of communication across the shuttle program hierarchy is structurally limited, both upward and downward.

The Board believes that deficiencies in communication, including those spelled out by the shuttle Independent Assessment Team, were a foundation for the Columbia accident. These deficiencies are byproducts of a cumbersome, bureaucratic, and highly complex Shuttle Program structure and the absence of authority in two key program areas that are responsible for integrating information across all programs and elements in the Shuttle Program.

Principles of Organizational Change: *The Board consistently searched for causal principles that would explain both the technical and organizational system failures. The Board's analysis of organizational causes supports the following principles that should govern the changes in the agency's organizational system.*

Leaders create culture. It is their responsibility to change it. Top administrators must take responsibility for risk, failure, and safety by remaining alert to the effects their decisions have on the system. Leaders are responsible for establishing the conditions that lead to their subordinates' successes or failures. The past decisions of national leaders - the White House, Congress, and NASA Headquarters - set the Columbia accident in motion by creating resource and schedule strains that compromised the principles of a high-risk technology organization. The measure of NASA's success became how much costs were reduced and how efficiently the schedule was met."

Changes in organizational structure should be made only with careful consideration of their effect on the system and their possible unintended consequences. Changes that make the organization more complex may create new ways that it can fail. When changes are put in place, the risk of error initially increases, as old ways of doing things compete with new. Institutional *memory is lost as personnel and records are moved and replaced. Changing the structure of organizations is complicated by external political and budgetary constraints, the inability of leaders to conceive of the full ramifications of their actions, the vested interests of insiders, and the failure to learn from the past."*

Strategies must increase the clarity, strength, and presence of signals that challenge assumptions about risk. Twice in NASA history, the agency embarked on a slippery slope that resulted in catastrophe. Each decision, taken by itself, seemed correct, routine, and indeed, insignificant and unremarkable. Yet in retrospect, the cumulative effect was stunning. In both pre-accident (Challenger, Columbia) periods, events unfolded over a long time and in small increments rather than in sudden and dramatic occurrences. NASA's challenge is to design systems that maximize the clarity of signals, amplify weak signals so they can be tracked, and account for missing signals. A safety team must have equal and independent representation so that managers are not again lulled into complacency by shifting definitions of risk. It is obvious but worth acknowledging that people who are marginal and powerless in organizations may have useful information or opinions that they don't express. Even when these people are encouraged to speak, the find it intimidating to contradict a leader's strategy or a group consensus. Extra effort must be made to contribute all relevant information to discussion of risk. Because ill-structured problems are less visible and therefore invite the normalization of deviance, they may be the most risky of all.

F.2.13 Summary

The history of major accidents involving engineered systems clearly shows that the vast majority of these accidents have their roots firmly embedded in human and organizational malfunctions or breakdowns. While the majority of these accidents develop during the operations and maintenance phases, the studies also clearly show that the majority of the flaws in the system are developed during the concept development and design phases.

A key signature of major accidents is that they generally develop over long periods of time, involve large numbers of people and different organizations, and involve a multitude of breakdowns or malfunctions; there is no such thing as a 'root cause' to explain these accidents. These major accidents are focused in organizational - institutional breakdowns; malfunctions of the Technology Delivery System that is used to develop, operate, and maintain the engineered systems. What is frequently indicated as an 'engineering failure' (or 'pilot error') is in fact a failure of the Technology Delivery System.

Breakdowns in Technology Delivery Systems are most often present in Low Reliability Organizations (LROs) and interfaces between such organizations. LROs are characterized by a focus on success rather than failure, and efficiency rather than reliability. The cognitive infrastructure is underdeveloped, failures are localized rather than generalized, and highly specified structures and processes are put in place that develop inertial blind spots that allow failures to cumulate and produce catastrophic outcomes. They do the same things in the face of changing events, these changes go undetected because people are rushed, distracted, careless, or ignorant. LROs are characterized by expensive and inefficient learning.

Diversity in problem solving is not welcomed. Information, particularly 'bad' or 'useless' information is not actively sought, failures are not taken as learning lessons, and new ideas are rejected; lethal arrogance. Divergent views are discouraged, so that there is a narrow set of assumptions that sensitize the LRO to a narrow variety of inputs. Under the assumption that success demonstrates competence, LROs drift into complacency, inattention, and habituated routines. Down-sizing and out-sourcing are used to further the drives of efficiency. Insensitivity is developed to overloading and its effects on judgement and performance. Robustness (damage and defect tolerance) is eliminated or reduced in the same drive resulting in elimination of cross checks, assumption that precautions and existing levels of training and experience are sufficient, and dependence on claimed levels of competence. With outsourcing, it is now the supplier, not the buyer, that must become preoccupied with failure. But, the supplier is preoccupied with success, not failure, and because of low-bid contracting, often is concerned with the lowest possible cost success. The buyer now becomes more mindless and if novel forms of failure are possible, the loss of a preoccupation with failure makes the buyer more vulnerable to failure. LROs tend to lean toward anticipation of expected surprises, risk aversion, and planned defenses against foreseeable accidents and risks; unforeseeable accidents and risks are not recognized or believed.

F.3 Quotations from Key Reports and Papers

F.3.1 Townsend, F. F. (2006). *The Federal Response to Hurricane Katrina, Lessons Learned*, Report to the President of the United States, The White House, Washington, DC, February.

Katrina creates an opportunity - indeed an imperative - for a national dialogue about true national preparedness, especially as it pertains to catastrophic events. We are not as prepared as we need to be at all levels within the country: Federal State, local, and individual. Hurricane Katrina obligates us to re-examine how we are organized and resourced to address the full range of catastrophic events - both natural and man-made. The storm and its aftermath provide us with the mandate to design and build such a system.

The magnitude of Hurricane Katrina does not excuse our inadequate preparedness and response, but rather it must serve as a catalyst for far-reaching reform and transformation. To do this, we must understand Hurricane Katrina in its proper context.

The storm surge, extreme amounts of rain, and high winds stressed the city's complex 350 mile levee system to its breaking point. Several of the levees and flood walls were overtopped, and some were breached through the day of landfall. It was this overtopping and breaches of the levee system that lead to the catastrophic flooding of New Orleans. In addition to the levee and floodwall breaches, many of the pumping stations - which would have otherwise removed water from the city and prevented some of the flooding - stopped working due to power outages and flooded pumping equipment.

Some overtopping of the levees was expected due to the intensity of the storm, which would result in localized flooding. However, such overtopping would not have lead to the catastrophic events that occurred due to the levee and flood wall breaches. Further, the New

Orleans Flood and Hurricane Protection System is designed so that individual breaches will not lead to catastrophic flooding. The compartmented design, with four main basins, is intended to minimize the threat of flood to the entire system. Thus, had only one basin experienced serious overtopping or a breach, it would have been possible to avoid the catastrophic flooding New Orleans experienced.

New Orleans flooded as the levees and flood walls gave way and the pumping stations stopped operating; at its height, approximately 80 percent of New Orleans was filled with water up to twenty feet deep. This unprecedented flooding transformed Hurricane Katrina into a "Catastrophe within a catastrophe" as the storm shattered the lives of countless residents and presented State and local officials with challenges far exceeding their capabilities.

We must expect more catastrophes like Hurricane Katrina - and possibly even worse. In fact, we will have compounded the tragedy if we fail to learn the lessons - good and bad - it has taught us and strengthen our system of preparedness and response. We cannot undo the mistakes of the past, but there is much we can do to learn from them and to be better prepared for the future. This is our duty.

F.3.2 Select Bipartisan Committee to Investigate the Preparation for and Response to Hurricane Katrina, 2006. *A Failure of Initiative*, U.S. Government Printing Office, Washington, DC.

The preparation for and response to Hurricane Katrina show we are still an analog government in a digital age. We must recognize that we are woefully incapable of storing, moving, and accessing information - especially in times of crisis. Many of the problems we have identified can be categorized as 'information gaps' - or at least problems with information-related implications, or failures to act decisively because information was sketchy at best. Better information would have been an optimal weapon against Katrina. Information sent to the right people at the right place at the right time.

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.

The levees protecting New Orleans were not built to survive the most severe hurricanes. It was a well-known and repeatedly documented fact that a severe hurricane could lead to overtopping or breaching of the levees and flooding of the metropolitan area. In fact, for years the U.S. Army Corps of Engineers (USACE) has had a written plan for dewatering (i.e. draining) New Orleans in such a contingency.

Once construction of the levees was completed by USACE, the responsibilities for operating and maintaining the levees were split among many local organizations, which is the standard cooperation agreement for carrying out flood control projects nationwide. The costs of constructing these projects are shared, with operation and maintenance being a 100 percent local responsibility. These include levee boards in each parish, as well as separate water and sewer boards. The number of organizations involved, and disagreements among them, makes accountably diffuse and creates potential gaps and weaknesses in parts of the flood protection system. In one case, improvements to levee strength which may have mitigated or prevented some of the critical breaches that flooded downtown New Orleans were rejected by the competing local organizations. There also appear to have been lapses in both maintenance and inspections of selected levees, including those that breached. Also, prior to Hurricane Katrina, residents along these same levees reported they were leaking, another potential lapse in maintenance.

Despite the well-known importance of the levees, and the consequences of failure, the local levee boards responsible for maintaining and operating the levees did not have any warning system in place. While federal regulations require that they monitor levees during periods of potential flooding, the requirement is impractical to implement during a hurricane. In addition to no warning system, the loss of communications and situational awareness, and only sporadic reports of flooding from a variety of sources, made it difficult to confirm that there were breaches in the levees and then to assess the damage. These factors, as well as physical difficulties of getting to the breach sites, combined to delay repair of the levee breaches.

A lot of hurricanes threaten the Gulf coast every year, and New Orleans is particularly vulnerable because of its location and topography. The majority of the metropolitan area is below sea level. Over the years, the city has continued to sink, due to drainage, subsidence, and compaction of the soils. As an example of previous damage, Hurricane Betsy brought extensive destruction to New Orleans when it made landfall in Louisiana in September 1965. Unfortunately, many of the descriptions and photos from Hurricane Betsy sound and look familiar to our nation as it considers the damage from Hurricane Katrina, forty years later.

After Hurricane Betsy in 1965, federal and state governments proposed a number of flood control projects to deal with the threat of hurricanes and the flooding they might cause in New Orleans. These included a series of control structures, concrete floodwalls, and levees along Lake Ponchartrain and several other waterways. One of the major projects is formally called the Lake Ponchartrain and Vicinity, Louisiana Hurricane Protection Project. This project included levees along the Lake Ponchartrain lakefront, the 17th Street Canal, the London Avenue Canal, the Orleans Avenue Canal, the Intercoastal waterway, the Industrial Canal, The Mississippi River Gulf Outlet, and other areas. Although the project was federally authorized, it was a joint federal, state, and local effort with shared costs.

"The levees protecting New Orleans were not designed to withstand the most severe hurricanes. According to USACE's plans for dewatering New Orleans, 'the hurricane protection system is not designed for the largest storms and as a result, the metropolitan area is vulnerable to flooding from hurricane storm surges.' USACE originally designed the levees around New Orleans to protect against a hurricane intensity that might occur once every 200-300 years.

According to USACE, the 'standard project hurricane' was used to design the New Orleans levees and is roughly equivalent to a fast moving, or moderate category 3 hurricane. However, there is no direct comparison of the standard project hurricane to a specific category on the Saffir-Simpson Hurricane Scale - which did not exist when the levees were designed. As shown in the table below, the standard project hurricane is equivalent to a hurricane with category 2 winds, category 3 storm surge, and category 4 barometric pressure.

In addition, there is no 'standard' hurricane - the actual forces that levees need to withstand are a function of several factors. According to the preliminary NSF study, 'the actual wind, wave, and storm surge loadings imposed at any location within the overall flood protection system are a function of location relative to the storm, wind speed and direction, orientation of levees, local bodies of water, channel configurations, offshore contours, vegetative cover, etc.. They also vary over time as the storm moves through the region.' Similarly, USACE documents indicate that overtopping will depend upon the intensity of the storm, the track that the center or eye of the storm follows and the speed at which it travels along the track.

Although the Lake Ponchartrain project is named a hurricane protection project, a number of factors other than saving lives and property are included in the design of such projects. For example, in addition to protection urban and community lives and health, the design of such projects must include environmental and economic effects, and ensure that benefits of the completed project outweigh its cost of construction. In discussing the design of the Lake Ponchartrain project in a 1978 hearing, USACE District Commander for New Orleans, Colonel Early Rush, stated 'Even Though economists may, and in this case did, favor protection to a lower scale to produce a higher ratio of benefits to costs, the threat of loss of human life mandated using the standard project hurricane.

Even with its hurricane protection system, it was common knowledge that New Orleans was susceptible to hurricane-caused flooding. The risks of a major hurricane and flooding in New Orleans had been covered in the general media - by Scientific American (October 2001) and National Geographic (October 2004) - as well as in emergency management literature. A recent article in the Natural Hazards Observer stated: 'When Hurricane Katrina came ashore on August 29, she ended decades of anticipation. There were few hazards in the United States more studied by scientists and engineers and there was ample warning that a strong storm could cause the City of New Orleans to flood.

Because of the well-known potential for flooding, USACE has had a plan for several years for draining New Orleans - *Dewater Plan, Greater Metropolitan Area, New Orleans, Louisiana*, dated August 18, 2000. This plan provides details on the hurricane protection system and describes methods to get the water out after catastrophic flooding from a hurricane. The premise of the plan is that a category 4 or 5 hurricane may produce storm surge water levels of sufficient height to overtop the existing protection system. The plan lays out a series of scenarios that could occur and suggests appropriate emergency responses to dewater the area. For example, in one case…'There is catastrophic flooding due to complete overtopping of the levees and floodwalls and inundation of the protected area. There will be extensive and severe erosion of levees and perhaps complete breaches. Due to the high water levels, all of the pumping stations will probably be flooded with major damages….The levee districts and drainage departments may be dysfunctional to some degree.

In more recent years, well before Hurricane Katrina, questions were raised about the ability of the Lake Ponchartrain project to withstand more powerful hurricanes than the 'standard project hurricane,' such as a category 4 or 5 hurricane. USACE had discussed undertaking a study of modifications needed to increase the strength of the exiting levees, but no formal study was undertaken.

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 of damaged by a flood.

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.

The local sponsors include a variety of separate local organizations. For example, different parts of the Lake Ponchartrain and Vicinity Louisiana Hurricane Protection Project, were turned over to four different local sponsors - to include the Orleans, East Jefferson, Lake Borgne, and Ponchartrain levee districts. In addition ,there are separate water and sever districts that are responsible for maintaining pumping stations.

The different local organizations involved had the effect of diffusing responsibility and creating potential weaknesses. For example, levee breaches and distress were repeatedly noted at transition sections, where different organizations were responsible for different pieces and thus two different levee or wall systems joined together. According to USACE, 'at sections where infrastructure elements were designed and maintained by multiple authorities, and their multiple protection elements came together, the weakest (or lowest) segment or element controlled the overall performance.

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.

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.

In addition, there was apparently seepage from one canal before Hurricane Katrina, indicating problems had developed in the levee after construction. Specifically, residents of New Orleans who live along the 17th Street Canal said water was leaking from the canal and seeping into their yards months before Hurricane Katrina caused the levee system to collapse. The leaks, they said, occurred within several hundred feet of the levee that later failed.

Because the eye of Katrina passed just slightly to the east of New Orleans, the hurricane threw unusually severe wind loads and storm surges on the flood protection systems. The surge overtopped large sections of the levees during the morning of August 29 east of New Orleans, in Orleans and St. Bernard Parish, and it also pushed water up the Intercoastal waterway and into the Industrial Canal. The water rise in Lake Ponchartrain strained the floodwalls along the canals adjacent to its southern shore, including the 17th Street Canal and the London Avenue Canal. Breaches along all of these canals led to flooding of 80 percent of New Orleans to depths up to 20 feet. The flooding of central New Orleans led to the most widespread and costly damage of the hurricane. It also lead to the difficulties encountered by emergency responders that are documented elsewhere in this report.

Despite the well-known importance of the levees, and the consequences of failure, the local levee boards responsible for maintaining and operating the levees do not have any warning system in place. Federal regulations require local sponsors to ensure that flood control structures are operating as intended and to continuously patrol the structure during flood periods to ensure that no conditions exist that might endanger it. However, it would be impractical to monitor the levees during a hurricane.

There were also physical barriers that made assessments and repair difficult. Specifically, emergency repair operations to close some of the breaches were seriously hampered by lack of access roads. USACE regulations generally require access roads on top of levees to allow for inspections, maintenance, and flood-fighting operations, and most USACE levees built in the United States meet this requirement. However, in New Orleans, exceptions were made to these regulations because of its highly urban nature. Access roads were foregone when it was decided to use I-walls in the levee crowns to minimize right-of-ways into surrounding neighborhoods. When Hurricane Katrina led to the breaches in the levees, the lack of access roads atop the levees resulted in very significant increases in time and cost to repair the damaged areas.

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.

The forces that destroyed the levees also destroyed the ability to quickly access damage and make repairs. The reasons for the levee failures appear to be some combination of nature's wrath (the storm was just too large) and man's folly (an assumption that the design, construction, and maintenance of the levees would be flawless). While there was not failure to predict the inevitability and consequences of a monster hurricane - Katrina in this case - there was a *failure of initiative* to get beyond design and organizational compromises to improve the level of protection afforded.

F.3.3 Report of the Committee on Homeland Security and Governmental Affairs. *Hurricane Katrina, A Nation Still Unprepared*, United States Senate, Washington, DC, May 2006.

The Contribution of the Mississippi River Gulf Outlet to Damage from Hurricane Katrina

Congress authorized construction of the Mississippi River Gulf Outlet (MRGO) in 1956 to facilitate commercial shipping access to the Port of New Orleans from the Gulf of Mexico. Upon its completion in 1965, the MRGO provided a route 40 miles shorter than the alternative up the Mississippi River. The MRGO also provides a connection from the Gulf of Mexico to the Gulf Intracoastal Waterway (GIWW), which is a recreational and commercial waterway running east-west from Texas to Florida. Though the MRGO produced commercial benefits, those benefits came at a cost to the environment. The Corps estimates that the construction of the channel led to substantial loss of wetlands, which, as noted above, help slow and decrease the power of storms before they hit populated areas.

The MRGO also contributed to a potential "funnel" for storm surges emerging from Lake Borgne and the Gulf into the New Orleans area. The "funnel" was created by the intersection of the MRGO from the southeast and the GIWW from the northwest into the confined channel, referred to as the GIWW/MRGO that separates New Orleans East and the Ninth Ward/St. Bernard Parish. The levees on the south side of the MRGO and the levees on the north side of the GIWW converge from being about 10 miles apart where they straddle Lake Borgne to a few hundred yards apart where the MRGO merges into the GIWW. The western part of the "funnel" is a 6 mile-long section of the combined GIWW/MRGO which was enlarged by a factor of three when the MRGO was built in order to expand from a barge channel to accommodate oceangoing vessels.

Prior to Hurricane Katrina, many warned that the potential funnel would accelerate and intensify storm surges emerging from Lake Borgne and the Gulf into the downtown New Orleans area. The funnel had been described as a "superhighway" for storm surges or the "Crescent City's Trojan Horse" that had the potential to "amplify storm surges by 20 to 40 percent," according to some storm modeling. Researchers at LSU believed that in creating this funnel, "the US Army Corps of Engineers had inadvertently designed an excellent storm surge delivery system - nothing less - to bring this mass of water with simply tremendous 'load' - potential energy - right into the middle of New Orleans.

The extent to which MRGO, and the funnel it helped create actually contributed to the hurricane's damage is still being investigated, but there have been some preliminary findings. A recent report issued by the Corps' IPET concluded that the portion of MRGO running from the GIWW to the Gulf (called "Reach 2") did not significantly impact the height of Katrina's storm surge, not because the "funnel" effect was nonexistent, but because the storm was so great it nullified the impact of either the wetlands or the [35] intersection of the MRGO and the GIWW - the funnel - at the height of the surge.

The building of MRGO and the combined GIWW/MRGO resulted in substantial environmental damage, including a significant loss of wetlands that had once formed a natural barrier against hurricanes threatening New Orleans from the east. MRGO and the GIWW/MRGO provided a connection between Lake Borgne and Lake Pontchartrain that allowed the much greater surge from Lake Borgne to flow into both New Orleans and Lake Pontchartrain. These channels further increased the speed and flow of the Katrina surge into New Orleans East and the Ninth Ward/St. Bernard Parish, increasing the destructive force against adjacent levees and contributing to their failure. As a result, MRGO and the combined GIWW/MRGO resulted in increased flooding and greater damage from hurricane Katrina.

The Roles and Responsibilities of the U.S. Army Corps of Engineers, the Louisiana Department of Transportation and Development and the Orleans Levee District:

The U.S. Army Corps of Engineers

Levee systems of the size needed to protect the New Orleans area are often collaborative efforts between federal and local governments. The federal role in such projects is carried out by the Corps, an agency within the Department of Defense (DOD) charged with both military and civilian missions. Military missions are assigned within the military command structure, while civilian flood control projects are authorized by Congress in legislation.

Flood-control projects usually begin when a community feels a need for protection and contacts the Corps. If the Corps does not already have the statutory authority to respond, then Congress may grant it. After initial studies, the Corps may enter into a project cooperation or assurance agreement with a local sponsor acting on behalf of the community. The assurance agreements for projects generally set forth roles of the parties, including payment obligations, design and construction responsibilities, and operations and maintenance (O&M) duties before and after the project is complete.

The levee system that protects most of New Orleans, including areas that experienced major breaches and flooding during Katrina - such as the 17th Street and London Avenue Canals, New Orleans East, and most of St. Bernard Parish - is a Corps project called the Lake Pontchartrain and Vicinity Hurricane Protection Project (Lake Pontchartrain Project). There are several other federal cost-shared projects that protect other parts of southeastern Louisiana. The Corps' involvement in these projects was mostly through its New Orleans District, one of the Corps' largest with more than 1,200 employees and part of the Corps' Mississippi Valley Division headquartered in Vicksburg, Mississippi. When Katrina made landfall, the New Orleans District was under the command of Colonel Richard P. Wagenaar, who had assumed control only six weeks before.

The assurance agreements for the Lake Pontchartrain Project made the Corps responsible for designing and constructing the project. Local sponsors provided the land for levee construction and rights-of-way, and agreed to share the cost. The Corps was to turn the completed project over to the local sponsors for O&M consistent with the Corps' standards, i.e., making sure the flood-control system actually works on a day-to-day basis and protects those living inside the system. 10 To help the local sponsor do this, the Corps is required by its rules and regulations to provide the local sponsor with an operations manual" and then conduct annual inspections to be sure the local sponsor is doing what it is supposed to do.

In addition to its authority to build flood-control projects, the Corps also has statutory authority in federal cost-share flood-control projects like the Lake Pontchartrain Project to act in anticipation of, or response to, flood emergencies. In this role, the Corps may help the local sponsors deal with the flood threat to the levee system, and aid state and local governments trying to prevent flood damage. This "flood-fighting" authority is authorized by Public Law 84-99, also known as the "Flood Act." In the days following Katrina, the Corps used its Flood Act authority to close off the levee breaches at the 17th Street and London Avenue Canals, which were filling the city with water, and to make other emergency repairs.

The Orleans Levee District

One of the local sponsors for the Lake Pontchartrain Project was the Orleans Levee District, one of the first five levee districts created by the state in 1879. The levee districts, which were established to be a funding source for and to ensure local involvement in levee construction and operation, all had the same general duty: to do what was necessary to "insure the thorough and adequate protection of the lands of the district from damage by flood ... for the adequate drainage control of the district."

Like the Corps under the Flood Act, the levee districts have broad statutory obligations in addition to their obligations under their assurance agreements on individual levee projects. For example, regardless whether a project was being designed and constructed by the Corps or had been turned over for O&M to the local sponsor, state law charged the levee districts with adopting rules and regulations for maintaining a "comprehensive levee system." State law authorized them to obtain engineering assistance from the Louisiana Department of Transportation and Development (LA DOTD) in Baton Rouge if they needed additional technical expertise.' State law also required levee-district board members to attend once during their term in office an educational program on how to care for and inspect levees.

To carry out their primary duty of flood control, state law not only authorized the levee districts to serve as local sponsors for federal cost-share projects, but also to raise money pursuant to taxing and bonding authorities. In the unique case of the Orleans Levee District, it was also authorized to engage in various business enterprises, [20] making the Orleans Levee District a unique entity with some governmental qualities (taxing and bonding authority) and some corporate qualities: the authority to engage in for-profit businesses like operating the Lakefront Airport, running two marinas along Lake Pontchartrain, and leasing dock space to a riverboat casino.

The revenues the Orleans Levee District earned from the businesses and its taxing and bonding authority were substantial. The Orleans Levee District financial statements for the fiscal year ending June 30, 2005, show it collected more than $24 million from property taxes and $14 million from its business-type activities in the previous 12 months. The same report said the district had $21 million in unallocated general funds and $13 million in a "special levee improvement fund. The levee improvement fund, according to the levee district's former president, Jim Huey, could "only be used for flood protection projects and/or flood-related projects.

Although the levee district's primary responsibility was flood protection it spent large amounts on non-flood related activities (e.g., the licensing of a casino or the operation of an airport and. marinas or the leasing of space to a karate club, beautician schools or restaurants) rather than apply the money to flood protection or emergency preparedness. [25] For example, the Orleans Levee District's Emergency Operations Center (EOC) sat outside the protection of the levee system at the Lakefront Airport, vulnerable to the very hurricanes the levee system was designed to protect against. For years the district had, studied moving its EOC inside the flood protection system, but never did. The levee district's Chief Engineer, Stevan Spencer, described the situation as a "very bad joke" that dated back to at least 1998, when Hurricane Georges flooded the airport. Spencer said "there was never funding" to move the EOC. Yet in 2003, the Orleans Levee District spent $2.4 million to repair the "Mardi Gras Fountain" in a park near Lake Pontchartrain. When Katrina made landfall, Orleans Levee District staff had to be rescued, mostly by boat, from the flooded EOC at the airport before they could survey damage or assist with repair efforts at the 17th Street and London Avenue Canals.

The Orleans Levee District was also aware of a levee in New Orleans East that was considered to be three feet below its design height. Levee-district board minutes and conversations with Corps personnel suggest that paying for repairs to this low levee was considered to be the Corps' responsibility. Federal funding was unavailable, but instead of paying for the repairs itself and asking for reimbursement from the Corps, as it had with previous projects, the levee district merely sent letters to its Congressional delegation asking for federal funding.

Pressed to explain how the Orleans Levee District made spending decisions, Huey offered no direct explanation, but focused on the district's multiple obligations - not only was the district responsible for flood control, but it also had statutory requirements to maintain recreational space and was authorized by state law to engage in non-flood related business ventures. A review of the levee-district board minutes of recent years revealed that the board and its various committees spent more time discussing its business operations than it did the flood-control system it was responsible for operating and maintaining.

The Louisiana Department of Transportation and Development (LA DOTD)

Though not a party to the assurance agreements for the Lake Pontchartrain Project, LA DOM and its Office of Public Works (OPW) have statutory responsibilities to assist and oversee certain levee district functions. State law tasks LA DOM with approving any activity that might compromise the levees, and with administering training sessions to levee-district board members and their inspectors on caring for and inspecting levees.

To the extent training sessions were held, they were organized by the Association of Levee Boards of Louisiana, an organization that lists Edmund Preau as its Secretary Treasurer. Preau is an Assistant Secretary in LA DOTD and leads the OPW within the Department, which is responsible for LA DOTD's levee-related activities.

When Huey, who served on the levee district's board for more than 13 years (nine as president), was read the section of state law describing the training requirement, he said it was the first he had heard of it. Huey explained: "You know what that is? That's going up to a workshop for a weekend and having a crawfish boil up here and hear a couple people talk about some things and they get a little piece of paper and they honored the law Huey was then asked whether the Association sessions addressed how to inspect levees. He responded, "No, nothing. LA DOTD also had the statutory responsibility to "review" each levee district's emergency-operations manual every two years . According to Preau, this review entailed checking whether relevant contact information had been updated and whether the levee district had included any new flood-control systems within its jurisdiction in its planning. The review entailed no assessment of whether the levee district had stockpiled materials or had the personnel necessary to assess an emergency and respond accordingly. Preau said he assumed any more elaborate review would have been done by the Louisiana Office of Homeland Security and Emergency Preparedness (LOHSEP).

Louisiana's Emergency Operations Plan (EOP) made the LA DOTI) the primary state agency overseeing Emergency Support Function (ESF-3), Public Works and Engineering. ESF-3 encompassed critical infrastructure in the state, including the "construction, maintenance and repair of state flood control works. ESF-3 also dictated that, "When an emergency is imminent, the ESF 3 Coordinator [who is to be designated by LA DOTD Secretary Johnny Bradberry] will assess the potential impact of the threat on the state's infrastructure and work with other authorities to ensure that any necessary immediate repairs or arrangements for critical structures and facilities are initiated. ESF-3 also said, "As the emergency progresses, the coordinator will monitor the status of the infrastructure and effect emergency repairs where needed and feasible."

The LA DOTD did not acknowledge or accept its responsibility under ESF-3. Preau told Committee investigators that he didn't think the provision applied to LA DOM "I'm not sure what that means, because we don't have any state flood control works. State doesn't own any flood control works. By Preau's reading, a levee project was covered only if it was owned by the state, not simply if it was in the state. As Preau read it, LA DOTD had no responsibility to coordinate with levee districts on critical facilities like the Lake Pontchartrain Project. This response is problematic: the responsibilities articulated under ESF-3 are specifically delegated to the LA DOTD, and the plain language employed by the State's Emergency Operations Plan cannot be unilaterally dismissed as meaningless by the people it covers.

The result was that neither LA DOTD nor any state agency made sure that the state's levee districts were integrated into the state's emergency-planning process, much less genuinely prepared for an emergency. As a result, when Katrina made landfall, no Orleans Levee District personnel were located at, or in contact with, emergency managers in Baton Rouge; nor was any mechanism in place to request additional support from the state. Not withstanding Preau's insistence that the LA DOTD had no responsibilities under ESF-3 for the levee system, LA DOTD ultimately played an active role in efforts to close levee breaches in New Orleans in the aftermath of Katrina.

Design and Construction of the Lake Pontchartrain Project

During Katrina, levees and floodwalls were overwhelmed throughout the New Orleans area, and in several places were breached. Some of these failures occurred in parts of the Lake Pontchartrain Project. Understanding the link between the breaches and the nature and organization of the Lake Pontchartrain Project requires some background. Congress authorized the Lake Pontchartrain Project in the Flood Control Act of 1965 to provide hurricane protection to areas around Lake Pontchartrain in Orleans, Jefferson, St. Bernard, and St. Charles Parishes. The project called for design and construction of about 125 miles of levees and floodwalls to be completed by 1978 at a cost of $85 million. The project was still not complete when Katrina hit, and its cost had grown to more than $750 million as of 2005 .

As authorized by Congress, the project was to protect the area from what the Corps called the "Standard Project Hurricane" (SPH), a model storm "based on the most severe combination of meteorological conditions considered reasonably characteristic of that region." The SPH was developed in 1959 by what was then called the United States Weather Bureau, which updated the SPH after the devastating impact of Hurricane Betsy in 1965. The SPH was revised again in 1970, 1977, and 1979 by the Weather Bureau's successor, the National Oceanic and Atmospheric Administration (NOAA). There is no evidence that design parameters of the Lake Pontchartrain Project were modified in light of NOAA's changes to the reference-model storm.

Nevertheless, the Corps has repeatedly maintained that the SPH was the equivalent of a fast-moving Category 3 storm on the Saffir-Simpson scale - a measurement scale that rates the strength of hurricanes on a scale of Category I to Category 5, with Category 5 being the most intense. For example, at a press conferences immediately after the storm, Lieutenant General Carl Strock, the Commander of the Corps and its Chief of Engineers, explicitly said that the Corps "knew" that the levee system "would protect from a Category 3 hurricane," and the page on the Lake Pontchartrain Project on the Corps' website after Katrina said, "The SPH is equivalent to a fast-moving Category 3 hurricane."

This claim is misleading: the Saffir-Simpson scale was not adopted until 1977, 12 years after the Lake Pontchartrain Project was authorized. Al Naomi, the Corps' Senior Project Manager for the project, acknowledged that the Corps never conducted a formal study comparing the SPH to the Saffir-Simpson scale, so the claim that the Lake Pontchartrain Project provided Category 3 protection was at best a rough estimate, and at worst, simply inaccurate:

> *SPH has ... wind speed, central pressure, and surge. You go in and say what is my wind speed for an SPH? You look at it. It's a very high Category 2 storm on the Saffir-Simpson Scale. I look at my central pressure for SPH. I go to the Saffir-Simpson Scale, it's a mid-range Cat 4. 1 say what is my surge? SPH surge in the lake at two and a half [feet] on the Saffir-Simpson that is a Category 3 range. What am I going to tell the Rotary Club? What do I have? Generally in talking to the hydrologist, you can say it's about equivalent to a fast moving Cat 3. It's not really that, but for their understanding that is what you can say. That is what we say. What happens is the press gets this and it says we have Cat 3 protection. That is not really true. It's SPH protection which may be equivalent to a fast moving Cat 3 storm.*

However, the view that the hurricane protection system could protect the greater New Orleans region from a moderate and/or fast-moving Category 3 storm was widely held within the Corps' New Orleans District. Prior to Hurricane Katrina, the New Orleans District issued numerous news releases to the general public (some of which are referenced below), stating that the hurricane protection system provided some level of Category 3 protection:

- *December 19, 200 1, N. 0. hurricane bridge contract awarded, Corps, Levee Board will floodproof two bridges in Gentilly: "The bridge floodproofing will protect neighborhoods along the London Avenue, Orleans Avenue and 17th Street canals from storm surges from Lake Pontchartrain. The system of levees,* *floodwalls and bridges is designed to protect against fast-moving Category 3 hurricanes."*

- *May 27, 2003, Cross Bayou Drainage Structure to reduce flooding in St. CharlesParish: "The structure is part of the Lake Pontchartrain Hurricane Protection Project and is the second of five such structures to be built in St. Charles Parish These contracts, to be completed in 2004, will result in a levee system that provides protection from a Category 3 storm for St. Charles Parish"*

- *August 21, 2003, Filmore Bridge in Gentilly will reopen on Friday, Aug. 22. Mirabeau Bridge is closing Wednesday, Aug. 27 for hurricane floodproofing: "The systems of levees, floodwalls and bridges is designed to protect against fast moving Category 3 hurricanes. This view was also held by the Corps' New Orleans District Commander (Col. Wagenaar 63) and the District's Emergency Manager (Michael Lowe). Further, the same representations were made in more substantive Corps written materials.*

Moreover, the Lake Pontchartrain Project, as it stood in the path of Katrina, was still not complete as designed. Some portions were still under construction, and soil subsidence (sinking) had left portions of the project with less elevation above sea level than intended. In other words, some elements of the project were not even high enough to protect against the Standard Project Hurricane, let alone a genuine Category 3 hurricane.

The Corps was well aware of this fact. As Jerry Colletti, the New Orleans District's Manager for Completed Works explained, the Corps never tried "to provide full-level protection on an annual basis.... we just can't raise everything to the design height for each storm that would come through."

Meanwhile, the National Weather Service (NWS) concluded from a new model of projected storm surges that the Lake Pontchartrain Project would be more vulnerable to hurricanes than previously thought - that more Category 3 and even certain Category 2 hurricanes would overtop parts of the levee system and produce flooding. Dr. Wilson Shaffer, who studies storm surges at NWS, said this discovery was shared with the Corps, perhaps as early as 2003, but certainly by 2004. The findings were also shared with LOHSEP and with state and local emergency managers at the Louisiana Emergency Preparedness Association's June conferences in 2004 and 2005 . At a minimum, this information should have prompted a fresh look at the adequacy of the Lake Pontchartrain Project, but like the NOAA updates to the Standard Project Hurricane in the 1970s, it does not appear that either the state or the Corps took any action to respond to the new information.

Effect of Subsidence on the Level of Protection

As noted earlier, the level of protection provided by the levee system was affected not only by its design, but also by geologic subsidence, or regional sinking. The entire coastal region of Louisiana had been subsiding for millions of years, as the enormous weight of the sediments continually deposited by the Mississippi River enters the Gulf of Mexico, pushing down on the earth's crust. Human activities like extracting oil and natural gas, pumping water, raising buildings, and even adding to levees and floodwalls all accelerate subsidence. (See Chapter 9.) As the entire region subsides, the effective height of the levees above sea level, and thus the level of protection they provide, decreases. A recent report concluded that a section of levee that was overtopped and failed during Katrina was nearly three feet below its design height.

All of these factors should have persuaded the Corps to reconsider its public claims that the Lake Pontchartrain Project provided Category 3 level protection.

Operation and Maintenance (O&M)

Maintaining a flood control system is essential, but is complicated in southeast Louisiana by the recurring need to rebuild levees to compensate for subsidence. The Corps is not supposed to turn over a project until it is complete; until then, the Corps is responsible for O&M. Once a project is turned over, the local sponsor must conduct O&M to Corp standards "to obtain maximum benefits." This includes checking for "undue settlement" of the levee, water seeping through or under it, and growth of damaging brush, and taking immediate action to address potential emergencies.

Because the Lake Pontchartrain Project was not complete, according to the Corps' Senior Project Manager for the project, none of it had been formally turned over to the local sponsor, but remained in an "interim" status:

> *There are still pieces that have to be done. We are not going to turn over a piece of the project until every piece in that ring of protection is completed. If there is one little thing left to do I think by regulation - I could be wrong - I think we have to have the entire system 100 percent complete so we turn over the entire segment that is protected, a certain area of the City.*

Nonetheless, the Corps did nominally turn over parts of the project to local sponsors to maintain when it determined that construction on that particular part or "reach" was complete. The Corps sent letters to the Orleans Levee District and others to this effect, informing each district that it now had O&M responsibility for that unit. Personnel within the Corps' New Orleans District referred to these letters as "turnover letters" even though they were not the "official total project completion turnover" letters. The Orleans Levee District did not respond to these letters or even acknowledge their receipt.

When the Committee asked for copies of the de-facto turnover letters, it received only a limited response. The letters submitted did not cover the entire project, and some were pre-1965, before the project was even authorized. In short, the exact legal status of the project segments and the degree to which the Corps and local sponsors like the Orleans Levee District were truly responsible for maintenance is at best uncertain.

Other conflicting and irregular procedures in the turnover process went beyond the turnover letters. The Corps was supposed to require local sponsors to report semiannually to its District Engineer on inspection and O&M for the flood-control system. Colletti, the Corps' Operations Manager for Completed Works, explained that the Corps unilaterally decided not to require the Orleans Levee District to provide the report. In addition, for each completed work, the Corps is required to give the local sponsor an operations manual . Colletti said his office gave no such manual to the Orleans Levee District for levees and floodwalls, but merely provided a one-page set of guidelines similar to a part of the Code of Federal Regulations that detailed obligations of local sponsors.

The Corps' observance of rules and regulations for completed projects took the form of a required annual inspection conducted around June 1 - the start of hurricane season - by representatives from the Corps, the Orleans Levee District, the LA DOTD, and other interested parties (e.g., the City and the Port of New Orleans). These inspections appear to have taken about four hours, covered at least a hundred miles of levees and floodwalls, and would usually involve a motorcade that would stop at pre-determined spots to allow the group to look over an area and discuss issues. The purpose of the inspections, according to the Corps, was to ensure O&M compliance by the local sponsor, but not to test the system's actual structural integrity or measure whether it was at design height. Perhaps the most colorful explanation of the annual inspection was offered by former Orleans Levee District president Huey, who suggested that the event was more of a social occasion than a genuine technical inspection:

> *They normally meet and get some beignets [pastries] and coffee in the morning and get to the buses. And the colonel and the brass are all dressed up. You have corrunissioners, they have some news cameras following you around and you have your little beignets and then you have a nice lunch somewhere or whatever. And that's what the inspections are about.*

Ineffective Inspection Regime

The weaknesses of this inspection approach can be seen in the last pre-Katrina annual inspection of the Lake Pontchartrain Project in May 2005. It apparently did not address some known vulnerabilities. The W-30 Floodgate along the Inner Harbor Navigation Canal had been destroyed by a train accident in 2004 by the New Orleans Public Belt Railroad . This gate was intended to close off the levee at a point where the railroad track passed through it. The railroad had provided money for repairs, but the floodgate was still broken when Katrina struck, even though Huey, then board president, told an April 5, 2005, levee-district board meeting that he considered the broken gate to be an "emergency." Under state law, Huey had the authority to address such emergencies without going through the standard contracting process. Asked why he did not use his emergency authority to repair the gate before hurricane season, Hue simply said, "I do not know. My bottom line straightforward answer: I don't know."

Another problem apparently not dealt with in the annual inspection was a levee in New Orleans East that was three feet short of its design height. Like the W-30 floodgate, the problem remained unaddressed when Katrina made landfall, even though Naomi, the Corps' Senior Project Manager, considered repair "vital" to protecting the city. In addition, Corps rules and regulations for completed works require local sponsors, like the Orleans Levee District, to fix defects promptly. Finally, the Corps' rules on levees require local sponsors to ensure that "No trees exist, the roots of which might extend under the wall and offer accelerated seepage paths." However, one of the forensic teams investigating the levees' failure, and Corps officials, found trees growing along the 17th Street and London Avenue Canals. In spite of the major defects requiring repairs, the Orleans Levee District's Chief Engineer said he expected the district to get "an outstanding review in regards to the maintenance of the levees" from the 2005 inspection.

The Committee learned during its investigation that the 17th Street and London Avenue Canal floodwalls weren't part of the 2005 inspection because they were inaccessible by car. It appears likely that they were never inspected by the Corps after construction was finished in the early 1990s, partially because the floodwalls abutted private property which made them difficult, but certainly not impossible, to access. It seems likely that the only physical inspections they received would have been conducted by Orleans Levee District personnel mowing the grass, making visual inspections, and identifying problems like holes dug by wild animals, significant erosion, etc. The personnel responsible for this work received no specialized training on care or inspection of levees and floodwalls, and supporting documentation of these inspections comprised nothing more than worker timesheets indicating the work conducted, such as mowing the grass, the location of the work, and the hours spent doing the job.

When asked who was responsible for fixing problems once they were identified, Orleans Levee District leadership explained that there was an undocumented understanding that "major" problems would be brought to the attention of the Corps and "minor" problems would remain the responsibility of levee district personnel . However, and as noted by the Orleans Levee District Chief Engineer, Steven Spencer, the district's total in-house, engineering expertise amounted to three engineers , a level of expertise not on par with the challenges posed by the hurricane protection system within the jurisdiction of the Orleans Levee District.

The only other inspection the Orleans Levee District claims to have made of the levees was a field survey of floodwall heights every two to three years to check for subsidence. If the Orleans Levee District did, in fact, conduct these surveys, they did not identify the severity of the subsidence along the 17th Street and London Avenue Canals documented by the Corps' forensic team. The Orleans Levee District certainly did not conduct any structural analysis of the floodwalls; nevertheless, when asked by the Committee about the quality of the Orleans Levee District's operations and maintenance regime over the years, Colletti said that the Corps "felt that they've done an outstanding job."

The Orleans Levee District's O&M practices and the passive oversight by the Corps did not meet what experts consider to be the standard of care for a flood control system like the Lake Pontchartrain Project. For example, in a letter to the Committee, Dr. Ernst G. Frankel of the Massachusetts Institute of Technology explained that visual surveys are not sufficient because potentially catastrophic voids can occur well below the surface of the levees. To expose internal degradation, holes must be drilled in the levees to retrieve core samples for analysis. Acoustic equipment can be used to scan the density of material layers at various depths. No entity conducted such an analysis of the New Orleans flood-control structures, nor were efforts made by the Levee District to obtain equipment to improve its inspection regime. Professor Frankel added that inspection of levees below the waterline was also necessary to detect hidden threats to their integrity. The Orleans Levee District's simple visual inspections failed in this respect as well.

Lack of Coordination with the Sewerage and Water Board of New Orleans

Because New Orleans and surrounding parishes are below sea level and ringed by levees, rain and flood waters that enter must be pumped out. The Sewerage and Water Board of New Orleans (the Water Board) has the responsibility for maintaining a system of pumps and canals for this purpose. (The Water Board also runs the municipal water and sewer systems.) Floodwalls along two of these drainage, or outfall, canals sustained major breaches - the 17th Street and London Avenue Canals. However, the Orleans Levee District and the Corps, at least to the extent the Corps had not turned over the entire project to the local sponsor, are responsible for the floodwalls that line these canals.

In the aftermath of Katrina, the New Orleans Times-Picayune newspaper reported that six months before Katrina, several residents near the 17th Street Canal reported to the Water Board that they had found water in their yards. A similar report was carried by National Public Radio. Following the Times Picayune report, the Water Board conducted an inquiry into these allegations and concluded that the water reported by these property owners was coming from a water-service line and not from the canal. This conclusion was documented in a letter from the Water Board to the Times-Picayune and provided to the Committee. The 17th Street Canal floodwall broke within several hundred feet of where the water seepage was reported. The Committee was not able to independently confirm either the news reports or the Water Board's explanation. However, it is clear that the Water Board had no plan in place or arrangement with either the Corps or the Orleans Levee District to address this sort of situation. The Water Board's Executive Director, Marcia St. Martin, explained how her organization dealt with such situations:

> *What we do is if a person says that there's water that's ponding in front of my house, we look to see whether or not a Board asset, which is the water meter, has a defect or a leak. If we determine it has a defect or a leak, we repair it. If we determine it's not coming from the Board's asset, we say to the customer, "It has to be a private property leak and you need to seek the services of a plumber.*

The Corps has relied on local residents to inform it about these types of problems, but had no public outreach program to urge residents to do so. When the Corps did receive reports of seepage or other issues, it had no process to formally document and address the issues. Likewise, the Orleans Levee District had no plan to reach out or communicate with residents to encourage the identification or the sharing of reports of leakage or other problems."

Subsidence in the Metropolitan New Orleans Area

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

As a result, it appears that the level of protection actually provided by the levee system in the New Orleans region, at the time of Katrina, was significantly less than intended: many sections of the levees and floodwalls were substantially below their original design elevations, an effective loss of protection. For example, the structures associated with the Inner Harbor Navigation Canal were originally constructed to an elevation of 15 feet (relative to mean sea level) but are now just over 12 feet, a typical loss of approximately 2.7 feet in elevation over the lifetime of the project. The report noted that "subsidence is occurring at a rate of up to one inch every three years" in the New Orleans region.

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

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

F.3.4 American Society of Civil Engineers External Review Panel (ERP). Letter to LTG Carl Strock, Chief of U.S. Army Corps of Engineers, February 20, 2006.

Four critical areas that warrant urgent and thorough examination:

Organizational issues: No one person or organization is in charge of the New Orleans hurricane protection system. Local levee districts are responsible for maintaining the levees. Local parishes are responsible for operating pump stations (and even for deciding whether they will be operated during a hurricane). Numerous penetrations affecting such infrastructure as rail lines, bridges, and roadways have been made below the tops of levees and floodwalls under various jurisdictions. Construction contracts are awarded piecemeal, sometimes resulting in abrupt discontinuities in the elevations of floodwalls or levees. Even within the U.S. Army Corps of engineers differing levels of responsibility exist at the district, division, and headquarters levels. The City of New Orleans, the state of Louisiana, and perhaps other entities also are involved in hurricane protection for New Orleans.

The ERP sees clearly that organizational complexities and the ways in which decisions are made are among the most important factors that influenced the performance of the hurricane protection system. Organizational effectiveness has been and will continue to be questioned, with justification. It is impossible for the ERP to conceive a mechanism through which the levee system can be rebuilt and operated effectively and efficiently with such organizational discontinuities and chaos. The ERP recommends that organizational issues be assessed critically and thoroughly as soon as possible.

System issues: The hurricane protection system of New Orleans evolved over a long period of time. The system is not an integrated, well-thought-out system; rather, it is a joined series of individual pieces conceived and constructed piecemeal. Examples include the following: (1) the canals, which evolved over a period of decades to accommodate the pumping technologies available at the time and the continuing land reclamation northward toward Lake Pontchartrain (even though the logic of having many miles of exposed levee and floodwalls along the canals as opposed to closing off the mouths of the canals with a gate or short section of levee, is weak at best); (2) the connections between rigid structures and earthen levees, which experienced numerous failures during Katrina; (3) discontinuities and differences in crest elevations of levees and floodwalls; and (4) the pumps, which were designed to remove rainwater and infiltrating groundwater but, when not turned on, are not protected from backflow and exacerbate flooding during a hurricane.

A logical hurricane protection system for New Orleans would integrate components and the management of components, would be robust and resilient, and would contain a level of redundancy sufficient that, if a levee failed, all would not be lost. A system wide strategy would also ensure that critical structures - for example, pumping stations, hospitals, places of refuge, and electrical generation and distribution nodes - were protected. The lack of a broader, system-oriented strategy exerted a major deleterious influence on the performance of the system and deserves serious consideration.

System development: It is obvious that the hurricane protection system for New Orleans failed miserably during Katrina. That the system was so clearly overwhelmed and failed so catastrophically demonstrates to the ERP that fundamental flaws were part of how the system was conceived and developed. For example, what was the basis for selecting the standard project hurricane and, hence, the authorized level of protection? What process was in place to review the safety of the design as new knowledge evolved over time? How safe and redundant was the system intended to be upon design? Was adequate funding in place to ensure that satisfactory design standards could be implemented? How were safety margins for design established, and are they appropriate in light of new knowledge and the risks involved? How was the potential for loss of life factored into decision making?

Overtopping of levees: A fundamental flaw in the floodwalls and levees is that they include no means of accommodating overtopping that does not inflict major damage or destruction. Once the levees were overtopped during Katrina, rushing water eroded away many sections of levee and in other cases undermined floodwalls. Most of the 350 miles of levees in New Orleans are unprotected from devastating damage and potentially total destruction if overtopped. No mater how high the levees are built, a possibility always remains of a hurricane causing a surge elevation that is even higher than the one for which the levees were designed.

One of the lessons of Katrina that is already obvious is that once the levees were overtopped, destruction was catastrophic. In addition to the tragic loss of life, there were at least two other critical results: extensive and catastrophic flooding and an enormous destruction of capital investment. The question is not whether the levees will again be overtopped but when and by how much they will be overtopped. The levees need to be protected from catastrophic failure resulting from overtopping.

On multiple occasions, statements by top Corps officials have assured the public that the levee system will be adequately safe, and its risks sufficiently low for displaced residents to return to the city by June 1. These statements have seriously compromised task 10 (risk assessment) efforts by introducing a motivational bias that predetermines the outcome of its risk determinations. This undermines the credibility of task 10 and ultimately of the Corps itself. The lesson to be learned is that task 10 will not produce technically sound risk estimates unless there is full support and cooperation from the Corps at the highest levels for unbiased outcomes free of any appearance of manipulation of predetermined conclusions.

F.3.5 Committee on New Orleans Regional Hurricane Protection Projects, National Academy of Engineering and the National Research Council, 2006. Report to The Honorable John Paul Woodley, Assistant Secretary of the Army, Civil Works, Washington, DC, February.

The New Orleans and southeastern Louisiana hurricane protection system includes many engineering, geologic, hydraulic and hydrologic, administrative, and economic and cultural features that interact in complex ways. the levees, floodwalls, and other protective structures in New Orleans and southeast Louisiana have been constructed in a region of active alluvial deposition, subsidence, and fluvial dynamics. The Mississippi River delta, for example, has changed location several times in the past 5,000 years. the region is underlain by deep deposits of recent sediments with high clay content and by sites with varying rates of geologic subsidence - conditions that pose many stringent engineering challenges.

In addition to geologic and engineering considerations, there is a long history of piecemeal construction and maintenance of the system. Construction of levees and floodwalls in the New Orleans area dates to early stages of urban development in the area. An important event in this history was Hurricane Betsy in 1965. Betsy was responsible for 75 deaths and billions of dollars of property damage, prompting efforts to create a regional program of hurricane protection. In the aftermath of Betsy, Congress authorized construction of a hurricane protection system to protect areas in the vicinity of Lake Pontchartrain and surrounding parishes from storm surges. The various projects that make up this system are paid for with a combination of federal state, and local funds. The decision-making and investment processes that have lead to the development of the system have involved numerous stakeholders for more than 50 years.

Primary responsibility for design and construction of hurricane protection projects has been assigned to the U.S. Army Corps of Engineers. Actual project construction has been contracted to numerous private sector firms. Once projects are constructed and fully completed, responsibility for their maintenance is often assigned to local authorities. Since 1965, approximately 125 miles of levees, concrete floodwalls, and other structures have been built in the New Orleans region. Not all projects authorized for construction by the U.S. Congress, however, had been completed as of August, 1005. The hurricane protection structures that existed in New Orleans and the surrounding area in August 2005 were not a single system constructed as part of a unified plan; rather, the system had been added to and repaired by different administrative units - federal, state, and local - operating with different mandates, levels of resources, and staff backgrounds and capacities. No single entity has been fully “in charge” of constructing and maintaining all hurricane protection structures, complicating efforts at systematic repair and construction and efforts to retrieve and assess data on historical decisions and pre-existing conditions.

F.3.6 U.S. Government Accountability Office, Army Corps of Engineers History of the Lake Pontchartrain and Vicinity Hurricane Protection Project, Statement of Anu Mittal, Director Natural Resources and Environment, Testimony Before the Committee on Environment and Public Works, U.S. Senate, November 9, 2005; also Testimony Before the Subcommittee on Energy and Water Development, Committee on Appropriations, House of Representatives, September 28, 2005.

What the GAO Found

Congress first authorized the Lake Pontchartrain and Vicinity, Louisiana Hurricane Protection Project in the Flood Control Act of 1965. The project was to construct a series of control structures, concrete floodwalls, and levees to provide hurricane protection to areas around Lake Pontchartrain. the project, when designed, was expected to take about 13 years to complete and cost about $85 million. Although federally authorized, it was a joint federal, state, and local effort.

The original project designs were developed based on the equivalent of what is now called a fast-moving Category 3 hurricane that might strike the coastal Louisiana region once in 200-300 years. As GAO reported in 1976 and 1982, since the beginning of the project the Corps has encountered project delays and cost increases due to design changes caused by technical issues, environmental concerns, legal challenges, and local opposition to portions of the project. As a result, in 1982, project costs had grown to $757 million and the expected completion date had slipped to 2008. None of the changes made to the project, however, are believed to have had any role in the levee breaches recently experienced as the alternative design selected was expected to provide the same level of protection. In fact, Corps officials believe that flooding would have been worse if the original proposed design had been built. When Hurricane Katrina struck, the project, including about 125 miles of levees, was estimated to be from 60-90 percent complete in different areas with an estimated completion date for the whole project of 2015. The floodwalls along the drainage canals that were breached were complete when the hurricane hit.

The current estimated cost of construction for the completed project is $738 million with the federal share being $528 million and the local share $210 million. Federal allocations for the project were $458 million as of the enactment of the fiscal year 2005 federal appropriation. This represents 87 percent of the federal government's responsibility of $528 million with about $70 million remaining to complete the project. Over the last 10 fiscal years (19965-2005), federal appropriations have totaled about $128.6 million and Corps reprogramming actions resulted in another $13 million being made available to the project. During that time, appropriations have generally declined from about $15 - 20 million annually in the earlier years to about $5-7 million in the last three fiscal years. while this may not be unusual given the state of completion of the project, the Corps' project fact sheet from May 2005 noted that the President's budget request for fiscal years 2005 and 2006, and the appropriated amount for fiscal year 2005 were insufficient to fund new construction contracts. The Corps had also stated that it could spend $20 million in fiscal year 2006 on the project if the funds were available. The Corps noted that several levees had settled and needed to be raised to provide the level of protection intended by the design.

During the first 17 years of construction on the barrier plan, the Corps continued to face project delays and cost increases due to design changes caused by technical issues, environmental concerns, legal challenges, and local opposition to various aspects of the project. For example, foundation problems were encountered during construction of levees and floodwalls which increased construction time; delays were also encountered in obtaining rights-of-ways from local interests who did not agree with all portions of the plan. By 1981, cost estimates had grown to $757 million for the barrier plan, not including the cost of any needed work along the drainage canals, and project completion had slipped to 2008. At that time, about $171 million had been made available to the project and the project was considered about 50 percent complete, mostly for the lakefront levees which were at least partially constructed in all areas and capable of providing some flood protection although from a smaller hurricane than that envisioned in the plan.

More importantly, during the 1970s, some features of the barrier plan were facing significant opposition from environmentalists and local groups who were concerned about environmental damages to the lake as well as inadequate protection from some aspects of the project. The threat of litigation by environmentalists delayed the project and local opposition to building the control complexes at Rigolets and Chef Menteur had the potential to seriously reduce the overall protection provided by the project. This opposition culminated in a December 1977 court decision that enjoined the Corps from constructing the barrier complexes, and certain other parts of the project until a revised environmental impact statement was prepared and accepted. After the court order, the Corps decided to change course and completed a project reevaluation report and prepared a draft revised Environmental Impact Statement in the mid-1980s that recommended abandoning the barrier plan and shifting to the high-level plan originally considered in the early 1960s.

In recent years, questions have been raised about the ability of the project to withstand larger hurricanes than it was designed for, such as a Category 4 or 5, or even a slow-moving Category 3 hurricane that lingered over the area and produced higher levels of rainfall. Along this line, the Corps completed in 2002 a reconnaissance or pre-feasibility study on whether to strengthen hurricane protection along the Louisiana coast. A full feasibility study was estimated to take at least five years to complete and cost about $8 million. In March 2005, the Corps reported that it was allocating $79,000 to complete a management plan for the feasibility study and a cost-share agreement with local sponsors. The President's fiscal year 2006 budget request did not include any funds for the feasibility project.

F.3.7 U.S. General Accounting Office, Improved Planning Needed by the Corps of Engineers to Resolve Environmental, Technical, and Financial Issues on the Lake Pontchartrain Hurricane Protection Project, Report to the Secretary of the Army, August 17, 1982.

Although the Corps' District Office in New Orleans considers this $924 million project a high priority, its completion date has slipped from 1978 to 2008. In the 17 years since congressional authorization in 1965, only about one-half of the project has been completed.

We believe that improved planning is needed by the Corps to resolve certain environmental, technical and financial issues. Environmental concerns have remained unresolved for almost 5 years after a court injunction prohibited the Corps from constructing certain parts of the project. The Corps is considering a change in its solution of providing protection from constructing barrier structures at the entrance to the lake and the raising of some levee heights (the barrier plan) to constructing much higher levees with no barriers (the high-level plan).

Various problems and conditions have caused delays in the project. Specifically: Engineering and environmental concerns have caused delays in project completion. Costly project work at the drainage canals has not been reported to the Congress, and technical and financial concerns which may impeded project completion remain unresolved. Current project financing by the local sponsors has not been assured because of limited resources. Project cost estimates are understated, and a project plan has not been formally adopted.

The local sponsors agreed with information in a draft of this report, but were concerned over their financial capability to meet their share of project costs. They believed the project construction could be pursued more expeditiously. One sponsor believed that Corps standards may be too high to obtain adequate, affordable, and speedy protection.

F.3.8 Houck, O. (2006). "Can We Save New Orleans?", Tulane Environmental Law Journal, Vol 19, Issue 1, 1-68, New Orleans, Louisiana.

On the other hand, for the City That Care Forgot to call anything 'fantasy' is a bit bold, and everything about the run-up to the Katrina disaster had fantasy written all of it: on slab development, on fill development, subdivisions in wetlands (protected by wooden fences), condos on beaches (protected by nothing), canals as senseless as the Mississippi River Gulf Outlet (MRGO), oil and gas channels by the thousands, coastal mitigation programs that failed to work (failed even to materialize), disappearing levee money, tinker-toy levee plans, what-the-hell levee construction, drive-by-and-when's-lunch levee inspections – and we haven't even gotten to FEMA yet. Detailed reporting in local papers, science colloquiums, National Geographic, NOVA and government planning sessions predicting this very storm in this very way with these very results were tossed away like so many Mardi Gras beads. So there is plenty of fantasy to go around.

We know a couple of things more, going in. For openers, we are short on land building materials. We live on a sinking delta, and the silts and plant mass that created it and offset its natural rate of subsidence are down to a fraction of their volumes a century ago. We have a lot less to work with than Mother Nature did. Even within the city, we are sinking. Post-Katrina surveys are finding many buildings about a half a foot lower than they were thought to be, and down by two feet in the East. Which is not good.

We also know that we are terribly late to the restoration game, about 1,900 square miles late, what is left is largely sick, and what we've managed to recoup over the past few years couldn't stand up to the latest storms. The newly restored marshes of the $80 million Canaervon diversion project ended on the rooftops in St. Bernard.

We know, worse, news, that hurricanes are coming more frequently now and with greater anger, that our levees are subpart, and – although it still seems to escape the grasp of the President and the Louisiana congressional delegation in Washington, D.C. – that the seas are rising and that global warming will raise them by more than a foot within the lifetimes of our children.

You would think that flood control and the protection of the City of New Orleans would be job one for the U.S. Army Corps of Engineers. And you would be wrong. It isn't, and it never was. ...The Army's field engineers were the only government entity around with the ability to blow things up and move dirt around, and so this became their job, to maintain navigation on the navigable waters of the United States. Navigation was interstate commerce, the means of interstate commerce, and it made money for people. Flood control, by contrast, was seen as a form of land use, a local affair, cemented in place when the federal government ceded lands to local levee boards in the 1850's, in part to persuade them to stay loyal to the Union. That part didn't work so well, but it set a mold for local levee boards that we have yet to change. It also further cemented the mindset that navigation comes first.

The Flood Control Act of 1936 opened a huge candy store, something like the discovery of gold at Sutters Mill, only this time the miners ere in Washington and wearing suits. Ostensibly authorizing the Corps of pursue projects for 'flood control and related purposes,' the other purposes quickly took over and by the 1960s the country was being dammed, drained, pumped, and leveed by hundreds of Corps projects feeding real estate development, energy production, soybean crops and right on down to recreational lakes with wave machines and the McCurtin County Catfish Farm. The Act's one caveat, that the benefits of these projects 'to whomsoever they may accrue,' was turned into a weapon of destruction, with the Corps discovering benefits so chimeric that they became legend in the fields of government and political science, the object of ridicule in the press that the government should participate in these projects 'if the benefits to whomever they may accrue are in excess of the estimated costs,' and recurrent calls for Corps Reform. Not to worry; the Corps had the ally that mattered, the Congress of the United States.

The rise of the water project bonanza has had several large consequences for flood control in south Louisiana. Basically, it eclipsed it. The first consequence is that flood control has no head. Unlike every other federal activity in the country, this one is overseen and directed by the Corps, members of Congress, local levee districts and lobbyists among which are found some of Louisiana's most illustrious power brokers: Bob Livingston, Bennet Johnston, John Breaux, Jimmy Hayes, just to start the list. Congress determines budgets, and promotion from Colonel to General. For Colonels heading the New Orleans District, it has been a trial by fire that has made and ended careers. It also produces conformity. When project funding for hurricane protection along Lake Pontchartrain dwindled in the early 1990s, nobody squawked out loud: a former director of the Corps Waterways Experiment Center in Vicksburg explained to the New York Times, 'I don't think it was culturally in the system for the corps to say this is crazy.' Whatever the merits of this diffusion of authority, it does not produce coherent flood control.

All of which works as long as there are no floods. Then, they become somebody else's fault. The didn't fund me. Well, you didn't ask. So it goes, and so it went after Katrina.

The second impact is that the program is not based on the completion of a few major projects but, rather, on spreading construction money and benefits around as many projects and about-to-be-made-happy constituencies as possible. This is true at the national level, where water resources bills are passed in omnibus fashion, meaning that they are approved in one big lump with something inside for everyone's district. Those brave or fiscally minded souls who object to a particularly sad entry end up ostracized or worse; one year the leadership announced the Pinocchio award for members who stuck their noses into other member's water resources projects.

So it is at the Louisiana level as well. Every cycle there is something in there for everyone, your new port, my new waterway, their pumps and drainage upstream. In this mix, New Orleans is just one more open beak among the chicks. It is not in the Corps' political interest and it is not in the Congress's political interest to satisfy one beak at the expense of others. The political objective is to spread the food around as widely as possible, and if that takes more time it also keeps more contractors working in more parts of the state. Inviolate Rule of Politics: Happier people is better than fewer happy people. Inevitable Effect of Rule: Short change for hurricane protection for the City of New Orleans.

Case in point: Louisiana has received nearly $2 billion for Corps water projects over the past 5 years. It has for time immemorial received the lion's share of water resources funding, with California, Texas, Illinois and Florida distant seconds (around $1.2 billion each over the last 5 years), and no one else even close. It's not a question of getting money down here. It's where it goes. In 2002, the Bush Administration rejected a Corps request for $27 million for additional hurricane protection along Lake Ponchartrain of which the Congress only restored $5.7 million in its appropriations. Meanwhile, Congress was boosting funding for the $780 million Industrial Canal Lock (the most expensive on record), a $194 million dredging project for the New Iberia, and tens of millions more on canals like the MRGO.

A third consequence of the game is that flood control for developed urban areas comes in last. The sad fact is, it doesn't make money for anyone. By leveeing off wetlands for new development makes lots of money in real estate (set aside the fact that the homes and streets will subside and begin to flood from spring rains). Floating boats also produces identifiable payouts (albeit they are calculated by asking shippers if they would like to use the canal once it is built, which is a little like using Monopoly money; very few Corps waterways live up to their traffic predictions, and some are ludicrously underused). Even converting cypress swamps to soybeans has a market price. By contrast, lives saved by levees don't receive economic benefits in the decisions that justify Corps projects and determine their funding priorities. Nor do they attract powerful lobbyists. The Industrial Canal lobby can afford to put ex-senators, congressmen and entire law firms on its payroll. The City of New Orleans, on the other hand is broke, and one doubts that St. Bernard and Plaquemine even field full-time representatives in Washington. Money talks.

A final most perverse effect of the water resources game is that it produces projects that not only conflict with flood control for money and fame, but cause floods as well. Big ones. The role of the MRGO in the Katrina and Rita flooding is by now undeniable. What remains impressive, however, is the tenacity with which the Corps and the Louisiana congressional delegation hung on to this project – indeed, continue to hang onto it – against the pleas of the St. Bernard Police Jury, the Lake Pontchartrain Basin Foundation, and coastal scientists who have been complaining that it had destroyed 20,000 acres of the Parish, was killing much of the lakeshore, and was going to bring major hurricanes right into the city. These claims were never rebutted. They were simply ignored.

What we have here, then, is a game that is not focused on flood control, and never has been. It has been focused on making money first for people with boats and then for as many people as possible, even when that has meant increasing hurricane risks and putting other people right into harm/s way. It has been denial about its impacts, and remains largely in denial. And it as been accompanied by a similar series of body blows to the coastal zone from another sources which is even more powerful and difficult to turn around: the oil and gas industry.

The impact of oil and gas extraction on the natural systems of the Louisiana coast is hard to exaggerate. The initial space of the access canals is relatively minor. It's what happens next that matters. The canals erode, exacerbated by wave wash from passing boats. In 10 years the widths have doubled; then they double again. While intact, the spoil banks cut off the natural drainage for hundreds of yards around, impounding half of the marsh and drowning the other half. Up the canal comes saltwater from the gulf. The grasses go belly up, the root masses die, the soils are released, the whole thing falls apart. Recent studies by the United States Geological survey discover a related phenomenon. The industry has excavated billions of gallons of brines, salts, and minerals from under the wetlands, much of it close to the surface, following which - surprise! - they caved in. Marsh erosion or subsurface extraction: pick your weapon, they both kill.

About 70 years ago, Louisiana made a deal with the oil and gas industry. the industry would get what it wanted; the state would get a piece of the take. In Plaquemines Parish the industry took nearly everything, save what it paid back to Leander Perez. The state's near slavish defense of the industry since that time is a matter of legend; Bennett Johnston was commonly referred to as the Senator from Oil, and his successor was one of the three Democratic votes to open the arctic wildlife refuge to oil and gas and to remove the rights of states to decide on drilling off their coasts. It's in the genes. As Louisiana moved forward on its coastal restoration plan, it would ask the federal government for massive amounts of money. Part of the rationale, no small part, was to protect the oil and gas industry's pipelines and infrastructure through the coastal zone. Nowhere, however, did the state ask the industry to pay a penny for the restoration that would save its base. Over 10,000 miles of canals are now eroding and the marshes are caving in and somebody big is walking away from the table.

There is something special about Louisianans when it comes to flood control. We could call it courage. We could call it denial. Or we could call it anything in between and probably all of them and not be wrong. but Louisianans settled a state that flooded regularly from the north and from the south, from rivers and the Gulf, and some of its most gripping stories - Lanterns on the Levee, Last Island - are scenes of tragedy from high winds and waters that no book or film could fully capture. and yet we built, and built again. For a long while, we tended to build elevated homes, on ridges, and kept the boats handy for what we knew would come. Then we raised levees. when they didn't work we got the federal government to raise levees and built out back into the swamps and put in pumps. Before long we were building on slab. and still we flooded. We lead the nation in flood losses. No reason not to. The federal government pays us for it.

And so we had a cozy game of build-flood-and-get-paid going until coastal erosion weighed in, and the onset of an awesome and unanticipated season of hurricanes that, apparently, has only just begun. Louisiana towns that used to sit well inland were finding themselves on the front line with the Gulf of Mexico, which has been coming north at about 10 to 30 meters a year. A 1990 report by the National Academy of Sciences recommended mapping the erosion zones and moving new construction away from them through the flood insurance program. there were no takers. Five years later, FEMA recommended that the government at least chart the zones. No takers either. Nor on its almost annual pleas to raise the flood insurance rates to something close to real life. Louisiana knows a good thing when it sees it.

The northeast gets its railroad subsidies, the far west gets grazing and timber subsidies; this one is ours." "The hurricanes came. They have, of course, always come, and when Betsy and Camille came ashore in the late 1960s the nation gasped. There were record storms, record damages, record loss of life, we must do something. What we did was go back on the same beaches and vulnerable strips of coastal wetlands and build the same stuff, only more expensive. there was a lull while it all came together - the casinos, the high rises, a building boom on Grand Isle, ditto Holly Beach, ditto a boomlette that was just starting down in the marshes of St Bernard, ditto all around Lake Pontchartrain - all subsidized by people who don't enjoy houses on the shore. No longer quaint low-end bungalows. Some very expensive housing for our wealthiest fellow citizens who get below cost flood insurance and income tax deductions for their second home mortgages. Another hayride.

Global temperatures rise and fall over geologic time. As they rise and fall, they produce sea changes in life history, species go extinct, civilizations advance and disappear. There is a normal range of variation. but the current climate is warming at a rate without precedent for the last several hundred thousand years.

So what? Here in Louisiana we will be warmer in summer (think, maybe, 103 degrees at Jazz fest), warmer in winter, and considerably drier (think about sugar, soybeans, rice and other wet-soil crops). Without winter freezes we'll have a lot more insects - mosquitoes, termite and cockroach numbers soared between 1990 and 1995 when there were no killing frosts - and the bayous will be blanketed with alge blooms. We're tough. We can handle that. Pass the pesticides.

What will be a little harder to handle is sea level rise. A heated ocean expands, and - according to the most definitive international panel on climate change yet assembled - the oceans will rise from a half a foot to three feet, absolute. that's before we get to subsidence in places like Louisiana, where the relative rise could go to four feet. And that's before adding increasing snowmelt and the run from polar glaciers. For which we add another half a foot. It's already happening. Rocky Mountain peaks are going dry. The famed snows of Kilimanjaro have about disappeared. Temperatures around the North Pole are rising so rapidly that a new sea route is opening between the oceans, expected to be clear even for unarmored ships within the next 30 years. Native Inuit report seeing warm weather birds, beyond anything in the legends of their people.

Four feet is a killer for South Louisiana. On a landscape as flat as the coastal zone, and where building elevations are in the single digits, relative sea rise of only a few inches covers an enormous amount of ground. Worse for New Orleans, which is buffered by coastal systems, for coastal towns that fish, trap and work their natural resources, and even for the oil and gas industry whose wells and pipelines lie increasingly exposed in open water above sinking bottoms, a few inches of relative sea rise will be enormously hard to match with coastal restoration programs. The game is not static. It's like trying to score touchdowns but they keep moving the goalposts back. Way back. Think about trying to devise a way to rebuild 1,000 square miles of Louisiana wetlands already lost and another 20 to 30 each year, against the relentless pressure of the Gulf of Mexico. Now add this: you will have to build and maintain the whole thing several more feet into the air.

And now we add this. an increasing body of data shows a strong correlation between warmer seas and violet hurricanes. And more frequent ones. It makes sense: warm waters are hurricane food, which is why the season comes at the end of the summer. The doubters have since weighed in with their list of unprovens - which is the way science works, healthy science anyway - and the case is not ironclad. But there seems to be good evidence that global warming is not only destroying Louisiana's defenses, it is also fueling what could be, any year, its ultimate storms.

Are We Serious Yet? Because we certainly haven't been serious up to this point at all. Katrina and Rita have to be the most well predicted and publicized disasters in history, and we did next to nothing to stave them off or to prepare for the hits. In August 2005, a couple of weeks before the storms, a Homeland Security brochure came in the mail on hurricane preparedness. It consisted of a map marking evacuation routes out of town, with major revelations like the existence of I-10 and I-59.

Meanwhile, we continued to treat flood control as the stepchild of navigation projects that were in large part boondoggles, and in full measure drained monies and attention away from the hurricane protection needs of the Crescent City. We treated the whole water resources effort more like a re-election machine than a serious program, run by local interests, lobbyists, congressmen and ex-congressmen who are glued to the status quo. We let the largest party in coastal destruction walk away from the table without paying, while we in turn pay no end of public subsidies for people to build and live in the hurricane hit zone. We turn our back on the pall of jeopardy that global warming and rising seas throw over the future of the region; worse, we advocate against doing anything about it. And that's just in Washington.

Back home, the scene is little more encouraging. We have a dysfunctional system for building levees, and even more dysfunctional one for maintaining them, aggravated by a Byzantine arrangement of levee boards, port authorities, and other bodies that so fragment the process that it seems primarily directed towards maintaining political alliances and local perks. Post-Katrina down here has been like the Wizard of Oz. When the curtain is finally pulled back, there are a couple of flood control guys in suits and uniforms and they haven't a clue. If they are not protected by sovereign immunity, they are facing the largest negligence verdict in history.

Hurricane Betsy brought a rude awakening to New Orleans and the Army Corps of Engineers. for more than a century they had been putting bigger and better locks on the front door, against the high spring floods of the Mississippi River. Now it was plain that the big one would come in the back door, with the capricious, violet, and increasingly frequent hurricanes of late summer and fall. And so, in 1965, Congress authorized the Corps to proceed with a plan to protect the city and the region from the east and south: the Lake Pontchartrain and Vicinity Hurricane Protection Project. It would defend against a Betsy-type storm, winds up to 100 mph, waves at maybe ten feet. It would take about 13 years to complete, with an estimated price tag of $85 million.

The Corps had two basic options, a high-level plan relying on levees fronting Pontchartrain along New Orleans and Jefferson Parish, or a lower set of levees, fronted by barriers 40 miles out at the inlets to Lake Pontchartrain across the Rigolets and the Chef Menteur pass. Initially, the barriers prevailed. They were seen as less costly, quicker to build (higher levees would require more time for the fill to settle), and - what many considered to be the driving factor at the time - they would allow for the drainage and development of wetlands in St. Charles Parish and New Orleans East where in the Corp's words 'protection would not be incrementally justified.' Indeed, some 79% of benefits came from protecting new wetland development; protection New Orleans came in a distant second.

Developing the wetlands was in high swing at the time. New Orleans itself had just finished expanding over marshes and swamps to the edge of the lake. (The streets and houses hadn't started to crack open yet.) President Lyndon Johnson was partner (with his wife and Dallas Cowboys owner Clint Murchison) in a project to develop new Orleans East (a Lenin's tomb-like monument along I-10 still bears the name), and had managed to finesse federal highway regulations to build three interchanges for the venture. A similar venture along the St Charles lakefront advertised scenes of upland development complete with contented dairy cows so obviously deceptive that it was shut down after protest by the Louisiana Attorney General. What these developers wanted, of course, was exactly what environmentalists feared. The barrier plan looked like a stalking horse for wetland development, New Orleans piggybacking the scheme.

The plan had another problem. It would block off most of the Rigolets and Chef passes, which were the migration corridors for the aquatic life of the interior lakes. Lake Pontchartrain had been the seafood market for the city, and crabbing along its banks was in the family memory of thousands of local families. Commercial fishers were worried as well and, despite Corps statements that gates in the barriers would maintain necessary flows, a groundswell of opposition grew on both sides of the lake. A poll by Congressman Bob Livingston showed his constituents doubting the barriers, causing him to express reservations as well. an Environmental lawsuit challenged the impact statement on the plan, which the Corps later admitted was a cursory job. Like so many such lawsuits at the time, the court found the statement inadequate and required the Corps to write a new one. Most of the time the Corps did just that, and then proceed with its original plan. In this case, though, the Corps changed its mind.

In 1982, its review completed, the Corps announced for the high levee option. It would turn out to be less expensive after all, they found, less harmful to the environment and more 0protecteditve as well. (Among other things it would guard against waves kicked up by hurricane-force winds across the lake itself). And so the project marched forward, its costs ballooning to an estimated $757 million, towards a pre-Katrina estimated completion date of 2015. At that point the Corps had thrown up 125 miles of levees around the city, in various stages of readiness. The all-important interior canal walls - the ones that failed - were parts of the project declared to be complete. Appropriations for the project were declining, however, from some $15-20 million annually in the early years to about $5-7 million in recent years. The monies were going elsewhere.

So when Katrina and Rita hit the fan, it was little surprising that two former Corps employees, high level ones at that, told the *L.A. Times* that environmentalists had drowned the city with their lawsuit. The Wall Street Journal, ever eager for news like that, and a pack of right wing blogs picked up the cry, which carried to Washington DC and the House Resources Committee. The Committee, in turn, ever eager for news like that, held hearings on it, absent the benefit of witnesses who had participated either in the project or the case. The United States Justice Department, ever eager for news like that, even asked its field offices to report any and all environmental cases that had obstructed Corps flood projects. None were ever disclosed.

In the end, the story flopped. The Chief of Engineers and the Government Accounting Office, which had been bird-dogging the project for years, both testified before other committees that the barrier plan would not have protected New Orleans any better than functioning levees, and in fact could have worsened the flooding by trapping the storm surge against the city. As serious investigations proceeded, it became clear that the problem was not the high levee plan. Category 3 levees would have kept the city dry. Instead, the city got tinker toys and they fell apart.

F.3.9 Member Scholars of the Center for Progressive Reform (2005). *An Unnatural Disaster: The Aftermath of Hurricane Katrina*, Center for Progressive Reform Publication, CPR Publication #512, September.

Hurricane Katrina tragedy is not a 'wake-up call,' as some have described it; rather, it is a consequence of past wake-up calls unheeded. By any reasonable measure, government failed the people of New Orleans. Hurricane Katrina was a natural disaster of enormous proportion, but its tragic consequences have been made even worse by an unnatural disaster - the failure of our government adequately to anticipate, prepare for, and respond to the devastation that the hurricane brought. One very powerful message of the ideology that now dominates both the executive and legislative branches of the federal government is that actions have consequences. The Katrina tragedy has demonstrated that inaction also has serious consequences.

New Orleans sat in the path of Katrina like a stretch of road with too little banking and with no one having taken responsibility for its repair. In this case, the government failures that preceded Katrina and made it worse seem to span a wide range of environmental, natural resource, disaster-planning, and emergency-response functions for which we rely upon government. Identifying those systematic and programmatic contributors to the Katrina disaster will give us the information we need to demand that government do better.

The proper response to Hurricane Katrina is action at every level of public life to restore the critical protections and safety nets that only government can provide for the people.

Today, government must again play an active role in protecting its citizens from the visibly power forces of nature and from the less visible, but equally powerful forces of policy-making that is sometimes slanted away from protecting and serving the public and toward protecting profit margins.

In addition, we strongly recommend that Congress create an independent commission to pursue these questions, in an atmosphere free of the bitter partisan strife that seems to swamp both houses in anticipation of the 2006 mid-term elections. The notion of a bipartisan, objective congressional investigation, promoted by the President, does not seem possible or desirable given the rancor of recent days.

The failure of New Orleans' levees was preceded by a failure of environmental protection and planning. Louisiana's coastal plain contains one of the largest expanses of coastal wetlands in the contiguous United States, but it is being lost at a rate of 6,600 acres per year. the main culprit in wetlands loss in the area is the vast network of levees, navigational channels, and oil-and-gas infrastructure. Important though the network is to safety and commerce, it accelerates coastal land loss by reducing the natural flow of a river's freshwater and sediment to wetland areas where lost land would then naturally be replenished. In addition, the area's major navigational channels pose their own special threat to flood control by sometimes acting as 'hurricane highways,' allowing storms to sweep inland, past marshland, like liquid bulldozers.

Broken Levees: Predictions that Came True. Over a period of many years, scientists had predicted that a strong storm could breach the levees, and some had predicted what appears to be the precise sequence of breaches that flooded the city. The failure to protect New Orleans resulted from inadequate planning by the Army Corps of Engineers (Corps), and from the failure of the federal government to fund badly needed improvements once those limitations were recognized. Neither the Corps nor Congress adequately accounted for the loss of life and property that would occur if a catastrophic hurricane hit New Orleans.

"Moreover, although the Mississippi River-Gulf Outlet (MRGO) canal was a primary cause of the flooding, it is seldom used and heavily subsidized by taxpayers. Less than three percent of the New Orleans port's cargo traffic uses the MRGO, less than a ship a day. Although New Orleans' vulnerability was widely predicted, the Corps declined to move forward with enhancements to the levee and flood wall system because 'no clear bureaucratic mandate exists for reassessing the blueprints once levees are built.' Moreover, when Congress has appropriated money to protect New Orleans better, the Corps has not been in a hurry to get the job done. Finally, the Bush Administration and its predecessors have failed to fund Corps requests.

Why the City Flooded. The water that flooded New Orleans did not flow over the levees situated between the lake and the city. Instead, it appears that the surge flowed up the 17th Street and London Avenue canals and caused one breach of the floodwall along the 17th Street canal and two breaches of the floodwall along the London Avenue canal. In other words, the water moved to the path of least resistance - the floodwalls along the canals.

The city also flooded because the levee system did not protect it from the 'end around' exposure that occurred during Hurricane Katrina. The hurricane surge entered Lake Borgne from the Gulf of Mexico and proceeded up the MRGO canal to the Industrial canal in the heart of New Orleans. Hurricane Katrina appears to have destroyed as much as 90 percent of the levees and flood walls along the MRGO canal in St. Bernard Parish as it pushed up the narrowing canal from Lake Borgne to the conjunction of the MRGO canal with the Industrial canal. Colonel Richard Wagenaar, the Corps head engineer for the New Orleans district, reported that the eastern levees were 'literally leveled in places'. That same surge probably caused the breaches in the floodwalls along the Industrial canal.

We Knew This Would Happen. Not long after the levees broke and water from Lake Pontchartrain on the north and Lake Borgne on the east began to fill New Orleans, President Bush told television correspondent Diane Sawyer that no one could have foreseen the breach of those levees. In fact, over a period of many years, scientists had predicted that a strong storm could also breach the levees. Scientists especially feared that even a relatively weak storm coming from the right direction would push a wall of water into the heart of New Orleans from Lake Borgne through the funnel-shaped MRGO canal and into the Industrial canal, destroying the levees along the canal and flooding much of St. Bernard Parish and the Lower Ninth Ward. It now appears that this is exactly what happened.

Moreover, the risks posed by the MRGO canal were evident. In 2002, the Corps of Engineers acknowledged that 'the MRGO levee is more likely to be affected than the area on the lake itself.' Proponents of closing the canal pointed out that, with the erosion of the wetlands in the unleveed stretches south and east of the city, it had 'evolved into a shotgun pointed straight at New Orleans'.

The Failure to Protect: Bad Planning, Skewed Priorities. The failure to protect New Orleans resulted from inadequate planning by the Corps to save the city, and from the failure of federal government to fund badly needed improvements once those limitations were recognized. Neither the Corps nor Congress adequately accounted for the loss of life and property that would occur if a catastrophic hurricane hit New Orleans.

The hurricane protection plan that was implemented after 1985 by the Corps was designed to protect the city against the 'standard project' hurricane that roughly corresponds to a fast-moving Category 3 storm. Scientists had for years prior to the storm predicted that the levee system woulc not withstand a Category 4 or Category 5 storm. Hurricane Katrina struck the Louisiana / Mississippi coast as a Category 4 storm.

Moreover, although the MRGO canal was a primary cause of the flooding, it is seldom used and heavily subsidized by taxpayers. The canal, which was completed in 1968, is a deep draft seaway channel that extends for approximately 76 miles east and southeast of New Orleans into Brenton Sound and the Gulf of Mexico. It was designed to shorten the distance for ships from the eastern shipping lanes of the gulf to New Orleans, but it has never lived up to its predicted economic expectations. Less than three percent of the New Orleans port's cargo traffic uses the MRGO; this amounts to less than one ship per day. According to one estimate, the government spends $7 to 8 million dollars per year (about $10,000 for every large vessel that uses the canal) just to maintain the canal.

Although the vulnerability of New Orleans to a catastrophe was well known and widely predicted, the Corps has floundered in its efforts enhance the protection of New Orleans from Lake Pontchartrain. In an award winning series of articles on the levee system, The Times-Picayune concluded that the Corps of Engineers has declined to move forward with enhancements to the levee and floodwall system because 'no clear bureaucratic mandate exists for reassessing the blueprints once levees are bu9ilt.' For example, an attempt in 1996 to reevaluate the Lake Pontchartrain levees broke down in disputes over modeling and other bureaucratic disagreements. When Congress has appropriated money to protect New Orleans better, the Corps has not been in a hurry to get the job done. For example, the Congress in 1999 appropriated money for a $12 million study to determine how much it would cost to protect New Orleans from a Category 5 hurricane, but the study had not even been launched as of September 2005.

In addition, the Bush Administration has failed to fund Corps requests. Mike Parker, a former Republican Congressman from Mississippi who was until 2002 the chief of the Corps, was forced to resign when he publicly sated to the Senate Budget Committee that the national interest was being harmed by President Bush's proposal to cut over $2 billion from the Corps' $6 billion budget. The Bush Administration rejected an Corps request for $27 million to pay for hurricane protection projects along Lake Pontchartrain and proposed a budget of only $3.7 million for the projects, but the Corps still had to delay seven levee improvement contracts. After Hurricane Katrina struck, Mr. Parker stated that President Bush had not adequately funded improvements to the very levees in New Orleans that had been breached; indeed, Mr. Parker stated that had full funding been authorized 'there would be less flooding than you have.' an official Corps memo dated May 2005, long after Parker left the agency, seemed to corroborate this possibility. It stated that the bush Administration funding levels for fiscal years 2005 and 2006 were not enough to pay for new construction on the New Orleans levees.

There are now strong indications that the critical floodwalls along the outlet canals did not breach because the water surged over them and eroded their support but because they were not capable of withstanding even the surge of a Category 3 hurricane. Whether this failure of the floodwalls was attributable to poor design or poor construction and maintenance remains to be seen, but in either case the Corps and the local levee authorities bore the responsibility for ensuring that the floodwalls were adequately designed, built, and maintained.

Although it is tempting to blame the current administration for the failure to fund critical levee improvement projects, the truth is that improving the Lake Pontchartrain levees has been a low priority for many administrations, Democratic and Republican, and for Congress. The Bush Administration and Congress have had other priorities over a longer period of time than the last four years. In fact, it seems clear that even the Louisiana congressional delegation has on occasion insisted that the Corps direct its resources to projects like a $194 million project for deepening the Port of Iberia and replacing the lock on the Industrial canal.

The Bush Administration and Congress are influential in setting budget priorities because the Corps is very reluctant to participate in the process of setting priorities for its projects. Moreover, once the Corps has determined that the benefits of a proposed project exceed its costs, the Corps leaves it to Congress to decide through the appropriations process which projects receive funding and which do not. Congress is ordinarily willing to consider passing appropriations for large public works projects, however, only in the wake of major disasters or after years and years of study.

The reasons why New Orleans and its vulnerable citizens were not better protected are clear. The levee system was not designed to protect the city from more than a Category 3 hurricane system and there was little administration or congressional support for making improvements in the levee system despite the fact that its limitations were widely recognized.

According to the Government Accountability Office (GAO), the Corps' guidance (Engineer Regulation 1105-2-100) directs analysts to address the issue of prevention of loss of life when evaluating alternative plans, but they are not required to formally estimate the number of lives saved or lost as a potential effect of a project.

F.3.10 Braun, S. and Vartabedian, R. (2005). "The Politics of Flood Control," Los Angeles Times, December 25.

NEW ORLEANS -- When the U.S. Army Corps of Engineers and New Orleans levee officials joined forces in July 1985 to protect the city from a long-feared hurricane, the two agencies could not agree on how to proceed. It was the beginning of a dysfunctional partnership that ushered in two decades of chronic government mismanagement.

Corps engineers wanted to install gates in front of the city's three main internal canals to protect against violent storm surges from Lake Pontchartrain. The Orleans Levee District, the city's flood protection agency, preferred to build higher flood walls for miles along the canals. For five years, neither side yielded.

But in October 1990, a deft behind-the-scenes maneuver by the levee board forced the corps to accept higher flood walls. As Senate and House negotiators gathered to craft the Water Resources Development Act of 1990, Louisiana's congressional delegation quietly inserted a lobbyist's phrasing ordering the corps to raise the levee walls. "It was stealth; legislative trickery," recalled New Orleans lawyer Bruce Feingerts, who lobbied for the levee board. "We had to push every button at our disposal."

The gambit was a crucial victory over the Corps by the Orleans levee district, the most powerful and well-financed among 18 Louisiana boards that supervise more than 340 miles of storm levees across the hurricane-prone southern half of the state. The Corps had to abandon its floodgate plan and shoulder 70% of the project's costs while allowing the Orleans board to hire its own consultants to design the strengthened levees.

But their fractious partnership proved disastrous. While the Corps and the Orleans board settled into an acrimonious 15-year relationship, spending $95 million to buttress the city's canal levees, their shared supervision failed to detect crucial weaknesses inside the flood walls before Hurricane Katrina struck. "No one felt the urgency, none of us," said Lambert C. Boissiere Jr., a former Orleans levee commissioner. "The corps and our own engineers told us the levees were strong enough. They were all dead wrong."

Structural inspections were cursory. Maintenance was minimal. A confusing regulatory patchwork of ownership over the levees and canals blurred the lines of authority -- all shortcomings cited by independent engineering teams analyzing the levees' collapse.

Although the Corps and federal officials kept a tight leash on funding, the Orleans board spent money lavishly, diverting resources to high-stakes investments such as casinos and marinas. The levee board's unusual authority to hire its own consultants allowed its officials to select firms that regularly gave campaign contributions to politicians with influence over levee board business.

Left unchecked because of repeated failures by the Louisiana Legislature to reform the levee board system, critics say, the Orleans district operated its own patronage system. "The New Orleans board had the reputation of being one of the worst -- by worst, I mean more political than professional," said former Louisiana Gov. Charles E. "Buddy" Roemer III, a Republican whose Orleans board appointees launched the 1990 power play in Congress.

When Katrina hit in late August, floodwater from Lake Pontchartrain burst through the walls of the 17th Street and London Avenue levees, where steel foundations gave way in porous soil. Storm water also flowed through a 200-foot gap in the Orleans Avenue levee, a section left unfinished due to Bush administration funding cuts.

Last week, the corps announced plans to seal off the three broken canals with permanent barriers and relocate New Orleans' pump houses from inside the city to the lakeshore -- at a cost of $3.1 billion. The corps' move to abandon the old flood-control system it built with the Orleans board came as a bitter coda to a 20-year relationship.

Least Cost Project. Money was the most pressing concern in July 1985, when Orleans levee officials signed "assurances" -- an official commitment -- to join the corps in buttressing New Orleans' hurricane protection system. The Corps' traditional preference for a "least cost" project made floodgates a far more attractive option -- at $20 million -- than the $60-million estimate for raising the levees. We were caught between the [Reagan] administration saying keep the cost down, and Congress and New Orleans officials saying spend more," said Fred H. Bayley III, then the Corps' director of engineering for the Lower Mississippi Valley Division.

But the Corps' proposed "butterfly-valve gate" -- a concrete-and-steel barrier that would open to let out water and close to seal off storm surges -- was untested in high storm conditions. The corps' plan also clashed with the city's practice of using its system of antiquated pump stations -- two miles inside the city -- to force floodwater out into the lake through the canals. Officials with the New Orleans Sewerage and Water Board who supervised the canals feared that in a major hurricane, the gates would jam with debris and canals would back up, submerging the city.

Corps engineers had been fixated on floodgates since the 1970s, when the agency proposed using towering gates to block off surges at the far eastern end of the lake. That plan was the corps' response to Hurricane Betsy, a storm that hit New Orleans in 1965, swamping the city's Lower 9th Ward, killing at least 75 people and causing more than $1 billion in property damage.

Louisiana's congressional delegation, led by Democratic Sens. Russell Long and J. Bennett Johnston, won legislative approval for the barrier plan. But by the early 1980s, the project was shelved, scuttled by a judge's order, opposition by environmental and business groups, and bickering levee boards.

The Corps, convinced that raising levees was risky, shifted its plans, proposing to build gates at the lakeshore. Higher flood walls required deep sheet piles -- heavy-gauge steel foundations -- sunk into the soft coastal soil to brace against water pressure. To raise the levees properly, corps engineers warned that houses along the 17th Street and London Avenue levees might have to be razed. But the corps refused to absorb the costs, and the levee board shied from taking on neighborhood groups -- a pivotal early error.

Eager to show off their prototype, corps engineers herded city officials into the Army's cavernous Hydraulics Lab in Vicksburg, Miss. The hinged doors opened and closed easily. But city sewerage officials peppered the engineers with doubting questions. Indeed, according to a November 1987 Corps report, the "original design did not perform as intended." Only when corps engineers altered the model, "the gate design performed satisfactorily."

Despite the skepticism, Corps officials moved firmly to clear a path for the floodgate plan. The Corps ruled that it would not pay for raising the levees because the city's canals were used for local drainage, not navigation -- beyond the scope of the Corps' authority over river and waterway projects.

The decision forced Orleans levee officials to gamble. Although the corps refused to pay for raising the levees, the Lake Pontchartrain, La., and Vicinity High-Level Plan was still in its planning stages. Under the drawn-out design process, levee officials still had the ability to research their own alternative -- at the board's cost. They aimed to keep the levee-raising option alive by hiring their own design consultants, then using political leverage to win their levee-raising plan later.

Involving Politics. From the Orleans levee office on Stars and Stripes Boulevard to the governor's mansion in Baton Rouge, Louisiana's political veterans knew the unstated rules of the levee-building game. There were scores of qualified civil engineers in New Orleans, all angling to score lucrative public contracts. Many firms boasted former Corps engineers who knew how the Corps worked and had friends still in the service.

"The Corps had these relationships with the levee boards," Roemer recalled acidly. "In their conversations, the levee board would ask the Corps: 'What do we need to do to have safety and economic development?' And the Corps would give unofficial answers. Then the levee board would hire a consulting engineer and go to the window the Corps had opened. It was sweet."

Normally, the Corps used its own contractors to design and build flood-control projects. But with the Corps' approval, levee boards could hire consultants as a way to pay their 30% local share of a project's cost. In hindsight, said the Corps' commander, Lt. Gen. Carl A. Strock, the decision to let the Orleans board hire its own contractors was "an unusual practice for us." Some Corps veterans worried about the intrusion of local politics and budget complications. "Generally, when there were more layers involved, it got more difficult," Bayley said.

The political lines stretched to Louisiana's governors, who chose the majority of commissioners on local levee boards. In 1985, the power in Baton Rouge was Roemer's predecessor, Democratic Gov. Edwin Edwards, who had installed New Orleans lawyer Emile Schneider as levee board president. Schneider moved quickly. The board issued $50 million in bonds, then began hiring private engineers. The consultants were chosen on their qualifications. But politics and hiring sometimes mixed, said former commissioners.

All three engineering consultants who were selected by the Orleans board to design the levees contributed to the political campaigns of officials with sway over the board. Burk-Kleinpeter Inc., the engineering firm that designed the raised London Avenue flood wall, gave $5,000 to Edwards in 1991 before he won the 1992 governor's race. Walter Baudier also donated during the period that his firm, Design Engineering Inc., planned the Orleans Avenue levee. Baudier gave $2,200 to Roemer in 1987 and $3,000 to Edwards in 1991. "Everybody gave to everybody," Baudier said. "That neutralized any advantage."

Baudier's firm was also awarded a separate contract with the Orleans district, coordinating other levee board projects. Louisiana's legislative analyst criticized the arrangement in 1992, warning of potential conflicts between the firm's dual roles. Baudier insists his firm dealt only with financing and did not "review other people's designs." Levee board contractors also frequently gave campaign money to Francis C. Heitmeier, a powerful state legislator from New Orleans who has long wielded influence over Orleans levee district affairs. Among Heitmeier's donors from 1996 through 2002 were Baudier ($5,000), Burk-Kleinpeter ($10,000), and Modjeski and Masters Inc., an engineering firm that designed the 17th Street levee ($750). Officials with Burk-Kleinpeter and Modjeski and Masters did not return calls seeking comment.

For years, former Orleans levee officials say, Heitmeier, who headed the state Senate's public works committee and now its Finance Committee, was influential in levee board decisions on hiring, policy and contracts. Roemer was stymied by Heitmeier when he tried to reform the levee board system and wrest contracts away from local authorities. His "biggest battles," Roemer said, were with Heitmeier. Just last month, Heitmeier again played obstructionist, helping to snuff out a post-Katrina attempt by reformers to create a unified state levee board. Critics howled. Heitmeier shrugged. "They can say what they want," he said.

<u>Questions About Depth</u>. By 1990, faced with spiraling costs for its gates at the 17th Street canal, the Corps agreed to pay for raised levees there. But the Corps still insisted on gates at Orleans and London avenues. Even before the Corps made its concession, the board had acted on its own, hiring a construction firm to drive sheet piles at 17th Street.

The Orleans board's impatience with the Corps was shared by neighboring levee agencies. In recent years, Plaquemines Levee District President Benny Rousselle twice ordered crews to raise levees along a local highway despite formal Corps orders to desist. And earlier this year, the East Jefferson Levee District bolstered its side of the 17th Street levee by a foot and a half without the corps' approval. "When you deal with the Corps, it takes years of studies," Rousselle said.

Corps engineers were openly peeved in 1990 when they learned about the Orleans board's decision. The move posed "an undesirable situation for this office and the Corps," Bayley wrote to the corps' district commander. Bayley also warned that work crews were not driving the steel foundations deep enough. It was the first alarm about shallow sheet piles under the levee.

Despite the Corps' recent insistence that 17th Street's foundations were properly designed at 17 feet below sea level, a National Science Foundation team of engineering experts has described the pile depths as inadequate.

By autumn of 1990, the Orleans board had also quietly hired Bruce Feingerts, a former aide to Russell Long, to lobby in Washington for levee expansion. Feingerts had discovered that the levees of Orleans and London avenues might win federal funding if he could persuade Congress to expand the coverage of the post-Betsy hurricane plan passed in 1965. Sens. Johnston and John B. Breaux agreed to help, Feingerts said, as did most of the state delegation. When Senate and House versions of the 1990 Water Resources bill neared passage in October, Feingerts went into action. Johnston recalled that former Louisiana Rep. Jimmy Hayes was the "point man" as a House manager for conference negotiations.

Now a Washington lobbyist, Hayes did not respond to interview requests. But a former aide, Rhod Shaw, said he often aided New Orleans projects and "would have been carrying whatever the delegation wanted." The military engineers were "asleep at the wheel," Feingerts said. "If they had seen it coming, they would have blown a gasket." The final bill passed with his language intact: “The conferees direct the Corps to treat the outfall canals as part of the overall hurricane project.”

As new levee construction projects geared up at Orleans and London avenues, work crews at the 17th Street canal were struggling with construction obstacles. Unable to operate from the land side of the canal because property lines backed tightly up against the levee, construction crews had to maneuver by barge up the canal with a 300-foot crane to drive steel piles and raise the concrete wall.

Lakeview resident Bud Thaller stormed outside one day when his house began to shake violently. A levee crew driving foundations at 17th Street with a vibrating hammer had just struck a sandbar. The foreman shrugged when Thaller approached. He told me they were having a hard time getting the piles in, Thaller recalled.

Boh Brothers, a Louisiana construction firm, was the first of three companies to drive sheet piles under the levee walls. They were joined by concrete specialists, some working for the Orleans board, others hired by the Corps and the sewerage board. A parade of inspectors and engineers also crowded over the site, so many that “it could get confusing,” recalled Boh Vice President Dale Biggers, then a crew foreman.

The Corps was always the final authority -- even overseeing the number of hammer blows used to drive in the sheet piles. But on any given day, crews also had to coordinate with state and city officials and inspectors for Modjeski and Masters, the levee board’s design consultant. The question of who performed the inspections is crucial because engineering experts have had difficulty learning how on-site decisions were made.

“No one was in charge,” said Raymond Seed, a UC Berkeley engineering professor leading a National Science Foundation inquiry. Seed’s team has heard allegations that piles were deliberately shortchanged. The Justice Department is investigating.

Structural engineer Herbert J. Roussel Jr., who testified for a construction firm that sued the corps during one dispute, recalled Army engineers as dismissive: “The Corps had an attitude problem. It was: ‘We’re the Army Corps of Engineers. We know what we’re doing and you don’t.’ “

Levee board officials complained about excessive Corps delays. They were slow. We’d come up with a design, and the corps would always send them back,” Boissiere said.

Army engineers raised their own complaints. Baudier’s firm was removed as Orleans Avenue designer in 1992, accused by the Corps of missing deadlines. As sections of the flood walls were finished piece by piece through the mid-1990s, the levee board’s emphasis turned to the mundane chores of grass-cutting and maintenance. That left ample time for board business that had little to do with flood protection.

<u>Outside Interests.</u> When lawyer Robert Harvey was installed as the Orleans district’s president in 1992, the levee board was a recreation powerhouse. A year after Mississippi River floods swamped New Orleans in 1927, Louisiana political legend Huey Long had prodded the state Legislature to allow the Orleans board to expand its influence into parks, beaches and other “places of amusement.

By the late 1980s, the board operated an airport, two marinas and lakeshore rental properties, but the agency was hemorrhaging money. Leases went unfilled at the airport, and its South Shore Marina had too many vacant boat slips. Instead of scaling back, Harvey accelerated the board's outside interests. The tough-talking lawyer won his post after contributing $5,000 to the 1991 campaign of Gov. Edwards, an old friend. "It's a plum job," Harvey recalled. "Your connection with the governor is close. You have 300 employees, lots of contracts."

When Edwards pushed for state gambling -- a position that led to his federal corruption conviction in 2001 -- Harvey wooed the Bally's gambling empire to locate a casino boat at a dock owned by the levee board. The boat brought in millions in gambling taxes, but other Harvey projects fell flat. A flirtation with film studios went nowhere. A series of probes by the state auditor found cases of financial mismanagement, conflicts of interest and risky investments. At one point, six attorneys were working for the board without formal contracts. And Harvey was accused by the New Orleans Metropolitan Crime Commission of padding the levee board payroll with old friends. The controversies took their toll. Harvey resigned in 1995, followed by an FBI probe of his levee board tenure. "They didn't find anything," Harvey said.

His successor, James P. Huey, waded into his own controversies. Huey's board hired his wife's first cousin, George Carmouche, as a lobbyist in Baton Rouge. After Katrina struck, the board sublet a Baton Rouge office from Carmouche. And Huey pocketed nearly $100,000 in back pay, failing to first obtain permission from state lawyers. He returned the money after resigning under pressure. Huey, who did not respond to interview requests, is under investigation by state and federal authorities.

At the same time, the newly raised flood walls received haphazard scrutiny. Harvey recalls staring jealously at East Jefferson Levee District's well-trimmed border of the 17th Street canal, then at untamed foliage and trees massed along the Orleans levee wall. "I'd look at the Orleans side and get depressed," he said.

Neither the corps nor the Orleans board had a rigorous program for scanning for structural defects. Instead, the two agencies joined twice a year for five-hour-long inspection tours. A caravan of officials would make random stops along the floodwalls. Sometimes corps officials issued citations. Then they would head out for long lunches. "That was always on the agenda," said former Orleans commissioner Peggy Wilson.

On one tour, Wilson was joined by only one other levee board official. When they stopped briefly at the levees, corps officials seemed in a rush. "I kept asking them what I was supposed to look for, puddles of water?" she said. They said, 'Oh, don't worry.' The agencies relied largely on maintenance crews and neighbors to flag levee problems. "If something structural came up, we'd tell the corps," said retired Orleans levee board crewman Ed Robbins."

But at 17th Street, Corps engineers were a rare sight, recalled Eric Moskau, a commercial real estate agent who has lived near the flood wall since 2001. "I'd just see them driving out near the walls," Moskau said. "I always wondered exactly what they did out there."

17th Street. When Katrina's swells blew out huge chunks of 17th Street's cement wall on the morning of Aug. 30, Harvey was prepared for disaster. Years of interagency spats with the Corps and his own engineers had left him a skeptic. He bought an inflatable rubber boat and stored it in the attic of his house near the 17th Street levee. When floodwaters rose, Harvey dragged down his boat and began rescuing neighbors. “Nobody wanted to go into a starvation mode and pay for real protection in the halls of Congress,” he said afterward.

Since 2001, the Bush administration had repeatedly turned down requests from the levee board and the Louisiana delegation for more flood protection. When Katrina struck, Orleans Avenue’s levee walls held firm. But when Walter Baudier, the levee’s original designer, drove out with another engineer to the canal weeks later, he was stunned to find a 200-foot gap between the levee wall and the pump station. The wall was left unfinished because of the government’s refusal to fund the project, according to the corps and levee officials. The gap allowed floodwater to flow freely into the city.

Near the breach at 17th Street, an 18-foot section of levee wall ended up in Moskau’s living room. Displaced to Idaho, Moskau returned weeks later to survey the damage. He hiked over hardened mud, gaping at the two-block-long rupture. Crowds of red-shirted corps engineers swarmed nearby, directing repairs. There were more engineers, he realized, than he had seen in the four years he had lived near the levee. The government was just like everybody who lived near the levee,” Moskau said later. “They took those walls for granted.

F.3.11 Vartabedian, R. and Braun, S. (2006). “Fatal Flaws: Why the Walls Tumbled in New Orleans,” Los Angeles Times, January 17.

NEW ORLEANS -- In the frantic days after Hurricane Katrina, the Army Corps of Engineers scrambled to plug a breach on the 17th Street levee, dropping massive sandbags from a fleet of helicopters. But the engineers were baffled: The sandbags kept disappearing into the watery breach. The pit eventually swallowed 2,000 sandbags, each weighing between 3,000 and 20,000 pounds. It was an early sign that the hurricane had opened an extraordinarily deep hole in the foundation of the storm wall, pointing to a fundamental breakdown in the engineering of the city’s levee system.

Investigators recently told The Times that the 17th Street levee failed because its engineers made a series of crucial mistakes, one of which was to base the levee design on the average strength of the soil rather than on the strength of its weakest layer. The errors may reflect a loss of expertise during the 1990s, when the corps sharply downsized its soil laboratories. The faulty soil analysis is one of many defects or flaws in concept, design, construction and maintenance that left many of the levees in New Orleans especially vulnerable to Katrina. Environmental miscalculations, including the loss of natural protection from marshes, added to the problems. The errors might have been offset had the corps required larger safety margins, and that raises questions about the corps’ internal culture.

Although the levees’ shortcomings became apparent shortly after the hurricane hit, experts are only now pinpointing the underlying causes of the collapses. What they find will determine who bears the political and legal responsibility for the flood and provide a technical basis for any future levee system to protect New Orleans from a monster storm. The levee failures were among the most costly engineering errors in the United States, measured by lives lost, people displaced and property destroyed, said half a dozen historians and disaster experts.

Katrina flooded New Orleans with about 250 billion gallons of water and killed more than 1,000 people. “I don’t think there is anything comparable in recent American history,” said retired engineering professor Edward Wenk Jr., a science advisor to three presidents and investigator of the Exxon Valdez accident.

Early blame for the levee failures has fallen largely on the Army Corps of Engineers, the principal architect of a 40-year project to protect New Orleans from hurricanes. Corps officials say they will accept responsibility for the failures if investigations prove that their supervision of the system was deficient. “What I don’t think we understand yet is the forces that caused those failures,” said Lt. Gen. Carl Strock, corps commander and its chief of engineers. “A failure is really where a design does not perform as intended. If forces we designed for were exceeded, there may not be a design failure.

However, a preliminary report funded by the National Science Foundation has found evidence of design flaws in the city’s concrete storm walls, where at least six catastrophic failures caused half of the flooding. A handful of technical, civil and criminal investigations are underway, including an effort by the Justice Department to look for possible criminal negligence. The corps is conducting the federal government’s official investigation, despite widespread concern that only an independent board of investigators is likely to be impartial.

The corps was slow to make public all of its engineering paperwork on the levees and has still not produced a full record of the internal correspondence that occurred during the last 15 years. Moreover, it is not examining what role its organization and culture played in technical lapses, which, Wenk said, typically are at the root of engineering disasters. The corps says it has addressed those concerns by recruiting outside experts to participate in its investigation. The agency is expected to make its final report in June.

The corps is attempting to temporarily repair 50 miles of damaged levees before the hurricane season next June. The Bush administration announced last month it would spend $3.1 billion for temporary levee repairs and limited upgrades in the next several years. However, many local leaders believe the levee system must be strengthened to withstand the strongest possible hurricane -- a Category 5 -- to restore full confidence in the city. Katrina, a Category 5 storm over the Gulf of Mexico, weakened to a Category 3 by the time it hit New Orleans.

Making his ninth visit to New Orleans since Katrina struck, President Bush last week praised the $3.1-billion initiative but said nothing about Category 5-level protection. And, according to the corps, even the temporary repairs and limited upgrades will not protect the city from another Category 3 storm, which has winds up to 130 mph and storm surges as high as 12 feet above normal.

Meanwhile, more than four months after the hurricane, investigators are still coming to grips with the levee system’s technical failures and shortcomings that paved the way for Katrina’s destruction.

Weak, Slippery Soil. No levee failure was more dramatic than the breach at the 17th Street Canal, where a 465-foot section of concrete wall gave way Aug. 29, flooding the affluent Lakeview section of New Orleans. Floodwaters were 3 to 5 feet below the top of the levee wall when it collapsed. The soil under the levee, composed of layers of loose clay and softer organic peat, was too weak to handle the weight of the water pushing against the levee walls.

The earthen base of the levee slid backward by about 45 feet, taking the concrete storm wall along for the ride. The whole system relied in part on heavy-gauge steel beams, called sheet piling, driven into the soil for reinforcement. But they only went to a depth of 17 feet below sea level, not deep enough to provide a strong foundation, National Science Foundation investigators say.

In rebuilding the damaged sections of the canal levees, the corps is sinking sheet piling 45 feet, and in some areas is using heavier gauge piling up to 70 feet deep. The corps says the deeper piles are needed because soil in the damaged areas is even weaker than before Katrina.

The levee design was overseen by the corps but assigned to two firms: Eustis Engineering, which analyzed the soil under the levee; and Modjeski and Masters Consulting Engineers, which did the structural design. (Neither firm returned phone calls seeking comment.). The levee design depended on crucial soil measurements along the canal that began in 1981. Technicians drilled for soil samples 300 to 500 feet apart to measure the strength of the soil.

The soil tests provided accurate and complete data about the weak soils, but government and private design engineers made three crucial errors analyzing the information, said Bob Bea, a UC Berkeley engineering professor who is part of the National Science Foundation investigating team. First, engineers determined the overall strength of the soil by averaging different layers and different sections along the banks of the canal. But it was the weakest layers of soil that would determine the overall strength, and using the average gave the engineers a false confidence, Bea said.

Second, the levee design failed to account for the fact that the soil would weaken significantly once the canals were full of water and the soil became saturated, Bea said. Soil tests conducted before the levees were built showed the soil's shear strength was about four times greater than after Katrina. The engineers incorrectly believed that sediment in the canals would prevent water from intruding through foundations, but dredging and other activity disturbed that natural seal, he said.

Finally, the engineers miscalculated how the levee foundation could slide, if it did fail. They assumed the greatest risk of failure was in one of the stronger layers of soil, whereas it failed in a weaker layer.

Since Katrina, the corps has proposed installing storm gates that would seal off the 17th Street Canal, along with the city's two other major drainage canals. Once the canals were sealed off from Lake Pontchartrain, hurricane surges would no longer be able to travel through them into the heart of the city.

Not long after construction started on the levee, signs of trouble popped up. The company that built the 17th Street storm wall, Pittman Construction, warned the corps in the early 1990s that the pilings were unstable and had caused problems during construction. The company filed a claim for more money but lost its case. "Pittman told the corps he was concerned about the weak soils," said Herbert Roussel, a consulting engineer hired by the company's owner, A.E. Pittman. "The corps acted as though it was his problem."

Loss of Expertise. As questions about the soils were being raised, the corps shut down its soils lab in the New Orleans district and curtailed its geotechnical research lab in

Vicksburg, Miss. The labs had long performed crucial soil analysis and research for projects around the country, but the corps' leadership wanted staff engineers to oversee outside contractors, said Bill Marcuson, the former director of the New Orleans soils lab and president-elect of the American Society of Civil Engineers.

"That trend leads to less in-house capability and competence," Marcuson said. "If the corps is not physically doing research, it is hard to evaluate the quality of others' research." Strock said the moves were part of a larger federal government trend to save money by turning over work to the private sector. He conceded that the practice "eroded our technical capability," but said the damage was limited.

But Bea countered that the agency lost significant technical capability, particularly in its large civilian workforce. "They don't have the number of people or the quality of people that they used to," said Bea, who began his engineering career with the corps.

Levees Without Armor. Along many levee sections, particularly those on the waterway known as the Industrial Canal, water poured over the tops of storm walls and cascaded down the backside, scouring and weakening the foundations. Eventually, the walls collapsed. If they had remained standing, they would have acted as a buffer and slowed the pace of flooding.

The levees could have survived the overtopping if the backs of the walls had had concrete or heavy stone pads at their base, a protection known as "armoring." Some of the storm walls in New Orleans were built with armored foundations and significantly stronger sheet piling, known as T-walls. Those levees did not fail and incurred far less damage during Katrina.

The corps generally assumed that hurricane flood waters would not rise high enough to spill over the levees. But most outside experts say that assumption was a mistake. "There are only two kinds of levees: those that have been overtopped and those that will be overtopped some day," said Gerald Galloway, a levee expert at the University of Maryland. He added that armoring "is not cheap or simple."

The corps is replacing some failed sections of levees with T-walls. Brig. Gen. Robert Crear, the corps' district engineer in New Orleans, said the agency was preparing to armor many levees under the $3.1-billion rebuilding program. The armoring will include placing beds of rock or concrete at the base of the walls to prevent erosion in future storms.

Thin Safety Margins. Doubts about the corps' oversight have also flared over the low margin for error designed into the canal floodwalls. Engineers design structures to withstand forces far greater than the maximum anticipated loads to compensate for uncertainties in their own understanding and for possible defects in construction.

According to Wenk, the engineering expert, public structures typically have safety margins as high as four, meaning they are four times as strong as it is anticipated they will need to be. Corps documents indicate that engineers approved a margin of 1.3 for the floodwalls. That meant the walls were designed to be 30% stronger than the maximum stress expected from a hurricane flood surge. Wenk said he was astounded by such a low factor, particularly for a system that protected such a large urban area.

Strock agreed that the issue needed close attention. "I was not aware before this event that the factor was 1.3," he said. Critics have questioned whether the corps devoted sufficient attention to safety, and Strock acknowledged that the low safety margins "may get back to the cultural issue."

Overgrown Trees, Brush. Years of neglected maintenance in southern Louisiana may have contributed to the heavy flooding, engineering experts said. The growth of large trees near the 17th Street Canal levee may have helped undermine the floodwall. Katrina's strong winds blew down a massive oak near the levee breach and investigators believe the roots of the tree pulled out a large plug of soil from the embankment.

The Orleans Levee District is responsible for maintenance and employs work crews to trim grass along the levee slope. But trees and bushes sprouted from the yards of private homes near the breach site and were left untrimmed for years because of opposition from homeowners and the failure of levee officials to move aggressively. The Orleans Levee District could have taken action, critics say. Just across the 17th Street Canal, the levee wall owned by the neighboring East Jefferson Levee District is regularly shorn of trees and heavy brush. "It is a major concern," said Jim Baker, superintendent of operations for the East Jefferson Levee District. "If you have a tree blow over, it can open up a good size hole. I don't like trees growing on our levees."

Lost Wetlands Barrier. Closer to the Gulf of Mexico, a different kind of environmental miscalculation also contributed to the disaster. Environmentalists, political leaders and engineers warn that decades of neglect and corps-sponsored dredging led to the disappearance of vital wetlands, allowing hurricane storm surges to threaten New Orleans.

When Hurricane Katrina roared up the Gulf of Mexico, it spawned a storm surge toward New Orleans through a navigation channel known as the Mississippi River Gulf Outlet, or MRGO. The outlet was built from marsh and wetlands by the corps in the early 1960s to allow large ships quicker access to the Port of New Orleans. Originally designed as a 300-foot-wide channel, the outlet has widened to more than 3,000 feet, the result of repeated dredging by the corps and of ships' wakes.

You can put more surge through a wider body," said Thomas Sands, a retired corps general who headed the New Orleans district. "When I was district engineer, the erosion along the MRGO was horrible." The project also allowed salt water to penetrate and destroy hundreds of square miles of wetlands that acted as a natural flood barrier.

Henry "Junior" Rodriguez, president of St. Bernard Parish, said that the heavy flooding that topped his community's levees during Katrina was far worse than during Hurricane Betsy in 1965. "Listen, we didn't even have levees during Hurricane Betsy and the flooding wasn't as bad," Rodriguez said.

After Katrina, the corps has pledged to halt dredging of the MRGO for at least a year and is considering proposals to scale it back. The agency is also proposing to channel sediments and freshwater into the marshes to reduce future wetlands losses, though the National Research Council recently termed the current proposals inadequate.

We will never be able to rebuild the coast we had 50 years ago, but the wetlands still out there can be preserved," said Carlton Dufrechou, executive director of the Lake Pontchartrain Basin Foundation, a leading environmental group in the region. "If we do nothing, the gulf will be lapping at the edges of New Orleans in future decades," Dufrechou said. "And if the MRGO stays open, you might as well put a bull's-eye on the city and tell everybody to clear out on June 1 when the hurricane season starts.

F.3.12 Irons, L. (2005). "Hurricane Katrina as a Predictable Surprise," Homeland Security Affairs, Vol. I, Issue 2, Article 7, http://hsaj.org/hs a.

How can a surprise be predictable? Paradoxically, many people think low-probability events are just that: low probability; not impossible but very unlikely. People find it difficult to sustain a high level of preparedness for events that are unlikely to happen on any given day, especially if the preparation requires spending scarce time and resources. As Max Bazerman and Michael Watkins observe in their recent book, Predictable Surprises: The Disasters You Should Have Seen Coming, And How To Prevent Them, 'We don't want to invest in preventing a problem that we have not experienced and cannot imagine with great specificity.

Bazerman and Watkins outline four major characteristic traits of predictable surprises.

1. Leaders know problems exist and will not solve themselves.
2. Organizational members realize a problem is getting worse.
3. Fixing the problem requires significant cost in the present with no immediate benefit (rewards for avoiding the costs of prevention are uncertain but potentially larger than incurring the costs).
4. Humans tend to maintain the status quo if it functions (minorities protect their own interests, subverting efforts by leaders to implement change.

One basic lesson to learn from Hurricane Katrina is that organizations managing preparedness for flood control and hurricanes, such as the U.S. Army Corps of Engineers, as well as organizations managing responses to disasters, such as FEMA, can benefit from developing learning organizational processes. Those same processes make it more likely that staff will avoid surprises by recognizing them, prioritizing the challenges, and mobilizing resources to prevent them from developing.

A basic step in preparing an organization to use the affect of its people to enhance their efficiency and effectiveness is for its leadership to admit that it is not perfect, that operations require continuous improvement. Professional criticisms of operational performance must flow up the organization as well as down, with the organization encouraging such contributions. Indeed, a learning organization does the following:

- defines a clear mission, designed to inspire workers to do their best;
- creates a culture that emphasizes professionalism;
- provides top-notch technical training;
- provides leadership development for managers;
- pushes responsibility down the ranks so employees in the field are authorized to act quickly; and
- advocates continuous improvement.

Learning organizations are challenges to promote a level of awareness sufficient to enable surprise-avoidance capability from their members. Indeed, the structure of large and complex organizations increases the difficulty leaders' face in anticipating predictable surprises. As the complexity of organizations, or even project teams, increases, the way expertise is coordinated tends to develop into silos. Organizational silos often disperse responsibility as well as information. In other words, organizational silos encourage staff to 'let someone else' deal with recognized problems, essentially supporting surprise-conducive processes.

Leadership is a key point of interest when considering the way organizations attempt to avoid, or mitigate the impact of, predictable surprises. There is little dispute of the point that local, state, and federal leaders knew about the vulnerability of the New Orleans' levee protection system and the threats it posed to the city. Although some officials initially claimed that non one expected the levees and flood walls in New Orleans to collapse, most experts knew about the vulnerability for many years.

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.

Improving the levee and floodwall system in New Orleans was a recognized challenge for decades, as was the challenge of a receding delta providing less protection to the New Orleans area from storm surges resulting from a hurricane. The Breaux Act of 1990 created a task force involving several federal agencies and gave it the mission of restoring wetlands. The task force received only forty million dollars per year to stop the erosion of the delta. A University of New Orleans study estimated the effort averted only about two percent of the overall loss, leaving an erosion rate of twenty-five square miles of delta per year.

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. the company recommended that, without test dredging, the bottom of the canal needed sealing with a concrete liner or building a seepage cutoff wall, like sheet pilings, to a depth of 65 feet below sea level versus the existing 12 feet. Engineers studying the levee breaches consider the report by Eustis significant because the stretch of canal the firm studied is widely considered to exhibit stronger soil layers than those that breached during Hurricane Katrina.

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.

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.

Though the construction company lost its suit against the Corps of Engineers, the gist of their complaints about the condition of the soil and existing foundation was not disproven. 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. The soil then allowed water to percolate under the levee and floodwalls, weakening the structure so that the storm surges from Hurricane Katrina moved it entirely, or breached it. 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?

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.

Bazerman and Watkins note that predictable surprises play out over long time frames, sometimes longer than the typical tenure of organizational leaders. They contend 'this creates a variation on the free-rider problem. Why, a leader might ask, should I be the one to grapple with this problem and take all the heat when nothing is likely to go wrong during my watch? In other words, members of the U.S. Army Corps of Engineers, conceivably, made a collective bet that the unlikely occurrences that, in fact, did end up happening, were not worth the expense, form a professional or organizational initiative point of view. …The sheer magnitude of the problems faced in the New Orleans levee protection system probably appeared overwhelming to members of an organization enduring ongoing budget concerns and staff turnover.

Consider the scale of the plans offered to fix the levee challenges: a plan floated in early 2001 involved two to three billion dollars proposed to divert sediment from the Mississippi River back into the delta, rather than allow the sediment to wash down the levee system and dump into deep water. The project was compared to the four billion dollar restoration initiative for the Florida Everglades. However, these projects are typically funded through matching grants in which the state has to match a federal dollar with one of its own. Louisiana was only able to match each dollar with fifteen to twenty-five cents. Facing the scale of such a challenge, and the state's limited ability to pay for its share of the costs, the response of most people was to maintain the status quo. the result was a catastrophic disaster that cost many times the few billion dollars needed to initiate a full-scale rebuilding program for the levee protection system and the surrounding wetlands. Essentially, those responsible for the levee protection system in New Orleans saved money in the short term only to permit one of the largest disasters in American history to occur over the long haul.

The U.S. Army Corps of Engineers currently finds its authority questioned by many, not because of the competence of its engineers' expertise, but rather due to concerns about its organizational processes that allowed such basic design flaws to go without sustained questioning by engineers exercising professional judgement.

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.

F.3.13 Congressional Research Service Report for Congress (2005). *Protecting New Orleans: From Hurricane Barriers to Floodwalls*, N. T. Carter, Washington DC, December.

Understanding why New Orleans' hurricane protection system failed is essential for moving beyond simply making repairs to damaged levees and floodwalls. Knowing why the floodwalls failed is central to assessing the city's vulnerability to storm surge flooding and deciding on how to most effectively combine approaches for managing flood risk during rebuilding efforts (.e.g, investing in coastal wetlands loss and hurricane protection infrastructure, requiring flood-proofing in certain areas, and mapping areas for the federal flood insurance program.

The original design of the Lake Pontchartrain project was sent to Congress in July 1965. The project was designed to protect the city from a standard hurricane for the region, which was roughly equivalent to a Category 3 hurricane on the Saffir-Simpson Scale. The standard hurricane was defined as high sustained wind speeds reasonably characteristic for a specified coastal location. Reasonably characteristic was defined as only a few hurricanes on record over the general region had been recorded to have more extreme wind and other meteorological characteristics. The standard hurricane was determined by the U.S. Weather Service.

Two months later in September 1965, Hurricane Betsy, a Category 3 hurricane, struck Louisiana's coast, causing damage in New Orleans. Congress authorized construction of the Lake Pontchartrain project in the Flood Control Act of 1965, enacted in October 1965. Modifications to the authorization have been made in subsequent legislation. Since that original design, there have been two major developments in the project relevant to current investigations into the floodwall failures: (1) the shift from the barriers at the inlets to Lake Pontchartrain to higher levees along the lake; and (2) the shift from floodgates at the mouth of the city's storm water outfall canals that drain into Lake Pontchartrain to higher floodwalls along the length of the canals.

The original July 1965 Lake Pontchartrain project design consisted of the Barrier Plan for constructing inlet barriers at Lake Pontchartrain's three main tidal entrances as well as levees and floodwalls for surge protection. The barriers generally would remain open and allow for navigation, and would close during coastal storms to reduce storm surges from entering the lake. Based on updated weather data and experience learned during the city's flooding in September 1965 by Hurricane Betsy, changes in project were sought before construction began. For almost two decades, technical issues, environmental concerns, legal challenges, and local opposition to various components slowed construction.

The design that the Corps eventually chose was the High-Level Plan which consists of higher levees and floodwalls, instead of the originally planned inlet barriers and lower levees and floodwalls. The change from the Barrier Plan to the High-Level Plan was approved by the Corps chief of Engineers in February 1985; both the barrier and the high-level plans were designed to protect from the rough equivalent of a fast-moving Category 3 hurricane. The Chief's decision to adopt the High Level Plan was based on a 1984 project reevaluation study conducted by the agency in response to a 1977 court injunction on the construction of inlet barriers until an adequate Environmental Impact Statement (pursuant to the National Environmental Policy Act of 1969 P.L. 91-190) was completed. the reevaluation study recommended the change because 'the High level Plan has greater net benefits, is less damaging to the environment, and is more acceptable to the public' than the Barrier Plan.

To drain the city of storm water (i.e., accumulated rainfall), the city pumps water into three outfall canals - the 17th Street canal, the Orleans Avenue canal, and the London Avenue canal - that flow into Lake Pontchartrain. The pumps are located at the southern ends of the canals, away from the lake. To protect the city from rising water in Lake Pontchartrain during hurricanes, levees were built along the length of the canals. The levees along the outfall canals were considered adequate when the Corps developed the original design for the Lake Pontchartrain project that was sent to Congress in July 1965.

Subsequent to the U.S. Weather Bureau's adoption of a more severe standard hurricane for the region, the Corps determined that the levees along the outfall canals were inadequate in their height and stability to protect the city from the standard hurricane. The Corps eventually integrated hurricane protection for the canals into its Lake Pontchartrain project. The Corps considered improved canal protection necessary regardless of the selection of the Barrier or High-Level Plan. The two basic canal options evaluated were: 'butterfly' floodgates at the mouths of the outfall canals that would close when water levels in Lake Pontchartrain exceeded levels in the canals (known as fronting protection); and higher and stronger levees and floodwalls along the canals (known as parallel protection).

The Orleans Levee District and the Sewerage and Water Board of New Orleans favored parallel protection over floodgates; they were concerned that the operation of the butterfly floodgates would reduce the ability to pump storm water out of the city during storms. The Corps analyzed the options and recommended parallel protection for the 17th Street Canal; in contrast, the Corps recommended butterfly flood gates for the Orleans and London Avenue canals. The Corps concluded that the butterfly floodgate plan for the London Avenue canal 'fully satisfies the project's mandate to provide protection against the hurricane generated tidal surges and yet provides the maximum latitude for operation of local interest interior drainage (i.e., storm water removal). The butterfly control valve plan has been shown to be the least costly fully responsive plan. When compared to the parallel protection plan it is approximately three times less costly'.

The conclusion for the Orleans Avenue canal was similar; the Corps found the butterfly gates to fully satisfy the project purpose of hurricane storm surge protection and to be one-fifth the cost of parallel protection.

Rather than having the Corps proceed with construction of the butterfly floodgates, the Orleans Levee District decided to construct on its own most elements of the parallel protection on the Orleans and London Avenue canals. this local construction was designed in accordance with Corps criteria, so that the parallel protection would be incorporated into the larger Lake Pontchartrain project. The Corps recommended that the federal cost-share contribution for the parallel protection of the two canals be capped at 70% of the less-costly butterfly floodgates design. In H. Rept. 101-966, the Conference Report for the Water Resources Development Act (WRDA) of 1990 (P.L. 101-640), Congress directed the Corps to consider favorably parallel protection for the two canals and for the federal government to bear part of the costs, but did not specify what percentage of the cost. This report was followed by the Energy and Water Development Appropriations Act of 1992 (P.L. 102-104) in which Congress stated: 'The Secretary of the Army is authorized and directed to provide parallel hurricane protection along the entire lengths of the outfall canals and other pertinent work necessary to complete an entire parallel protection system, to be cost shared as an authorized project feature, The Federal cost participation in which shall be 70 percent of the total cost of the entire parallel protection system, and the local cost participation in which shall be 30 percent of the total cost of such entire parallel protection system'.

Concerns about levee and floodwall reliability are compounded by concerns about the level of protection provided by the existing infrastructure given New Orleans' increasing vulnerability to hurricane storm surge. Land in the city has subsided; barrier islands and wetlands have been disappearing; and sea levels have risen. These factors have raised concerns about the ability of the city's infrastructure to provide Category 3 protection. According to the project justification sheet included in the Administration's Corps FY 2006 budge request, 'the project was initially designed in the 1960s, and a reanalysis was performed for part of the project in the mid-1980s. Continuing coastal land loss and settlement of land in the project may have impacted the ability of the project to withstand the design storm.' The challenge of protecting New Orleans could become even greater. According to some scientists, higher sea surface temperatures may result in increased hurricane intensity. Climate change concerns and other factors have raised questions about whether both estimates of the likelihood of hurricanes of various strengths and past infrastructure investment decisions based on these estimates need to be reevaluated.

Hurricane Katrina has resulted in some questioning why a Category 4 or 5 hurricane protection system was not in place for New Orleans, and whether it should be part of the rebuilding effort. The Corps currently only as congressional authorization for a Category 3 system; additional congressional authorization would be necessary to build a more protective system Discussions of Category 4 or 5 protection for the city often include the extent to which coastal wetlands restoration may play a role in reducing the city's vulnerability to storm surge and whether some of the regional navigation improvements may increase storm surge vulnerability. these discussions raise broader policy issues related to the appropriate level of investment to protect against low probability-high consequence events; to protect against loss of life and economic disruption; and whether structural storm and flood control measures provide a false sense of security in vulnerable areas like New Orleans. The corps' cost estimates are $1.6 billion to return coastal Louisiana's federal levees and floodwalls to pre-Katrina conditions by June 2006, and an additional $3.5 billion to increase protection for New Orleans from Category 3 to Category 5. State officials have estimated the cost of Category 5 protection and wetlands restoration for all of coastal Louisiana as high as $32 billion. Most local stakeholders argue for the inclusion of coastal wetlands restoration in any plan to improve hurricane protection.

Understanding why the hurricane protection system failed in New Orleans is essential to moving beyond simply making repairs, to identifying and reducing vulnerabilities in the system, addressing coastal wetlands loss, and rebuilding the city. Nonetheless, the Corps is having to proceed with available information in order to perform repairs to the failed floodwalls and other breaches to meet the June 2006 deadline, which marks the start of the hurricane season. Consequently, congressional oversight of New Orleans' hurricane protection is likely to continue as the nation grapples with decisions on what type and level of hurricane protection to provide New Orleans and other coastal areas around the nation, and who should bear responsibility and costs for protection in coastal, floodplain, and other hazard-prone areas.

F.3.14 Congressional Research Service Report for Congress (2005). *Flood Risk Management: Federal Role in Infrastructure*, N. T. Carter, October, Washington DC.

The U.S. Army Corps of Engineers is responsible for much of the federal investment in flood control and storm protection infrastructure. Corps involvement in flood control construction is predicated on the project being in the national interest, which is determined by the likelihood of widespread and general benefits, a shortfall in the local ability to solve the water resources problem, the national savings achieved, and precedent and law.

The 100-year flood standard was established at the recommendation of a group of experts in the late 1960s. 'It was selected because it was already being used by some agencies, and it was thought that a flood of that magnitude and frequency represented a reasonable probability of occurrence and loss worth protection against and an intermediate level that would alert planners and property owners to the effects of even greater floods. The adoption of the 100-year flood standard in many respects guides perceptions of what is an acceptable level of vulnerability. The 100-year flood standard is a vulnerability standard, and not a risk standard. Thus, the question of does the 100-year flood standard combined with threat and consequence information result in an acceptable level of risk remains largely unaddressed; this question is especially relevant for low probability, high consequence events such as a Category 4 hurricane hitting a major urban center.

Attempting to provide at least 100-year flood protection largely drives local floodplain management and infrastructure investments, resulting in a measure of equity within and across communities. That equity in vulnerability, however, results in uneven levels of risk because flooding of different communities has different consequences, such as differences in the potential loss of life, social disruption, structures damaged, and economic impact because of variations in land use and development patterns.

The residual flood risk behind levees or downstream of dams remains largely unaccounted for in the National Flood Insurance Plan and often is not incorporated into individual, local, and state decision-making. Residual risk is the portion of risk that remains after flood control structures have been built. Risk remains because of the likelihood of the measures' design being surpassed by floods' intensity and of structural failure of the measures. Often when the designs of flood control structures are surpassed or when structures fail for other reasons, the resulting flood is catastrophic, as shown by the floodwall breaches in New Orleans (LA) with Hurricane Katrina. The consequences of floods increase as development occurs behind levees and below dams; ironically, this development may occur because of the flood protection provided. The nation's risk of low-probability events (e.g., 150-year flood, or Category 4 hurricane) having high-consequences in terms of lives lost, economic disruption, and property damage is increased by overconfidence in the level and reliability of structural flood protection for events that are less probability than the 100-year flood.

The risk posed by low-probability events may be underestimated by the current methods for analyzing flood control investments. The benefit-cost analyses compiled to support federal decision-making for water resources projects focus on the 'national economic development benefits' of investments; regional, social, and environmental benefits may be analyzed but often are largely excluded from the decision-making. Moreover, the Corps generally limits its benefit-cost analyses of the consequences of flooding to damages. That is, estimated benefits from flood control infrastructure investments are primarily the avoided losses to existing structures and land uses.

The Corps' benefit-cost analysis of a project may result in a recommended plan for flood control infrastructure providing for protection greater than or less than the 100-year flood. Local project sponsors can request that a 'locally preferred alternative' be built, instead of the plan identified by the benefit-cost analysis. The National Flood Insurance Plan creates incentives for communities to support flood control alternatives providing at least the 100-year level of protection, but the program provides few incentives for more protection. For some local leaders and communities, the financial capital required to cost-share a Corps flood control project may represent a barrier to pursuing greater protection.

The Corps' benefit-cost analysis does not constitute a comprehensive risk analysis, because the consequences considered are largely limited to property damage, leaving out other potential consequences, such as loss of life, public heath problems, and economic and social disruption. ..Although potential loss of life is noted in Corps feasibility reports, there are no Corps regulations or guidelines for how to incorporate loss of life into the agency's benefit-cost analyses. …Therefore, although preventing loss of life is a goal of federal flood control policy, current practice results in property damage being the primary consequence metric used for making Corps flood control investment decisions. A related benefit-cost analysis issue commonly debated is whether there is a bias toward lower levels of flood protection for low-income communities due to their lower property values. another commonly debated issue is whether there is a bias toward structural flood control measures over nonstructural options (e.g. buyouts of structures in flood-prone areas).

Because the Corps' benefit-cost analyses are focused on damages, the Corps projects funded in the Administration's FY 2006 request are those that reduce the most damages per dollar spent, which may not be the projects most efficient at reducing risk more broadly. Also, the remaining benefits to remaining costs (RB/RC) metric is used for multiple types of Corps water resources projects - navigation, flood control, and storm protection. Because the Corps benefit-cost procedures vary by project type, comparisons of the RB/RC ratio of navigation projects, flood control, and storm protection projects may be misleading, especially if significant benefits derived from projects, such as the potential benefits of lives saved, are not quantified. In other words, benefit-cost analyses as applied by the Corps are tools for informing decisions on individual projects but were not performed with the intent to determine the most cost-effective projects. Metrics that include consequences in addition to damages could be combined and weighted to produce a risk-ranking for flood control projects; however, attempts to prioritize the Corps budget across multiple types of water resources projects continues to be a challenge because of the varying and inter-related types of benefits and costs of ecosystem restoration, flood control, navigation, and multi-purpose projects.

A fundamental question being raised in the aftermath of Hurricanes Katrina and Rita is: do current federal policy, programs, practices result in an acceptable level of aggregate risk for the nation? Risk management is being increasingly viewed as a method for setting priorities for managing some hazards in the United States. Because floodplain and coastal development are largely managed by local governments, some aspects of national flood risk management likely would be unwelcome and infeasible, and could be perceived as resulting in an inequitable distribution of flood protection. For example, if floods in large urban concentrations are perceived as representing a greater risk for the nation, federal resources may be directed away from protecting smaller communities and less-populated states. Two of the concerns raised in discussions of greater emphasis on risk analysis in the development and design of specific projects are that risk analysis may result in lower levels of protection being implemented in some areas, and that information and knowledge are insufficient to perform an adequate analysis. However, an argument can be made that the federal government has an interest in reducing risks resulting in national consequences, and in prioritizing federal involvement and appropriations accordingly.

"actors complicating the determination of the nation's flood risk include changing conditions and incomplete information. For example, many flood control projects were built decades ago using the available data and scientific knowledge of the period that may have underestimated flood hazards for particular areas. Similarly, there are issues with changes in risk over time due to processes such as land loss, subsidence, sea-level rise, reduced natural buffers, urban development, and infrastructure aging. For existing dams, there is some information on consequences of failure as measured by loss of life, economic loss, environmental loss, and disruption of lifeline infrastructure (such as bridges and power grids); however, the database with this information only tracks the amount and type of losses, not the likelihood of failure.

A risk-reduction approach for organizing federal flood-related investments likely would incorporate many structural and nonstructural flood management measures already being considered and implemented, but change their priority and mix. Options considered in a risk-centered approach may include shifting federal policy toward wise use of flood-prone areas (e.g. rules or incentives to limit some types of development in floodplains), incorporating residual risk and differences in riverine and coastal flood risk into federal programs (e.g. residual risk premiums as part of the National Flood Insurance Program), creating a national inventory and inspection program for levees, promoting greater flood mitigation and damage mitigation investments, re-evaluating operations of flood control reservoirs for climate variability and uncertainty, and investing in technology and science for improved understanding of the flooding threats.

Hurricanes Katrina and Rita have focused the nation's attention once again on issues that flood experts have debated for decades. The disasters have renewed public concerns about reliability of the nation's aging flood control levees and dams. The debate over what is an acceptable level of risk - especially for low-probability, high-consequence events - and who should bear that risk is taking place not only in the states affected by the hurricanes, but nationally. The concerns being raised range widely, including interest in providing more protection for concentrated urban populations, risk to the nation's public and private economic infrastructure, support for reducing vulnerability by investing in natural buffers, and equity in protection for low-income and minority populations.

The response to Hurricanes Katrina and Rita have included discussions of expanding mitigation activities (such as floodproofing structures and buyouts of structures on the most flood-prone lands), investing in efforts to restore natural flood and storm surge attenuation, and assuring vigilant maintenance of existing flood control structures, as well as interest in new and augmented structural flood protection measures. Although major flood events, such as the Midwest Flood of 1993, generally spur these discussions, the policy changes implemented often are incremental. The 109th Congress, like previous Congresses, faces a challenge in reaching consensus on how to proceed on anything other than incremental change because of the wealth of constituencies and communities affected by federal flood policy. Another practical challenge is the division of congressional committee jurisdictions over the federal agencies and programs involved in flood mitigation, protection, and response.

For example, Senate Committees that would likely have jurisdiction over elements of any comprehensive change in federal flood policy would include Banking, Housing, and Urban Affairs; Environment and Public Works; and Homeland Security and Government Affairs.

F.3.15 Office of Management and Budget (2006). *Agency Scorecards*, Washington, DC.

Good intentions and good beginnings are not the measure of success. What matters in the end is completion: performance and results. Not just making promises, but making good promises.

The scorecard employs a simple 'traffic light' grading system common today in well-run businesses: green for success, yellow for mixed results, and red for unsatisfactory. Scores are based on five standards for success defined by the President's Management Council and discussed with experts throughout government and academe, including individual fellows from the National Academy of Public Administration.

The Corps of Engineers ratings: Human Capital - yellow, Competitive Sourcing - Red, Financial Performance - Red, Enhancing E-Government - Red, and Budget Performance and Integration - Red

Reducing the Construction Backlog. Between 2000 and 2005, funding for the Corps construction program increased by 30 percent in nominal terms. Much of this increase was for work on projects with relatively low benefits or outside of the Corps' three main mission areas: 1) facilitating commercial navigation; 2) reducing damages caused by floods and storms; and 3) restoring aquatic ecosystems. During the same period, the Corps construction workload grew at an unmanageable rate and more projects faced construction delays, as additional projects were authorized without funding for timely completion. This growth trend has resulted in a $50 billion cost to complete authorized projects, of which only $15 billion is for projects that are both within the Corps' main mission areas and meet current economic and environmental performance standards. Funding new projects further stresses the Corps' workload as these projects inevitably compete for funding with ongoing projects that offer much greater benefits, relative to their costs. As a result, some projects cost more than they need to, and most projects are completed many months - and sometimes years - later than they could.

F.3.16 Senator Susan Collins and Senator Joseph Liberman, Senate Homeland Security Committee Holds Hurricane Katrina Hearing to Examine Levees in New Orleans, Press Release, November 2, 2005.

Examining why the levees in New Orleans failed following Hurricane Katrina is a crucial part of our committee's investigation. While some of the flood walls and levees were overtopped, something much more catastrophic happened that was not anticipated. Some of the levees and flood walls failed outright, leaving gaping holes through which water rushed uncontrollably into the neighborhoods of New Orleans.

This flooding caused enormous destruction and tragic loss of life that would not have occurred if the levees had held. The people of New Orleans put their faith in the levee system and unless the cause of this failure is investigated and addressed, New Orleans will remain a city in jeopardy.

A lot of the flooding of New Orleans should not have happened, and would not have happened if not for human error and the 0possibility of malfeasance suggested by one of our witnesses in the design and construction of the city's levees.

Today's testimony about the inadequacy of the levees to protect the people of New Orleans is as disheartening, as heartbreaking, as infuriating, and ultimately as embarrassing as the scenes of degradation and despair that we saw in the immediate aftermath of Hurricane Katrina.

Both Senators expressed their concern by the fact that the levees were constructed to withstand a Category 3 hurricane. But while Katrina was only a Category 1 when it hit parts of New Orleans, the levees still failed, causing 80 percent of the city to flood, more than twice as much as would have occurred had the levees held.

F.3.17 Senator Susan Collins (2005). "Hurricane Katrina: Who's In Charge of the New Orleans Levees?" Hearing Statement Before Homeland Security and Governmental Affairs Committee, December 15, Washington, DC.

While the levees were absolutely critical to the survival of the city, our November 2nd hearing demonstrated that this last line of defense was fatally flawed in design, construction, or maintenance. The people of New Orleans and surrounding parishes depended on the levees to protect them. It now appears their faith had little foundation. Even though the hurricane caused extensive damage, it was the flooding from the levee breaches that actually destroyed the City of New Orleans.

The Army Corps of Engineers, the Orleans Levee District, and the Louisiana Department of Transportation and Development are the key players. But they each played their parts in a system fragmented by overlapping obligations and inexplicable past practices. Once the levees were constructed the Army Corps of engineers is expected to: turn over completed sections to the Orleans Levee District; perform an annual inspection with the District; and review the semi-annual reports filed by the District.

The Orleans Levee District is charged by law with: operating and maintaining the levees; conducting a quarterly inspection of the levees at least once every 90 days; and filing a semi-annual report with the Army Corps. The Louisiana Department of Transportation is obligated by state law to: approve the soundness of the engineering practice and the feasibility of the plans and specifications submitted by the Orleans Levee District; conduct training of the District's commissioners; and review the District's emergency plans.

Today we will hear about the reality, about the confusion on issues as fundamental as control, the misunderstandings, and what appear to be outright abdications of responsibility." "the uncertainty about control, combined with overlapping responsibility for emergency management, affected the repair efforts at one of the breach sites after Hurricane Katrina. In a staff interview, the Commander of the New Orleans District of the Army Corps of Engineers described the confusion: 'Who is in charge? Where's the Parish President? Where is the Mayor? And then the State?…Who is in charge?"

F.3.18 Herman Leonard and Arnold Howitt (2006). "Katrina as Prelude: Preparing for and Responding to Future Katrina-Class Disturbances in the United States," Testimony U.S. Senate Homeland Security and Governmental Affairs Committee, Washington DC, March 8.

The inescapable reality is that the United States - its governmental units and its society as a whole - is not now and never has been prepared adequately to deal with a disaster the scale of Hurricane Katrina. … but while there were individual failures involved, the story is not principally a story of individual failures - it is, instead, a story of failures of systems and of failures to construct systems in advance that would have permitted and helped to produce better performance and outcomes.

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 previous (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.

F.3.19 Congressional Research Service (2003). *Army Corps of Engineers Civil Works Program: Issues for Congress*, Issue Brief for Congress, N. Carter and P. Sheikh, Washington DC, May 21.

The Corps is a unique federal agency located in the Department of Defense with military and civilian responsibilities; it is staffed predominantly by civilians. Through its military program, the Corps provides engineering, construction, and environmental management services to the Army, Air Force, government agencies, and foreign governments. the Corps military program is currently active in restoring the capability for oil production, oil refining, and gas processing as well as other activities in Iraq.

At the direction of Congress, the Corps plans, builds, operates, and maintains a wide range of water resources facilities under its civil works program. The Corps' oldest civil responsibilities are creating navigable channels and controlling floods. during the last decade, Congress has increased Corps responsibilities in the areas of ecosystem restoration, environmental infrastructure, and other non-traditional activities such as disaster relief and remediation of formerly used nuclear sites. The economic and environmental impacts of Corps projects can be significant locally and regionally, and at times are quite controversial.

The civil works budget of the Corps consists primarily of funding for the planning, construction, and maintenance of specific projects; appropriations are made as part of the Energy and Water Development Appropriations bills. Funding for Corps civil works has often been a contentious issue between the Administration and Congress, with appropriations typically providing more funding than the Administration has requested, regardless of which political party controls the white House and Congress.

Congress typically authorizes Corps projects as part of a biennial consideration of a Water Resources Development Act (WRDA). The trend in the last decade has been to authorize projects earlier in the development and review process than in the past. Congress might authorize a project following a review by the Assistant Secretary of the Army for Civil Works and the Executive Office of the President, Office of Management and Budget (OMB) and a favorable Chief of Engineers report; on the basis of a favorable Chief's report without senior administrative review; or contingent on a favorable Chief's report being completed within a year. Most projects authorized since WRDA 1996 have not undergone senior administrative or OMB review prior to receiving congressional authorization.

Contingent authorization, authorization prior to OMB review, and another practice - authorization in appropriations bills - have been criticized by some Members of Congress and Corps critics. The critics contend that contingent authorization rushes projects through critical stages of the development process and that congressional decisions are made without basic project information. They also argue that authorizations prior to senior review by the Administration result in insufficient review from a national perspective.

There also has been criticism regarding the type of projects authorized in recent WRDAs. Local sponsors of navigation and flood control projects fear that the Corps' growing involvement in ecosystem restoration and other new responsibilities detracts from the agency's more traditional missions.

Criticism of Corps project development has been raised for decades, particularly since the growth of the environmental opposition to large water resources development projects in the 1970s. Although Congress passed greater local cost-sharing requirements in 19865, it has enacted few changes to how the Corps develops and evaluates projects.

In response to two events in 2000, support for changing how the Corps undertakes and reviews projects has gained some momentum. First, the Washington Post published a series of articles raising questions about the integrity of the Corps planning process. Second, a Corps economist when public as a whistleblower contending that Corps officials manipulated a benefit-cost analysis to support expensive lock improvements on the Upper Mississippi River-Illinois Waterway.

The Bush Administration has generally approached reform as a fiscal issue linked primarily to the agency's growing construction backlog. Over the longer term, many more projects have received authorization than appropriations, resulting in a backlog consisting of over 500 'active' authorized projects with a federal cost of approximately $44 billion. To reduce the construction backlog, the President's FY 2004 budget request focuses the agency's civil works activities on specific projects within the agency's water resources missions of navigation, flood control, and environmental restoration. during the 1990s, Congress continued biennial authorizations of navigation and flood control projects and began authorizing more environmental activities and non-traditional projects.

In contrast, legislative proposals during the 107th and 106th Congresses consisted less of fiscal reforms and more of improved project development processes and review procedures. In 2003, Corps officials testified on how the agency is 'transforming' itself in response to the criticism levied against its practices. Corps officials defended the integrity of the agency's review processes and detailed recent efforts to further strengthen it.

There are currently two initiatives to change the operation of the Corps civil works program: the government-wide President's Management Agenda and an Army initiative referred to as the Third Wave. Neither initiative specifically targets the Corps, but both encompass Corps activities. The President's Management Agenda was undertaken by the Bush Administration as part of a movement toward more entrepreneurial government; one of the five components of the President's Management Agenda is a competitive sourcing initiative. The President's Management Agenda directed executive agencies to competitively source commercial activities in order to produce quality services at a reasonable cost through efficient and effective competition between public and private sources. The administration mandated for FY 2002 and FY 2003 the competition of 5% and 10%, respectively, of the positions performing commercial activities at agencies, including the Corps.

The Army's Third Wave initiative is broader than the President's Management Agenda. The Third Wave is a search for ways to improve the Army's operations by focusing its energies on its core war-fighting competencies. This includes a review of all positions and functions (i.e., entire areas of responsibilities and missions, such as wetlands regulation) that are not part of the Army's core military competencies. Actions that can be considered under the Third Wave for non-core functions and positions include competitive sourcing, privatization, transfer of responsibilities to other agencies, and divestiture. A significant portion of the Corps workforce was included in the first phase of the third Wave because much of the water resources work performed by the Corps is not considered essential to the Army's war fighting competencies.

F.3.20 U.S. General Accounting Office (2003). Corps of Engineers Improved Analysis of Costs and Benefits Needed for Sacramento Flood Protection Project, Report to Congressional Requesters, GAO-04-30, Washington DC, October.

The Corps did not fully analyze likely cost increases for the Common Features Project or report them to Congress in a timely manner. Corps guidance generally directs the Corps to seek new spending authority from Congress if it determines, before issuing the first construction contract, that it cannot complete the project without exceeding its spending limit. A severe storm in January 1997 demonstrated vulnerabilities in the American River levees and alerted the Corps of the need to do additional work to close the gaps in the cut-off walls at bridges and other areas and extend the depth of some cut-off walls from about 20 feet to about 60 feet. Although these design changes were likely to increase project costs significantly, the Corps did not use cost risk analysis, or any other analysis, to determine the potential extent of the increases. the Corps then began constructing the redesigned American River levee improvements without communicating to Congress the project's potential exposure to substantial cost overruns. In 2002, when the Corps finally updated project costs, it had already completed or contracted at a much higher cost for most of the American River levee improvements that were authorized in 1996. Because of the reporting delay, Congress did not have the opportunity to determine whether, at these higher costs, building these levee improvements was an efficient and effective use of public funds. by 2003, the corps had committed most of the funding authorized for the entire Common Features Project to the 1996

American River work, thereby leaving the 1999 work and the Natomas Basin improvements without funding.

In response to the criticism that the Corps had failed to design the levee protection to account for seepage that caused failure of some of the levees in the 1997 flooding, the Corps replied to the GAO: "The Army stated that the levee improvements were not originally designed to withstand the destructive effect of seepage and that this design was not an error. Rather, an unknown condition (i.e., the potential for destructive seepage under the levees) resulted in design changes and increased costs.

The Corps made several mistakes in estimating the economic benefits for the American River levee improvements. First, in 1996, the Corps incorrectly calculated the economic benefits by over-counting the residential properties that the levees would protect. The actual number of protected residential properties was about 20 percent less than the number that the Corps estimated. although the Corps updated its benefit estimate in 2002, it again made mistakes in estimating benefits because it incorrectly determined that the levee improvements authorized in 1999 would protect a larger area from flooding that they will and used an inappropriate methodology to determine the amount of flood damages the levee improvements would prevent. However, it is also important to recognize that the levee improvements may reduce the loss of human lives in the event of a flood, which is a benefit that is not included in the Corps' analysis. Second, although the Corps' policy calls for reporting a range of benefits from the levee improvements and the likelihood of realizing them, in 2002 the Corps reported only a single estimate of benefits. The Corps did not provide a range of benefits to Congress because it did not use the most current version available of its computer software, which could have performed the analysis. Finally, although the Corps has a three-tiered quality control process to ensure that it prepares economic analyses accurately and appropriately, this process did not identify the mistakes we found, which raises questions about the effectiveness of the Corps quality control process.

It is important to remember that, in addition to the economic benefits from preventing property damage, levee improvements may reduce the risk of loss of human lives, which is a benefit that is not included in the Corps' calculations. According to the Corps, about 305,000 people live within the American River floodplain and the number of lives lost because of levee failure would depend on a variety of factors, such as the size of the flood, warning time, time of day, and availability of evacuation routes. Because of the many factors involved and the lack of historical data, the Corps was not able to estimate the number of lives that would be lost as a result of levee failure and flooding in the Sacramento area.

The Corps' guidance (Engineer Regulation 1105-2-100) directs the Corps to address the issue of prevention of loss of life when evaluating alternative plans - which the Corps did. However, the Corps is not required to formally estimate the number of lives saved or lost as a potential effect of a project. In situations where historical data exist, the Corps has the option to estimate the number of persons potentially affected by a project, and include this number as an additional factor for the consideration of decision makers.

It is critical that decision making and priority setting be informed by accurate information and credible analysis. Reliable information form the Corps about costs and benefits for the American River component of the Common Features Project has not been present to this point. the analysis on which Congress has relied contained significant mistakes.

and of most relevance today, the analyses for the remaining work do not provide a reliable economic basis upon which to make decisions concerning the American River levee improvements authorized in the WRDA of 1999. To provide a reliable economic basis for determining whether these improvements are a sound investment, the Corps' analysis needs to adequately account for the risk that project costs could increase substantially, correctly count and value the properties the project would protect, and include information on the range of potential project costs and benefits.

F.3.21 Heinzerling, L. and Ackerman, F. (2002). "Pricing the Priceless: Cost-Benefit Analysis of Environmental Protection," Georgetown Environmental Law and Policy Institute, Georgetown University Law Center.

Proponents of cost-benefit analysis make two basic arguments in its favor. First, use of cost-benefit analysis ostensibly leads to more efficient allocation of society's resources by better identifying which potential regulatory actions are worth undertaking and in what fashion. advocates of cost-benefit analysis also contend that this method produces more objective and more transparent government decision-making by making more explicit the assumptions and methods underlying regulatory actions.

In fact, cost-benefit analysis is incapable of delivering what it promises. First cost-benefit analysis cannot produce more efficient decisions because the process of reducing life, health, and the natural world to monetary values is inherently flawed. Efforts to value life illustrate the basic problems. Cost-benefit analysis implicitly equates the risk of death with death itself, when in fact they are quite different and should be accounted for separately in considering the benefits of regulatory actions. Cost-benefit analysis also ignores the fact that citizens are concerned about risks to their families and others as well as themselves, ignores the fact that market decisions are generally very different from political decisions, and ignores the incomparability of many different types of risks to human life. the kinds of problems which arise in attempting to define the value of human life in monetary terms also arise in evaluating the benefits of protecting human health and the environment in general.

Second, the use of discounting systematically and improperly downgrades the importance of environmental regulation. While discounting makes sense in comparing alternative financial investments, it cannot reasonably be used to make a choice between preventing non-economic harms to present generations and preventing similar harms to future generations. Nor can discounting reasonably be used to even make a choice between harms to the current generation; the choice between preventing an automobile fatality and a cancer death should not turn on prevailing rates of return on financial investments. In addition, discounting tends to trivialize long-term environmental risks, minimizing the very real threat our society faces from potential catastrophes and irreversible environmental harms, such as those posed by global warming and nuclear waste.

Third, cost-benefit analysis ignores the question of who suffers as a result of environmental problems and, therefore, threatens to reinforce existing patterns of economic and social inequality. Cost-benefit analysis treats questions about equity as, at best, side issues, contradicting the widely shared view that equity should count in public policy. Poor countries, communities, and individuals are likely to express less willingness to pay to avoid environmental harms simply because they have fewer resources. Therefore, cost-benefit analysis would justify imposing greater environmental burdens on them than on their wealthier counterparts. With this kind of analysis, the poor get poorer.

Finally, cost-benefit analysis fails to produce the greater objectivity and transparency promised by its proponents. For the reasons described above, cost-benefit analysis rests on a series of assumptions and value judgments that cannot remotely be described as objective. Moreover, the highly complex, resource-intensive, and expert-driven nature of this method makes it extremely difficult for the public to understand and participate in the process. Thus, in practice, cost-benefit analysis is anything but transparent.

F.4 References

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