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The New Orleans Levees:
The Worst Engineering Catastrophe in U.S. History –
What Went Wrong and Why

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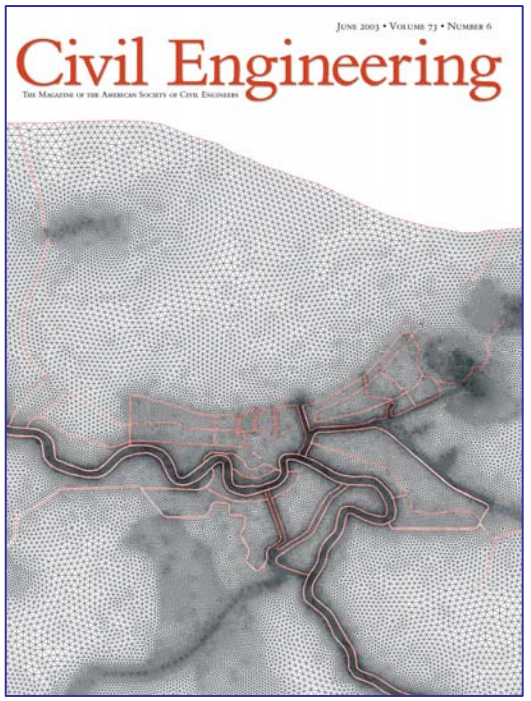
Deputy Executive Director

Discussion

- USACE IPET and ASCE's ERP
- The setting
- What went wrong?
- Lessons learned
- What must we do next?

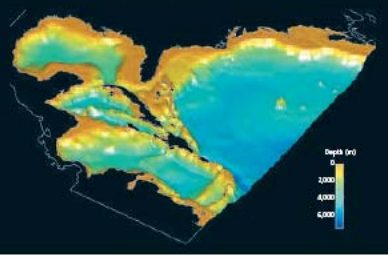
We saw it coming

- ". . . If a lingering category 3 storm – or a stronger storm, say category 4 or 5 – were to hit the city, much of New Orleans could find itself under more than 20 ft (6 m) of water. . ."



THE CREEPING STORM

During the past 40 years the U.S. Army Corps of Engineers has spent hundreds of millions of dollars constructing a barrier around the low-lying city of New Orleans to protect it from hurricanes. But is the system of levees high enough? And can any defense ultimately protect a city that is perpetually sinking—in some areas at a rate of half an inch per year? **By Greg Brouwer**



With a bathymetric model of the Gulf Coast, left, and a finite-element grid representing the same area, below, researchers are able to predict the storm surge and flood risk associated with hurricanes. The grid is most refined in and around southeast Louisiana, where the predictions can determine the fate of levee projects worth billions of dollars.

In the late summer of 1965 a disorganized storm system formed over the warm, tropical waters of the mid Atlantic. Soon the storm grew into a high-powered cyclone—a twisting mass of wind and water that would torment the Gulf Coast in the coming days. The National Hurricane Center gave it a hauntingly innocuous name: Hurricane Betsy.

Storm prediction was still in its infancy then and researchers could not get a read on Betsy's erratic path. She zigzagged north from Puerto Rico and first seemed to be heading straight toward the Carolinas. At the last moment, however, Betsy swerved toward the Bahamas, then again toward Florida, finally veering west of the peninsula and straight toward Louisiana.

On September 9 Betsy hit the southern tip of the state. Almost every building in the small coastal town of Grand Isle was quickly destroyed. With 150 mph (240 km/h) winds, Betsy barreled up the Barataria Basin toward New Orleans. Lake Pontchartrain—which is just north of the city and is connected to the Gulf of Mexico—swelled with raging waters. Easterly winds pounded the high waters, in some areas easily topping the levees meant to protect the city. In streets in the eastern part of town water reached the eaves of houses.

Betsy finally calmed near Little Rock, Arkansas. She had dropped only 4 in. (100 mm) of rain on New Orleans and had claimed 81 lives and caused more than $1 billion in damage. Unlike any storm before it, Betsy made clear that the city was all too vulnerable to hurricanes. Cradled in a wide southern meander of the Mississippi River just north of the Gulf of Mexico, New Orleans is surrounded by Lake Pontchartrain to the north, Lake Borgne to the east, and lakes Cataouatche and Salvador to the south. This ring of freshwater is also surrounded by hundreds of square miles of wetlands and the Gulf of Mexico. To make matters worse, most of the city is below sea level.

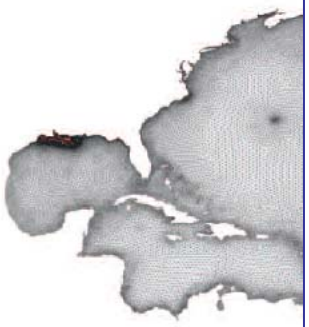
Soon after the damage from Betsy was assessed, Congress made a historic decision to appropriate federal funds to build a system of levees to protect the city from a similar storm in the future. In cultural significance aside, New Orleans was fast becoming the most important port in the nation—feeding commodities up the Mississippi to all of the Midwest and serving as an important base for the burgeoning oil and gas industry. Congress was not about to let it wash away.

Today New Orleans rests within a bowl formed by 16 ft (4.9 m) tall levees, locks, floodgates, and seawalls, the edge of the bowl extending for hundreds of miles. It is bisected from west to east by the Mississippi River, which is also contained within massive engineered embankments. Water flows through and all around the city while its residents go about their daily routines. A system of levees forming a ring around the northern half of the city to protect it from surging waters in Lake Pontchartrain is set to be completed within the next decade. Construction of a similar system around the southern half of the city will probably take several years longer than that.

But almost 40 years after beginning these projects, the U.S. Army Corps of Engineers is in the midst of reassessing them on the basis of an ominous question: Are the protective barriers high enough?

The design of the original levees, which dates to the 1960s, was based on rudimentary storm modeling that, it is now realized, might underestimate the threat of a potential hurricane. Even if the modeling was adequate, however, the levees were designed to withstand only forces associated with a fast-moving hurricane that, according to the National Weather Service's Saffir-Simpson scale, would be placed in category 3. If a lingering category 3 storm—or a stronger storm, say, category 4 or 5—were to hit the city, much of New Orleans could find itself under more than 20 ft (6 m) of water.

Some experts worry that even a less severe storm could flood the city. In the 40 years since the design criteria were established for New Orleans's hurricane protection levees, southeastern Louisiana's coastline has been subsiding—settling in on top of itself—even as the natural height of the sea rises. A century ago any hurricane heading toward New Orleans would have had to traverse a 50 mi (80 km) buffer of marshland. Today that marsh area is only half as broad and the hurricane would be striking a city that itself sinks lower every day.



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Katrina caught us

- Ill prepared
- Hesitant, unwilling, or unable to evacuate
- With inadequate defenses

Hurricane Katrina – August 29, 2005

- In New Orleans and southeast Louisiana
  - >1100 people killed, >130 missing
  - Flooding covered 80 percent of the city to depths of 10+ feet (3+ m)
  - 400,000 people fled
  - 125,000 jobs lost
  - >$100 billion in damages to residences, businesses, and infrastructure
  - Communities destroyed

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IPET

- Established by LTG Strock, Chief of Engineers
- > 150 individuals from more than 50 organizations
  - The Corps
  - Other federal agencies
  - Private sector
  - Academia
- Purpose
  - Understand the design and pre-Katrina condition of the HPS
  - Understand the surge and wave levels
  - Determine the forces experienced by the HPS
  - Determine the most likely causes for observed behavior
  - Characterize the consequences of flooding
  - Perform a risk and reliability assessment of the HPS
- Also, provide information for Task Force Guardian

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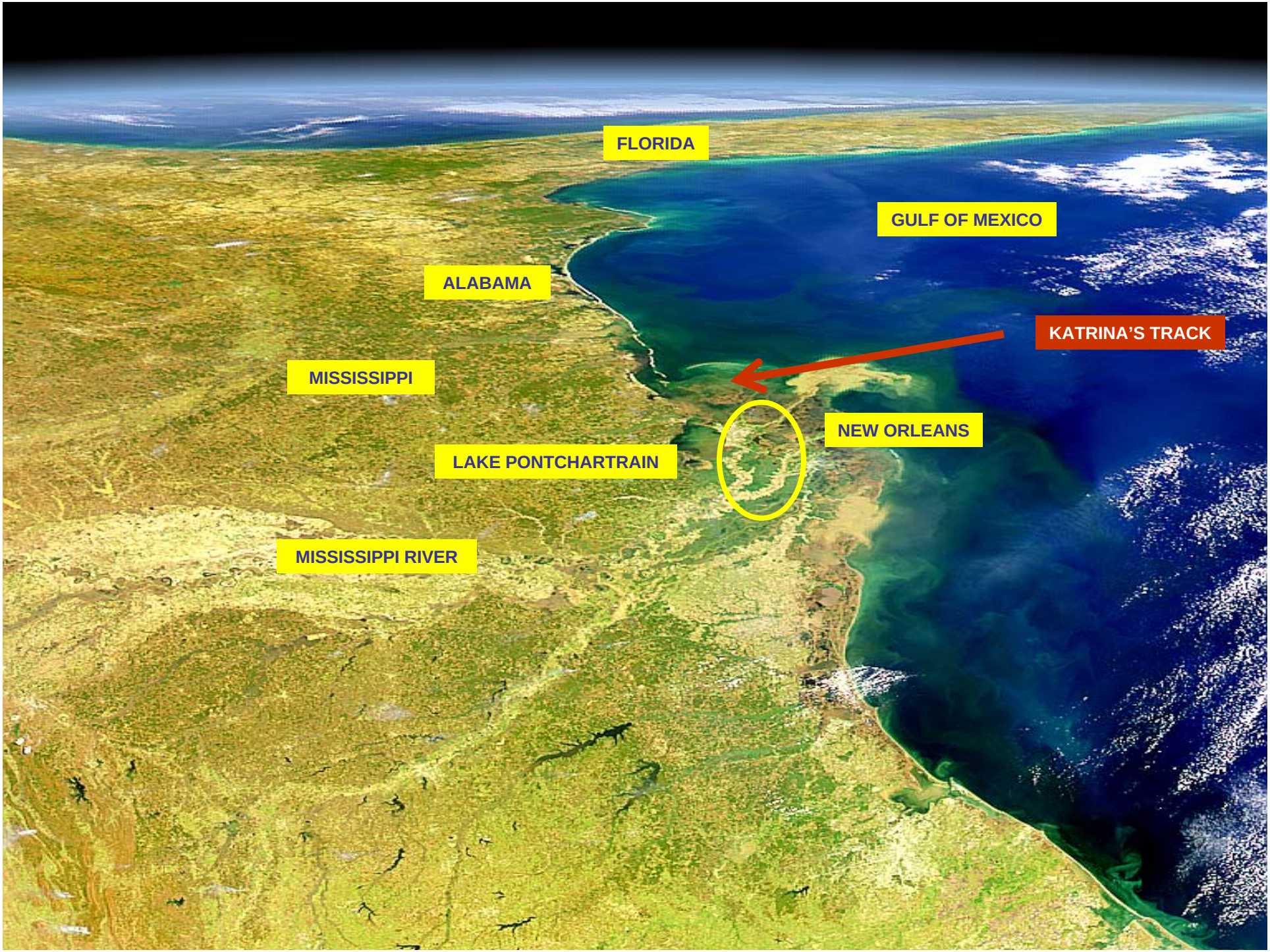
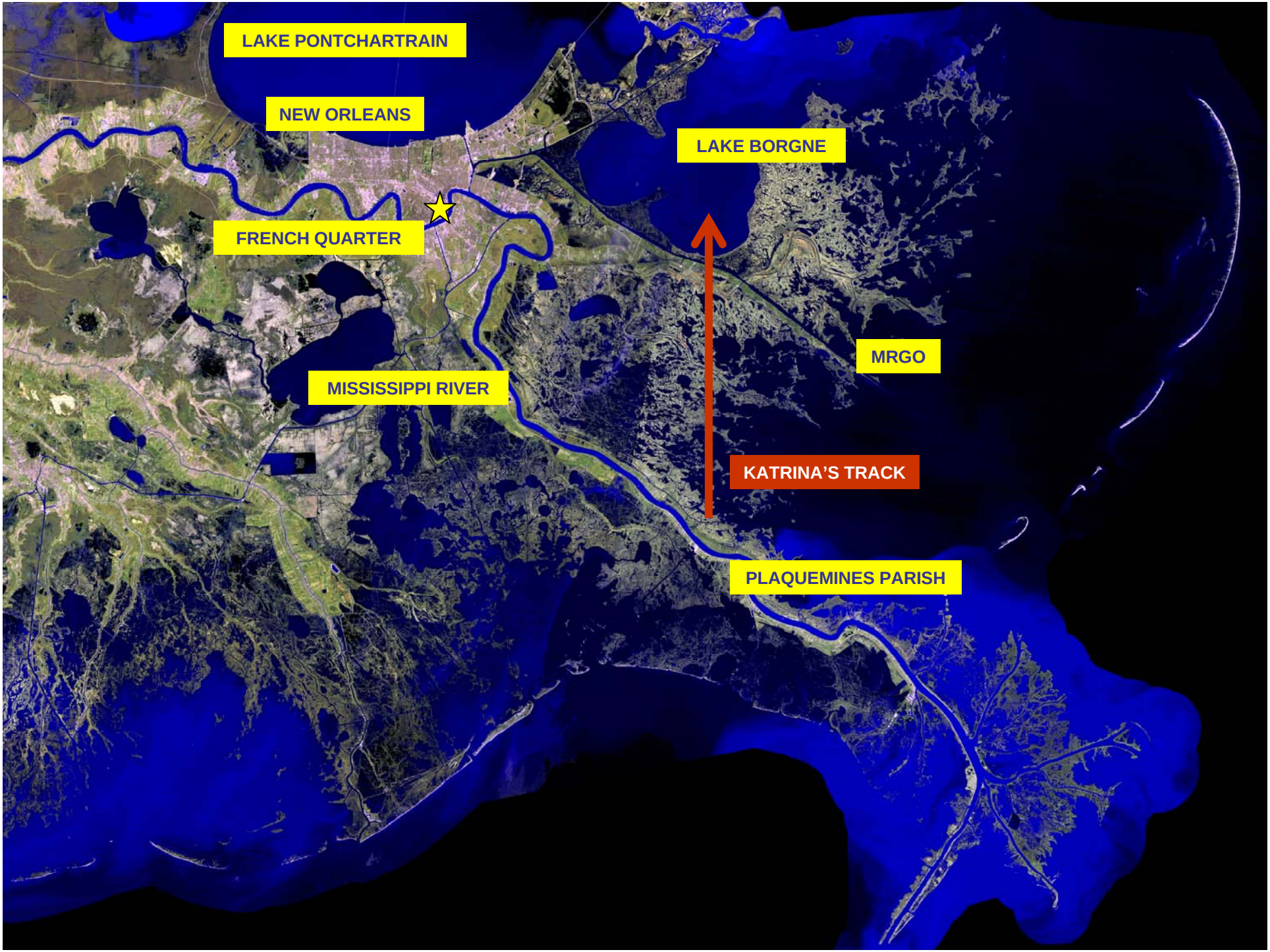
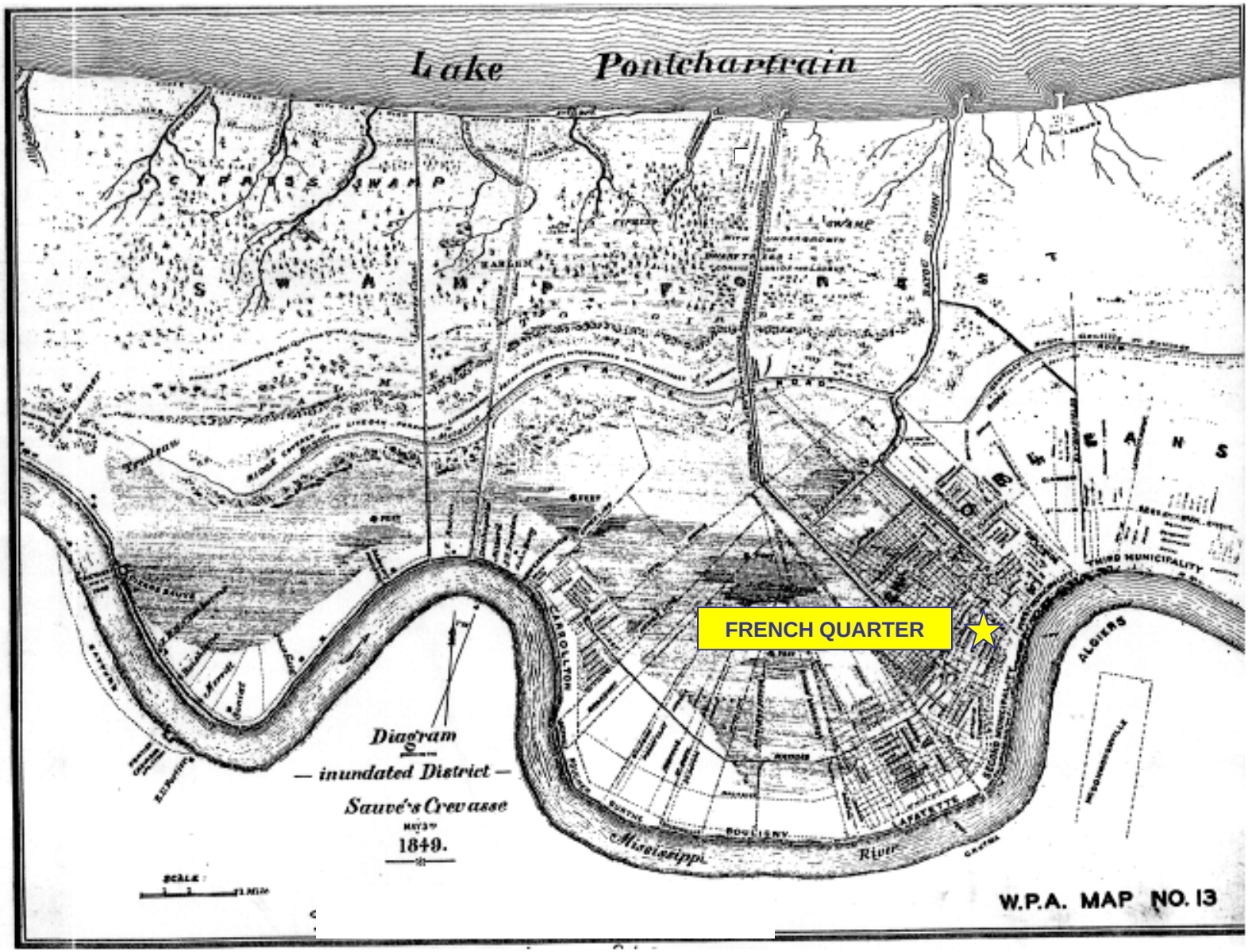
ASCE's ERP

- Requested of ASCE by LTG Strock, Chief of Engineers
- Comprises 14 experts from industry, academia, and government with a broad range of experience and expertise
- Purpose: provide continuous, real-time review of the work of the IPET

The Setting


FLORIDA
GULF OF MEXICO
ALABAMA
KATRINA'S TRACK
MISSISSIPPI
NEW ORLEANS
LAKE PONTCHARTRAIN
MISSISSIPPI RIVER


LAKE PONTCHARTRAIN
NEW ORLEANS
LAKE BORGNE
FRENCH QUARTER
MRGO
MISSISSIPPI RIVER
KATRINA'S TRACK
PLAQUEMINES PARISH



New Orleans – 1849

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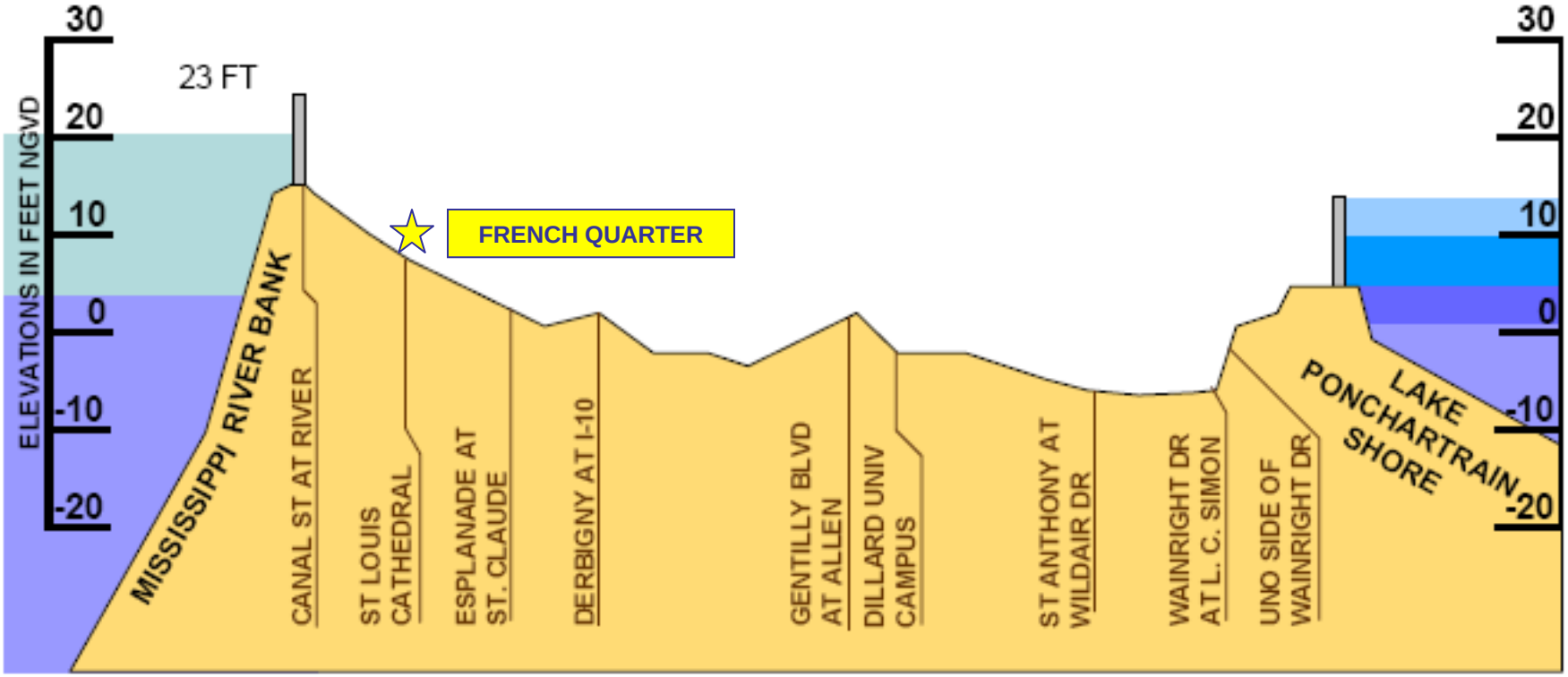

New Orleans

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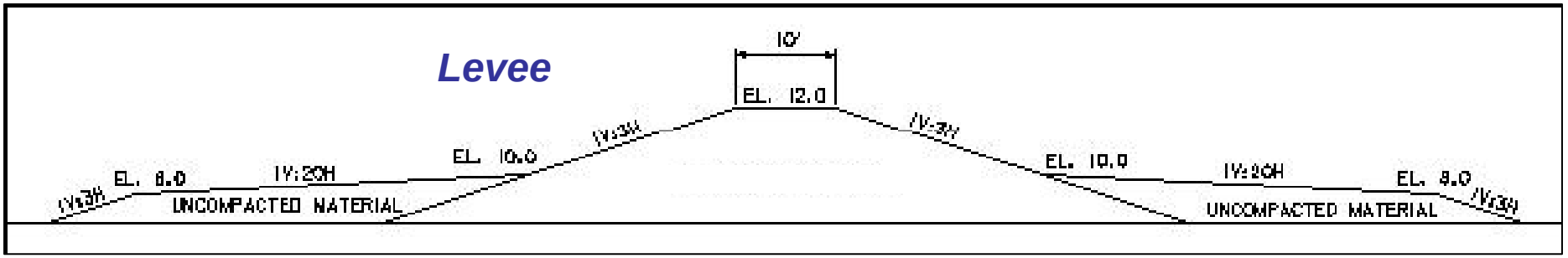
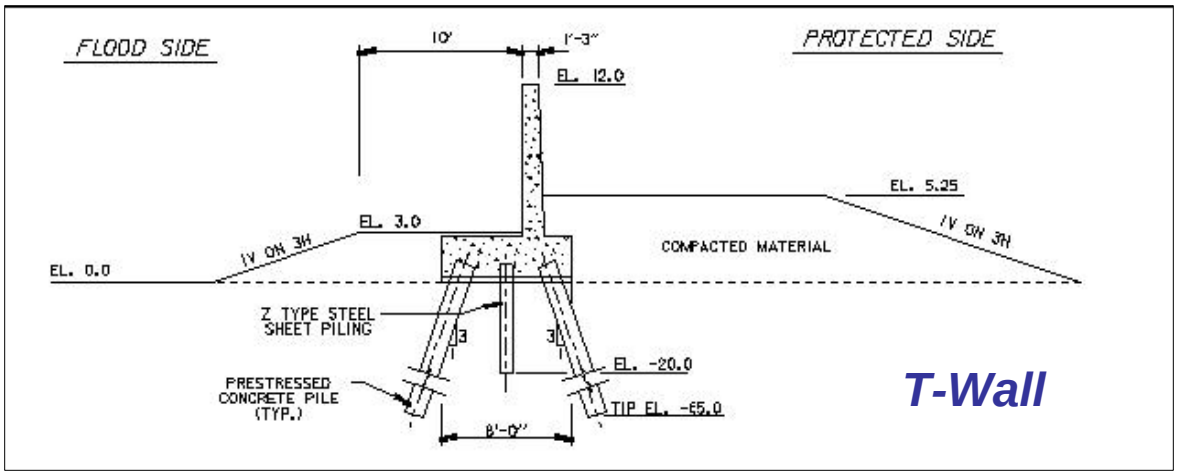
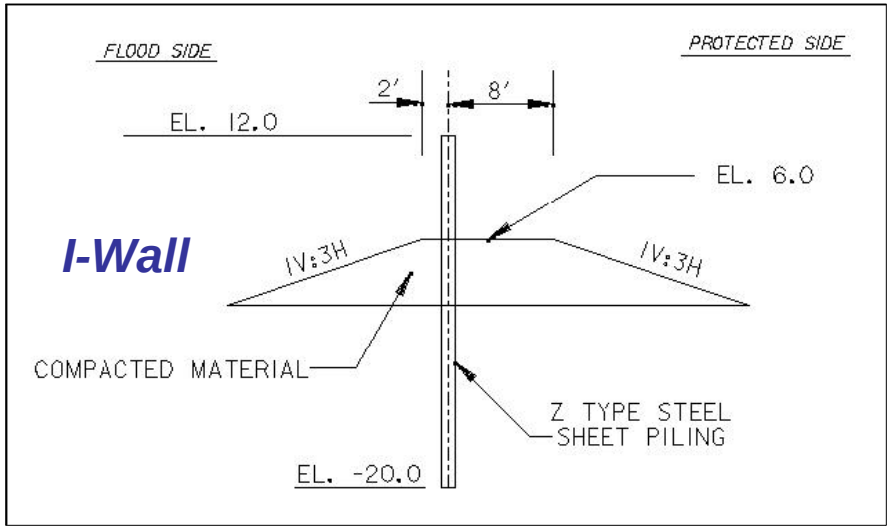


The HPS

- Begun in **1965**
- Scheduled for completion in **2015**
- 350 miles in length
- 12-15 feet above MSL





- 284 miles of federal levees
- 66 miles of non-federal levees
- 56 miles of I-wall
- 2 miles of T-wall

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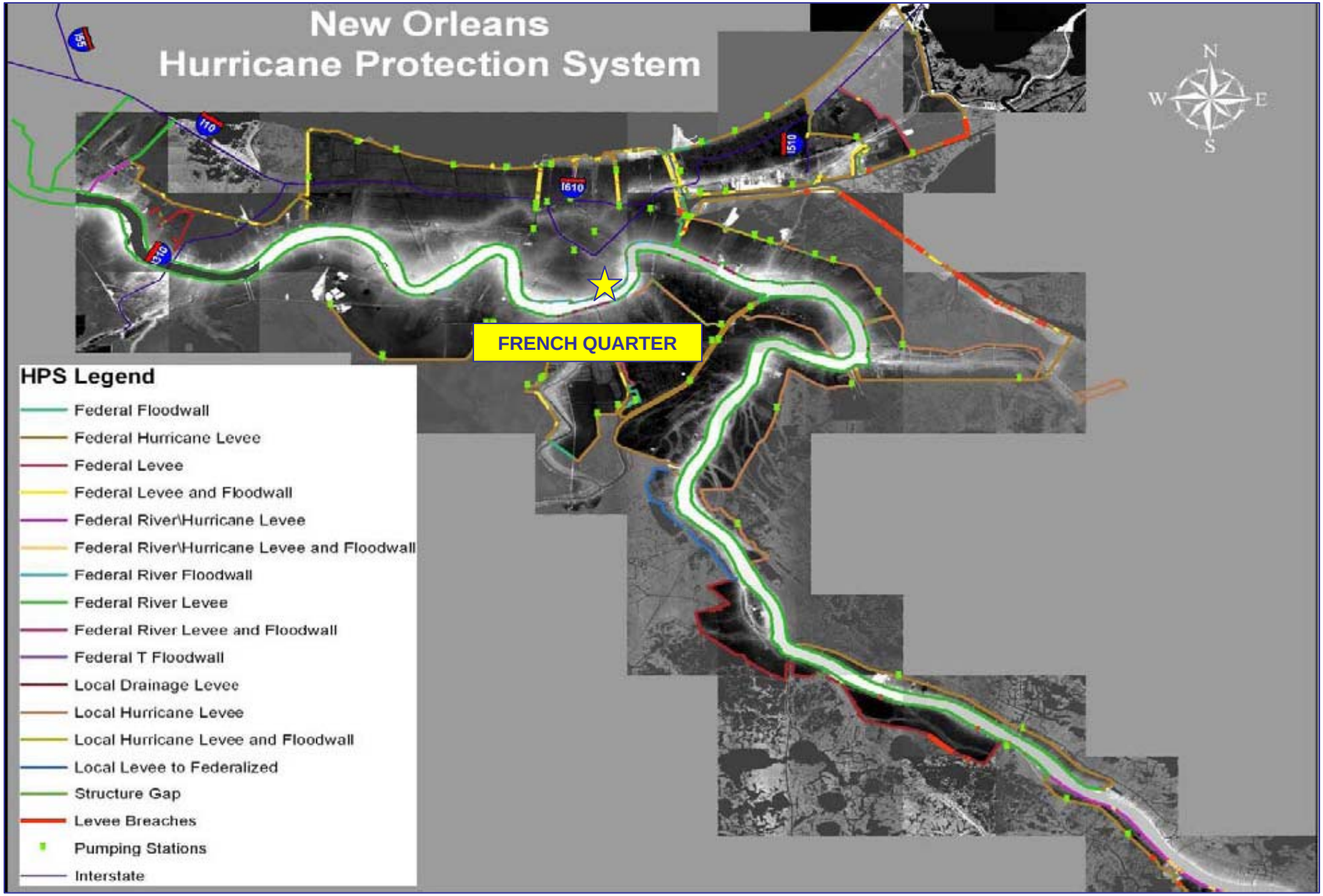
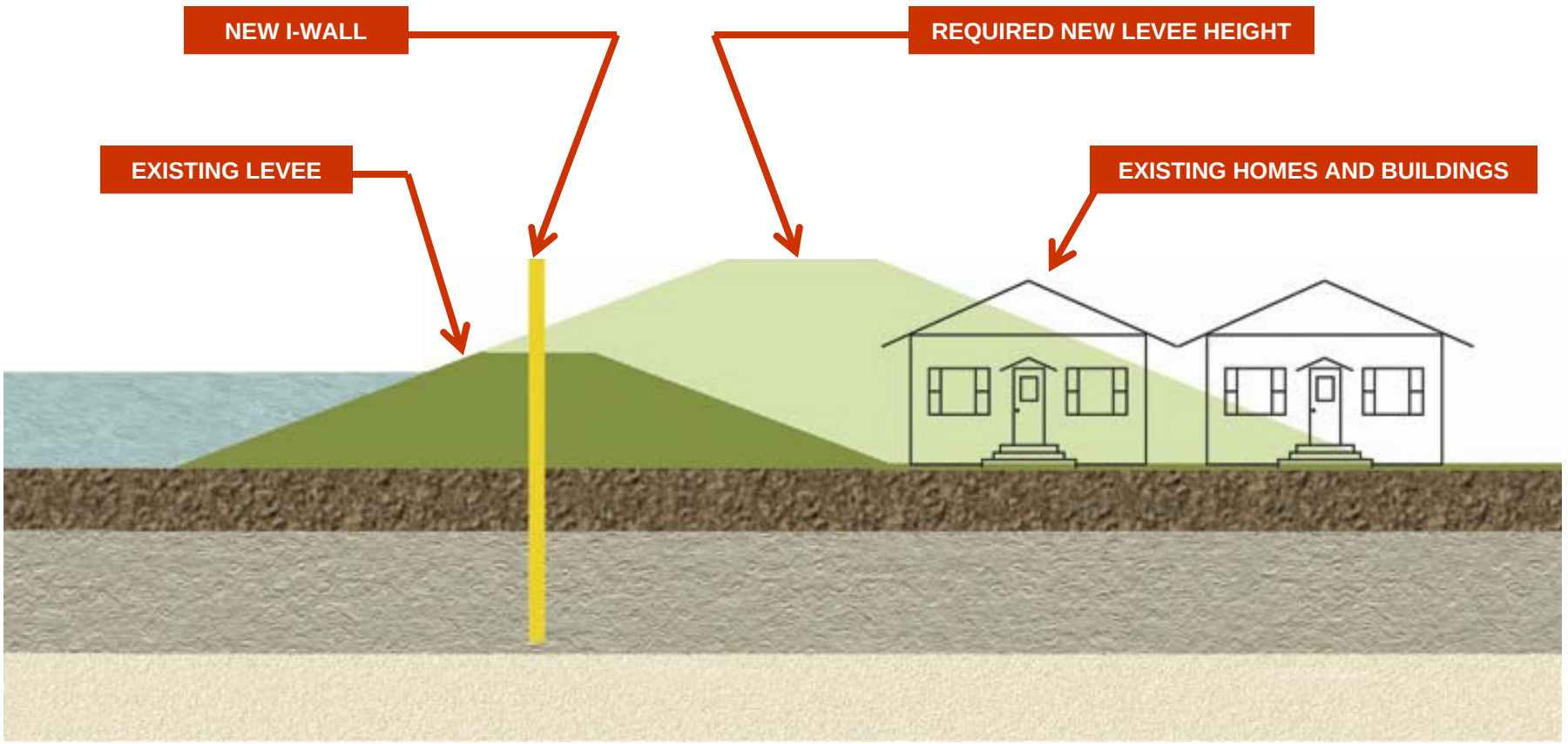

New Orleans
Hurricane Protection System
FRENCH QUARTER
HPS Legend
Federal Floodwall
Federal Hurricane Levee
Federal Levee
Federal Levee and Floodwall
Federal River\Hurricane Levee
Federal River\Hurricane Levee and Floodwall
Federal River Floodwall
Federal River Levee
Federal River Levee and Floodwall
Federal T Floodwall
Local Drainage Levee
Local Hurricane Levee
Local Hurricane Levee and Floodwall
Local Levee to Federalized
Structure Gap
Levee Breaches
Pumping Stations
Interstate
N
W
E
S
I10
I610
I510
I310



Raising the height of an earth levee

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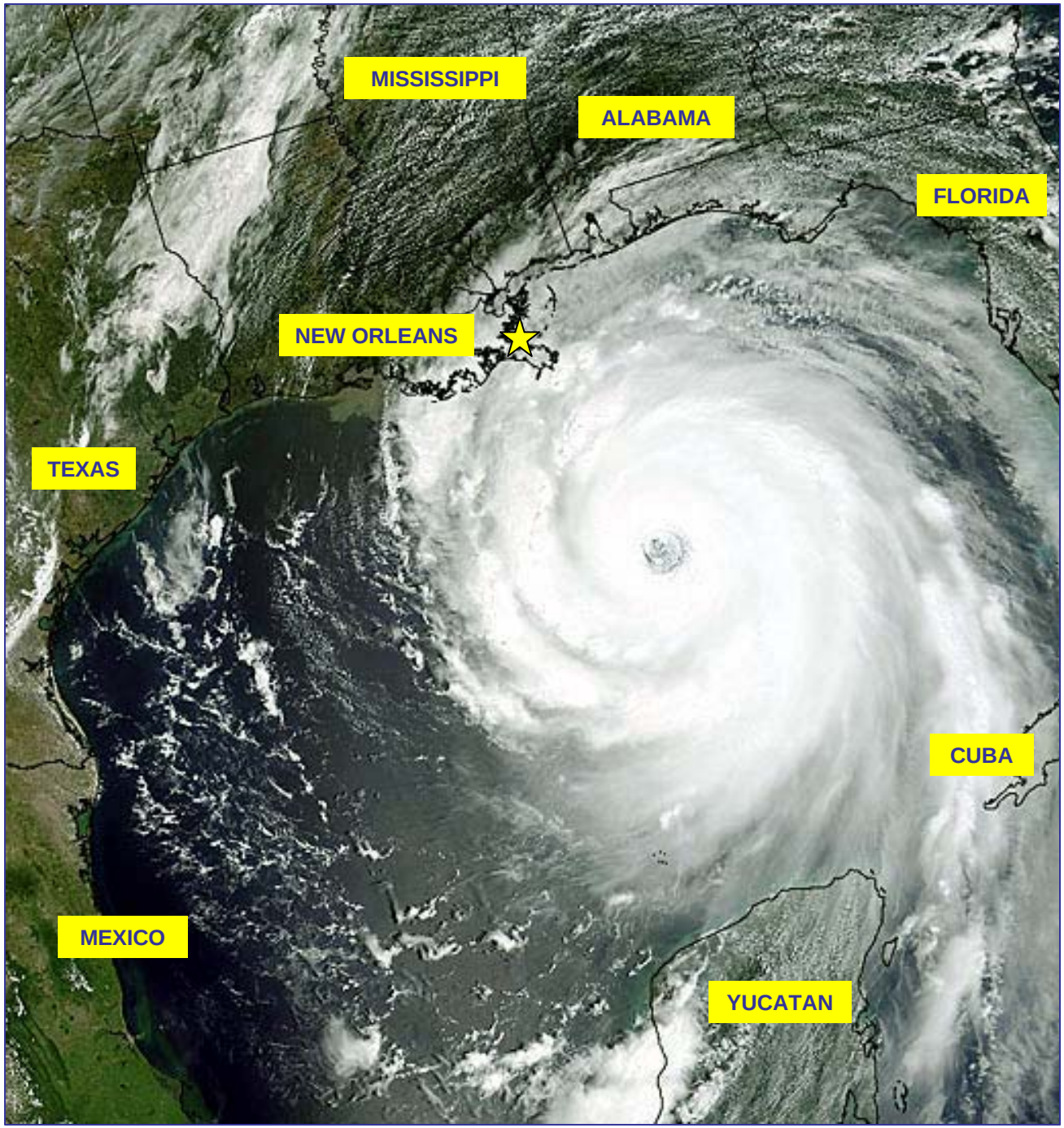

Hurricane Katrina

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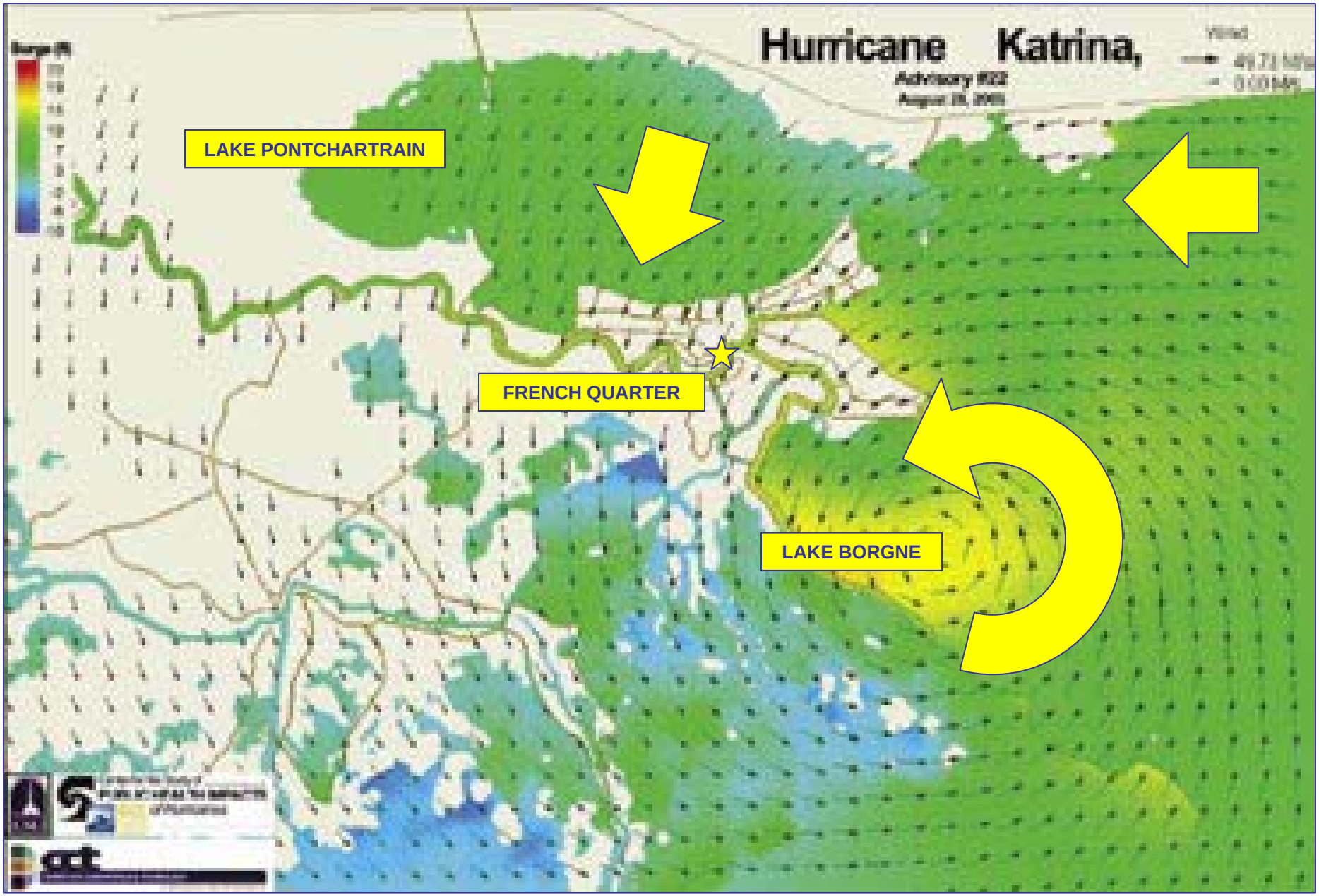
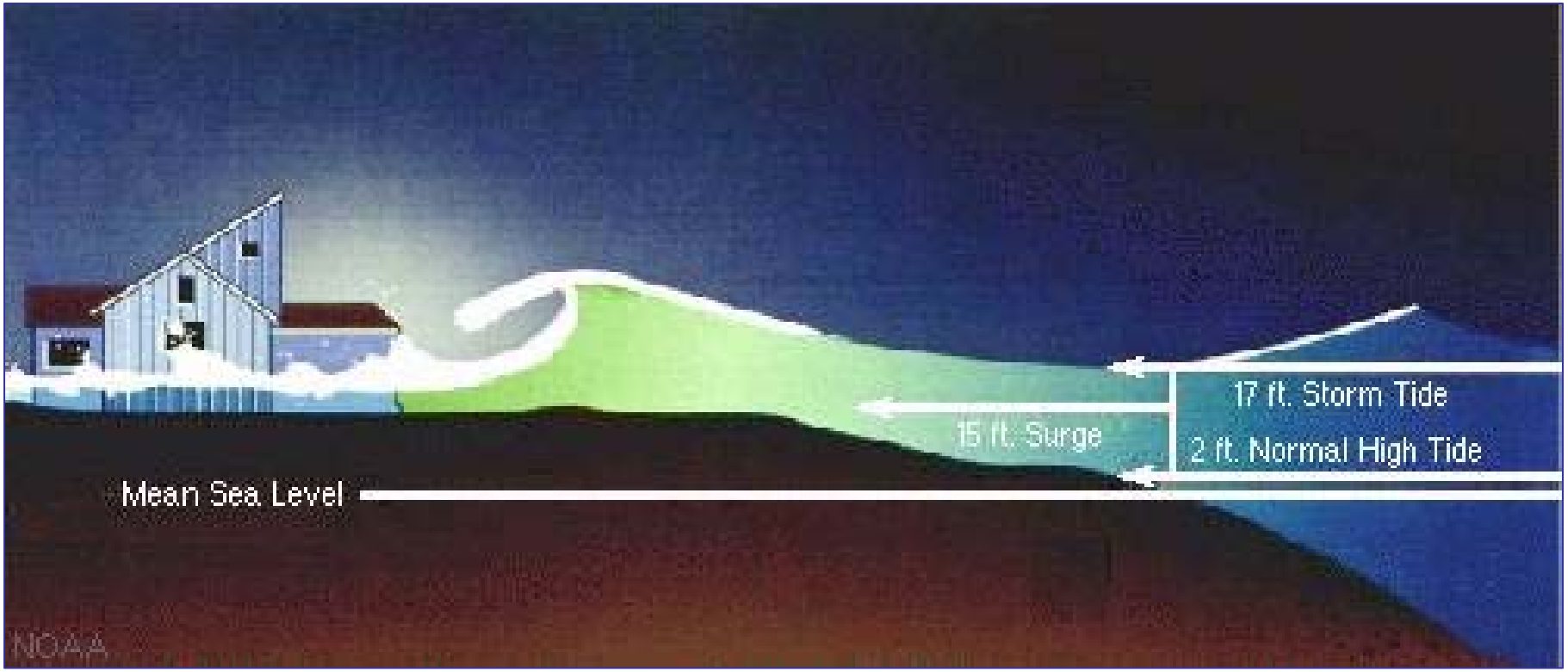


Wind vectors



Storm surge

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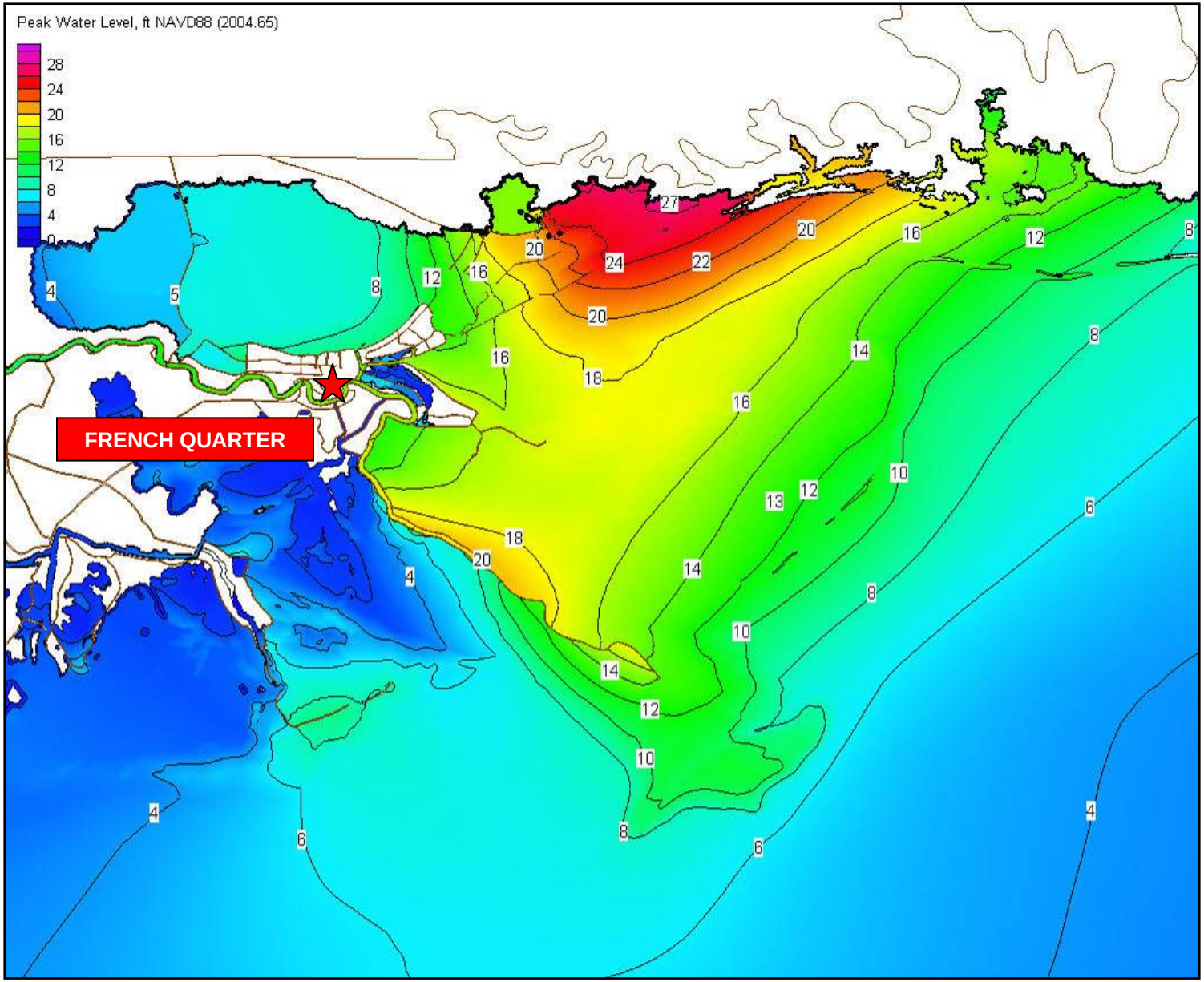

Storm surge

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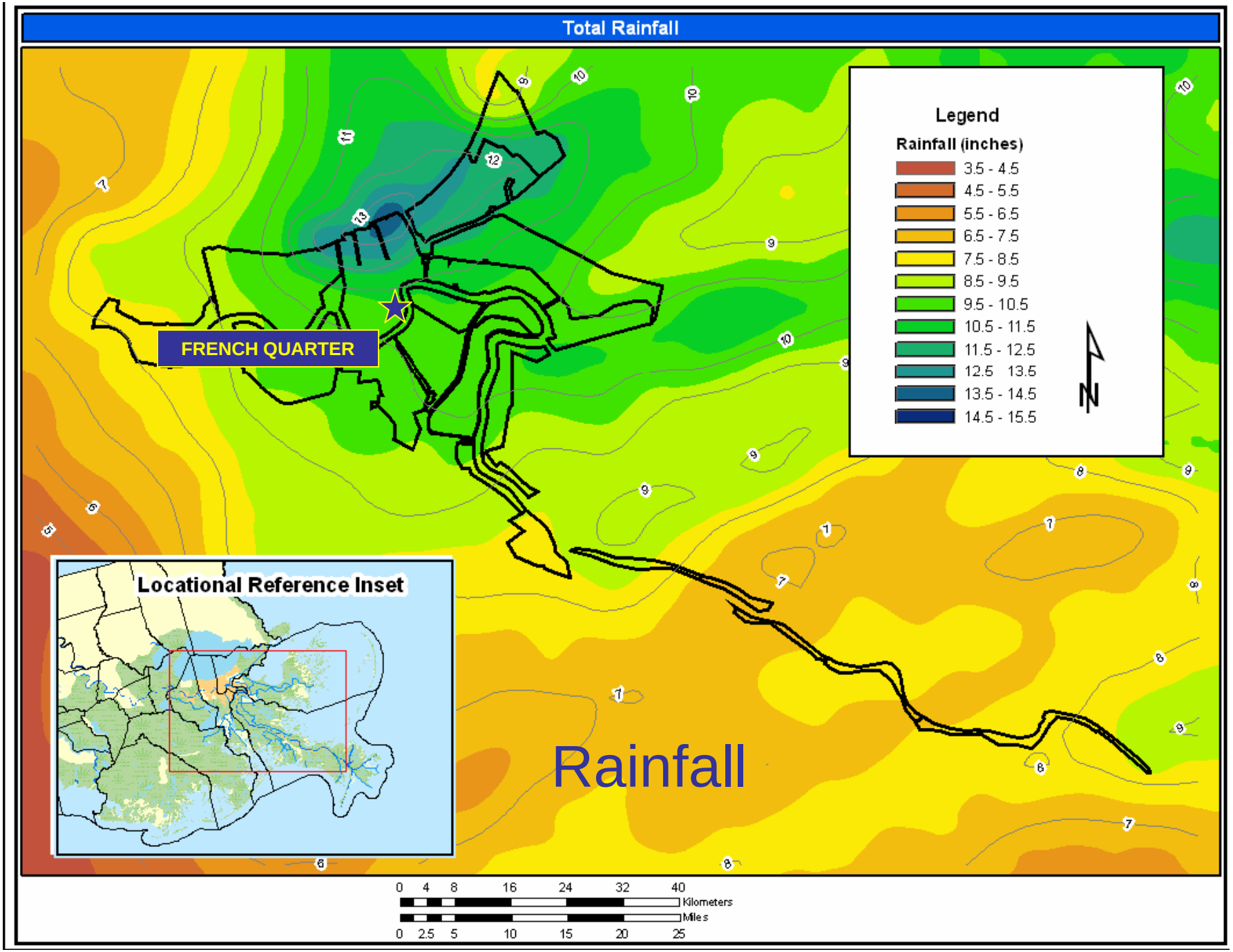
Total Rainfall
Legend
Rainfall (inches)
3.5 - 4.5
4.5 - 5.5
5.5 - 6.5
6.5 - 7.5
7.5 - 8.5
8.5 - 9.5
9.5 - 10.5
10.5 - 11.5
11.5 - 12.5
12.5 13.5
13.5 - 14.5
14.5 - 15.5
N
FRENCH QUARTER
Locational Reference Inset
Rainfall
0 4 8 16 24 32 40
Kilometers
Miles
0 2.5 5 10 15 20 25

What Went Wrong

The catastrophe was born out of a failure to recognize

- How fragile the levees were
- How devastating the consequences would be

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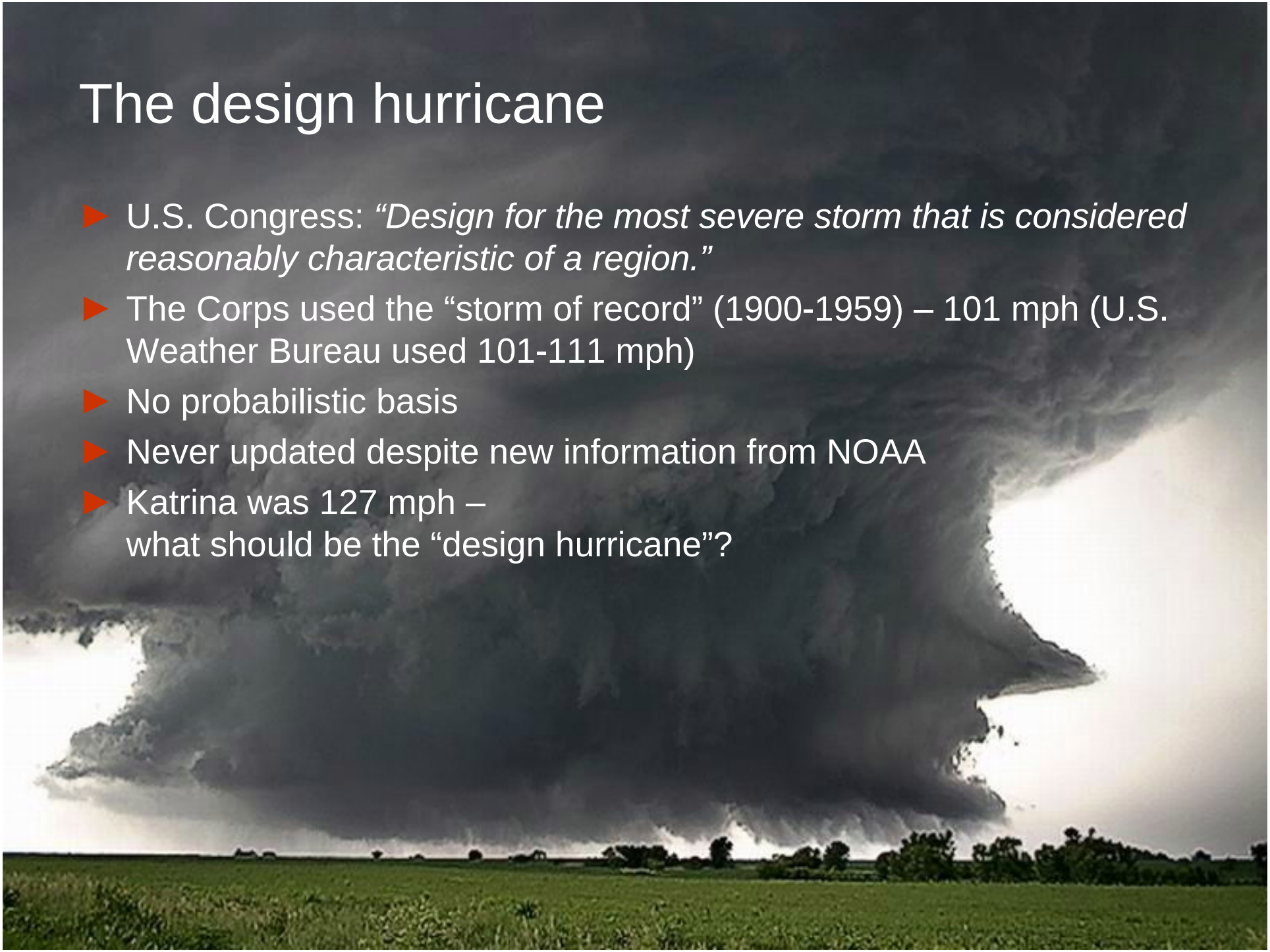
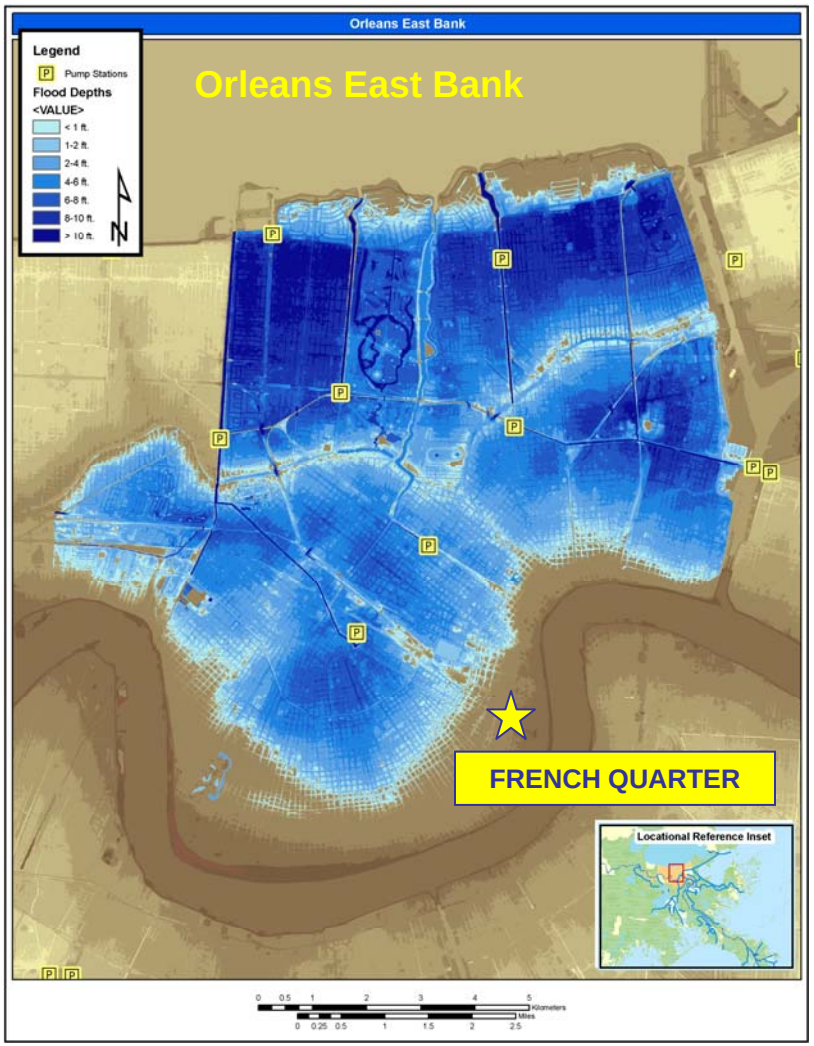
The design hurricane

- U.S. Congress: *“Design for the most severe storm that is considered reasonably characteristic of a region.”*
- The Corps used the “storm of record” (1900-1959) – 101 mph (U.S. Weather Bureau used 101-111 mph)
- No probabilistic basis
- Never updated despite new information from NOAA
- Katrina was 127 mph –
  what should be the “design hurricane”?

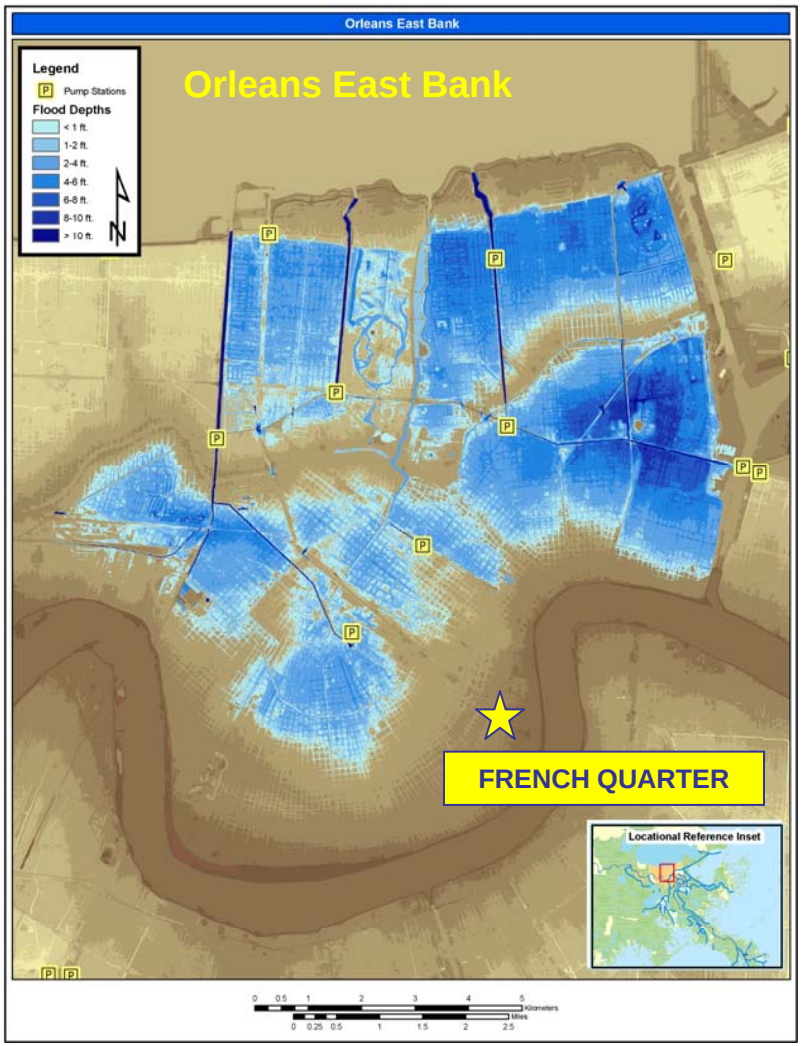


Katrina simply overwhelmed the HPS

- The storm exceeded the design, but the constructed project did not meet the design intent
- 169 miles of damaged levees
- 50 breaches, which increased flooding by at least 300 percent



- Breaching



- No breaching

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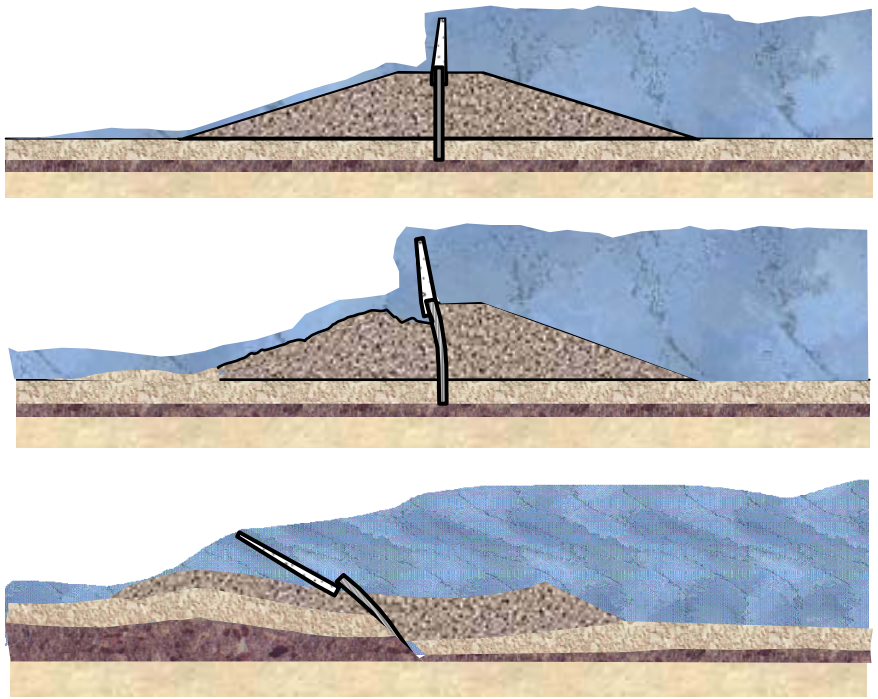
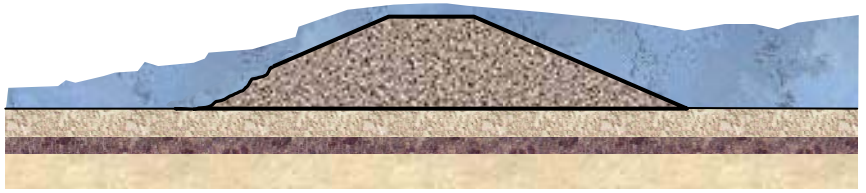
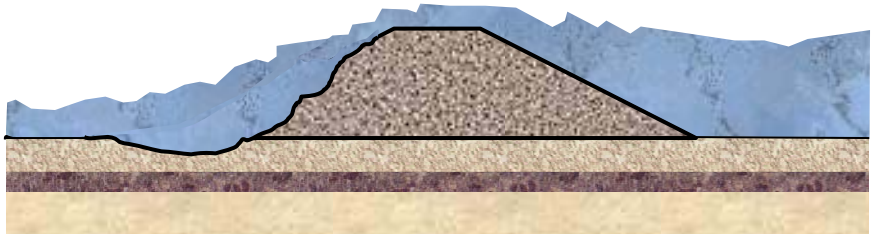
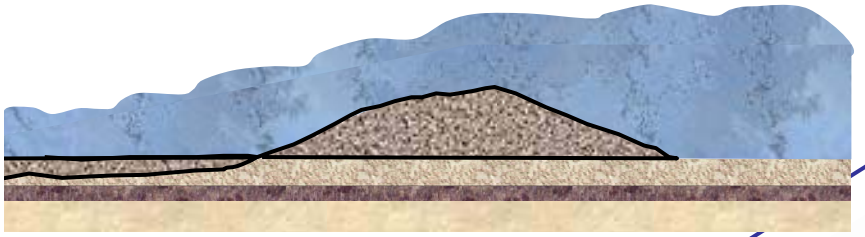
Two direct causes of breaching

- Uncontrolled overtopping and ensuing erosion led to catastrophic failure of levees and floodwalls









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Katrina’s surge in East Orleans

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- Four I-walls collapsed before water reached design levels – designs failed to account for:
  - Variability in soil strength
  - Wall deformation, which opened a water-filled gap on the flood side
  - Critical water pressures beneath the levees

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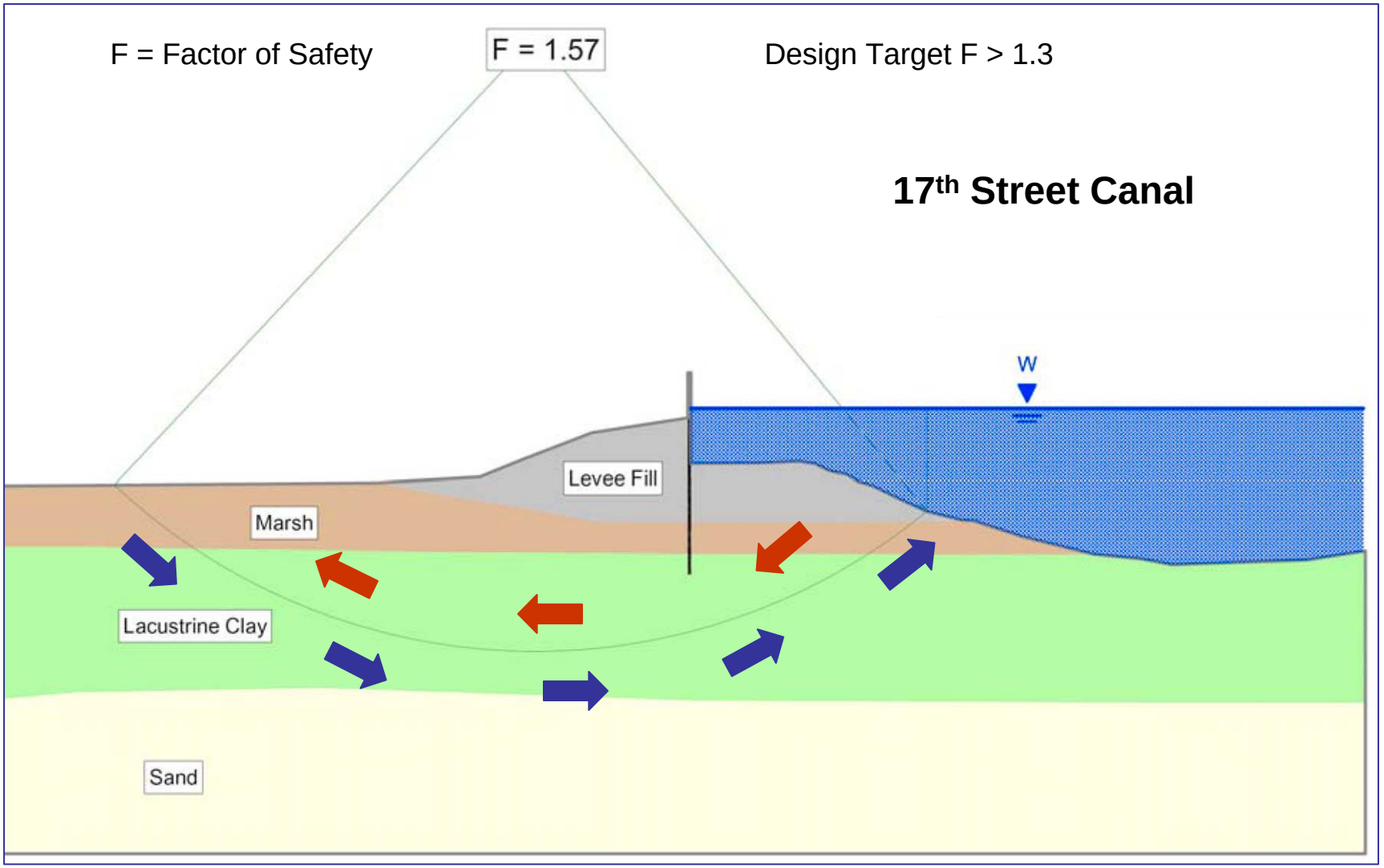
17th Street Canal

F = Factor of Safety



$$F = \frac{\text{Shear Strength}}{\text{Shear Stress}}$$

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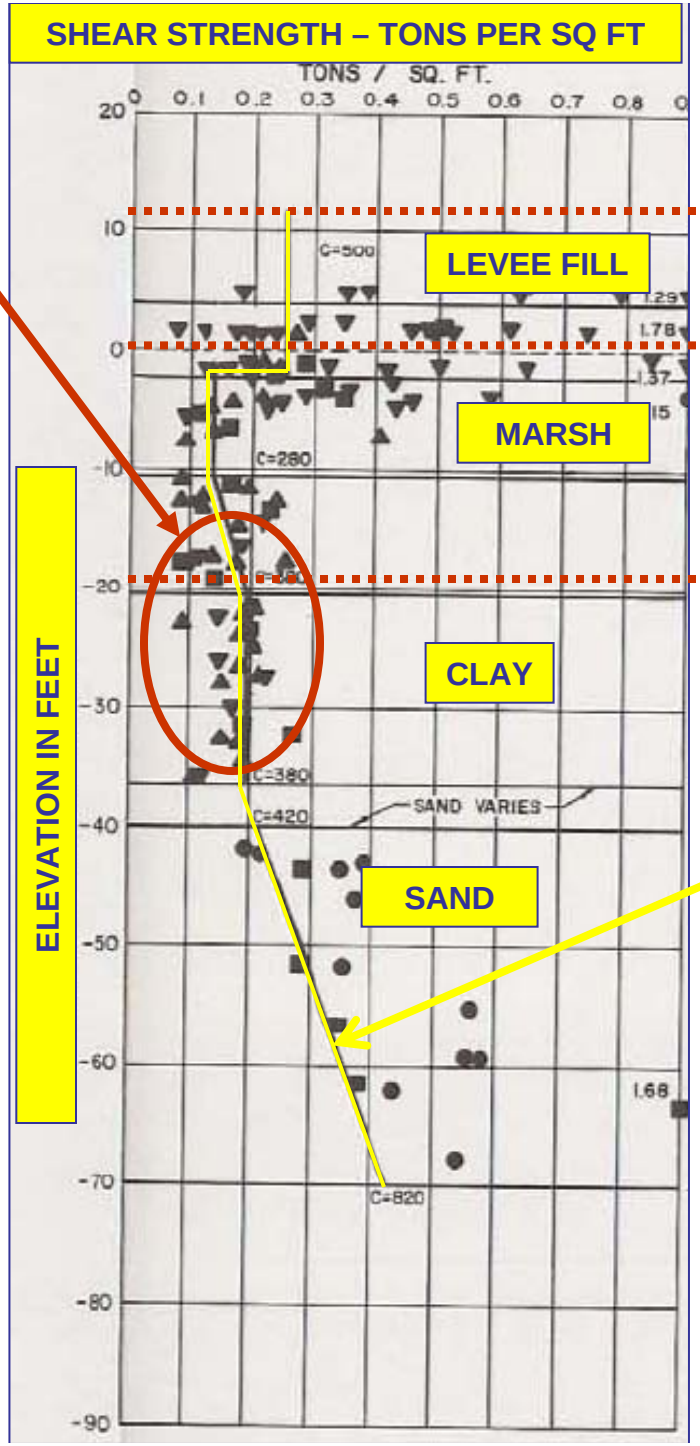

Shear strength

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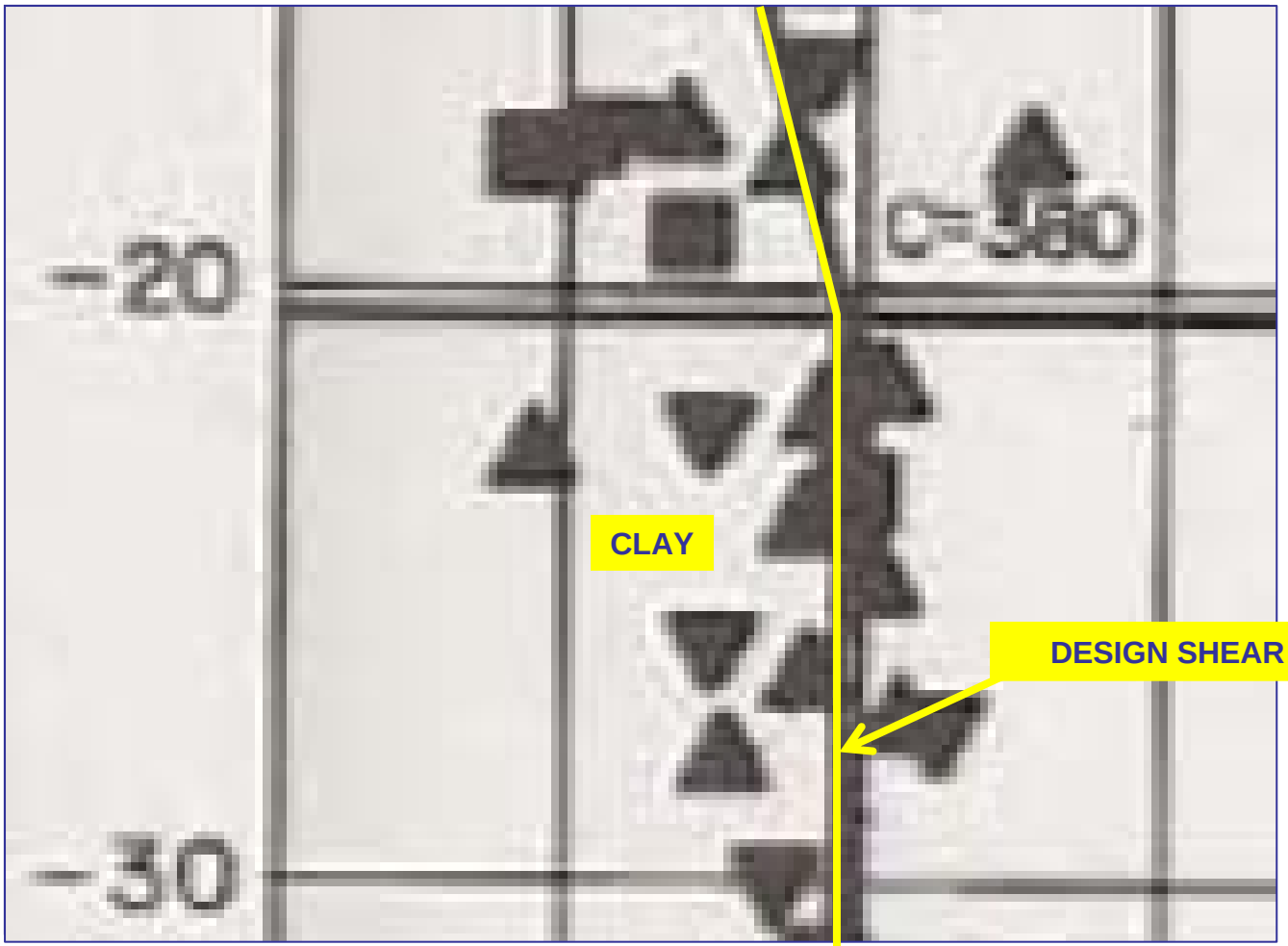
Un-conservative estimate of soil strength



ELEVATION IN FEET

CLAY

DESIGN SHEAR STRENGTH ENVELOPE

0 0.1 0.2 0.3

SHEAR STRENGTH – TONS PER SQ FT

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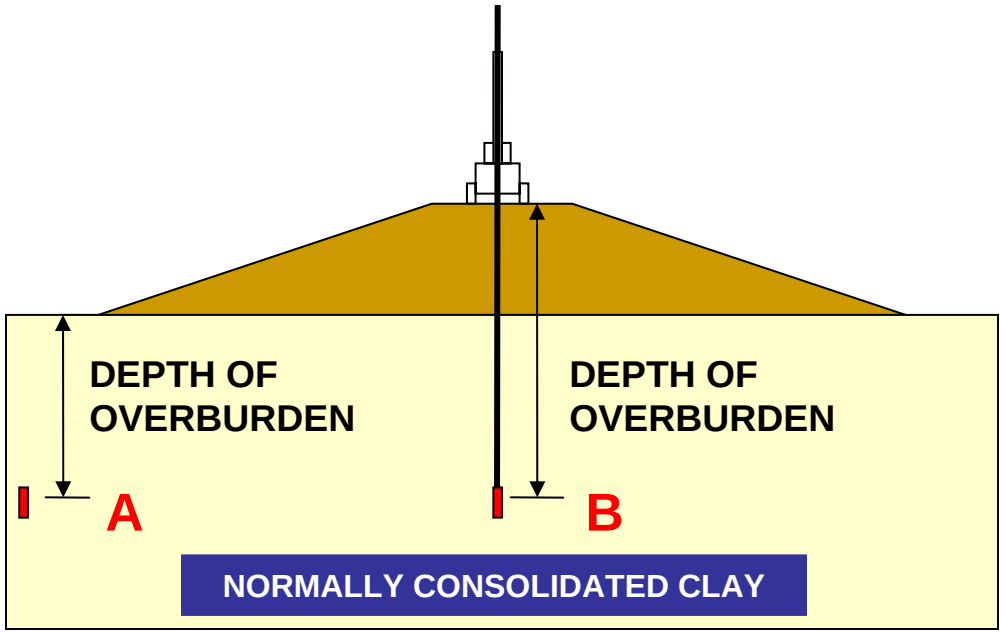

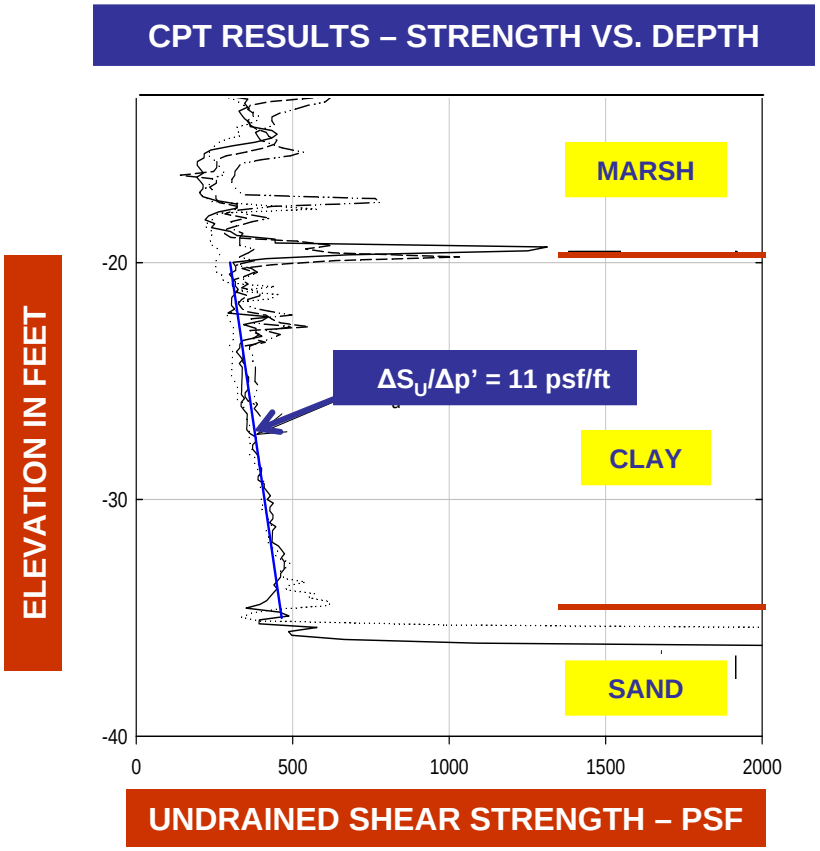

- Borings made at levee centerline
- Designer assumed A and B to have equal strength
- But, strength = *fn* (depth of overburden) for a normally consolidated clay
- So, the strength at A << strength at B

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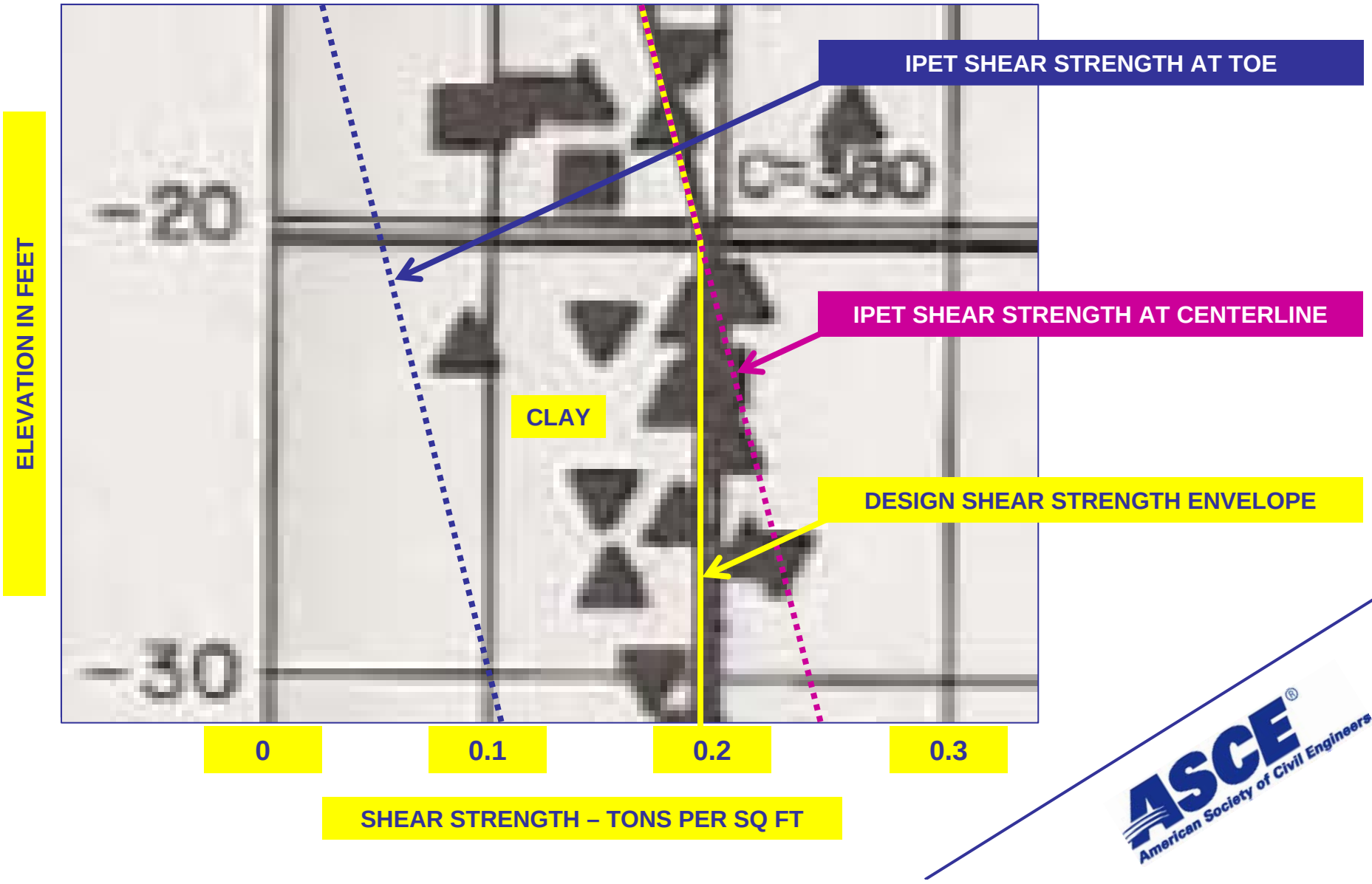
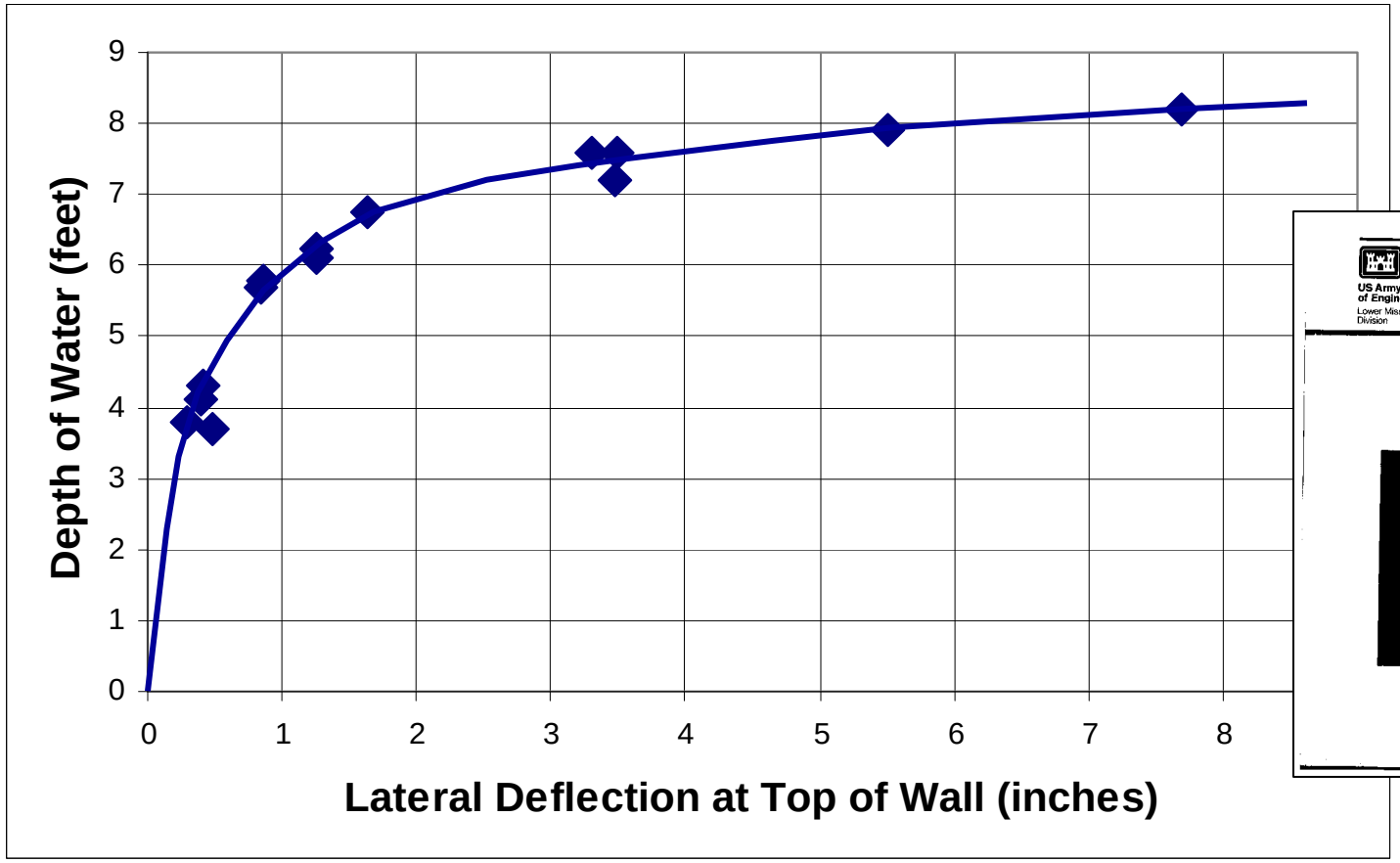
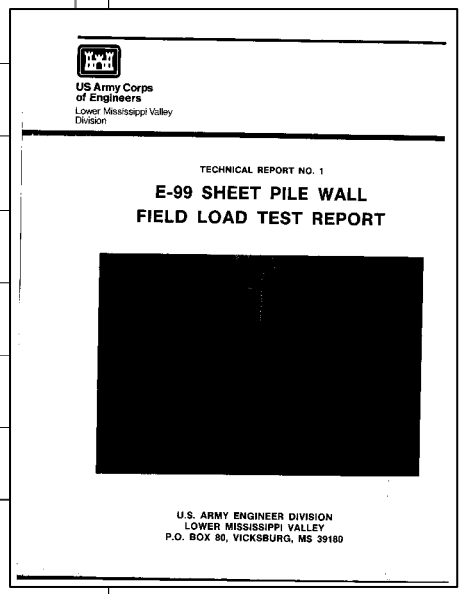
Un-conservative estimate of soil strength



The Corps ignored its own research on I-walls





- From the E-99 report: “Although the test wall was not loaded to ‘failure,’…failure may have been imminent.”

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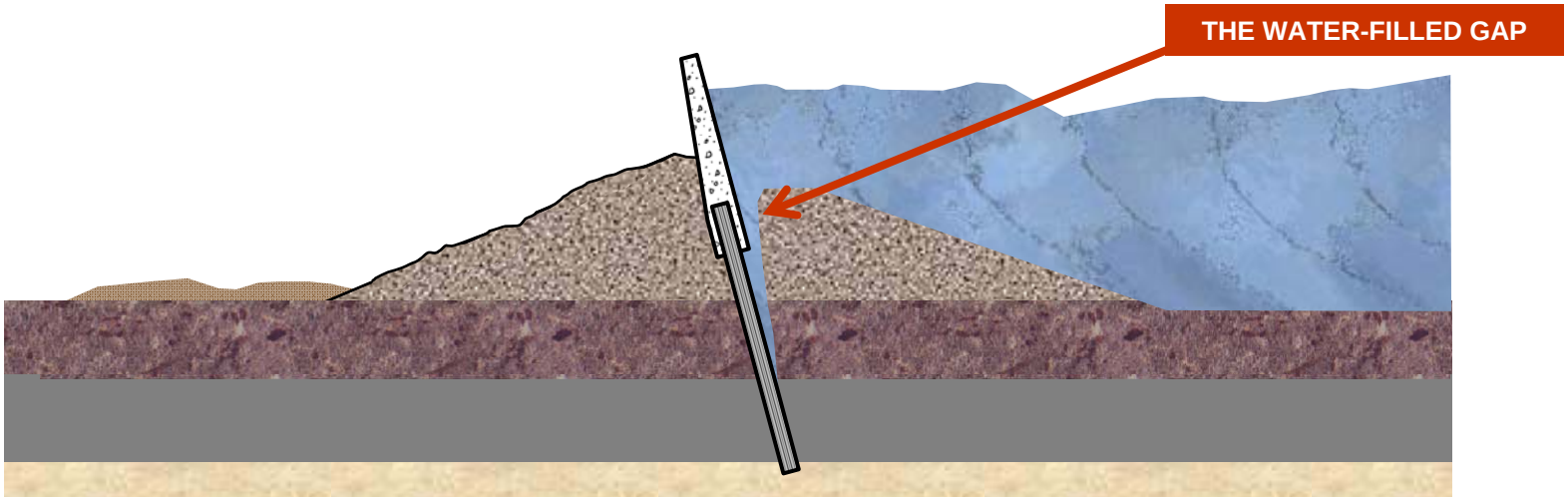

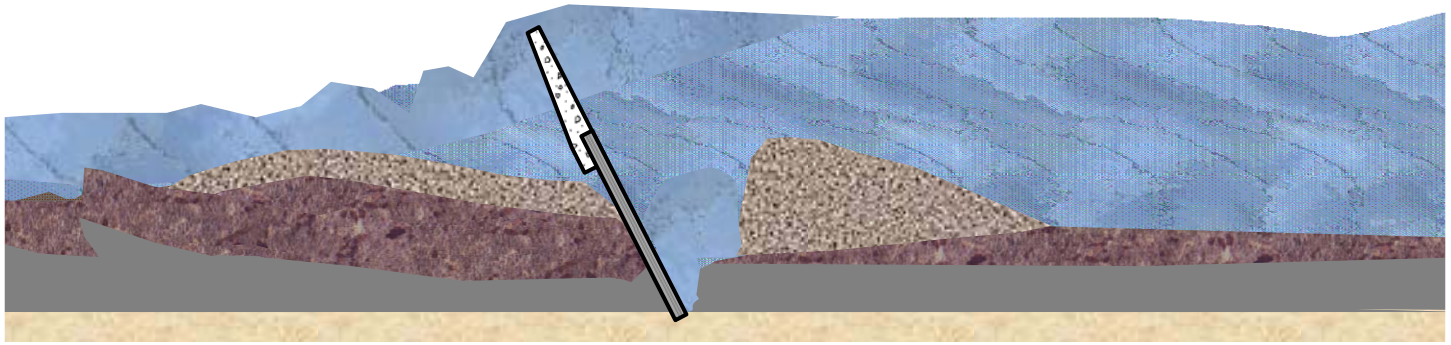

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THE WATER-FILLED GAP

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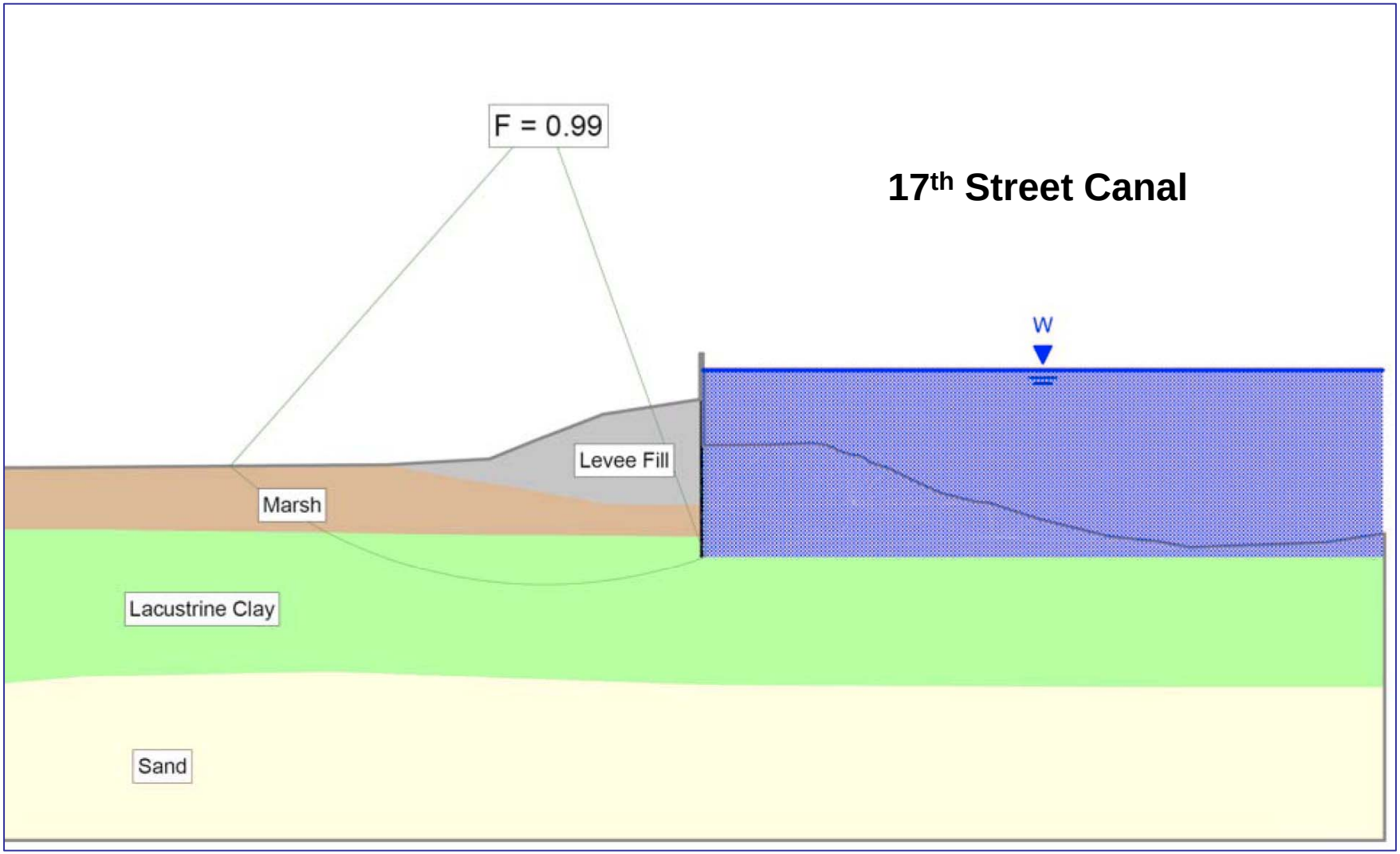

- Strengths over-estimated
- Loads under-estimated
- F < 1

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London Avenue – North

London Avenue – South

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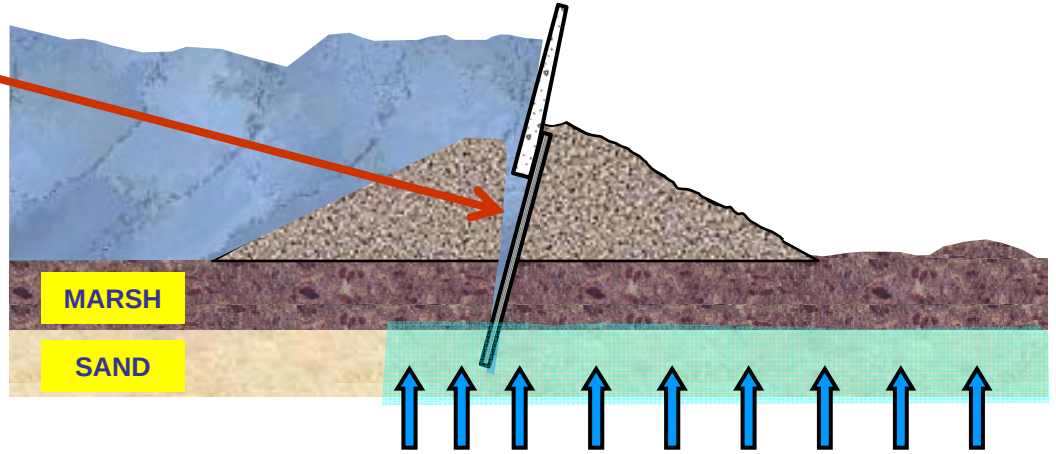
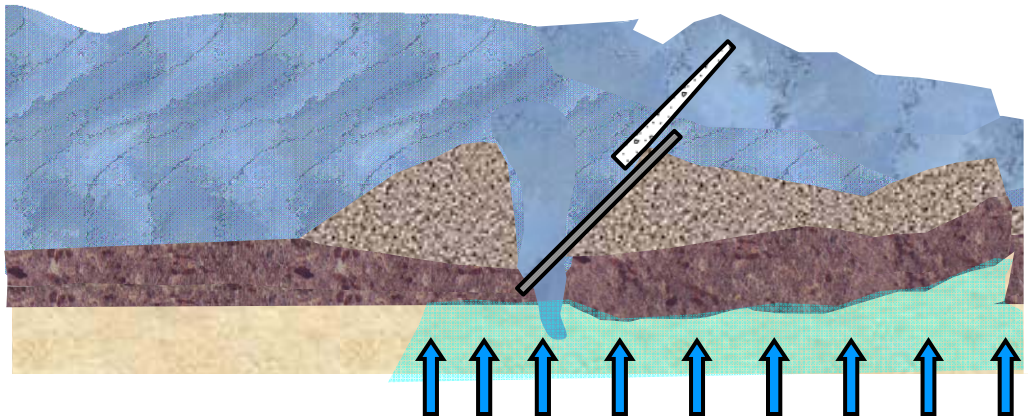
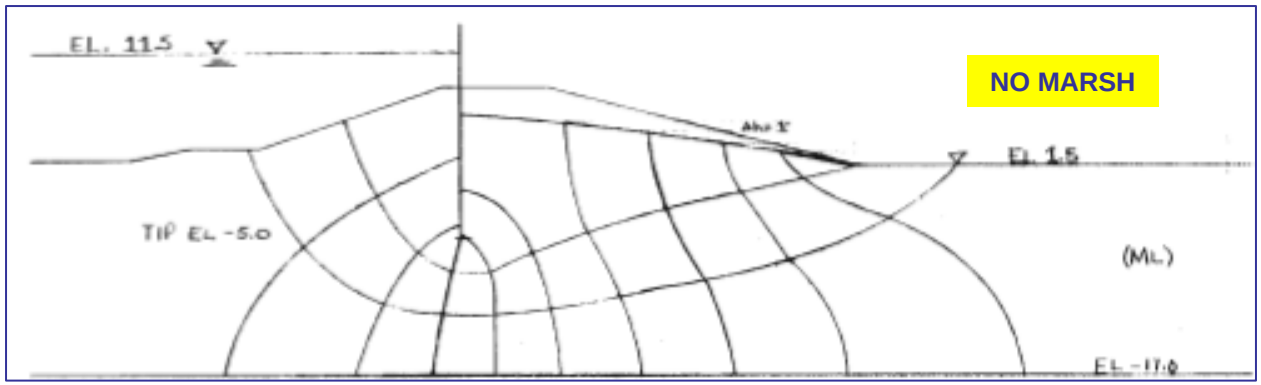
THE WATER-FILLED GAP



- With a proper flow net
  - FS = 0.8-1.05 (no water-filled gap)
  - FS = 0.74-0.89 (with water-filled gap)



DESIGN FLOW NET



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Contributing causes

- The HPS was a system in name only
- The management of the HPS was chaotic and dysfunctional
  - Multiplicity of jurisdictions
  - No one person or entity was in charge
- Questionable land use decisions allowed building homes up to 10 feet (3 m) below sea level
- Broader protection strategies were blocked by court orders and local opposition
- Pressure at all levels to cut costs ended up compromising safety
- Numerous penetrations were left “open” during the storm

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GATE

I-WALL

EARTH LEVEE

DESIGN LEVEE HEIGHT

ORLEANS LEVEE DISTRICT

STATE OF LOUISIANA

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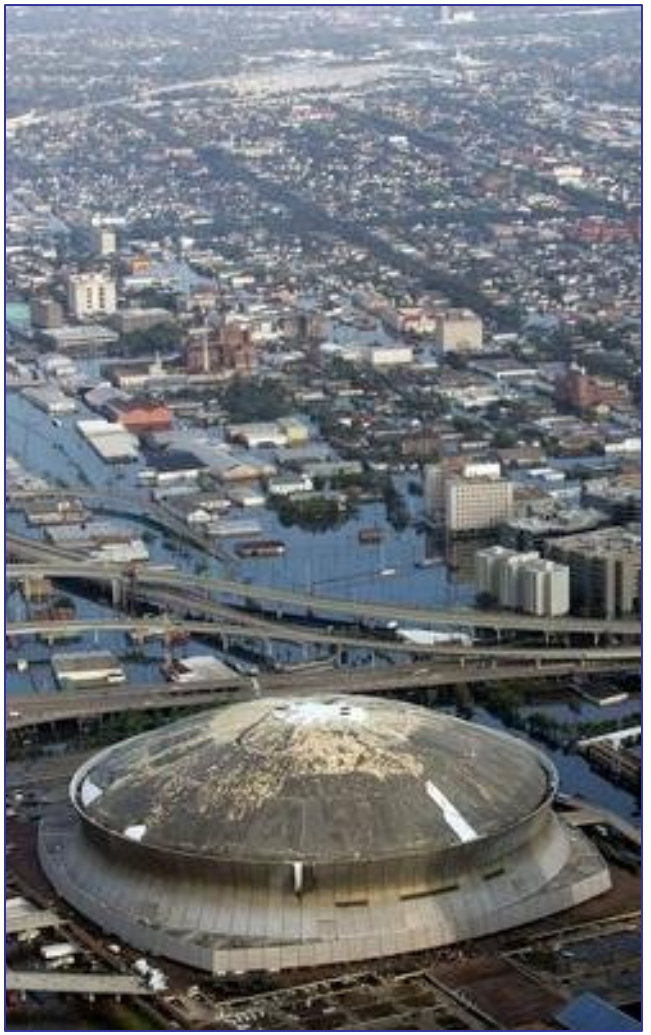
Contributing causes

- Most levees were >2 feet too low
  - The vertical datum was inaccurate and never updated
  - Regional subsidence was ignored
- The margin of safety was too low at each step of the way
- There was no independent review
- The pumping system, designed for rainfall events, was useless
- Construction was piecemeal over 40 years leaving some sections too low, or incomplete
- Risk was never quantified, communicated, or taken into account in a rigorous way
- By omission or commission, the HPS was not considered a critical life-safety system



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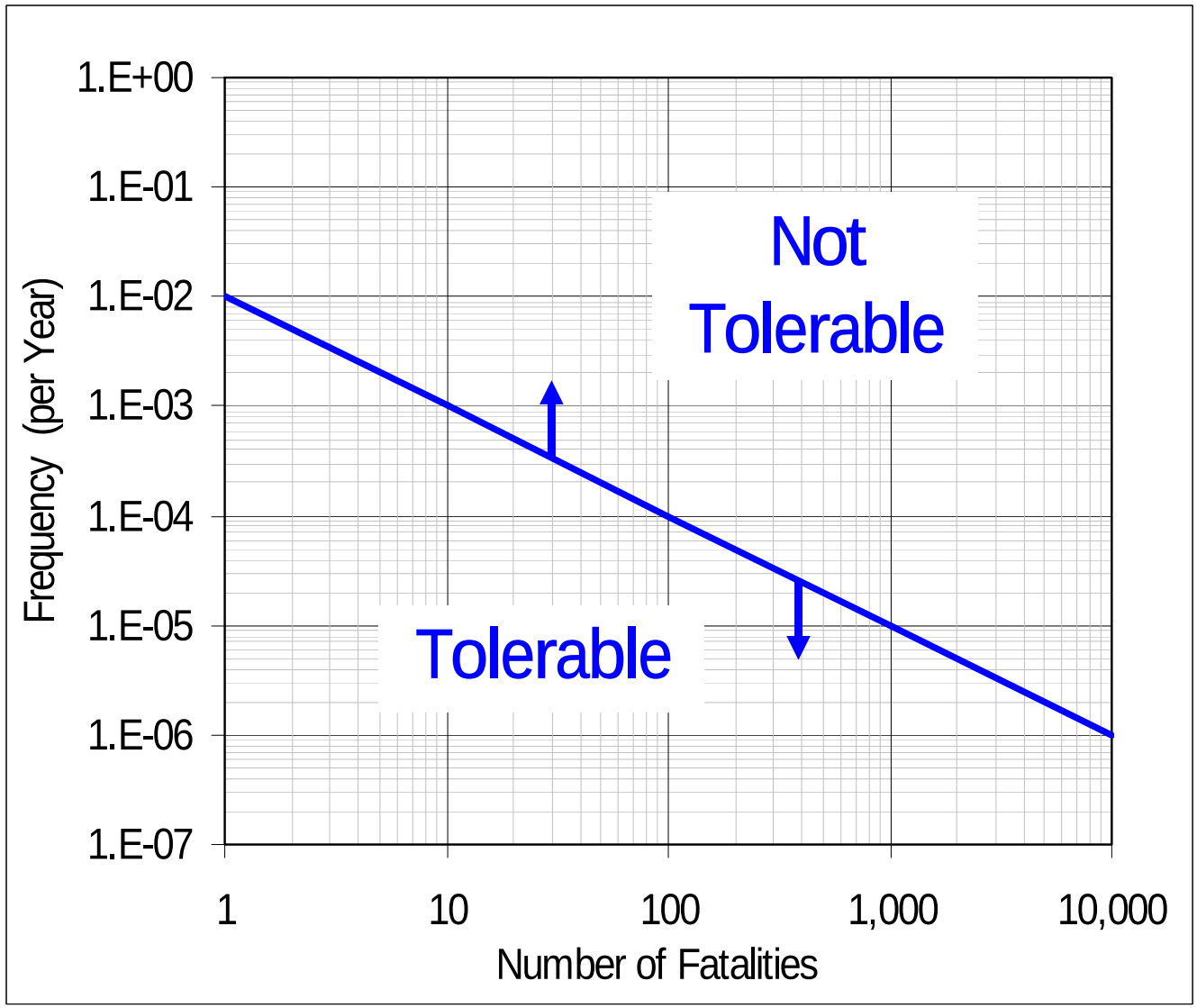
The risk to people was misunderstood



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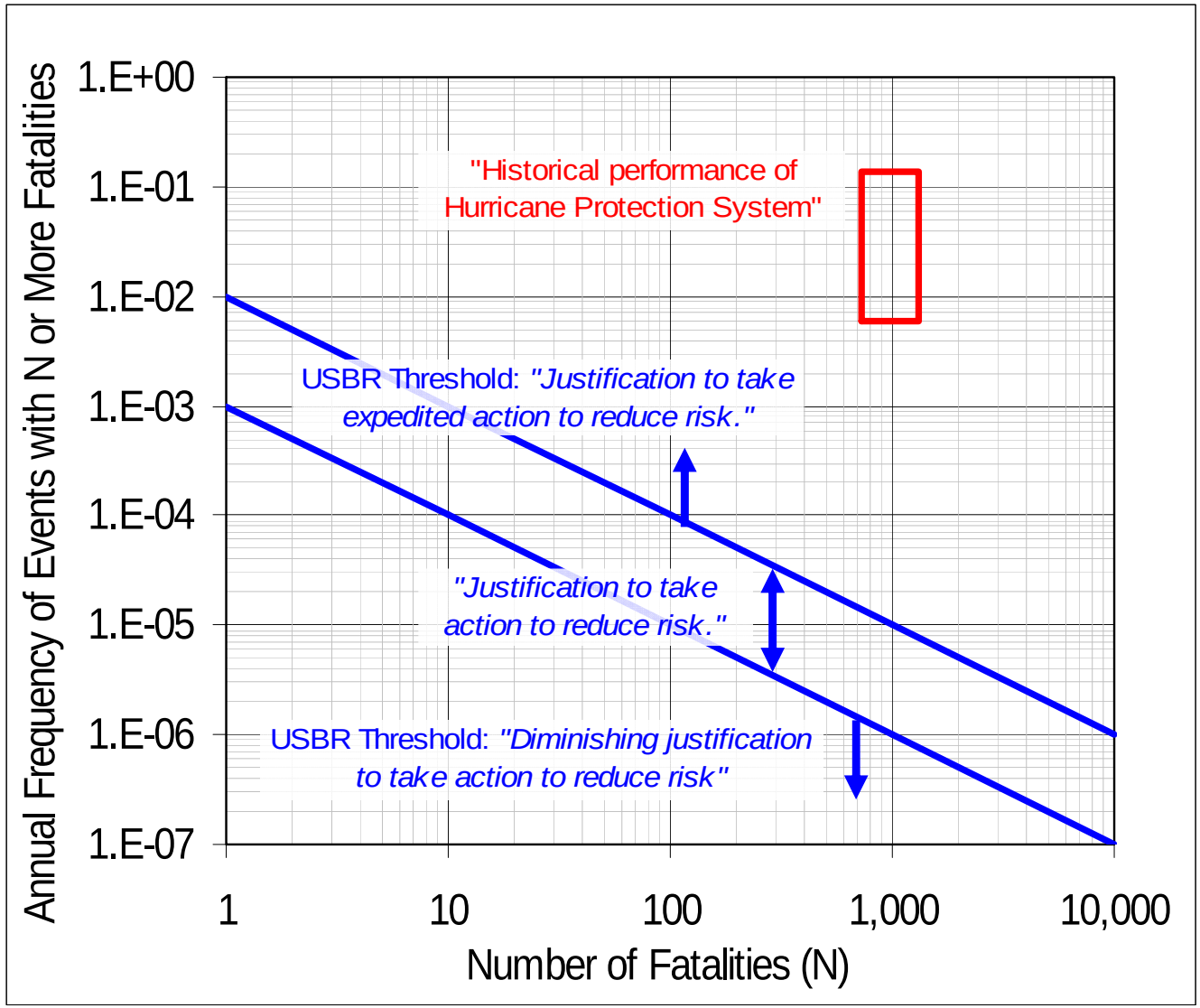
USBR guidance for large dams



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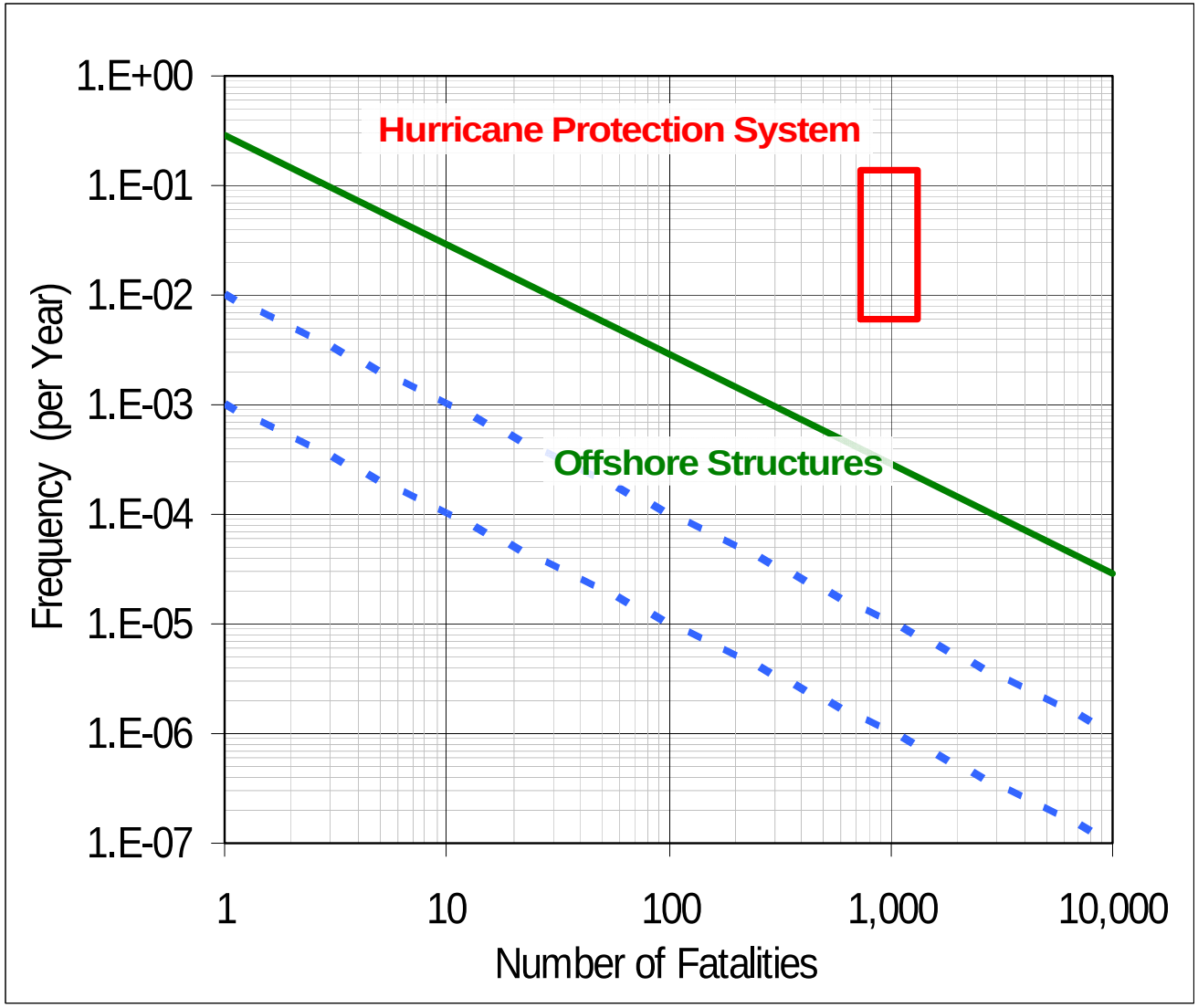
Guidance for offshore structures in the Gulf



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Offshore structures

- $30 billion in damages
- 100 percent evacuation
- 0 fatalities

NOLA HPS

- $100+ billion in damages
- 80 percent evacuation
- >1100 fatalities

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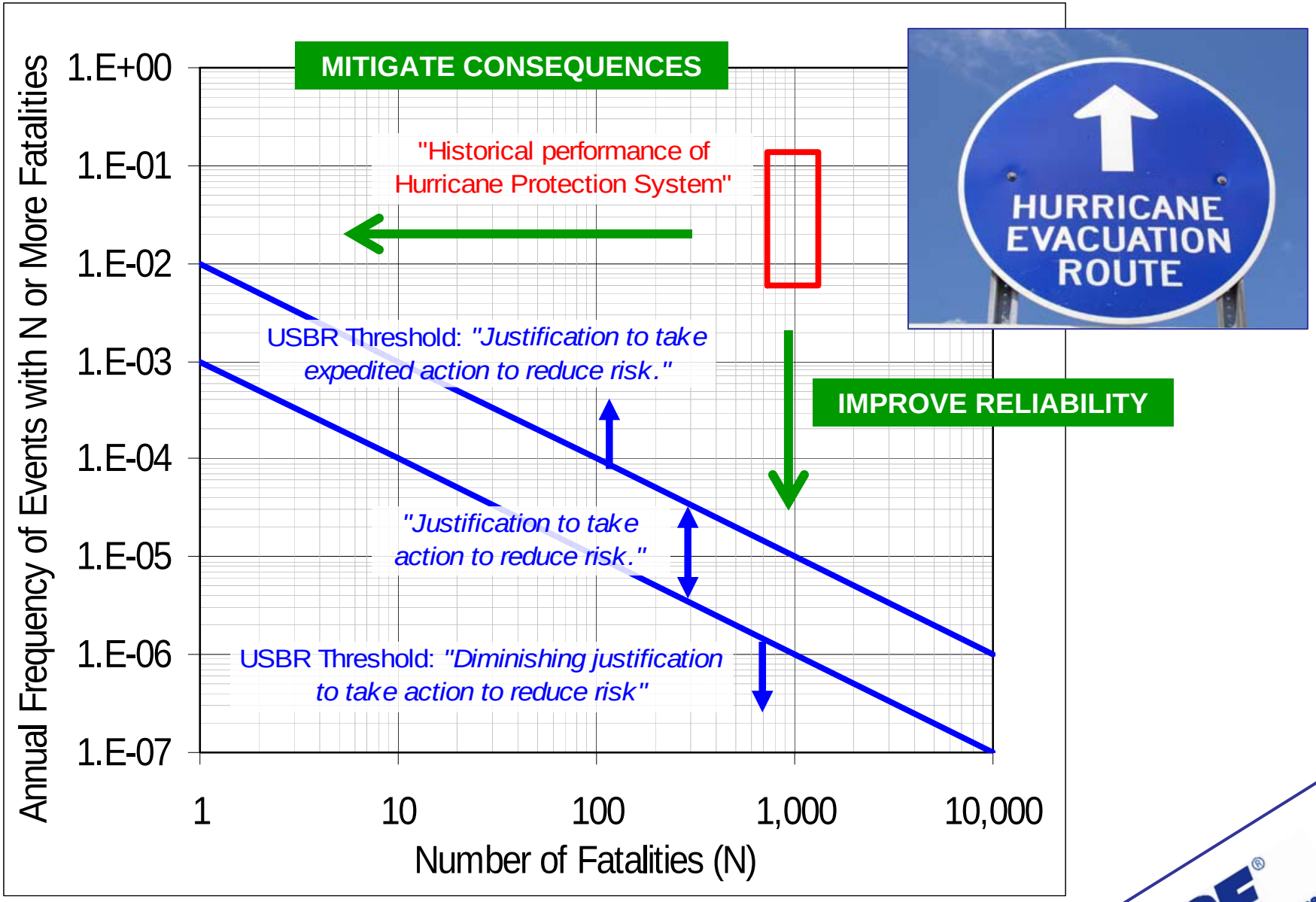

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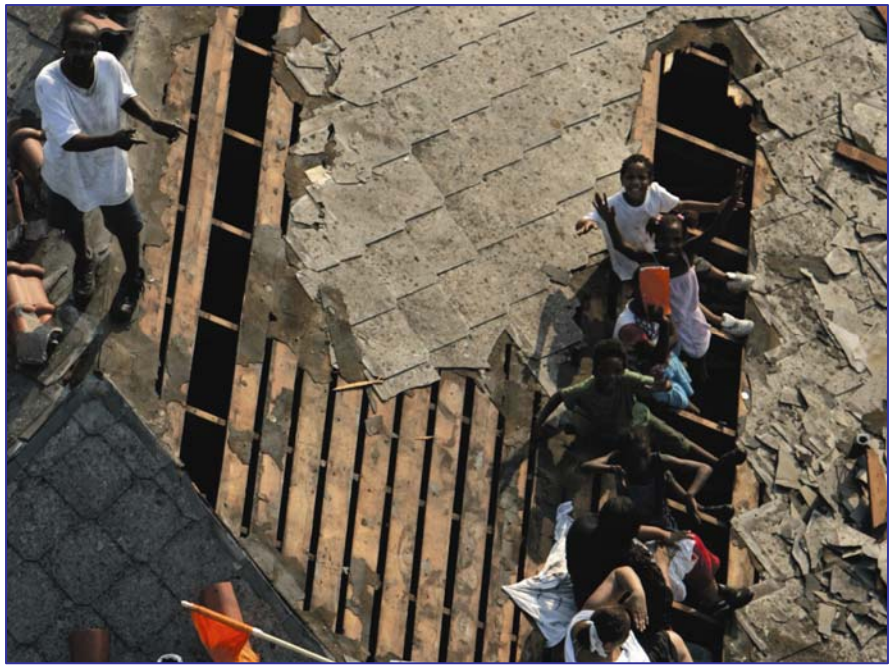
Eric Holdeman on the four stages of denial

- It won't happen
- If it happens, it won't happen to me
- If it happens, and it happens to me, it won't be so bad
- If it happens, and it happens to me, and it's bad, there is nothing I can do to stop it anyway



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The HPS was severely compromised by

- Questionable engineering decisions
- Inadequate and dysfunctional interfaces between organizations
- A political culture that:
  - Did not understand the potential for catastrophe
  - Was unwilling to pay the price
  - Put life-threatening risk on the back burner

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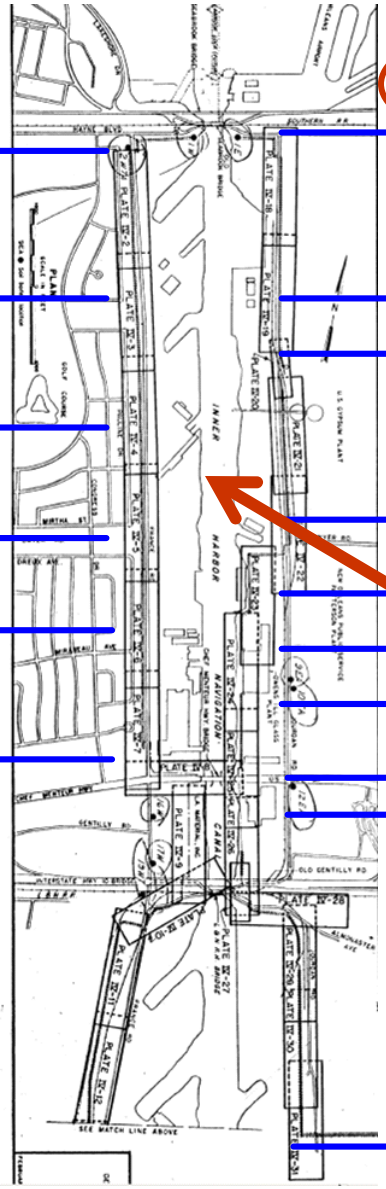
Ten Lessons Learned

1. Failure to think globally, act locally



CURRENT ELEV	DESIGN ELEV
12.5	14.0
12.0	14.25
12.5	14.5
12.8	14.75
12.5	15.0
12.7	varies

DESIGN ELEV	CURRENT ELEV
14.0	11.9
14.25	12.0
14.5	12.1
14.75	12.7
15.0	12.8
14.5	13.0
15.0	12.5
14.5	12.3
15.0	11.1 to 13.1

typically varies
1.5 to 2.5 feet

INNER HARBOR NAVIGATION CANAL

- Subsidence and vertical datum adjustments were not considered
- The Standard Project Hurricane was never updated

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We must

- Ensure that we account for issues that are beyond the bounds of a specific project – for example
  - Regional subsidence
  - Sea-level rise and climate change
  - Regional geologic hazards
  - Sustainability

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2. Failure to absorb new knowledge

- Geodetic elevations were not referenced to local MSL before new construction projects began
- Design criteria were based on assumptions and conditions made at the beginning of the HPS – no systematic updates were made
- The Corps ignored its own research on I-walls

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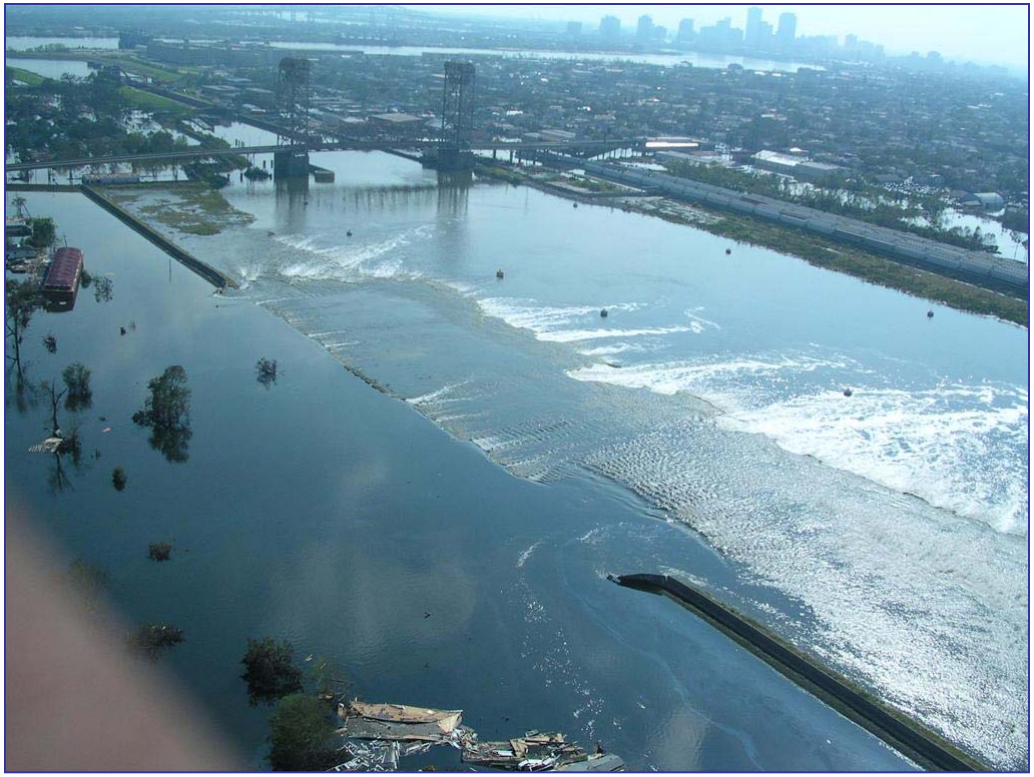
We must

- Plan for the long term
- Establish mechanisms to incorporate changing information
- Update projects regularly based on review of recent research, case histories, and new standards



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3. Failure to understand, manage, and communicate risk

- Risks were seriously underestimated
- Designs pushed the envelope at each stage
- I-wall designs were not sufficiently conservative to deal with unknowns

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We must

- Use a rigorous, risk-based approach to:
  - Select an appropriate level of protection for public safety, health, and welfare
  - Compare alternatives for managing consequences
  - Inform the public in clear and concise terms of potential consequences of decisions being made

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4. Failure to build quality in

- Rigorous internal review processes (QA-QC) would have assured that designs met project goals
- External peer review could have been effective
  - At embedding an appropriate margin of safety into the culture of the design process
  - Ensuring that designs meet the appropriate standards of practice

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We must

- Understand expectations of all project stakeholders
- Ensure project performance meets those expectations

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5. Failure to build resilience in

- I-walls and earth levees failed suddenly and completely leading to catastrophic breaching and greatly increased flooding

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We must

- Recognize that resilience is key to avoiding catastrophic failure
- Use design criteria that provides resilience to reduce vulnerability
- Plan for failure and take steps to avoid it

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6. Failure to provide redundancy

- Flooding was worsened because water flowed from one polder to others
- Compartmentalization would have reduced the extent of flooding

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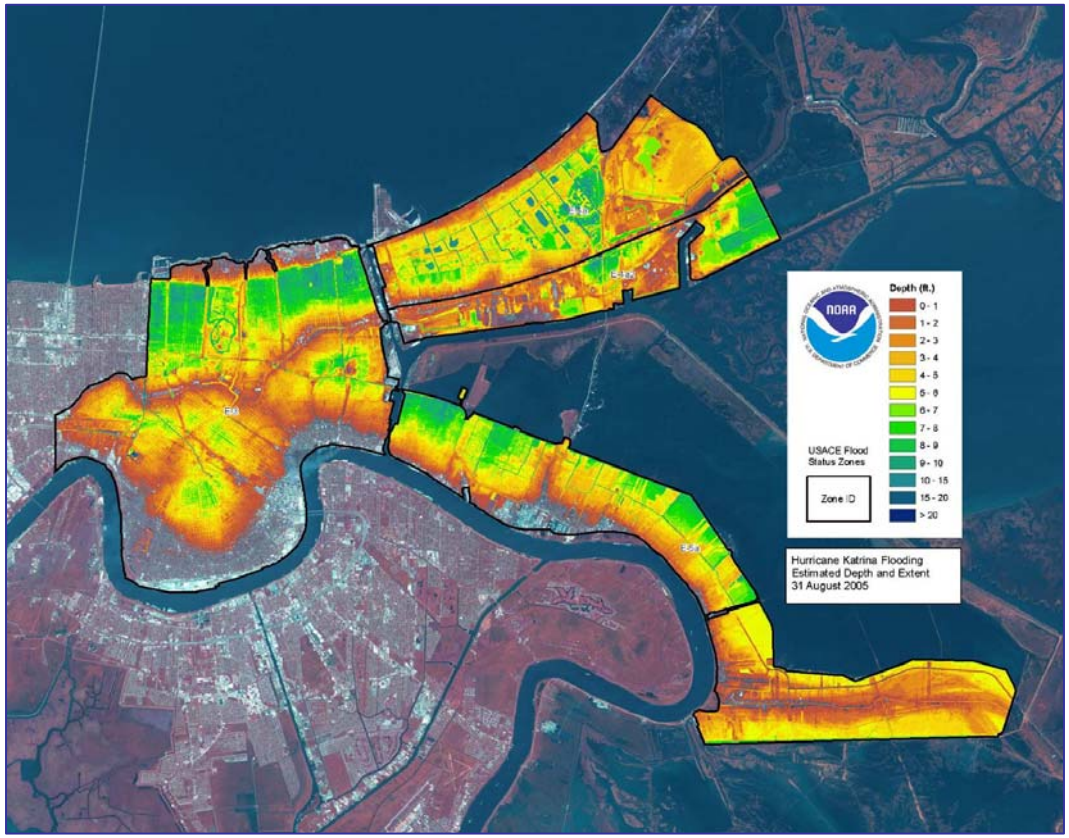
We must

- Routinely provide redundancy in design criteria so that if one part fails, all is not lost
- Think about what could go wrong, and use a second line of defense wherever it is needed



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7. Failure to see that the sum of many parts ≠ a system

- There was no system-wide approach to design or operation
- Land use and environmental issues were not considered
- The HPS was constructed piecemeal over four decades
- The pumping system was designed for rain events, not hurricane protection

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We must

- Consider land use and environmental issues
- Use system-wide approaches to planning, design, and operations and maintenance to
  - Enable optimizing performance of project components
  - Guard against unanticipated impacts and consequences
- Focus on the system, not just its parts
- Remember: A chain is only as strong as its weakest link

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8. The buck couldn't find a place to stop

- Who was in charge?
  - Congress?
  - The Corps?
  - Levee boards – if so, which one?
- No one was in charge – organizational discontinuities put public safety at risk
- No amount of engineering can offset organizational dysfunction

ORLEANS LEVEE DISTRICT
STATE OF LOUISIANA

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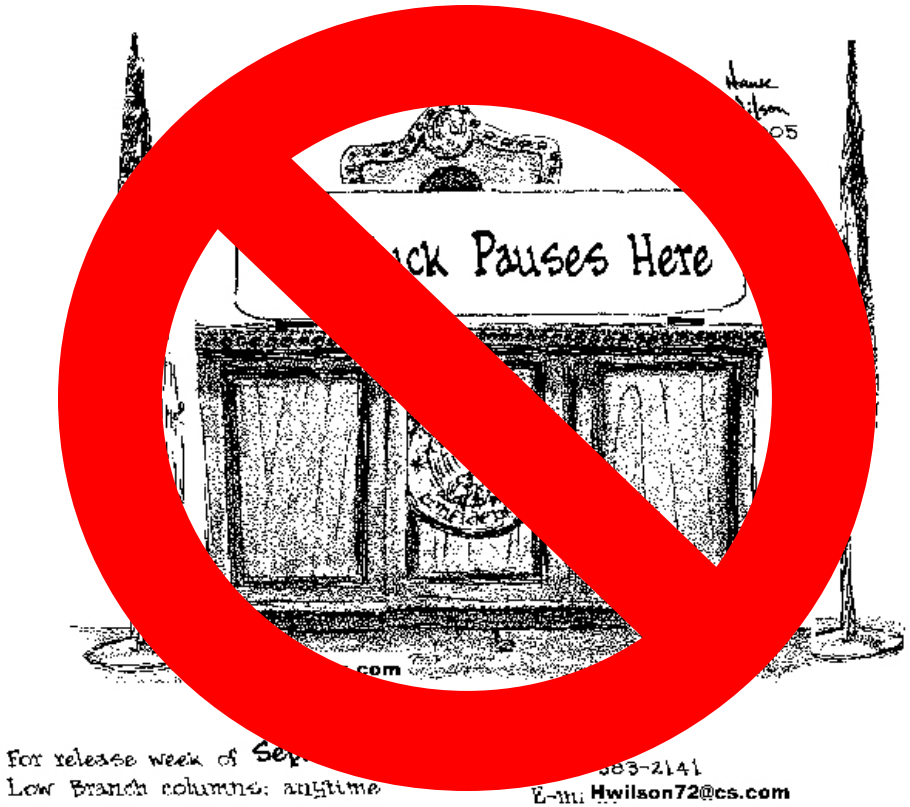
We must

- Make sure someone is in responsible charge
- Set and communicate expectations



9. Beware of interfaces

- Numerous failures occurred at interfaces between floodwall materials, and between jurisdictions

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We must

- Recognize that problems concentrate at interfaces – for example
  - Between materials
  - Between jurisdictional entities
  - Between members of the design team
  - Between project participants (owner, sponsor, designer, and constructor)

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10. Follow the money

- People responsible for design and construction decisions did not control purse strings
- Pressure for tradeoffs and low-cost solutions compromised quality, reliability, and safety

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We must

- Ensure adequate safeguards so that money is spent as intended
- Tie responsibilities for funding and for technical decision-making together

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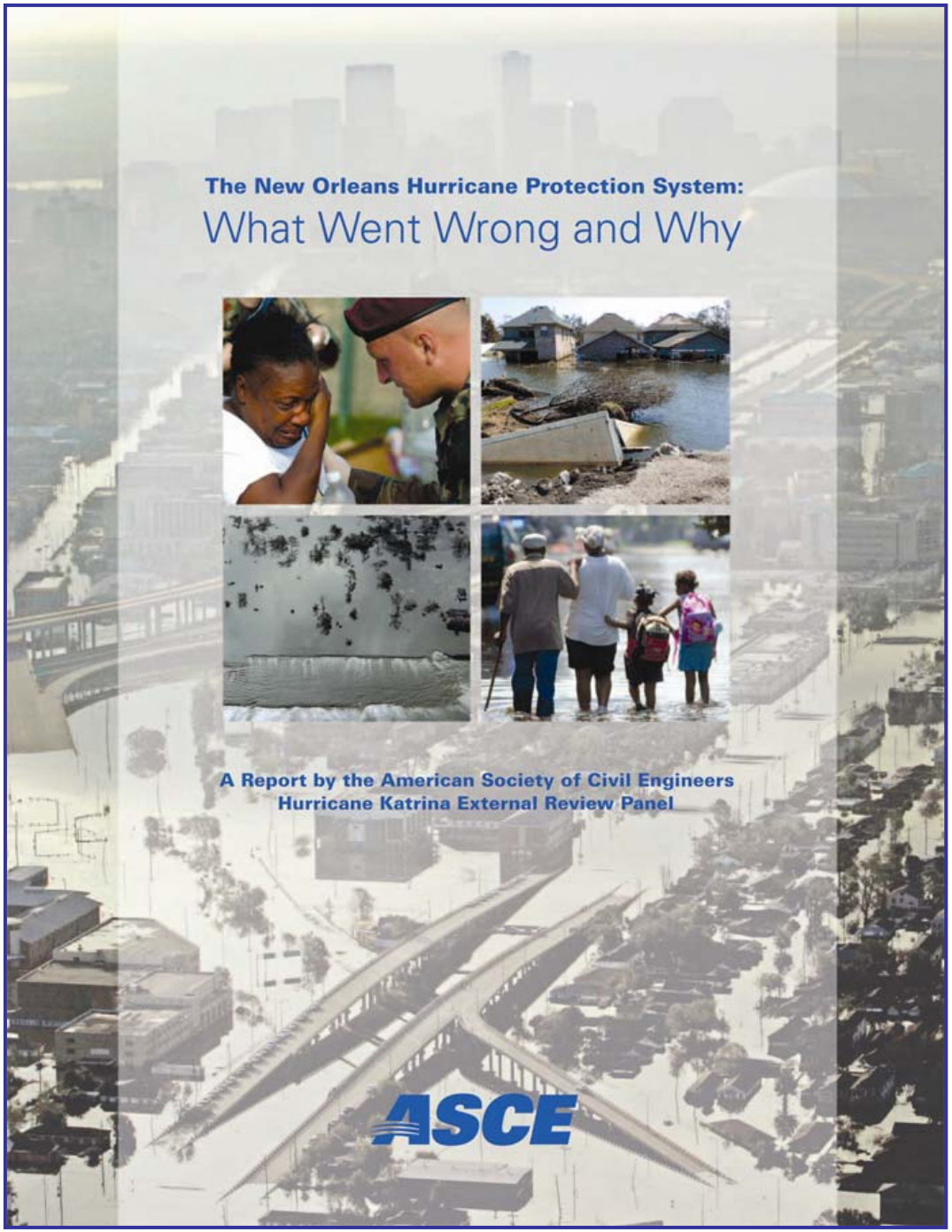
What Must We Do Next?



ERP Final Report

- www.asce.org
  - Free download
  - Hard copy purchase

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Understand risk and embrace safety

- Keep safety at the forefront of public priorities
- Quantify the risks
- Communicate the risks and decide how much is acceptable

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Reevaluate and fix the HPS

- Rethink the whole system, including land use
- Correct the deficiencies

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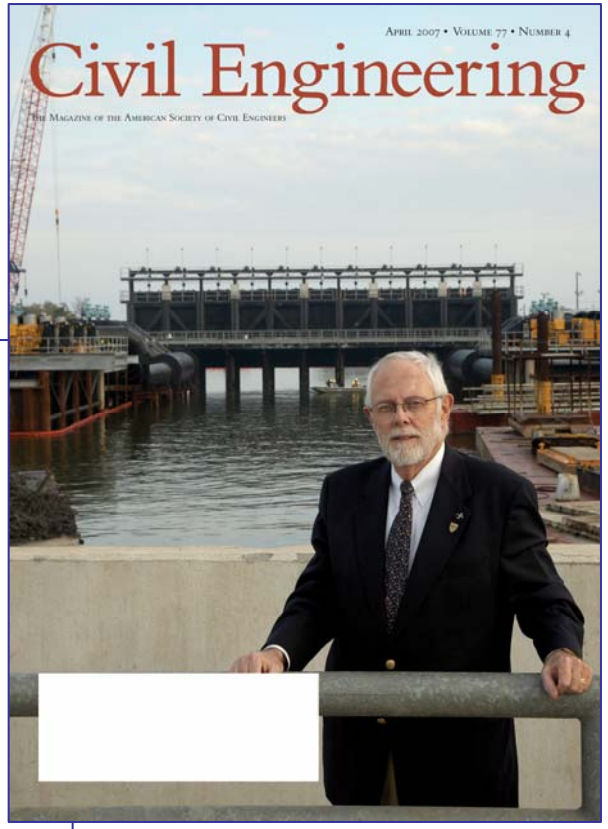
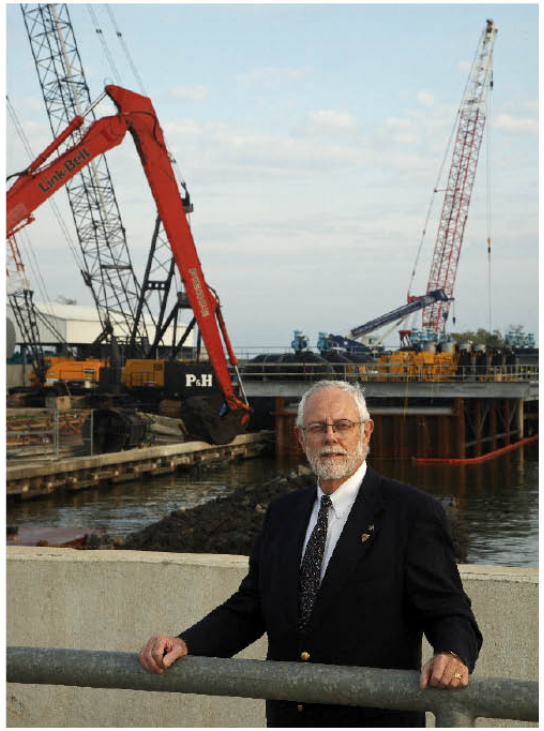
Revamp the management of the HPS

- Put someone in charge
- Improve inter-agency coordination





Levee Leader

Thomas L. Jackson, a past president of ASCE, has taken on a new presidential role—leading one of the two new "super levee boards" in New Orleans that have been designed to replace a fragmented system based on political patronage with a consolidated approach focused on technical expertise in flood control.

By Robert L. Reid Portrait by Richard Sexton

The flooding of more than 80 percent of New Orleans in August and September 2005 that resulted when levees and floodwalls failed during the hurricanes Katrina and Rita also washed away the city's fragmented system of multiple levee boards that had long been run mostly by political appointees with little knowledge of modern flood protection practices. In place of the levee boards, the State of Louisiana proposed an amendment to its constitution that would create two new flood protection authorities for the New Orleans area—the Southeast Louisiana Flood Protection Authority–East (SLFPA–E), which has jurisdiction over the former levee districts and certain other regions on the east side of the Mississippi, and the Southeast Louisiana Flood Protection Authority–West (SLFPA–W), which has jurisdiction over a former levee district and part of another district on the west side of the Mississippi. The amendment was overwhelmingly approved by Louisiana voters on September 30, 2006.

The amendment also mandated that the new regional authorities be staffed by engineers and scientists, including at least one civil engineer and one person who is a hydrologist or geologist. In January of this year the SLFPA–E held its first meetings and elected as its president a past president of ASCE, Thomas L. Jackson, P.E., D.WRE, F.ASCE, who retired from DMJM Harris in early 2006 as the firm's chief engineer and a senior vice president. Jackson, a resident of Metairie, Louisiana—a New Orleans suburb—had to evacuate his own home temporarily because of Hurricane Katrina. He also delayed his retirement from September 2005 until February 2006 to help DMJM Harris relocate its New Orleans employees to an office in Baton Rouge and to lend a hand in rescuing equipment and files from the firm's New Orleans office, located across from the Louisiana Superdome.

"Learning the ways of government is key" to success in his new role as the president of the Southeast Louisiana Flood Protection Authority–East, says Thomas L. Jackson, P.E., D.WRE, F.ASCE. Jackson, a former ASCE president who retired from DMJM Harris in early 2006 as a senior vice president and the firm's chief engineer, also stresses the need for his organization to establish a "full partnership" with the U.S. Army Corps of Engineers for future work on the New Orleans flood control system. Jackson is shown here near the Corps's project to construct a closure gate for the 17th Street Canal, the site of one of the breaches that flooded the city in August 2005.

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Demand engineering quality

- Upgrade engineering design procedures
- Bring in independent experts
- Engineers *must* place safety first

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