CHAPTER SEVEN: THE NEW ORLEANS EAST PROTECTED AREA

7.1 Introduction

Figure 7.1 shows the New Orleans East (NEO) protected area, a contiguously ringed area that includes some of the lowest ground in the metropolitan region. This is a repeat of Figure 2.4, and the blue stars again represent levee breaches, and the red stars locations of significant levee distress. Multiple levee breaches and significant overtopping produced complete flooding of this protected area, and the resulting damage was extensive.

The New Orleans East protected area had a pre-Katrina population of approximately 96,000 people residing in over 30,000 households. Most of these residences were located in the western portion of the polder (protected area) between Lake Pontchartrain and Chef Menteur Highway (Highway I-10). The residential neighborhoods are suburban in character, with many of the homes dating to the 1960s and 1970s. Ironically, a number of these homes were built in response to the devastation inflicted by Hurricane Betsy in 1965, which had also left much of New Orleans East submerged by floodwater. This protected area also includes an industrial corridor located along its southern fringe, adjacent to the Gulf Intracoastal Waterway (GIWW) which runs adjacent to its southern edge. The eastern limits of the protected area are largely comprised of wetlands that border Lake Pontchartrain/Lake Borgne water systems and/or the swamplands between them.

The New Orleans East protected area extends over approximately 70 square miles and is bounded by Lake Pontchartrain to the north, the GIWW shipping channel to the south, and the Inner Harbor Navigation Channel (IHNC) to the west. Lake Borgne abuts the south facing levees at the southeast corner of this protected area.

Figure 7.3 shows the depths of flooding on September 2, four days after hurricane Katrina, at a time when the water levels were at equilibrium with the still slightly swollen waters of Lake Pontchartrain (Elev. ~ +1 foot, MSL), and this map of flooding depths thus serves well to illustrate the distribution of ground elevations across this protected area. Elevations typically range from approximately +10 feet to -8 feet (MSL), with the higher elevation reaches located south of the Chef Menteur Highway. This Highway follows along a ridge of "high ground" known as the Bayou Sauvage ridge which is the result of an earlier river depositional channel (see Chapter 3), and this slight ridge serves to nearly separate the large northern section of the protected area from a smaller basin to the south. This separation was incomplete, however, as floodwaters managed to cross this ridge at a number of locations.

The New Orleans East protected area encompasses some of the lowest elevation lands in the greater New Orleans populated region, and the results of the full flooding of this protected basin were thus catastrophic, especially with regard to damage to homes and properties. As shown in Figure 2.12, loss of life was moderate (on the order of 120 persons, to date), however, largely because of the relatively effective pre-evacuation of this exposed outlying area, and the relatively moderate rate at which the waters eventually filled the low-lying populous areas at the western end of this protected area. Because the area flooded and filled progressively over the course of the day on August 29, the storm surge subsided as it filled and the eventual filling extended only to approximately +2 feet (MSL) in the populous western end of the protected area; accordingly portions of the "high ground" along the southwest edge of the protected area remained above water (as shown in Figure 7.4.) The open, unpopulated eastern portion of the protected area initially filled to somewhat higher elevations, however, as it was relatively rapidly filled by the massive beaching and erosion of the New Orleans East back levees fronting the GIWW channel and Lake Borgne.

7.2 New Orleans East Hurricane Protection System

Figure 7.2 shows the results of a post-hurricane assessment of the condition of the primary levee system surrounding the protected area (IPET; March 10, 2006.) This protection system, which includes earthen levees, I-wall, T-wall, and sheet pile sections, was designed by the USACE as part of the Lake Pontchartrain and Vicinity Hurricane Protection Project. The NEO protected area also includes a secondary or "local" levee that separates the developed portions of the region from the wetlands to the east (Figure 7.1). The primary purpose of the secondary levee is interior drainage control rather than hurricane protection, and it was of lesser height than the main frontage levees (elevations typically on the order of +5 to +6 feet, MSL as opposed to elevations of +14 to +18 feet for the main perimeter frontage levees.)

The New Orleans East hurricane protection system is divided for planning and management purposes into individual segments, or "reaches," which are defined by physical characteristics, elevation, and/or potential consequences. For consistency, the names assigned to the individual reaches by the USACE will be used in this chapter. Figure 7.5 illustrates these section designations, and also indicates the locations of other points that will be discussed in this chapter.

The eastern edge of the protected area is defended by the New Orleans East Levee, an approximately 8.5 mile long earthen levee segment consisting largely earthen levees with 3 to 4 horizontal: 1 vertical side slopes, fronted on the outboard side by cypress swamps and wetlands. The southern boundary of the protected area (along the north bank of the east-west trending shared GIWW/MRGO channel) is defended by the New Orleans East Back Levee (to the east) and the adjacent Citrus Back Levee (to the west). These two reaches, which together measure approximately 18 miles in length, are largely comprised of earthen levee sections interspersed with sections comprised of concrete floodwalls atop lower height earthen levee sections and/or sheet pile wall segments. The IHNC East Levee is an approximately 3-mile reach primarily comprised of concrete floodwalls atop earthen levees. As its name implies, the portion of the levee system separates the western edge of the protected area from the adjacent IHNC. Continuing clockwise are the New Orleans Lakefront and Citrus Lakefront Levees, which include both earthen levees and composite concrete floodwall/earthen levee sections. Finally, the eastern 12.5 miles of the northern Lake Pontchartrain frontage is the New Orleans East Lakefront levee, and earthen levee with geometry similar to that of the adjoining New Orleans East Back Levee (just around the corner, along the eastern edge of the protected area.)

7.3 Performance of the New Orleans East Hurricane Protection System in Hurricane Katrina

7.3.1 Overview

Figures 7.1 and 7.2 show the locations of damage to the levee system surrounding the New Orleans East (NOE) protected area. The most significant damage to the system occurred to East Back Levee that fronts the GIWW and Lake Borgne. Here the storm surge completely destroyed (and massively eroded) large expanses of earthen levee in the southeastern corner of the NOE protected area. Additional smaller, but nevertheless significant breaches also occurred along other portions of these NOE back levee reaches. As the storm surge next passed west two significant levee breaches occurred, both due to overtopping, along the north bank of the east-west trending channel of the GIWW/MRGO. Damage (mostly in the form of scour) also occurred along the IHNC East Levee and portions of the New Orleans Lakefront Levee located near the Lakefront Airport as the storm surge raised the water levels within the IHNC. Finally, the reverse (counterclockwise) swirl of the storm winds raised the levels along the south shore of Lake Pontchartrain. Portions of the levee system fronting Lake Pontchartrain, such as the New Orleans Lakefront, Citrus Lakefront, and New Orleans East Lakefront Levees, generally performed well in the hurricane, as did most of the New Orleans East Levee located to the east.

7.3.2 Chronology of Events in the New Orleans East Protected Area

It is believed that water first entered the NOE protected area between about 5:00 a.m. to 5:45 a.m. on August 29 as a large section of earthen levee in the southeastern corner of the protected area catastrophically eroded and breached, as a result of wave action and possible seepage associated with the rising storm surge from Lake Borgne. The levee system at this location was so severely damaged that it ultimately did little, if anything, to impede the storm surge that later peaked at this location. Water entering the NOE protected area through this breach then crossed the adjacent wetlands before being channeled, initially, by the Bayou Sauvage ridge (high ground underlying Highway 90) to the west. Video footage (and eyewitnesses) recorded at the Entergy Power Utility Plant near the Michoud Canal show this inflowing water appearing to arrive from the east at approximately 6:15 a.m. Storm surge simulations by the IPET team (IPET Report 2, March 10, 2006) indicate relatively low water levels in the adjacent GIWW at the 6:00 a.m. hour, indicating that the water first arriving at the Entergy plant did not result from simple overtopping of the levees closely adjacent to this plant.

The storm surge then passed westward along the east-west trending GIWW/MRGO shared channel and produced levee damage and several smaller breaches on the north side of the channel. These breaches added to the water already flowing into the area through the major breaches in the southeast corner. The surge then continued westward reaching the GIWW's “T” intersection with the IHNC channel. The surge passed to the north (and south) along the IHNC, and damaged a number of sections along the IHNC frontage.

As the hurricane then passed northward to the east of New Orleans, the counterclockwise direction of the storm winds also produced a storm surge southward towards the shore of Lake Pontchartrain. The lake level rose, but largely stayed below the crests of most of the lakefront levees. The lake rose approximately to the tops of the lakefront levees at a number of locations, especially along the shoreline of New Orleans East, and there was modest overtopping (storm surge + wave splash-over) and some resulting erosion on the crests and inboard faces of some lakefront levee sections along the Lake frontage. However, there were no breaches in this area. Overtopping occurred over a section of floodwall near the west end of the New Orleans East protected area lakefront, where the floodwall was lower than the adjacent earthen levee sections. This, too, added to the flow into the New Orleans East protected area, which was now beginning to fill with water even as the original storm surges subsided. As shown in Figure 7.4, water depths ultimately approached 10 feet in area. Sadly, some of the deepest waters were in the NOE protected area's principal residential neighborhoods.

7.3.3 Damage to Levee System Frontages

The following sections summarize damage to the individual frontages of the levee system (Figures 7.1 and 7.2). For consistency, locations are referred to using the designations assigned by the USACE Task Force Guardian levee system rebuilding team. These names associated with each of the main levee sections are shown in Figure 7.5.

7.3.3.1 GIWW/Lake Borgne Frontage; the New Orleans East Back Levee

As shown in Figure 7.5, the New Orleans East back levee extends from the southeast corner of the NOE protected area west along the GIWW waterway, and it fronts both the GIWW channel and Lake Borgne as well. As noted earlier, the most severe damage to the NOE Levee System occurred along an approximately 5,300 foot long section of the New Orleans East Back levee, which is situated in the southeast corner of the protected area (Figures 7.1 and 7.2). The protection system at this location consists of earthen levee sloped at 4 horizontal: 1 vertical with a 10-foot wide crown.

This damage to this segment of the levee system was similar to that which occurred along the Mississippi River Gulf Outlet (MRGO) levees in St. Bernard Parish: entire sections were completely eroded leaving virtually no trace of the original earthen levee (Figures 7.1 and 7.2). Figure 7.6 shows typical erosion along the eastern end of this levee frontage; the levee embankment is entirely removed by erosion along much of this reach.

This NOE back levee frontage is a “sister” section to the MRGO levee frontage along the northeast edge of the St. Bernard/Lower Ninth Ward protected area that also suffered similarly catastrophic erosion along miles of its length (see Chapter 6, Section 6.2.) These two levee frontages share a number of unfortunate, deadly characteristics. Both sections were constructed in large part using materials from the excavation of the adjacent shipping channels (the MRGO and the GIWW, respectively), and as a result both were comprised largely of unacceptably highly erodeable soils; including large quantities of sands and lightweight shell sands. (Figure 7.3 shows the official material designations for the constructed perimeter levees surrounding the NOE protected area. All are nominally compacted fills, except for the "hydraulic fill" section along the NOE back levee.) Both levee frontages directly fronted the swollen waters of "Lake" Borgne (which is actually a bay, being directly connected to the open Gulf of Mexico), and so both sections experienced storm waves driven by winds that passed across large open distances; waves that gathered significant energy. Both sections had little or no effective protection on the outboard side from swamps or cypress groves, or other vegetation, etc., that could reduce the intensity of these waves. And both sections appear to have failed catastrophically, and eroded massively, producing massive breaches along thousands of feet through which passed a majority of the floodwaters that so catastrophically devastated the St. Bernard/Lower Ninth Ward and the NOE protected areas.

As described previously in Chapter 6, it is the conclusion of out ILIT investigation that the MRGO frontage levees likely failed, and suffered significant breaching, well before they experienced significant overtopping. The discussion of potential erosion mechanisms presented in Section 6.2 is applicable again here, and is worth revisiting on the part of the reader.

Whereas our investigation concluded that the MRGO frontage levees were apparently compromised before they were significantly overtopped, with the "sister" levees along the NOE back levee frontage it can be conclusively demonstrated that massive failures occurred prior to overtopping.

Figure 7.7 shows hydrographs of calculated (modeled, back-calculated) water levels vs. time during and after hurricane Katrina's passage, as calculated by IPET, for locations at and near the NOE back levee frontage. Similar calculations by Team Louisiana give similar results. The storm surge at the western end of Lake Borgne rose fairly slowly to Elev. +4 feet (MSL), then as the eye of the storm approached more closely it rose rapidly and peaked at about Elev. +16 to +18 at about 8:30 a.m.(CDT; local New Orleans time.) After peaking, the storm surge dropped rapidly at this location. [Many of the hydrographs in this report, and others, are based on GMT (Greenwich Mean Time), and so must be converted to CDT (local time). Similarly, the hydrographs of Figures 7.7 and 7.9 are based on the NGVD datum, and actual MSL elevations are approximately 1.7 feet lower. Some adjustment to elevations as shown are being inferred herein, as the calculated elevations of Figures 7.7 and 7.9 may be a bit low (on the order of about a foot or so) based on field observations and similar calculations by Team Louisiana.]

Figure 7.8 shows calculated maximum storm surge (and also storm surge + wave) elevations, again based on IPET analyses, and also levee crest heights along this frontage. This figure shows that peak surge + waves might have overtopped this frontage at several locations at the eastern end, and at the far west end as the GIWW and MRGO "funnel" necks down to become the joint, east-west trending shared GIWW/MRGO channel.

There is well established evidence, however, that significant breaching had already occurred between about 5:00 a.m. to 6:00 a.m. Eyewitnesses, and a hand held video, clearly show that significant floodwaters approached from the east and arrived at the Entergy power plant located along the north side of the GIWW/MRGO waterway at 6:15 a.m., and that the depth of water increased rapidly over the next few minutes (indicating a large source.)

Figure 7.9 (top) shows the location of this power plant. There are only three possible breaches/sites that could have been the source of these well-timed floodwaters; (1) overtopping, and two breaches, along the Citris levees (along the GIWW/MRGO channel, to the west, (2) local overtopping adjacent to the power plant itself, and (3) the massive breaches at the southeast corner of NOE, along the NOE back levees fronting Lake Borgne. Given the crest heights, and water elevations vs. time, it can be established that the overtopping required for options (1) and (2) above did not begin until well after 7:00 a.m., so the only likely source of these floodwaters appears to be the massively eroded sections of the NOE back levee frontage.

Floodwaters from these breaches would have been channeled by the Bayou Sauvage ridge (high ground underlying Highway 90), and would have come west around the top of the Michoud Canal to the Entergy power plant fairly rapidly. Allowing for the distances involved, there must have been significant breaching and inflow by at least 6:00 a.m., and likely earlier. Water levels along this frontage would only have been on the order of Elev. +8 to +10 feet (MSL) by 6:00 a.m., and would not have passed over (even with wave run-up) the levees along this frontage (with crest elevations of +15.5 to +19 feet, MSL.) Accordingly, it appears that significant levee failures, and breaching, occurred prior to significant overtopping.

Like the MRGO frontage levees discussed in Section 6.2, this catastrophic failure was due primarily to the use of inappropriate, highly erodeable levee embankment fill materials, including sands and lightweight shell-sands. As discussed in Section 6.2, the actual mechanisms of erosion that led to this failure are likely to have included wave scour on the outboard sides, wave run-up and resulting notching and crenellation of the levee crests, exploitation of this by splashover overtopping, and through-flow erosion (which would have, initially, been most pronounced low on the back or protected side of the levees.) These mechanisms, working alone or in combination, appear to have compromised the earthen levees well before the storm surge peaked, and therefore, well before the levees were overtopped in the conventional sense of the word.

Damage to the NOE back levee reach also occurred further west, between the interior secondary levee and the Michoud Canal. A sheetpile levee "transition" section located near Pump Station 15 deflected and tilted inward (i.e., toward the protected side, see Figure 7.10), as the result of overtopping-induced erosion at the base of the backside of the sheetpile wall. Sheet piling was used at these locations to transition between concrete floodwall and full-height earthen levee sections. The tops of the damage sheet pile wall had pre-Katrina elevations that were less then the immediately adjacent concrete floodwall sections, and hence scour at this location was worsened by preferential overtopping during the peak of the storm surge. Further to the west near the Air Products Corporation site, a similar sheet pile transition section overturned and collapsed in response to scour and the associated loss of passive resistance on the protected side (Figures 7.12 and 7.13). Once again, the top of the damaged section was at a lower elevation then adjacent levee segments resulting in highly concentrated overflow (and resulting scour, that laterally unbraced the sheetpile wall) at this location. Note that there is little or no evidence of overtopping erosion adjacent to the failed sheetpile transition section. This is one of numerous cases wherein the adjacent long reaches of full-height earthen levee and concrete floodwall-topped levee both performed well, but where inadequate attention was paid to effecting a safe "transition" between these two major project elements; a tragic failure of attention to detail, and an adverse product of the piecemeal process by which these massive and complex levee systems are constructed in individual segments and stages.

7.3.3.2 The Michoud Area and the Citrus Back Levee

The Michoud area levee systems site extends along the GIWW from Michoud Slip to (and around) the Michoud Canal. The site is located below and immediately west of the Interstate 510/Highway 47 bridge near the Entergy New Orleans Corporation's power plant. Scour was noted at the base of the rear side of the concrete floodwalls surrounding both Michoud Slip and Michoud Canal; however, breaching did not occur at this location and overall system performance was good (Figure. 7.11). In addition to the video of early morning flooding here highlighted earlier, mounted security cameras later captured dramatic images of levee overtopping during the peak of the storm surge (see Figures 7.17 and 7.18.)

West of the Michoud sector, the remainder of the levee reaches along the north bank of the GIWW/MRGO channel constitute the main Citrus back levee section. As the risen waters of Lake Borgne were pushed west along the shared GIWW/MRGO channel, overtopping occurred along considerable lengths of the Citrus back levee frontage. Many earthen embankment sections sustained this overtopping with little or no damage, while adjacent sections suffered variable amounts of overtopping-induced erosion on their back (inboard side) slopes, but without full breaching.

A major failure did occur along this frontage, at the Citrus back levee floodwall. This site is located in the industrial corridor south of Chef Menteur Highway along the GIWW. Because its protection system consists of a relatively short floodwall segment situated between longer stretches of full-height earthen levee, the site provides a unique opportunity to compare the performance of different types of levees subjected to identical storm surge loadings. The levee system at the site principally consists of an approximately 3000 foot long I-wall with a short (~ 80 feet) T-wall section, and a 50-foot long T-section with a steel gate. The adjacent earthen levee sections are sloped at 4 horizontal: 1 vertical and include a 10 foot wide crown. The I-wall tilted and deflected significantly in response to the rising storm surge. Deflection along the 3000-foot length of the concrete I-wall section from severe (i.e., almost completely tilted over, Figure 7.15) to moderate (i.e., lateral movement of several feet, with limited tilting, Figure 7.14). Deflections were generally greater near the eastern and middle segments of the floodwall.

Scour trenches developed along the full length of the floodwall on the protected side, as overtopping cascaded over the tops of the floodwalls. In many instances, these trenches were located several feet from the base of the wall (indicating progressive tilting of the floodwalls, and thus the waters falling farther to the inboard side) and some had widths of 7 feet or more. A massive scour hole was found behind to the most tilted segment of the I-wall system. Localized scour was also noted at the western edge of the I-wall where it connects to the earthen levee, representing yet another example of an inadequate "transition" detail connecting two disparate sections. These scour-induced trenched reduced the lateral support for the sheetpiles and the concrete floodwall they supported, and the lateral forces of the outboard side storm surge pushed the laterally unbraced floodwalls sideways. Figure 7.14 shows the eroded trench at the inboard side of a floodwall section that experienced only limited movement; note the heave of soils immediately at the toe of the sheetpiles/floodwall. Figure 7.15 shows a view of the outboard side of a floodwall section that was nearly completely overturned. In this figure, the "gap" between the sheetpiles and the non-displaced outboard side levee embankment toe can be clearly seen. As discussed in numerous other sections of this report, the formation of this water-filled gap served to increase the lateral forces acting against the outboard side of the sheetpile/floodwall.

Post-event topographic maps of the area show a localized low area close to the large scour hole. The tilting of the wall effectively reduced its top elevation, which is likely to have attracted additional overtopping at this location, causing localized erosion that ultimately developed into the large scour hole. This may have, in turn, further exacerbated tilting of the floodwall due to loss of passive soil resistance. It is worth noting that damage to the levee system at this location was almost entirely limited to the relatively short floodwall segment. The adjacent earthen levee segments performed well despite having been subjected to an identical storm surge loading.

As noted above, the floodwall protection system included two isolated segments which were T-wall segments, both of which performed well (i.e., little if any permanent deflection) despite the scour that occurred along their bases. This suggests that the increases lateral and rotational stability and stiffness provided by the battered structural piles supporting these T-wall sections were very useful at this location.

The earthen levee sections east and west of the floodwalls also performed well (i.e., no breaching or significant distress), though at some sections, particularly to the east of the floodwalls, isolated scour holes developed along the levee slopes on the protected side. One of the worst of these is shown in Figure 7.16. The soil exposed in these scours indicated the levees were comprised of largely cohesive materials, and this likely explains their favorable performance with regard to successfully resisting erosion and full breaching (failure) during sustained overtopping.

Figure 7.17 shows a still image from a security videotape showing significant overtopping of the earthen levee adjacent to the Entergy power plant, immediately east of the highway bridge to the St. Bernard parish. Figure 7.18 shows the same site after the hurricane had passed. The overtopping had produces moderate damage, but again no beaching of the levee crest and no failure at this location. Erosion-related performance was generally more favorable than these two examples along the earthen levees that comprised most of the Citrus levee frontage, and many sections showed no indication of overtopping erosion whatsoever.

7.3.3.3 The IHNC Frontage (IHNC East Levee)

The levee system located along the IHNC is primarily comprised of conventional floodwall-topped levee sections interspersed with a number of gate and transitions structures. Overtopping occurred along almost all of this levee frontage. Overall performance was good along most of this frontage, with only one major breach at the extreme north end of this reach.

There were also, however, numerous partially evolved erosional problems at "transitions" along this frontage, and some of these might have been more serious if the inboard side had not already been filling with water from breaches at other locations.

Figure 7.19 shows a typical example of overtopping-induced scour behing a concrete floodwall along this frontage. This was common along this frontage, but no full failures resulted. It is not possible to know with certainty to what extent this type of erosional damage was limited by the fact that waters were likely already accumulating at the inboard sides of these floodwalls due to overtopping and breaches at other locations.

Figures 7.20 through 7.22 show several examples of the 8 locations along this frontage where erosion occurred, but did not develop fully to the point of "failure", at transitions between adjoining flood system elements. Transitions between full height earthen levees and adjacent, composite levee/floodwall sections, and transitions between levees and concrete gate structures (with rolling steel floodgates), were routinely problematic in this regard, and it was common to find partially developed erosion problems at both ends of most gate structures along this frontage. Inadequate attention to transition details, especially to lateral embedment of transitions, and differences in top elevations of adjoining elements, were common. Also disconcerting were sites where the eroded materials appeared to be comprised, at least in part, of lightweight shell-sands; materials notorious for lack of erosion resistance that have no place in these levees protecting large populations.

At all locations, these "transition" erosional features were partially developed, and so no full failures developed. This initially puzzled our field teams, until we learned that floodwaters had been already rising on the inboard (protected) side of levees and floodwalls while the overtopping was occurring; effectively reducing the gradient across these erosional features and minimizing the progression of the erosion. These are features that warrant significant additional attention during reconstruction, as these features might otherwise prove far more dangerous in future events if the inboard side is not already flooding.

At the north end of the IHNC frontage, at the corner where it joins the Lakefront levees, a full breach did occur. This was a complex "transition" section where three utilities consisting of (1) a major highway (the I-10), (2) an adjacent active railroad line, and (3) a surface roadway between these two, all cross the federal perimeter levees. This transition is rendered even more complex by the fact that it is the "corner" of the NOE protected area.

Figure 7.23 shows this location in plan view. Significant overtopping occurred along a nearly mile-long section of the Lakefront levee that had an unexpectedly low floodwall crst height, and this flow passed through the gravel ballast of the railroad embankment (a local low spot, as it was pervious) and eroded the adjacent earthen perimeter levee. This flow also eroded the transition between a concrete floodwall and the adjoining earthen levee section beneath the elevated highway, as shown in Figure 7.24.

7.3.3.4 The New Orleans Lakefront and Citrus Lakefront Levee Frontages

The lakefront levee systems include both earthen levees and composite levee/floodwall sections. With one exception, these performed well. This exception was a nearly mile-long section of floodwall at the west end, behind the Old Lakefront Airport. This section had a unexpectedly low floodwall crest elevation, and it experienced significant localized overtopping, and resultant scour at the inboard side toe of the concrete floodwall, as shown in Figure 7.26. This overtopping-induced scour did not produce a failure, however, so the overtopping flow simply added to the misery of an area that was already flooding as a result of numerous failures that had already occurred to the south.

Only modest damage, primarily in the form of scour, occurred along the remainder of the Lake Pontchartrain frontage. The levee system along this reach was comprised of both floodwall and conventional earthen sections. Storm surge simulations indicate that the lake levels were close to but not greater then the top of the levees, and therefore the scour most likely resulting from wave splash over rather than sustained sheetflow overtopping. Figure 7.27 shows one of the few locations where minor repairs had to be made for erosion. Figure 7.28 shows a second location where limited overtopping produced minor erosional damage. Overall, the performance of levees along the Lakefront, east of the Old Lakefront Airport, was very good.

7.3.3.5 The New Orleans East Levee Frontage

Similar performance was also noted along the eastern levee frontage, which is buffered from the nearby lake systems by a large stretch of wetlands to the east. Figure 7.29 shows a post-event view of a typical levee segment along this frontage. No damage at all was noted along most of this frontage, and only limited erosion at a few locations. This was despite evidence suggesting that overtopping had occurred along at least some portions of this frontage. This favorable performance was likely due to: (1) the use of compacted, clayey fill for the levee embankments (materials with a high resistance to erosion), and (2) the presence of significant widths of swamps and cypress and other vegetation on the outboard sides of the levee (which served to buffer the wave action.)

The only notable damage that occurred in this area was scour in a floodwall-earthen levee transition section that was part of a railroad gate structure. This produced a minor "breach", but given the massive flows that were admitted through the catastrophically eroded lengths of the New Orleans East back levee immediately to the south, this was a relatively unimportant feature in this event. It does, however, provide yet another example of problems with handling of "transitions", and the site should be re-asessed and mitigated as it might represent a more serious potential vulnerable point in future events if the inboard side lands are not already rapidly filling with floodwaters.

7.4 Summary of Findings for the New Orleans East Protected Area

The key findings of this chapter may be summarized as follows:

- The catastrophic breaching of the New Orleans East Bask Levee System in the southeast corner of the polder was responsible for much of the flooding of the New Orleans East protected area. While there is limited data as to the exact time that the breach developed, the available evidence strongly suggests this occurred well in advance of the peak of the storm surge. This implies that the levee at this location failed not in response to simple overtopping, but rather as a result of wave action and/or through-seepage erosion, and this levee frontage appears to have been significantly compromised, related to the rising water levels in the GIWW. The use of fill materials known to be highly erodeable, from the excavation of the adjacent GIWW shipping channel, resulted in short-term cost savings that are, in hindsight, difficult to justify against the massive damages and the loss of life engendered by the catastrophic erosion and failure of these levees.

- With the notable exception of the levee system in the southeast corner, the conventional full-height earthen levees that protect most of the New Orleans East protected area performed quite well. This is despite, in some cases, significant overtopping that occurred during the peak of the storm surge.

- The performance of concrete floodwalls was uneven. In some cases these systems performed well even when overtopped (e.g. along the IHNC frontage). In other situations (e.g. collapsed Citrus Back Levee Floodwall) the performance was unsatisfactory.

- Levee transition sections and gate structures were routinely problematic. Common problems, often because of the differences in elevation between adjacent sections, which resulted in concentrated or preferential overtopping. In many instances, damage also occurred at these locations because of the contrast in erosion resistance between adjoining sections (e.g. flood wall-earthen levee transitions).

7.5 References

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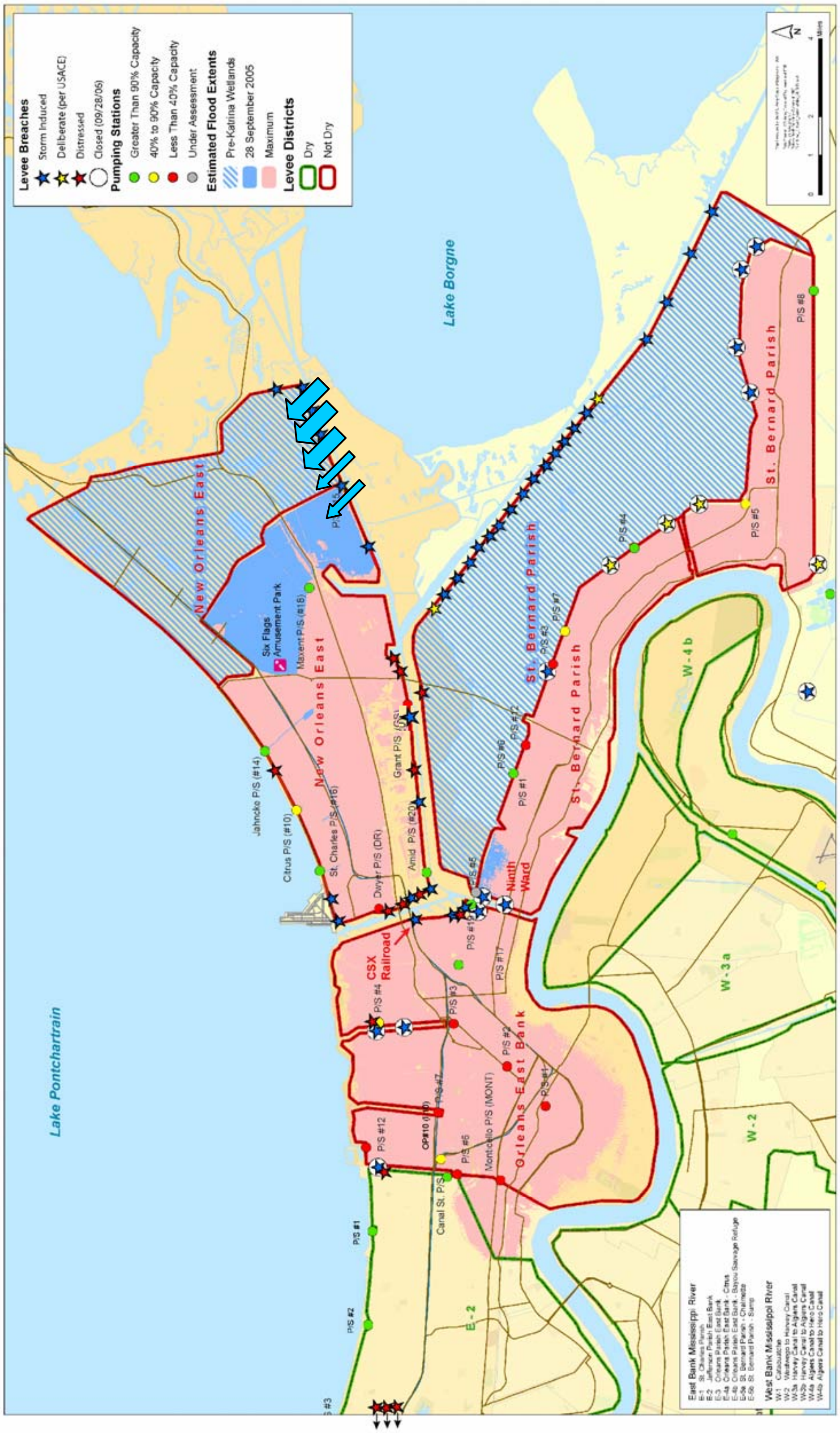


Source: Modified after USACE, 2005

Figure 7.1: Map showing principal features of the main flood protection rings or “protected areas” in the New Orleans area.

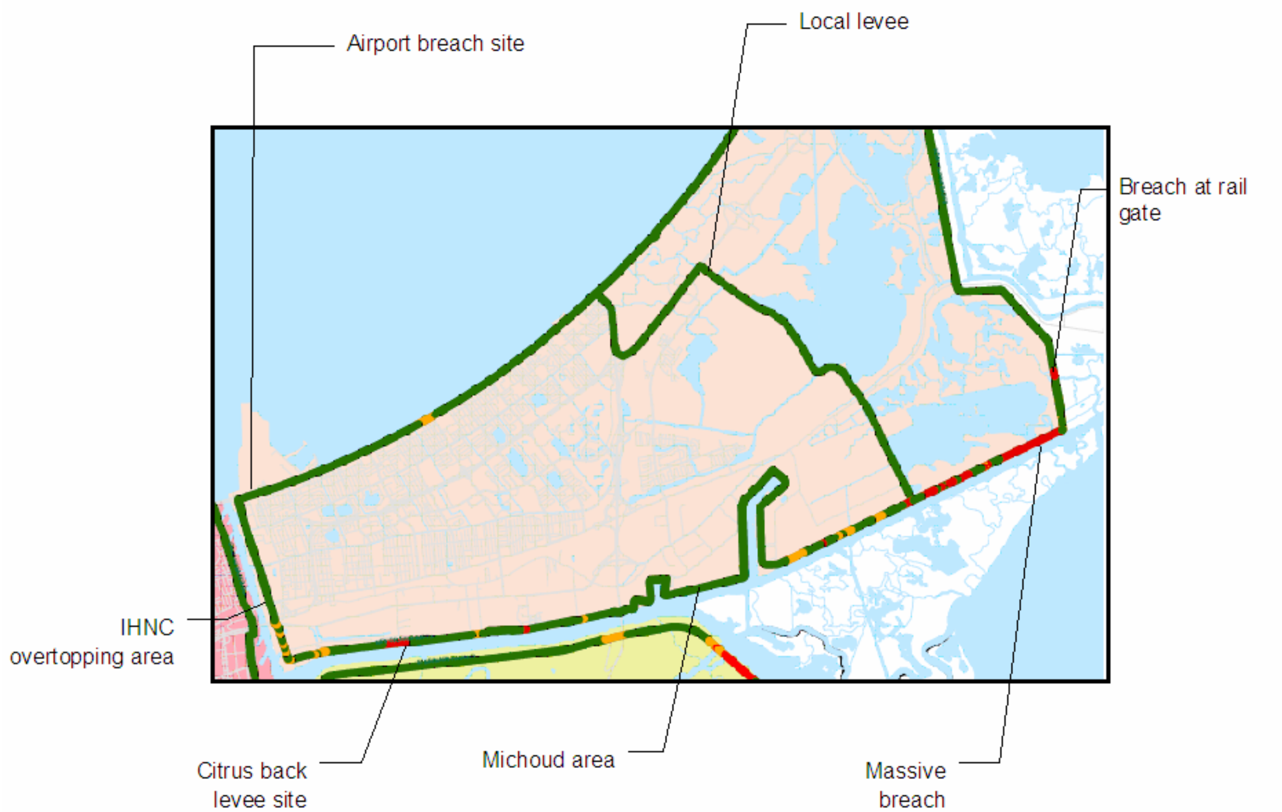
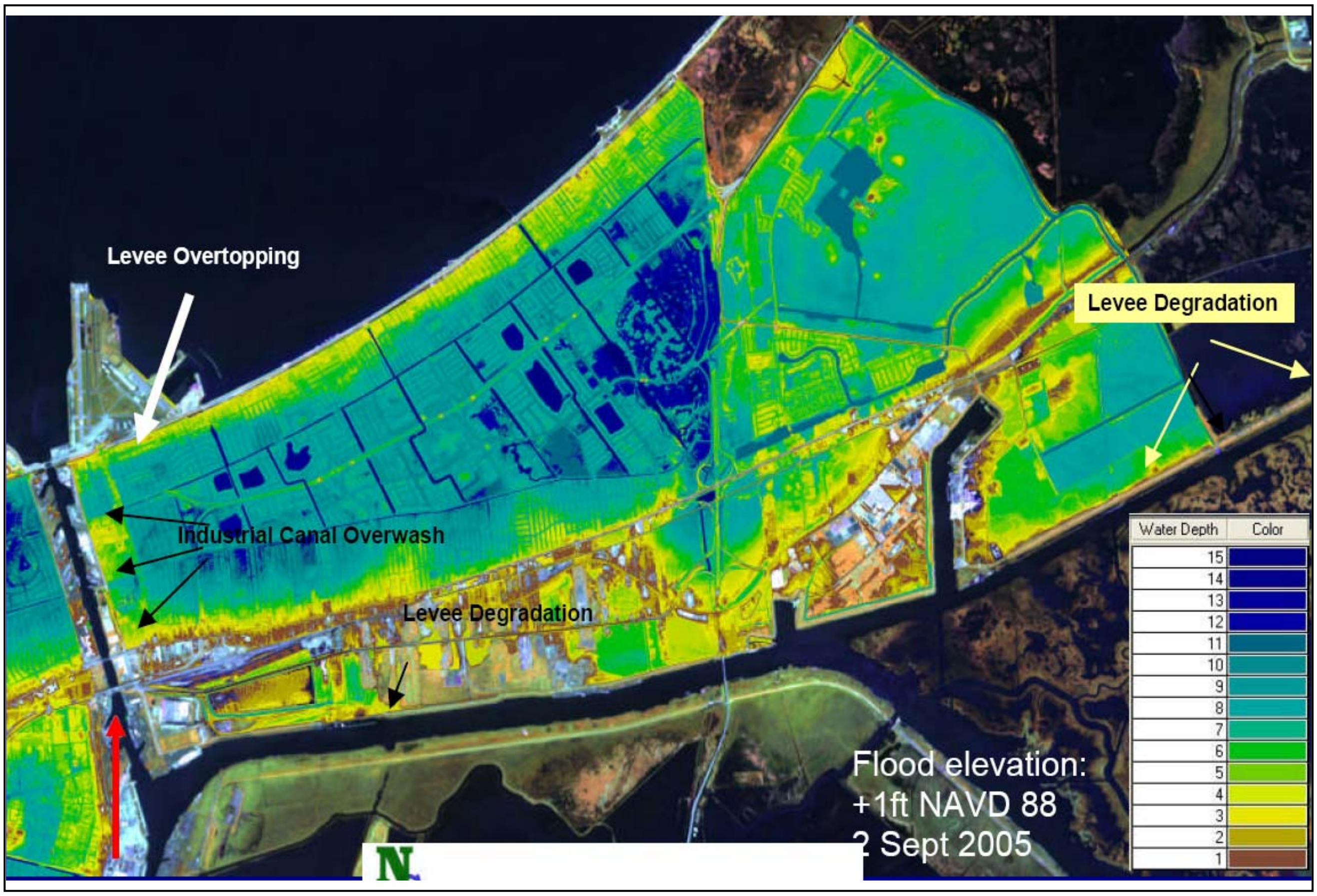


Figure 7.2: Damage locations in the NOE protected area (base map from USACE.) Color indicates severity of damage, with red being the worst. [IPET; March 10, 2006]

Figure 7.3: Construction materials and methods, New Orleans East. [IPET; June 1, 2006]



Source: LSU Hurricane Center, 2006

Figure 7.4: Depth of flooding of New Orleans East on September 2nd (4 days after Hurricane Katrina)

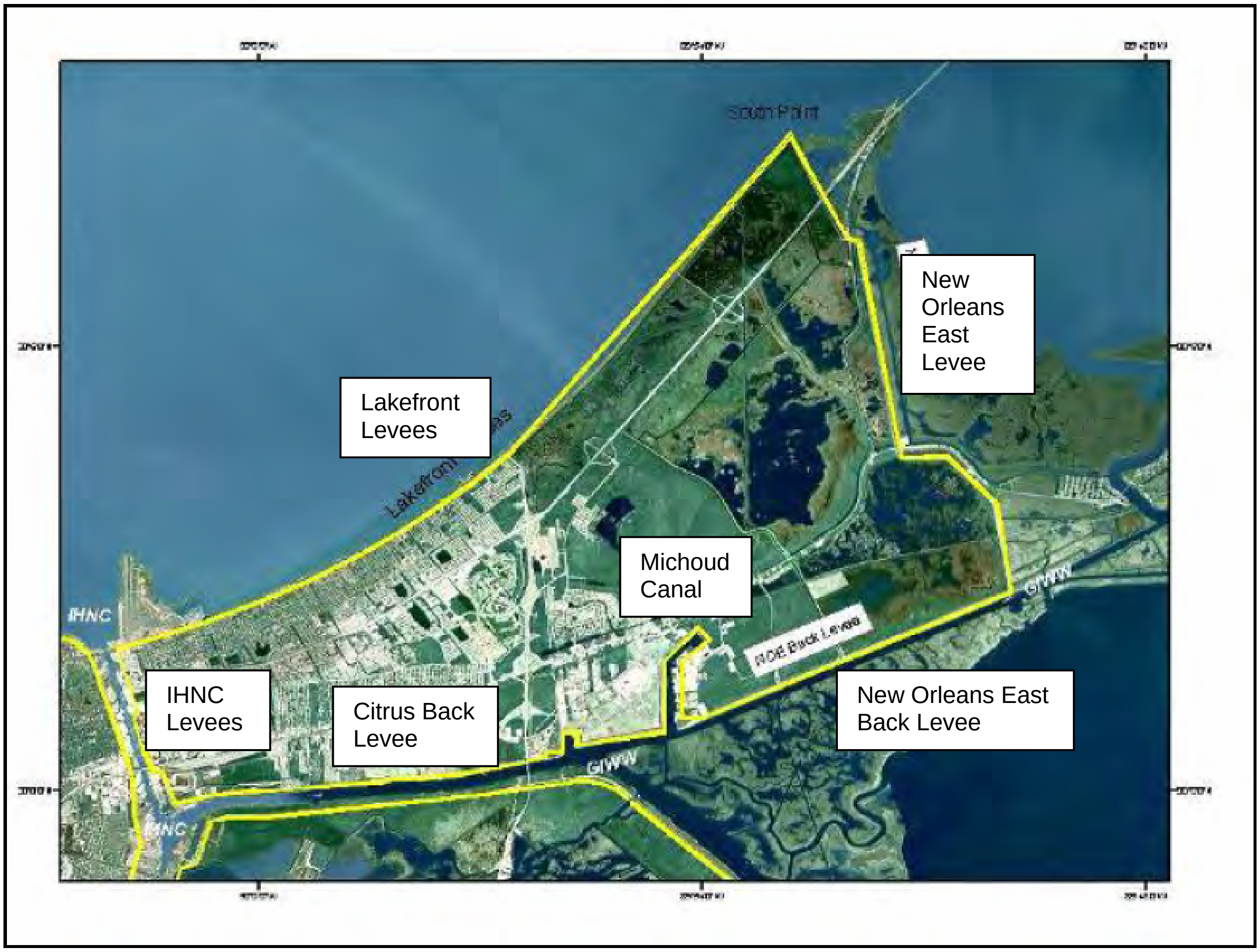


Figure 7.5: Principal sections of the New Orleans East perimeter defense levees; including the Lakefront Levees, the New Orleans East Levee, the New Orleans East Back Levee, the Michoud Canal, the Citrus Back Levee, and the IHNC Levees.

Photo courtesy of USACE

Figure 7.6: Some of the most severe damage to the New Orleans regional levee system occurred along this section of the New Orleans East Back levee, which is situated in the southeast corner of the protected area, facing south toward Lake Borgne.

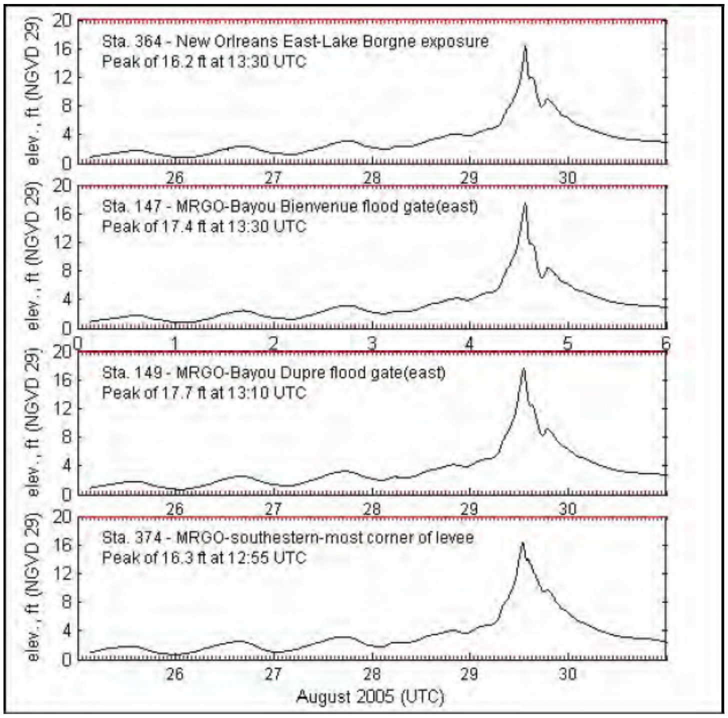


Figure 7.7: Approximate hydrograph of storm surge elevation (feet, MSL) vs. time at the west end of Lake Borgne. [IPET Interim Report; April, 2006]

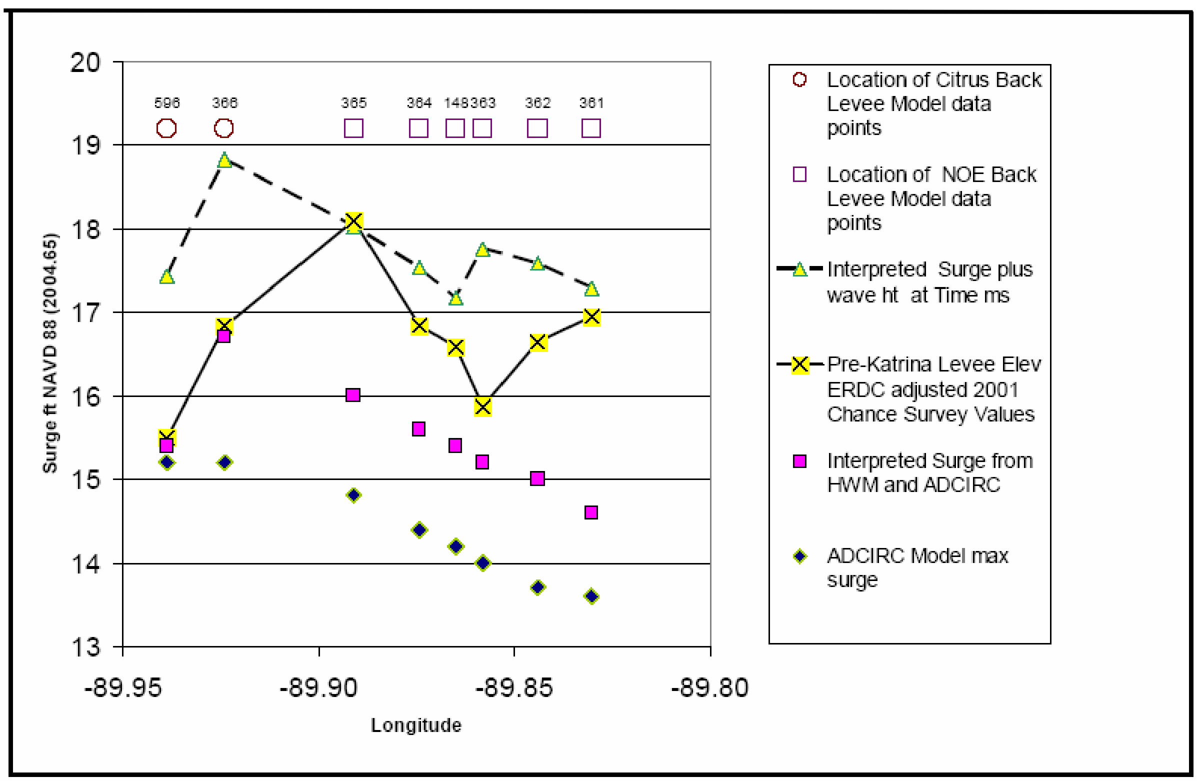


Figure 7.8: Pre-Katrina crest elevations, and various estimates of storm surge + wave height; New Orleans East back levee facing Lake Borgne [IPET; June 1, 2006]

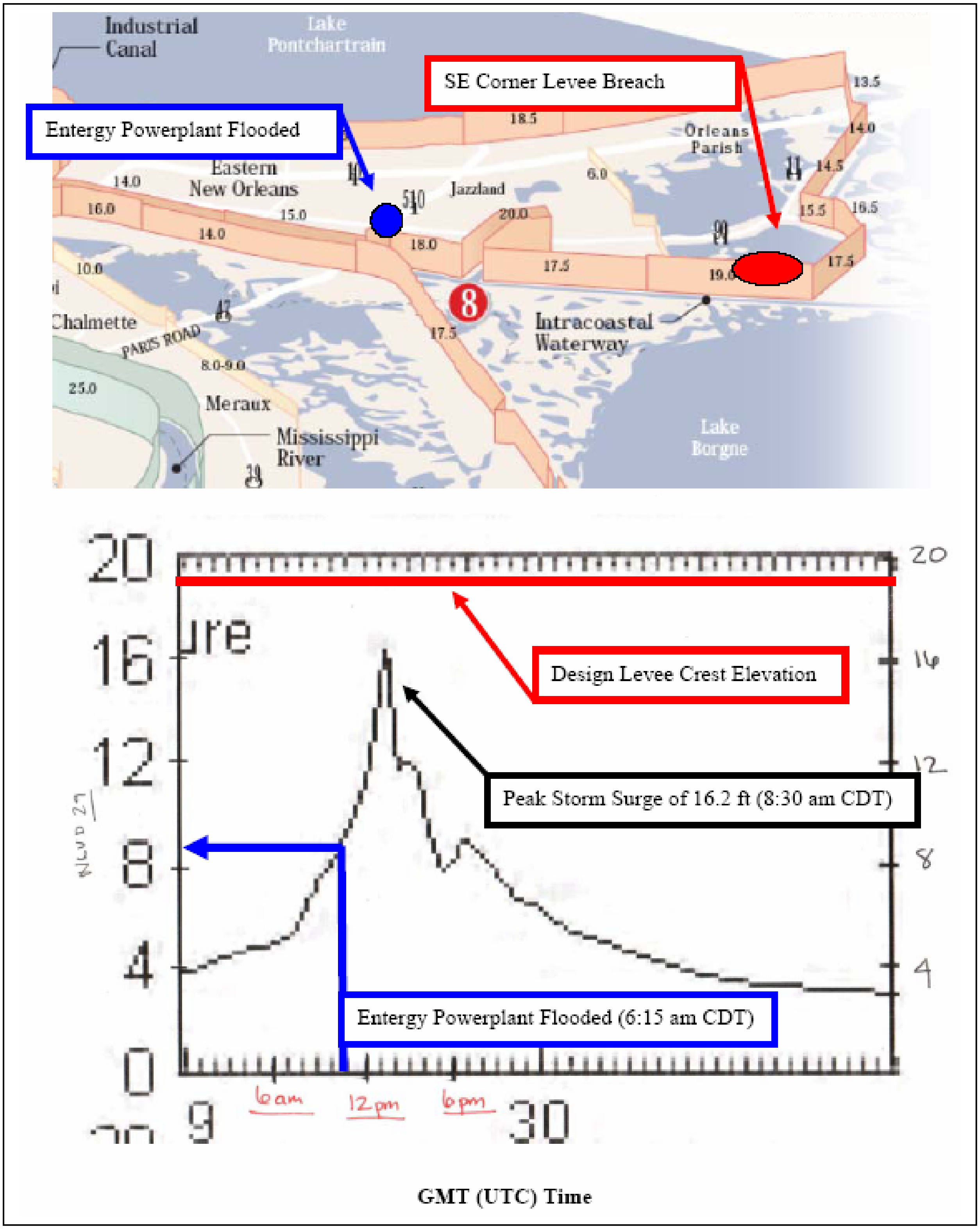


Figure 7.9: Timing of observed flooding at Entergy Powerplant and storm surge at New Orleans East back levee breach (southeast corner fronting Lake Borgne.) [Times shown are UTC or Greenwich Mean Time. Elevations shown are in feet, NGVD29.]

Photograph by J. Wartman

Figure 7.10: Deflected and tilted sheet pile sections near Pump Station 15.

Photograph by J. Wartman

Figure 7.11: Scour at the base of floodwalls near the Michoud Canal.

Photo by Dr. Les Harder

Figure 7.12: Failed sheetpile transition at the Air Products Corporation site; NOE back levee.

Photo courtesy of USACE

Figure 7.13: Second view of failed sheetpile transition.

Photograph by J. Wartman

Figure 7.14: Significant lateral deflection of the Citrus Back Levee floodwall, seen from the inboard (protected) side. Note the heave adjacent to the displaced sheetpiles and wall.

Photograph by J. Wartman

Figure 7.15: Deflection and tilting of another section of the Citrus Back Levee Floodwall, this time viewed from the outboard side. Note the gap between the outboard levee toe section and the sheetpile curtain.

Photograph by J. Wartman

Figure 7.16: Scour varied greatly along the Citrus Back Levee. It was significant on the back (inboard side) slope of the levee at this location; nearly breaching the levee crest.

Sill photo from security video at Entergy Powerplant

Figure 7.17: Still image from security videotape taken at Entergy power plant showing overtopping adjacent to the I-510/Hwy 47 Bridge on the NOE Back Levee.

Photograph by Rune Storesund

Figure 7.18: Post-Katrina photo of the same levee section shown above in Figure 7.17.

Photograph by J. Wartman

Figure 7.19: Minor scour along the base of the IHNC floodwall. Note the boat pushed against the outboard (flood) side of the wall.

Photograph by Rune Storesund

Figure 7.20: One of numerous examples of partially exploited erosive vulnerability at a "transition" section along the IHNC levee frontage; in this case a transition from a gated concrete floodwall to a full height earthen levee section.

Photograph by Francisco Silva-Tulla

Figure 7.21: Another example of partially exploited erosive vulnerability at a "transition" section along the IHNC levee frontage; in this case a transition from a roadway floodgate to a full height earthen levee section.

Photograph by Rune Storesund

Figure 7.22: Erosion at the east bank IHNC CSX Rail Crossing.

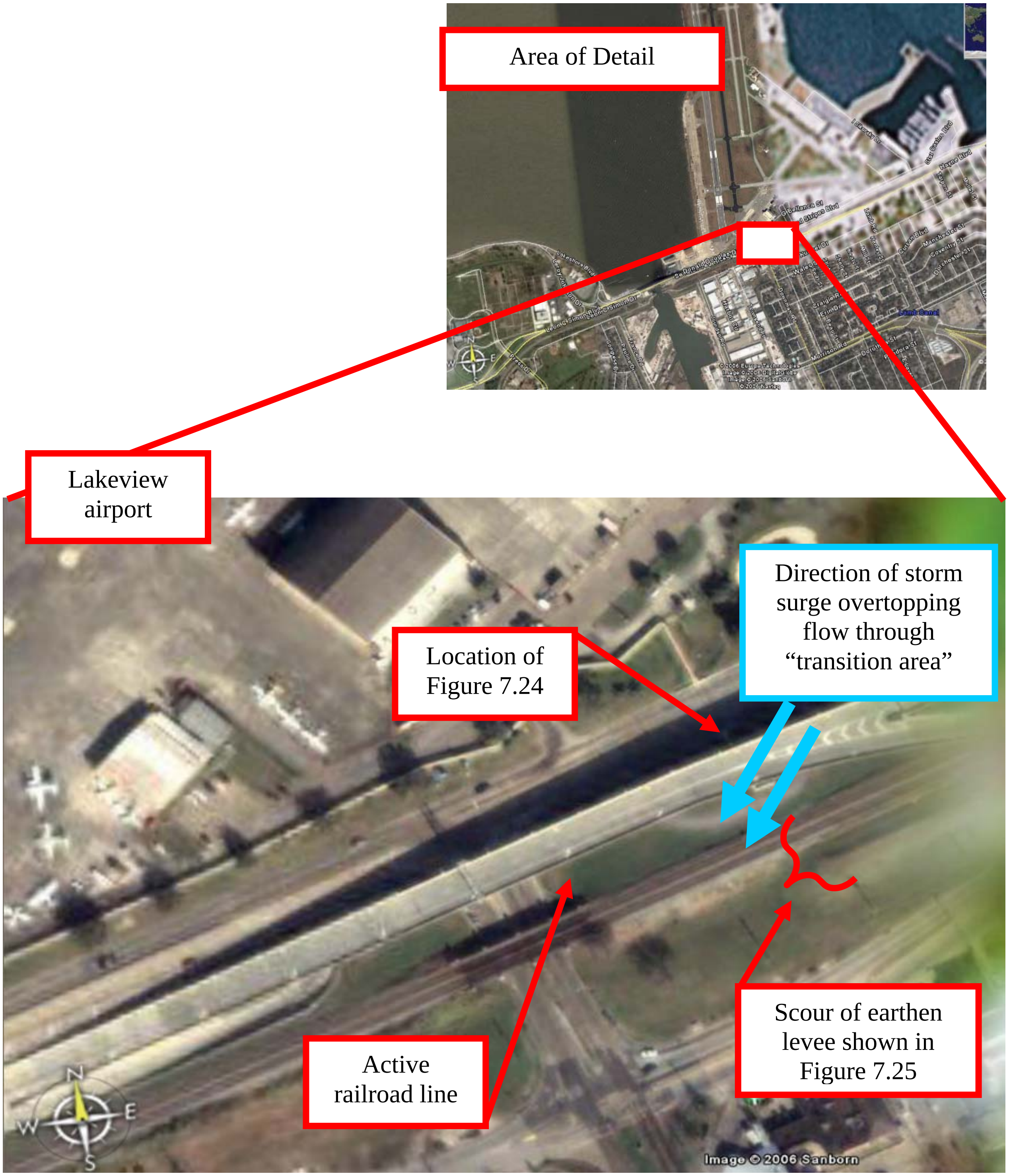
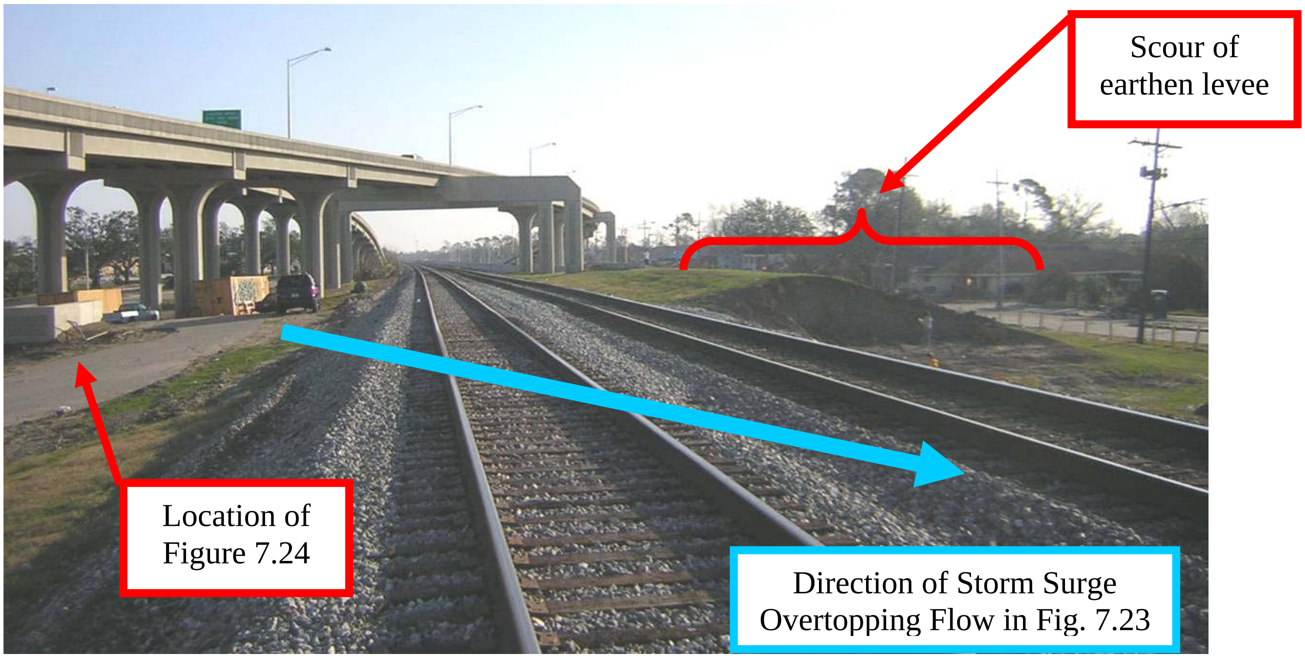


Figure 7.23: Storm-surge induced overtopping traveled through the granular gravel ballast for the railroad line and eroded the railroad line embankment, which served as a transition levee between the concrete floodwall and the earthen levee shown in Figure 7.25. [Base image from Google Earth, 2006]

Photograph by Rune Storesund

Figure 7.24: IHNC levee near the Lakefront Airport adjacent to the railroad section from Figure 7.23, showing erosional failure and scour at transition to concrete floodwall protecting highway support.



Photograph by Rune Storesund

Figure 7.25: Significant erosion was observed on the levee adjacent to (and behind) the floodwall shown in Figure 7.24. The storm surge overtopped the floodwall and railroad ballast and failed the earthen levee behind the railroad.

Photograph by J. Wartman

Figure 7.26: Scour near the base of a floodwall near the Lakefront Airport.

Photograph by Rune Storesund

Figure 7.27: Lakefront levee near the Jahncke Pump Station outfall structure, where minor overtopping erosion occurred. These levees performed well and only minor, surficial damage was observed.

Photograph by Rune Storesund

Figure 7.28: Observed scour at the Jahncke Pump Station outfall structure, Lakefront. Scour was limited to areas of soil-structure interfaces, and no full breach occurred.

Photograph by Rune Storesund

Figure 7.29: Condition of levees east of HWY 11 (location 3 on Figure 10.6) in October 2005. These levees performed exceptionally well and were not eroded during Hurricanes Katrina or Rita.