

Interaction between the US Army Corps of Engineers and the Orleans Levee Board preceding the drainage canal wall failures and catastrophic flooding of New Orleans in 2005

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Abstract

The authors hope to correct any premature conclusions about the role of the pre-Katrina Orleans Levee Board (OLB) in the failure of the outfall drainage canals in New Orleans during the 2005 hurricane – conclusions that appear to have been based on inaccurate information and/or assumptions. With regard to the 17th Street and London Avenue Canals, the authors have not uncovered any information that would suggest that the OLB behaved irresponsibly in its duties. What is evident from the project record is that the Army Corps of Engineers recommended raising the canal floodwalls for the 17th Street Canal, but recommended gated structures at the mouths of the Orleans and London Avenue Canals because the latter plan was less expensive. The OLB convinced Congress to pass legislation that required the Corps to raise the floodwalls for all three canals. Furthermore, the Corps, in a separate attempt to limit project costs, initiated a sheet pile load test (E-99 Study), but misinterpreted the results and wrongly concluded that sheet piles needed to be driven to depths of only 17 feet (1 foot = 0.3048 meters) instead of between 31 and 46 feet. That decision saved approximately US\$100 million, but significantly reduced overall engineering reliability.

Keywords: Army Corps of Engineers; E-99 study; J. David Rogers; London Avenue Canal; Orleans Levee Board; Paul Kemp; Raymond Seed; 17th Street Canal

1. Introduction

On 29 August 2005, a horrified world watched an American city drown in what seemed to be a natural disaster, but is now recognized as primarily a civil engineering disaster (Christian, 2010). Levees and

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floodwalls in New Orleans had collapsed, some at water levels far below their design capacity. How could the US Army Corps of Engineers – the agency responsible for the performance of the hurricane surge protection – allow this to happen? An engaged world wanted to know, and quickly.

In this context of haste and confusion, top officials with the Corps, and others, created a template, which they relayed consistently to the media and to stakeholder groups. While these officials did concede that the Corps was ultimately responsible for the system performance, they also stated that local New Orleans officials played a contributing role in the failure of levees and floodwalls along the city's three largest drainage canals. The storyline was that the Corps had originally proposed gated structures at the mouths of the 17th Street and London Avenue Canals (and the Orleans Avenue Canal) to prevent storm surge from entering the city, but the Corps had been blocked by the Orleans Levee Board (OLB), which forced the Corps to initiate the 'next fallback plan' (Schwartz, 2006).

This presumption of wrongdoing by the OLB was repeated by high-level Corps officials for several years thereafter. For example, a major general with the Corps, speaking before an environmental coalition in December 2007, appeared to characterize the local citizenry as obstructionists to the Corps' proposed plans in the past when he stated, 'we proposed gates (for Lake Pontchartrain), and local citizens said no, fearing flooding (from) rainfall' (Grissett, 2007).

Ultimately, in this environment, an erroneous conclusion was drawn by one of the authors, namely that the Corps had been forced to build what it considered an inappropriate and inferior system of flood protection (Rogers, 2008). This conclusion was also voiced in Chapter 15 – Summary and Findings of the Independent Levee Investigation Team (ILIT) report funded by the National Science Foundation, and co-chaired by Drs Raymond Seed, Robert Bea and J. David Rogers (2006):

'... The USACE had tried for many years to obtain authorization to install floodgates at the north ends of the three drainage canals that could be closed to prevent storm surges from raising the water levels within the canals. That would have been the superior technical solution. Dysfunctional interaction between the local Levee Board (who were responsible for levees and floodwalls, etc.) and the local Water and Sewer Board (who were responsible for pumping water from the city via the drainage canals) prevented the installation of these gates, however, and as a result many miles of the sides of these canals had instead to be lined with levees and floodwalls ...'

Years later, and after many subsequent, and often better-financed, studies have been completed, it has been found that these conclusions may have been both historically and logically flawed. But, first a little background.

2. Short history of the Orleans Levee District

The pre-Katrina Orleans Levee District (OLD), governed by the OLB, owned considerable assets, mainly real estate, a peculiarity that stems from its history. In the early 20th century, the OLD reclaimed a portion of Lake Pontchartrain (a 24-mile-wide lake north of New Orleans; 1 mile = 1.60934 kilometers), developed the land, and sold it to raise money to build and improve levees. The OLD also owned a marina and a small commercial airport on a man-made peninsula created from dredged material in the early 1930s.

In the Flood Control Act of 1965 – legislation enacted in response to losses exceeding US\$1 billion¹ (including multiple levee failures) during Hurricane Betsy – Congress directed the Corps, from then forward, to be responsible for design and construction of the hurricane flood protection system enveloping New Orleans. The Corps was ordered to work in consultation with the OLD, which became the local sponsor for the ‘Lake Pontchartrain and Vicinity Hurricane Protection Project.’ When designed, the project was expected to take about 13 years to complete, but repeated reallocation and rescission proposals to shave the federal budget by the federal government in the previous two decades resulted in delaying the estimated date of project completion until 2015. However, the floodwalls along the three outfall drainage canals, the subject of this paper, were essentially complete by 2005.

Owing to the 1965 legislation, the OLD’s duties regarding hurricane surge protection were now limited to collecting the 30% cost share for project design and construction, and to maintaining and operating completed flood protection structures (Mittal, 2005). However, the OLD still retained extensive assets, which by state law needed to be managed. By the early 1990s, the OLB was composed of eight paid commissioners appointed by the Governor. Four of the board members served on the Engineering Committee, which operated with advice from the Chief Staff Engineer, the Assistant Chief Staff Engineer and two staffers who were civil engineers or had engineering experience. In addition, as many as 30 civil engineering experts and consultants offered their advice to the Committee. Some of these advisors were employed by the Corps.

The New Orleans District is the largest District of the Corps of Engineers in the nation; commensurate with the number of projects, level of funding and national interest in maintaining the Mississippi floodway for commercial navigation as well as flood control (the Mississippi River drains 41% of the lower 48 states). The district employs about four times the number of personnel as compared to other regional districts.

Similarly, the local levee district was also one of the largest in the nation in terms of assets and number of personnel. Owing to its extensive land holdings, members of the OLB served on committees to oversee the airport, the marina and other real estate. Committee meetings were held monthly – generally, two weeks before each board meeting.

A post-Katrina news article observed that the OLB enjoyed ‘relatively cushy finances, pumped millions into road projects, bridges, a marina and ill-fated studies of everything from a movie studio to a fiber-optic network to a man-made island near Lake Pontchartrain’s south shore’ (Donze, 2006). This would seem to describe how far-reaching the OLB was in its commercial interests, and it is clear that members of the OLB attended meetings to discuss issues not specifically related to engineering and flood protection. The airport and disputed land claims over oil producing properties consumed much of the OLB’s focus in working with the state legislature, as well as litigation.

Congress’s decision in 1965 to place responsibility for flood protection design and construction with the Corps affected the role of the OLB and, gradually, it became apparent that perhaps a different form of levee board governance might be more appropriate for a major marine terminal like New Orleans. Nevertheless, the issue of whether the members of the OLB Engineering Committee acted incompetently or negligently in its decisions specifically regarding the 17th Street, Orleans and London Avenue Canals deserves examination in the light of subsequently emerging data.

¹ Throughout the paper, the term ‘billion’ represents 10⁹.

3. Frontage versus parallel protection

In 1965, Hurricane Betsy struck Louisiana and triggered levee breaches, which flooded parts of the Lower Ninth Ward neighborhood of New Orleans. The hurricane's storm surge along the south-westerly shores of Lake Pontchartrain also overtopped the earthen levees of all three outfall drainage canals, flooding adjacent neighborhoods and causing substantial property damage amounting to US\$1.42 billion. In response, the Corps re-evaluated their design assumptions for a Category 3 storm surge along the Gulf Coast, Lake Borgne and Lake Pontchartrain, adopted in October 1967.

Between 1970 and 1975, the Corps developed a plan for massive sea gates for the region east of New Orleans that would prevent storm surge from flowing through Lake Borgne and into Lake Pontchartrain through two narrow channels at the Rigolets and Chef Menteur passes. The proposed gates had embankment footprints up to 2,000-foot wide (1 foot = 0.3048 meters). Referred to as the Barrier Plan, it included a series of levees along Lake Pontchartrain and the Gulf Intracoastal Waterway (GIWW), a navigable inland waterway. The gates would have allowed water to flow back and forth between the lakes, but would have been closed in advance of a hurricane (Kysar & McGarity, 2006).

A small group, led by Luke Fontana, filed a lawsuit against the Barrier Plan in 1976 over the Corps' Environmental Impact Study (EIS). In *Save our Wetlands v Rush*, the plaintiffs claimed that the Corps' EIS did not meet the requirements of Section 102 of the National Environmental Policy Act (NEPA), a federal law enacted in 1969 (Kysar & McGarity, 2006).

The court agreed with Fontana noting, among other things, that the EIS was based on obsolete data and that the Corps' biological analysis 'relied entirely on a single telephone conversation with a marine biologist' (Verchick, 2010). To put this in perspective, the Corps' final EIS, representing the entire review of a multi-year, multimillion-dollar project, consisted of only four typewritten pages. As noted by Robert Verchick, author of *Facing Catastrophe* (2010):

'An EIS is a comprehensive document. Today, EISs are hundreds even thousands of pages long, but even in the 1970s, when NEPA was still being defined by the courts, federal agencies knew that courts wanted a serious effort.'

Judge Charles Schwartz issued an injunction preventing further progress on the barrier option until the Corps revised its EIS. He also wrote, however, that upon proper compliance with NEPA, 'the injunction shall be dissolved and any hurricane plan thus properly presented will be allowed to proceed' (Kysar & McGarity, 2006). In other words, the Judge invited the Corps to return with a more comprehensive EIS.

Ultimately, however, the Corps did not return and, in 1980, concluded that an alternative option of higher levees providing hurricane protection was less costly, less damaging to the environment and more acceptable to local interests (Woolley & Shabman, 2008).

Immediately after Katrina, the Corps' abandonment of the Barrier Plan became the subject of journalists who alleged that environmentalists had blocked the Corps' original plans for barrier structures and forced the agency to choose an alternate, and inferior, design that could not protect the city. The Barrier Plan was 'stopped in its tracks,' claimed a Los Angeles Times front-page news story (Vartabedian, 2005).

Two law professors, Thomas McGarity and Douglas Kysar, in their article that highlighted the 'hazards of hindsight analysis,' put the process under the microscope. They found that subsequent to Judge Schwartz's injunction, intense public opposition arose based on concerns for the environment

and fears of increased flooding for people and property outside the barrier walls. Simultaneously, costs were ballooning due to new design requirements and general delay. As observed by Verchick (2010):

‘One can say that environmental concerns contributed to the political opposition and the litigation provided the information and the time for activists to organize. But at the same time, one must acknowledge that nothing prevented the Corps from acting more quickly to perform a sufficient environmental review and get the project approved. Had it believed that superior benefits of the option justified increased costs, it could surely have moved forward.’

We have not found any documented evidence in the project record or any other indication that reveals that the Corps believed its switch from the Barrier Plan to the High Level Plan would increase the risk of flooding to New Orleans. With regard to concerns of increased risk, the authors of the *Decision-Making Chronology* note that the project record ‘shows that the switch to the High Level Plan involved those limited project changes that were necessary to move the project forward’ (Woolley & Shabman, 2008).

By 1981, the Corps had begun working out the engineering details for implementing the High Level Plan to protect the city from storm surges that could enter the outfall drainage canals. This was necessary, because the new post-Hurricane Betsy design water levels exceeded the crest heights of most of the existing earthen levees along the outfall drainage canals and also along the Inner Harbor Navigation Canal (IHNC).

The Corps initially considered five alternatives to address this threat, but eventually narrowed their alternatives to the two most cost-effective alternatives, which were (1) raising the height of the canal temporary floodwalls (‘parallel’ protection) or (2) installing gates at the canal mouths (‘frontage’ protection).

The Corps presented both the Parallel and Frontage Protection plans – plans that it apparently considered equally effective – to the local sponsor before making its final recommendations. Meeting minutes from January 1988 to December 1991, critical years in the decision-making process, reveal that there were many additional meetings, entitled ‘Special Meetings,’ devoted solely to discussions of flood protection. In these meetings, the Engineering Committee asked the Corps many detailed questions about ‘storm proofing’ the outfall drainage canals.

The minutes also reveal that the OLB and the Sewerage and Water Board of New Orleans (S&WB) shared concerns over the Corps’ consideration of a prototype gate plan employing self-actuating butterfly check valves, a plan that included no auxiliary pump stations like those constructed after Katrina. Both agencies viewed the gates-only plan as being incompatible with their interior drainage responsibilities and were concerned that when the gates were shut during a hurricane, the pumping stations would not be able to pump rainwater out of the city (Woolley & Shabman, 2008).

The OLB and the S&WB also questioned whether the untested prototype gates would work properly during storm events. The complex gate system would require interior drainage pumping to cease at times when the city was likely to be experiencing heavy rainfall. The OLB and the S&WB also shared concerns that the butterfly gates might limit their ability to increase drainage discharge capacity in the future. Furthermore, the gates had already failed in a much publicized model test attended by OLB members at the Corps’ Waterways Experiment Station (WES) in Vicksburg (Van Heerden et al., 2006).

Post-Katrina investigations correctly observed that the adoption of parallel protection for the outfall canals would significantly increase the number of miles of floodwalls and other structures exposed to

storm surges, and would increase the probability that a storm surge could find a weak spot in the project perimeter. However, in the 1990s, this risk did not appear to have been recognized and/or communicated.

On this issue, the Interagency Performance Evaluation Task Force (IPET), which was convened and managed by the Army Corps of Engineers after Katrina, observed:

‘... A series of incremental decisions extending from the original ‘barrier’ plan to the ‘parallel protection’ structures ultimately constructed, systematically increased the inherent risk in the system without recognition or acknowledgment ...’

This observation is corroborated by federally appointed water experts [Woolley & Shabman \(2008\)](#), authors of the *Decision-Making Chronology for the Lake Pontchartrain & Vicinity Hurricane Protection Project*. Regarding the recommendation of the parallel plan, they wrote ([Woolley & Shabman, 2008](#)):

‘There is no evidence in the project record indicating that project engineers believed that the decisions made would threaten engineering reliability.’

From today’s vantage point, it appears that the local sponsors were led to believe that the ‘higher walls’ plan was technically equivalent to the ‘gates-no-pumps’ plan, but was just more expensive. As observed by the authors of Louisiana Department of Transportation and Development (DOTD) sponsored report *Team Louisiana*, led by coastal researcher [Van Heerden et al. \(2006\)](#):

‘They believed they had a right to pursue a more costly alternative if it would accomplish other purposes in addition to the hurricane protection objective. They believed the USACE, in recommending the less costly fronting protection plan, was simply establishing a limit to the portion that the federal government would be willing to pay.’

Apparently in the belief that both plans were equally effective, cost became the pre-eminent factor in the Corps’ consideration of frontage versus parallel protection. The Corps considered it a congressional mandate (and their standard of practice) to implement the least expensive alternative, assuming all of the choices to be adequately engineered.

Eventually, the Corps did recommend parallel protection for the 17th Street Canal. For reasons unique to this canal, there was no significant stated difference in the cost between the two approaches due to newly authorized sheet pile construction guidelines (to be discussed later) and other factors ([Lansden, 1990](#)). Another reason noted in the project record was that the OLB and the S&WB preferred it.

It is interesting to note that the 17th Street Canal was the largest and most important drainage canal in the city of New Orleans. Operating with Pumping Station No. 6 – which at that time was the most powerful pumping station in the world – the 17th Street Canal was capable of conveying 9,200 cubic feet per second (cfs) of water, more than the Orleans Avenue and London Avenue Canals combined. (The Orleans Avenue Canal, at maximum capacity, could pump 2,200 cfs and the London Avenue Canal, at maximum capacity, could pump 5,200 cfs.)

However, for the much smaller capacity London and Orleans Avenue Canals, the Corps stood by its recommendation for the gates-no-pumps plan because it was significantly less expensive. The parallel protection plan was estimated in the 1980s to cost three times more than the gates plan for the London

Avenue Canal (Lansden, 1990) and to cost five times more than the gates plan for the Orleans Avenue Canal (Carter, 2005).

The information gleaned from the minutes of the Engineering Committee meetings – which had previously been unavailable to the authors of the ILIT report – shed considerable light on the decision-making processes that led to the adoption of the parallel plan for the 17th Street Canal.

4. The OLB goes to Washington

In 1988, the OLB began an aggressive push to convince the Corps to recommend parallel plans (flood walls) for all three canals. Then-OLB President, Steven Medo, hired lobbyist Bruce Feingerts to lead a legislative effort to secure the most federal aid participation possible to fund the parallel plan².

Regarding this effort, the authors of the *Decision-Making Chronology*, Woolley & Shabman (2008), would observe exactly 20 years later:

‘... from the local perspective, the parallel protection plan was the best way to address both hurricane protection and interior drainage objectives and secure 70% federal funding toward those ends ...’

Working with the support of the S&WB and neighborhood groups, Feingerts lobbied the Louisiana Congressional Delegation for the parallel plan for the Orleans and London Avenue Canals.

The OLB made no secret of its preference for the parallel plan for all three outfall canals, and discussed the issue frequently in the various meetings convened between 1988 and 1991. Members of the Corps were nearly always present at these meetings. Thus, the Corps was aware that the OLB preferred the parallel plan for all three canals, and that the OLB was compensating Feingerts to lobby for congressional support of such a scheme in Washington DC.

Feingerts detailed the local sponsor’s concerns in a Briefing Paper in September of 1990. The paper addressed the OLB’s concerns that ‘in the event of overtopping of the levees of these canals, many businesses and an estimated 56,000 residents of Orleans Parish would be flooded’ (Board of Commissioners of the Orleans Levee District, 1990). The OLB wanted the more expensive ‘high level plan’ over the less expensive ‘gates plan,’ because they believed it was the superior plan.

Significant progress was made when Feingerts suggested to members of the Louisiana Delegation that, in conferencing, they insert a ruling or ‘language’ into an engrossed amendment of the approved version of the 1990 Water Resources Development Act (WRDA). The language redefined the Orleans and London Avenue Canals as part of the Hurricane Protection Project, which were, therefore, now a federal responsibility. The 1990 WRDA was signed by President George Bush and passed into law. The OLB had succeeded in getting the authorization for a project that they believed would keep people safe, but which would also reduce how much those same people had to contribute to the cost. Authorization for the funding and cost share soon followed.

On 30 May 1991, a local affiliate of NBC TV televised a news story with anchorwoman Leslie Hill of WDSU featuring triumphant OLB members and proud legislators.

² The roll of the OLB meeting minutes of 20 April 1988, page 1, shows that Feingerts was present.

5. A red herring

Fifteen years later, a Los Angeles Times article would lay blame for the outfall canal floodwall failures heavily on the OLB in light of the 1990 WRDA (Braun & Vartabedian, 2005). The reporters for the Christmas Day 2005 story described ‘a deft behind-the-scenes maneuver’ by the OLB that forced the Corps to accept the higher floodwalls. The article stated that ‘Corps engineers were openly peeved in 1990 when they learned about the Orleans board’s decision.’

Nonetheless, the Corps had not been caught by surprise. As previously established in this paper, the Corps had (1) already recommended the parallel plan for the 17th Street Canal, (2) was aware that the OLB preferred the same approach for the other two drainage canals, and (3) was aware that the OLB was compensating a lawyer to go to Washington DC to lobby for the parallel plan alternative.

It is clear that there was some eleventh-hour maneuvering, however, this is pretty typical of how laws are passed in Washington DC. US Senator Bennett Johnston addressed this particular bit of ‘midnight magic’ in the OLB meeting minutes on 30 May 1991 (Lansden, 1991):

‘The more important things that are done, the things that touch people’s lives and pocketbooks, and the things that really measure the effectiveness of what Congress does as far as people in the State of Louisiana, are done quietly, and are done by virtue of knowing what you are doing or the position of power that you are in.’

As previously noted, in their statements to the media following Katrina, Corps spokespersons, in the context of haste and confusion, laid partial responsibility for the collapse of the outfall canal floodwalls upon the OLB. However, the authors of the IPET report gave only cursory discussion to the years-long decision-making process that eventually settled upon the parallel protection plan. Its mandate was focused primarily on unraveling physical failure mechanisms rather than on the history of the decision-making processes responsible for selecting various systems of flood protection. This is what the IPET report stated regarding the decision-making process for flood protection improvements for the three outfall canals in its 7,000-page report (IPET, 2006):

‘The New Orleans District commenced examining two alternative plans for providing ‘high level’ SPH [surge protection height] protection for the outfall canals – frontage protection in the form of gated structures at the canal entrances from the lake, and parallel protection in the form of floodwalls and flood proofing of bridges. The plans and designs for the outfall canals called for gated control structures at or near the canal entrances to the lake, but the local sponsor, the OLB, indicated its preference for parallel protection. Congress settled the dispute through the 1992 Energy and Water Development Appropriations Act, which mandated construction of the parallel protection plan.’

6. Time to get to work

Indeed, on page 4 of the 1992 WRDA, Congress defined the cost for the two outfall canals to be shared, namely, that the federal cost participation shall be 70% and the local cost participation 30%. The Corps now had a direct order from Congress to raise the heights of the London and Orleans Avenue Canals, the same plan that was already well on its way to being implemented along the 17th

Street Canal. There were several options available to the Corps to accomplish that: taller earthen levees, T-walls, and I-walls.

Earthen levees require a wide base, generally six times the height of the embankment. This alternative would not fit the existing rights of way along the edges of the outfall drainage canals, except near their mouths. Inverted T-walls are conventional reinforced concrete retaining walls, which are supported on piles driven into the crown of the levee. I-walls are simple cantilever walls constructed of steel sheet piles driven into the crown. I-walls cost about one-third as much as the pile-supported T-walls.

The records show that T-walls were built into selected sections in short portions (e.g. next to bridges and gates) along the canals, but I-walls were used extensively everywhere else to reduce costs (Van Heerden *et al.*, 2006).

Faced with ever-increasing costs, the Corps of Engineers Mississippi Valley Division headquarters in Vicksburg initiated a large-scale Sheet Pile Test (the E-99 Study) in the Atchafalaya Basin, a region with soft clayey and organic soils, similar to those in New Orleans. In 1985, the Corps misinterpreted the results of the E-99 Study and concluded that (Woolley & Shabman, 2008):

‘... when foundation soils were poor, sheet pile penetration depth beyond a certain point would not significantly increase I-wall stability under the type of short-term loading conditions believed to characterize hurricane events ...’

In other words, the Corps determined that it needed to drive sheet piles down to depths of only 17 feet instead of between 31 and 46 feet, introducing a shortcoming revealed during Hurricane Katrina. At that time, the Corps believed that ‘sheet pile penetration beyond a certain depth would not improve wall stability and therefore was a wasteful expenditure.’

The misinterpretation occurred apparently because the Corps had draped a tarpaulin over the gap that formed between the bases of the deflecting sheet piles and the soil in which they were embedded, so they did not see the gap. The tarpaulin was there for safety and to stop water that would seep through the interlocks (Bea, 2008). Failure to include the gap in interpretation of the test results introduced unconservatism in the final designs based on these tests. It allowed the use of shorter sheet piles, and reduced overall flood protection reliability.

Ultimately, on 23 December 1987, the Division Headquarters issued new criteria guidance to the New Orleans District on sheet-piling design based on the E-99 tests (IPET, 2006). This switch by the Corps to significantly shorter sheet piles saved approximately US\$100,000,000. However, these cost savings would come at the expense of engineering reliability as the floodwalls were eventually constructed between 1993 and 1999 (IPET, 2006).

The authors of the *Decision-Making Chronology* state repeatedly that there is nothing in the available project records to suggest that the Corps was aware that its decision would jeopardize the integrity of the flood protection structures (Woolley & Shabman, 2008).

7. Hurricane Katrina

On 29 August 2005, the wind and storm surge associated with Hurricane Katrina arrived. At least 50 breaches occurred in the Lake Pontchartrain and Vicinity Protection Project within a few hours. The authors of the IPET (2006) observed:

‘At the 17th Street Canal, failure began with apparent displacement of a wall panel at about 0630 hr and ended with a full breach by 0900 hr. At about 0630 hr, the water level was estimated to have been 7 to 8 feet, and possibly 1 to 2 feet higher at the time of the catastrophic breach created by displacement of a levee section. No overtopping had occurred and the design water elevations had not been reached at the time of levee displacement.’

The water level at the time of failure was about five feet lower than the top of the I-wall. As the storm surge water poured through this initial breach, carrying with it sections of the concrete floodwall and earthen levee, it weakened adjacent concrete floodwall sections and the breach quickly expanded into a 450-foot wide gap. The flooding directly and indirectly killed hundreds in the adjacent neighborhood of Lakeview and caused multiple billions of dollars in property damage.

Meanwhile, the similarly catastrophic east failures and breaches on the London Avenue Canal were also initiating. As with the 17th Street Canal, water elevations several feet below the design levels caused a crack to form between the sheet piles and the foundation soils in which they were embedded on the waterside of the floodwall, and this crack or ‘gap’ allowed high pressures to be introduced directly into the foundation materials of the levee.

The London Avenue Canal was breached in two locations on either side, and both failures occurred at surge levels more than four feet below design specifications. The east breach occurred around 6 to 7 a. m. and sent tons of sand and water into the neighborhood of Mirabeau. The west breach occurred around 7 or 8 a.m. and flooded the adjacent neighborhood of Lake Vista (Anderson et al., 2007).

For the 17th Street and London Avenue Canals, the new I-walls embedded in the levees deflected when water pressure was placed against them, creating open gaps behind the sheet piles, which allowed infilling water to exert hydrostatic pressures against the full embedded length of the sheet piles within minutes of their being loaded (Anderson et al., 2007).

The Orleans Avenue Canal had similar I-walls, but these did not breach due, in part, to the presence of an unintended 100-foot-long ‘spillway,’ a section of legacy wall that was significantly lower than the adjacent newer floodwalls adjacent to Pump Station No. 7 at the south end of this canal (IPET, 2006). The unintended ‘spillway’ was located in an area where eventual floodwall (I-wall) construction would require coordinated efforts between the OLB, the S&WB, the DOTD and, possibly, the Federal Highway Administration. This had not been resolved at the time of Hurricane Katrina’s arrival, so floodwaters simply poured through the open gap, which served to partially relieve water levels within the canal.

This inadvertent ‘spillway’ (gap in the I-wall) was located under a viaduct carrying Interstate-610 where the top of the existing earthen levee crest lay approximately 5–6 feet below the tops of the adjacent concrete floodwalls. Completion of the floodwall would have likely caused the brick walls of the old pump station to fail unless they had been significantly reinforced.

The presence of this spillway (gap) was a sore spot on the record of the OLB and the S&WB. Had the canal walls of the 17th Street Canal and the London Avenue Canal not been breached, this spillway could have allowed overtopping for several hours resulting in significant flooding, although not catastrophic flooding. In the end, of course, the failures of the 17th Street and London Avenue Canals made this issue moot.

With regard to the severity of Katrina’s storm surge in Lake Pontchartrain, wave heights were typically similar to those assumed for the design of the structures (IPET, 2006). The Corps had designed for surge heights of about 12 feet, and the estimate of Katrina’s storm surge along the drainage canal frontage was about 11 feet. Therefore, the three catastrophic breaches that occurred within the 17th Street

and London Avenue drainage outfall canals represented failures of the system to meet design objectives (IPET, 2006).

The breach of the 17th Street Canal and the two breaches of the London Avenue Canal caused at least US\$27 billion combined in direct residential, commercial, and public property damage in the city's main basin (Anderson et al., 2007).

8. Monday morning quarterbacking

After the 2005 hurricane, critics of the pre-Katrina OLB contend that the agency should have questioned the ability of the Corps to competently construct the parallel plan for the three outfall canals. However, one must keep in mind that the Corps was the federal agency that had previously built thousands of miles of levees along the Ohio, Missouri and Mississippi Rivers capable of withstanding surge heights of up to 20 feet for 30 days or more. Why would the OLB believe the Corps could not build levees along a few miles of drainage canals capable of withstanding surge heights of about nine feet for a period of a few hours? As observed by Van Heerden et al. (2006):

'... These were modern structures designed to protect a high-value, heavily populated urban area by what was thought to be the world's premier civil engineering organization ...'

According to the authors of the Team Louisiana report, some Corps spokespersons appear to have used an 'I told you so' logic to defend the federal agency for the catastrophic failure of the outfall drainage canals (Van Heerden et al., 2006). Nonetheless, at the heart of the argument of why the local agencies should share in the blame was the assumption that the gates-no-pumps plan would have kept the city safe and dry.

There were 50 breaches in the flood protection project on 29 August 2005 (US Army Corps of Engineers, 2012). Any attempt to pass the buck to the OLB regarding the failed outfall drainage canal walls is founded in an unexamined presupposition that the Corps' preferred gates-no-pumps plan would have protected the city from flooding. It is instructive to note that after Katrina, the Corps installed floodgates with enormous auxiliary pump stations (Eisler, 2009) funded as an emergency measure of Congress at a cost to the American taxpayers of hundreds of millions of dollars (Garzino, 2009). Furthermore, all repairs of breached I-walls were repaired with the more conservative T-walls.

But no matter what plan was selected in the early 1990s, as professional engineers, the Corps had a duty to design and construct its Congressionally-mandated flood protection in a professional and competent manner. As noted by Van Heerden et al. (2006):

'... the principles of foundation design, which rests primarily on the interpretation of subsurface information derived from suitably detailed boring programs, and from long experience with the response of soils and structures to the forces developed under critical conditions were well understood by practicing civil engineers of the late 1980s and early 1990s ...'

The authors of the Team Louisiana report also suggest that perhaps the Corps may have felt absolved, to some degree, from some responsibility to assure the effectiveness of the hurricane protection for the three drainage canals when the local sponsors so vigorously pursued their parallel protection plan (Van

Heerden *et al.*, 2006). As was the Corps' congressional mandate, it would appear that the Corps was vigorously searching for ways to reduce costs for the more expensive parallel plans.

The authors of this paper find it particularly ironic that the Corps initiated a series of sheet pile wall load tests, but misinterpreted the results, drawing conclusions that severely limited the ability of the 17th Street and London Avenue drainage canal walls to perform as assumed. The field tests were precisely what was needed to validate the design assumptions, but these were not subjected to peer review by anyone outside of the Corps because the services of WES's permanent geotechnical consulting board had been terminated in 1978 as another federal cost-saving measure (Fatherree, 2006).

The authors of the IPET report observed that the E-99 Study in 1985 – and the subsequent failure of the outfall canals in 2005 – points out a dilemma. They wrote:

'While new pieces of knowledge were available over time that were relevant to the ultimate performance of the I-walls on the outfall canals, the pieces were not put together to solve the puzzle of the failure mechanism that occurred. The Corps' own testing of sheet-pile stability (E-99) in the mid-1980s was not directed at the behavior of I-walls, but with hindsight, some of the behavior observed was indicative of the deflection of a structure that designers essentially assume to be rigid' (IPET, 2006).

These same authors also wrote about a distinct loss in energy and resources expended in the search for new knowledge in design criteria, particularly in the domain of hurricane and flood protection, specifically in the geotechnical fields that are at the heart of the levee and floodwall performance issues in Katrina. For a solution, they suggest a 'push' and a 'pull' (IPET, 2006).

'Awareness and capability are gained best when there is both technology push (research creating new knowledge and capabilities) and requirements pull (designers/constructors seeking and pulling information from the research and professional communities). The solution is not more research or more outreach alone, it is the ability of the design/construction and research communities to work together in an environment enabling collaboration and experimentation with new knowledge and approaches to old and new problems.'

After the city of New Orleans was dewatered and its residents began their journey toward rebuilding, there were two takeaways firmly cemented into the minds of Americans, pinning blame on local residents for their misfortune. The most misleading 'accepted truth,' which has been discussed here in depth, was that the Corps had been thwarted by a politically connected local levee board.

There was also a second takeaway sound bite firmly planted in the minds of many Americans. After Katrina, news stories reported that 'annual levee inspections in Orleans Parish tended to be quick drive-by affairs ending with lunch for 40–60 people costing the state as much as \$900' (Marshall, 2005). This is true, but the reports went on to suggest that the inspections might have contributed to the catastrophic flooding and that the OLD might be partly responsible (Russell, 2005). Neither suggestion was ultimately borne out by the facts.

The authors suggest that there may be confusion relating to the word 'inspection.' Pre-Katrina, the Corps was required to administer annual levee inspections of maintenance of federally built flood protection in Orleans Parish. Termed 'Inspections of Completed Works,' these were designed to ensure that the OLD was complying with its federally mandated levee maintenance (Engineer Regulations, 1996). The responsibility of the OLD was mainly cutting the grass on levee embankments, removing unwanted

vegetation and debris, and visually judging the surface manifestations of under seepage. The OLD also performed informal year-round ‘inspections’ including, but not limited to, inspecting for ruts, depressions, and erosion of their earthen levees.

Legal responsibility for the annual Inspection of Completed Works belongs to the Corps. For clarity, the Corps’ inspections should be thought of as independent, once-per-year ‘quality audits’ of the OLD’s year-round maintenance activities. Furthermore, as observed in the *Decision-Making Chronology* (Woolley & Shabman, 2008):

‘... The annual inspections of levees and floodwalls involve visual verifications of local sponsors’ compliance with required maintenance; they do not, however, include the types of engineering assessments that would be needed to verify structure stability and performance ...’

We have found no documented evidence that improper maintenance on the part of the OLD played a role in the failure of the 17th Street and London Avenue Canals. The authors of the *Decision-Making Chronology* did not include any detailed discussion of the inspections in the body of their paper. Instead, they were relegated to, and placed into, text boxes, indicating their minimal significance.

9. Post-Katrina legislation

Before Katrina, five different levee districts operated as separate local sponsors for the federally built flood protection in the Greater New Orleans area. Soon after the levees broke in 2005, the presumption – made in haste in a complex environment – was that the commissioners of the OLB were not paying enough attention to flood protection and were therefore partly responsible for the flood disaster. So Congress, with relative speed, ordered the creation of a single state agency to be the local sponsor and, in response, the State of Louisiana created the Coastal Protection and Restoration Authority, in 2006.

Concurrently, there was a separate local effort to pass legislation to create a new board that would replace the five separate levee boards. The legislation was intended to (1) remove distractions, (2) replace parochial flood control with regional flood control, and (3) require commissioners to have professional expertise including hydrology, construction engineering and civil engineering (Donze, 2006).

While a direct causal link between the actions of the pre-Katrina OLB and the breaching of the outfall drainage canals has not been established, few would disagree that a new form of levee board governance might be necessary and beneficial for a major marine terminal like Greater New Orleans. Ultimately, two levee board ‘authorities’ were created, each of which had jurisdiction on opposite sides of the Mississippi River.

The historic levee board legislation put Louisiana on the frontier of good governance, as it was the first state in the nation to legislate such requirements. Soon after, California followed suit and voted for a package of flood bills that required professional backgrounds of its flood protection board members similar to Louisiana (Russo, 2007).

10. Post-Katrina litigation

Numerous class-action lawsuits were filed against the Corps after Katrina, and these were consolidated by US District Court Judge Stanwood R. Duval, Jr. into two separate cases. The Mississippi

River Gulf Outlet (MR-GO) case alleged that the Corps was negligent in its maintenance of a 76-mile shipping channel constructed by the agency in the mid-20th century. The suit alleged that its design allowed salt-water intrusion that damaged buffering cypress forests and wetlands, which historically had protected the New Orleans region from storm surge (Freudenburg et al., 2009).

In September 2009, federal District Judge Stanwood Duval approved a US\$5 million settlement of a federal class-action lawsuit against the OLD. It is instructive to note, however, that in a case such as this where the settlement money comes from insurance resulting from policies the OLD held on the levees, a settlement should not be considered evidence of wrongdoing. Insurance companies have a risk of being found in bad faith for refusing a bona fide settlement offer within or at policy limits (Rawls & Hudson, 2006). Explained more simply, if an insurer refuses to pay a proposed settlement, they could potentially become liable for the full amount of any future settlement or a judgment even if it exceeds their policy limits. The total damages claimed by the plaintiffs for the levee and floodwall failures were many billions of dollars. In this case, the insurer had the choice to pay US\$5 million or possibly become bankrupt. The settlement reflects a legal strategy on the part of both defendants and plaintiffs.

In November 2009, Judge Duval ruled that the Corps' mismanagement of maintenance at the MR-GO was directly responsible for flood damage in St. Bernard Parish and the Lower 9th Ward neighborhood after Katrina (Schleifstein, 2009). The US 5th Circuit Court of Appeals ruled in March 2012 that Judge Duval was correct in his groundbreaking decision; however, the panel reversed its own decision six months later (Schleifstein, 2012). The Corps was immune from damages because of a provision governing suits against the federal government that protects an agency when it makes a discretionary decision.

The second case, commonly called the LEVEE case, included areas that flooded due to the outfall canal floodwall failures and also the IHNC failures. In January 2008, Judge Duval placed responsibility for the floodwall collapses of the 17th Street and London Avenue Canals on the Corps (Nossiter, 2008). However, the Corps could not be found financially liable due to sovereign immunity established by the Flood Control Act of 1928. Judge Duval wrote (Katrina Canal Breaches Consolidated Litigation, 2008):

'The cruel irony here is that the Corps cast a blind eye, either as a result of executive directives or bureaucratic parsimony, to flooding caused by drainage needs and until otherwise directed by Congress, solely focused on flooding caused by storm surge. Nonetheless, damage caused by either type of flooding is ultimately borne by the same public fisc. Such egregious myopia is a caricature of bureaucratic inefficiency.'

Judge Duval dismissed the case, which has not been appealed.

11. Conclusions

Any investigative study ought to be considered preliminary until better researched and documented data are introduced. Clarification of vetted facts is important because previous conclusions regarding the local New Orleans officials' roles in the flooding disaster of 2005, made in the context of haste, have been oft-repeated in books and articles, and may even have been injurious to the flood survivors.

There can be no doubt that individuals on the pre-Katrina OLB spent time and locally generated funds on ancillary issues that were not directly related to flood safety. Owing to its history of land acquisition to finance levee building, the OLB had extensive assets, which under state law needed to be managed,

and by 2005, the need for a different form of levee board governance was emerging. Also, as demonstrated by the unintended spillway at the transition between the Orleans Avenue Canal and Pump Station No. 7, there were periods of less- than- functional interaction between the OLB, the S&WB and other state agencies in the years immediately preceding Hurricane Katrina.

Nonetheless, with regard to the 17th Street and the London Avenue Canals, we have not uncovered any information that would suggest that the members of the OLB who served on the Engineering Committee or the OLD staff engineers behaved irresponsibly or in a manner that did not place the interests of the city residents at the forefront. Neither have we have found any data with regard to the 17th Street and the London Avenue Canals suggesting that the OLD failed to perform its congressionally mandated duties, which were to collect the 30% cost share for project design and construction, and to maintain and operate completed structures.

What is evident from the project record is that the Corps recommended parallel protection for the 17th Street Canal, but recommended frontage protection for the Orleans and London Avenue Canals because the plan for the latter two canals was less expensive, in keeping with its congressional mandate to employ measures with the most favorable cost–benefit ratios. The OLB lobbied its congressional delegation, which succeeded in convincing Congress to pass legislation that required the Corps to provide parallel protection for all three canals, not just the 17th Street Canal.

What is also evident is that the Corps, in a separate attempt to limit project costs, initiated a sheet pile load test (E-99 Study) in the Atchafalaya Basin of Louisiana, but misinterpreted the results and concluded that sheet piles needed to be driven to depths of only 17 feet instead of between 31 and 46 feet. That decision saved approximately US\$100 million, but significantly reduced the reliability of the floodwalls during Hurricane Katrina.

With regard to both the Corps' recommendation to build the parallel plan for the 17th Street Canal, and to reduce the depths of the sheet piling in the I-walls, there is no evidence that either the Corps or the OLB believed that risk would be significantly increased.

And so here, we hope to correct any premature conclusions that appear to have been based on inaccurate information and/or assumptions about the role of the pre-Katrina OLB in the failure of the outfall drainage canals in New Orleans. The conclusions presented here are based upon a subsequently emerging volume of consistent, comprehensive and compelling data gleaned from interviews with the actual participants and from the transcripts of public meetings that were previously unavailable.

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