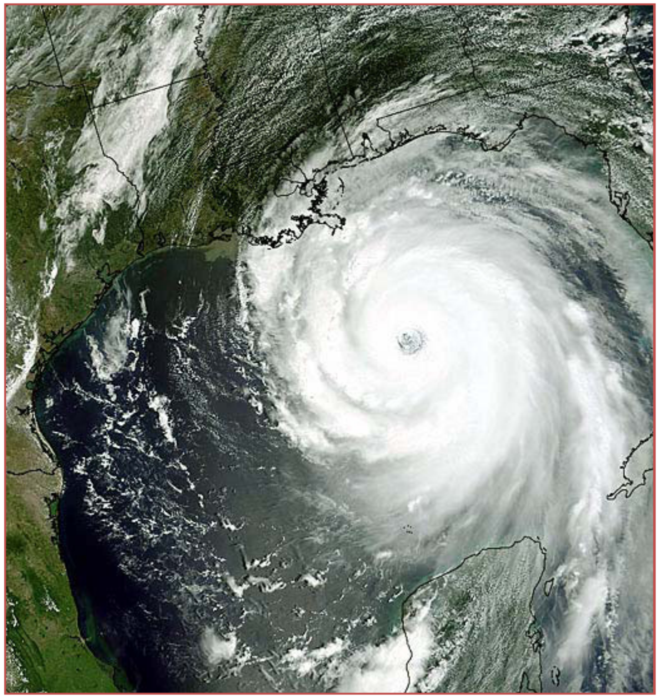
Katrina Through Your Rearview Mirror

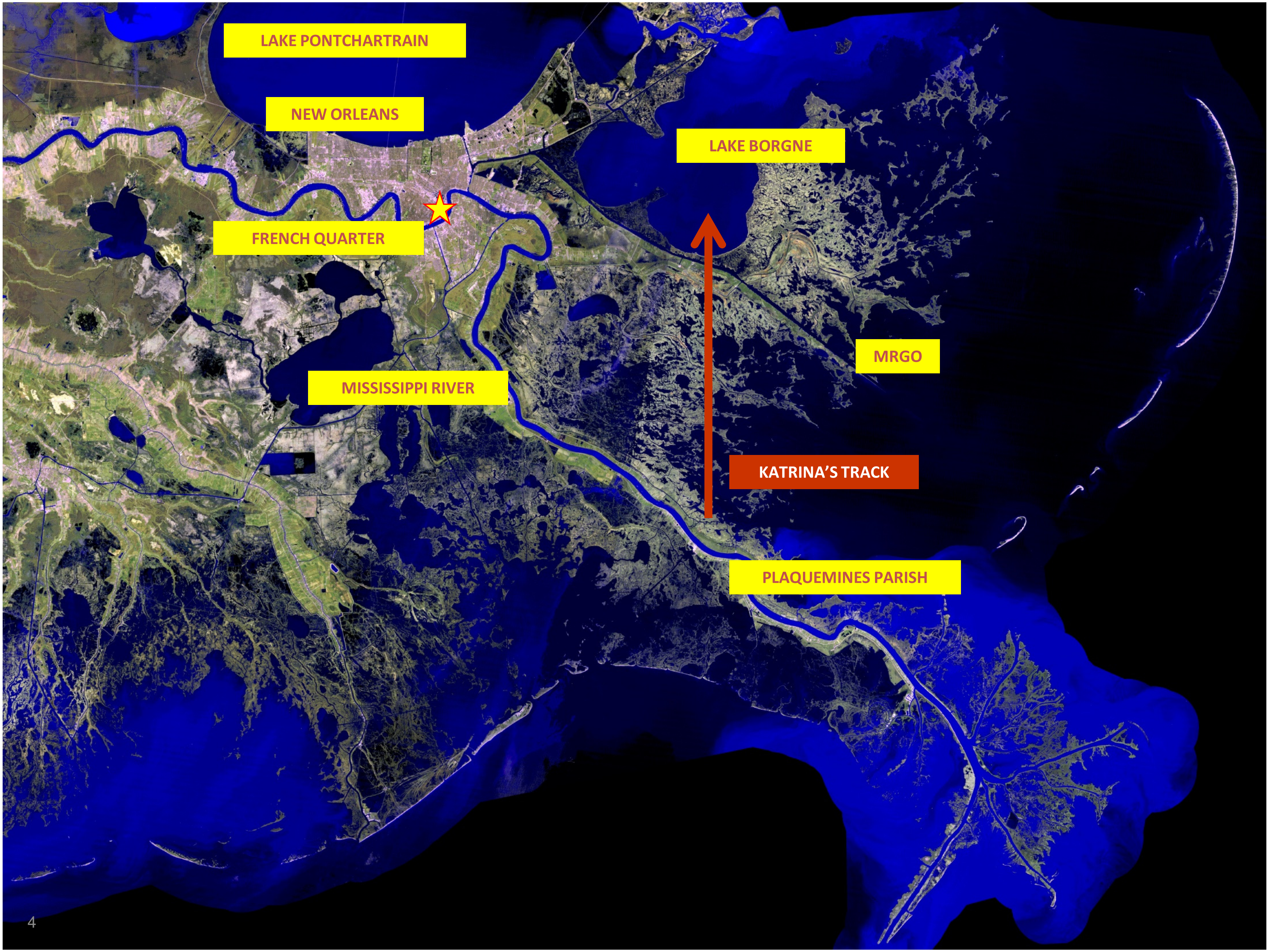


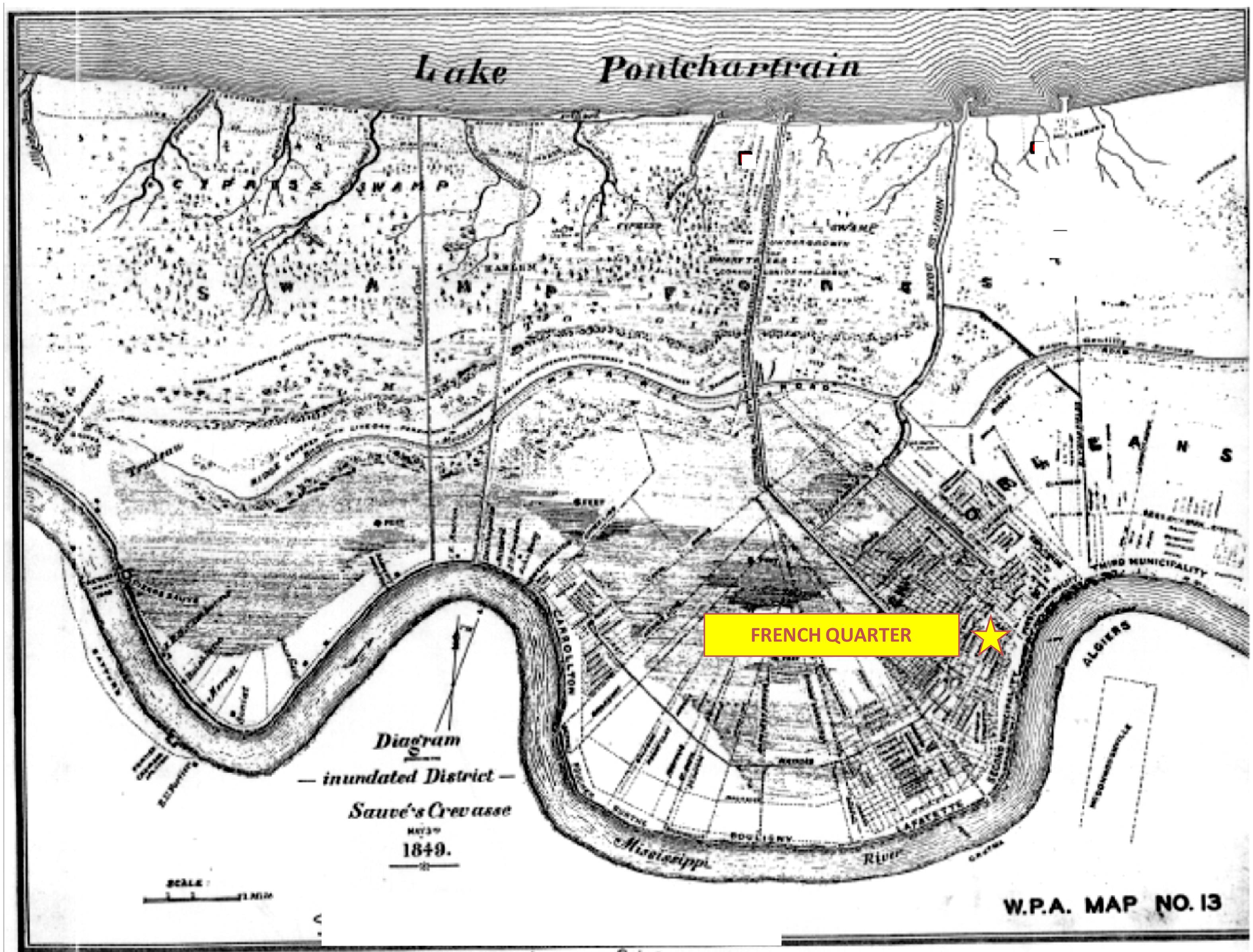
W. F. Marcuson, III
Director Emeritus, Geotechnical Laboratory
U.S. Army Engineer Waterways Experiment Station
Vicksburg, Mississippi

Path Forward

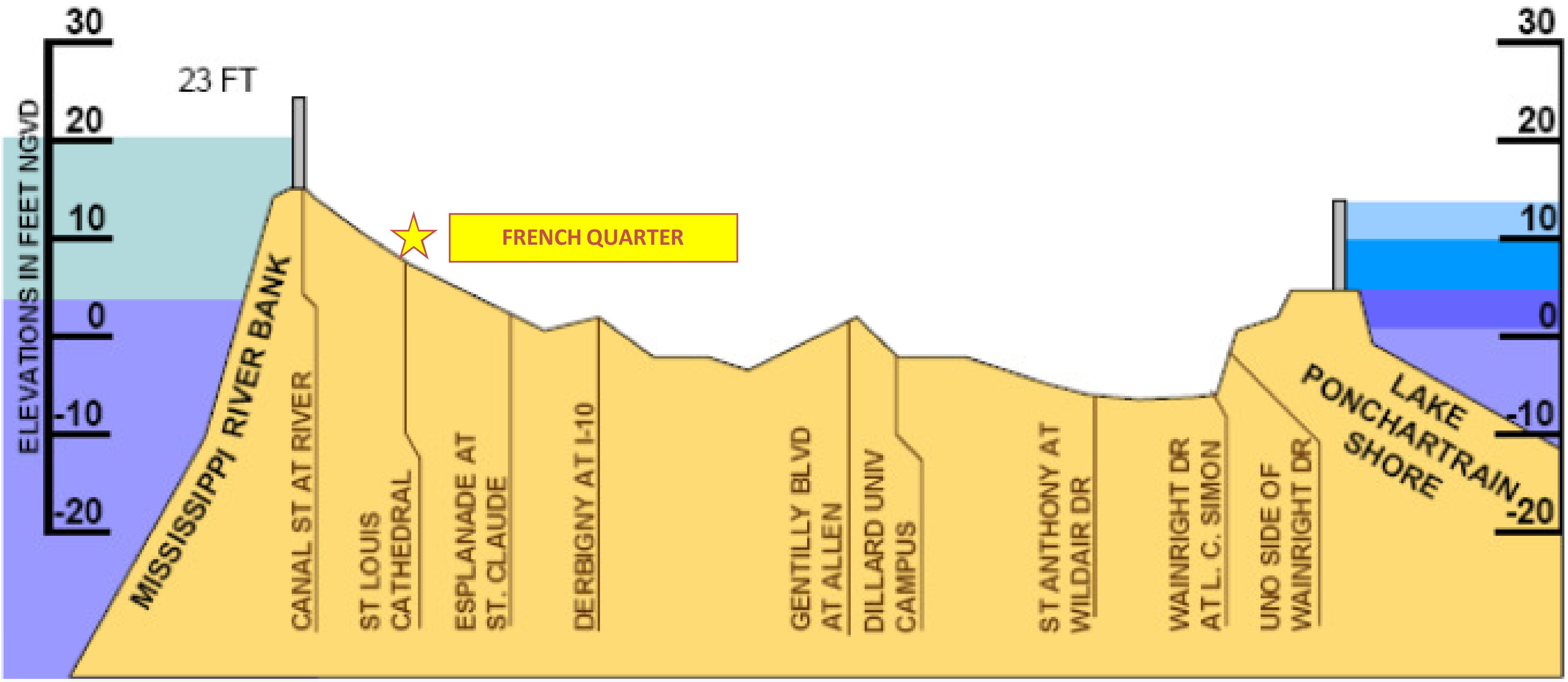
- The Setting
- What Went Wrong
- Risk
- Lessons Learned
- Conclusions

The Setting

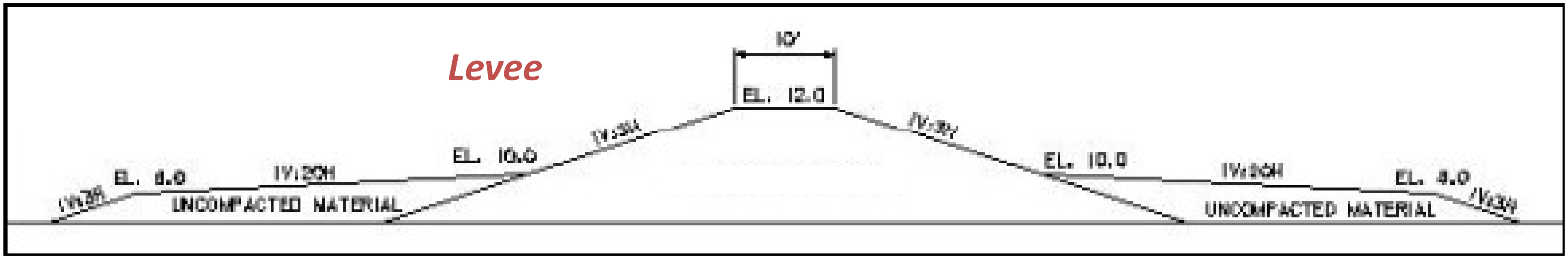

LAKE PONTCHARTRAIN
NEW ORLEANS
LAKE BORGNE
FRENCH QUARTER
MRGO
MISSISSIPPI RIVER
KATRINA'S TRACK
PLAQUEMINES PARISH



New Orleans – 1849

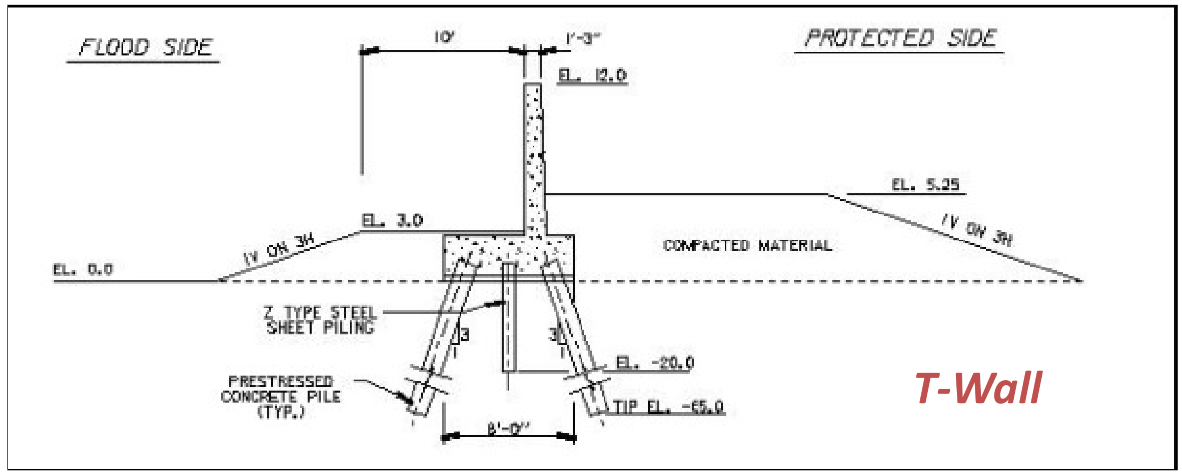

30
20
10
0
-10
-20
ELEVATIONS IN FEET NGVD
23 FT
FRENCH QUARTER
MISSISSIPPI RIVER BANK
CANAL ST AT RIVER
ST LOUIS CATHEDRAL
ESPLANADE AT ST. CLAUDE
DERBIGNY AT I-10
GENTILLY BLVD AT ALLEN
DILLARD UNIV CAMPUS
ST ANTHONY AT WILDAIR DR
WAINRIGHT DR AT L. C. SIMON
UNO SIDE OF WAINRIGHT DR
LAKE PONCHARTRAIN SHORE
30
20
10
0
-10
-20

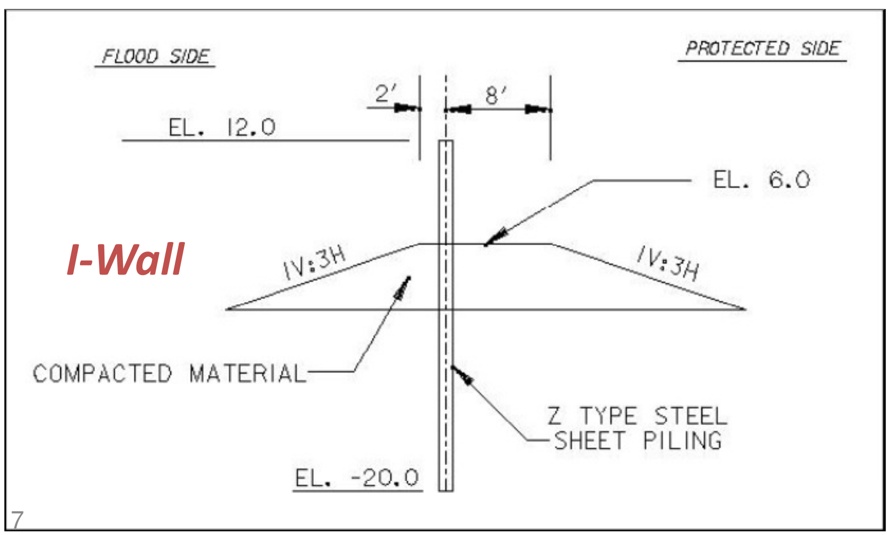
New Orleans



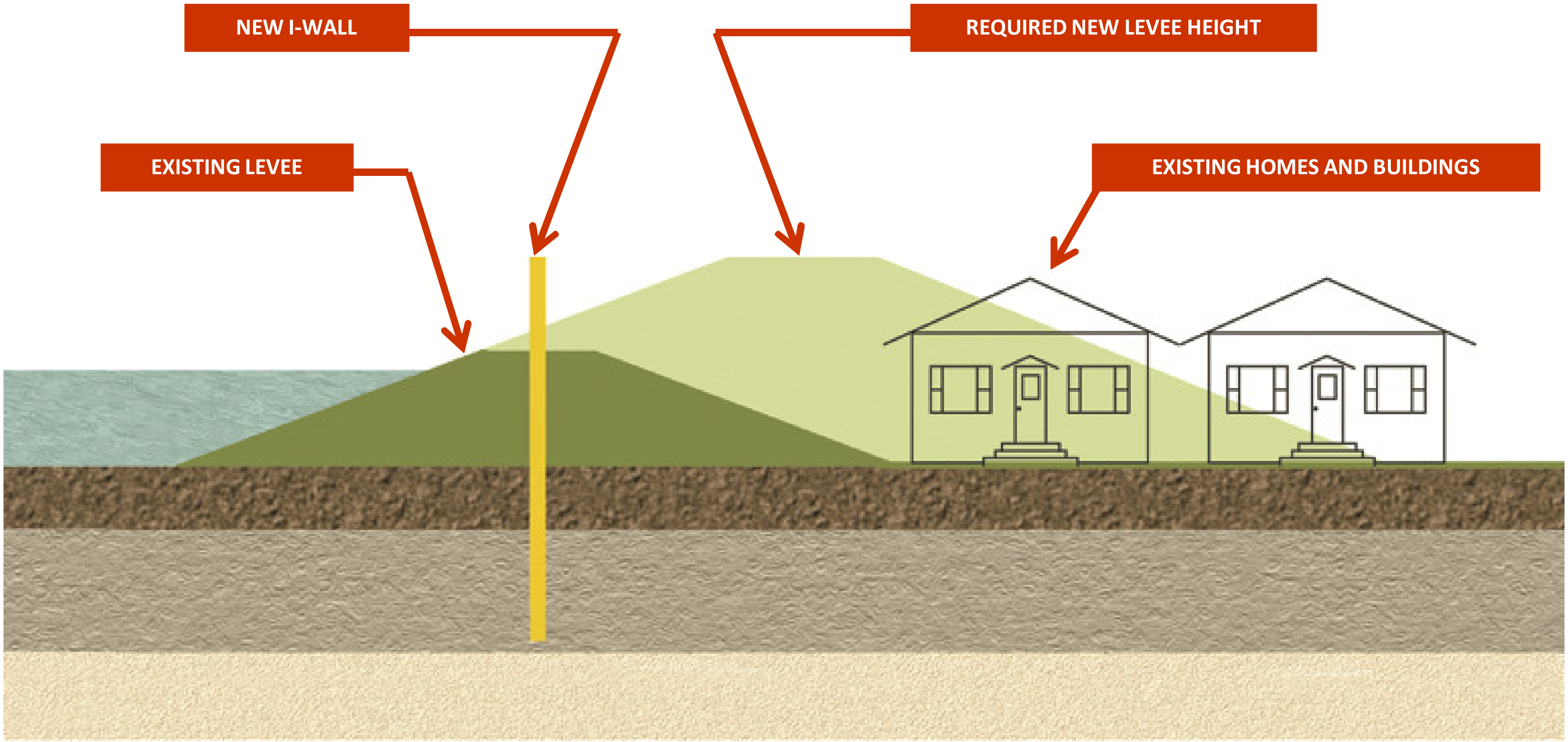
The HPS

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



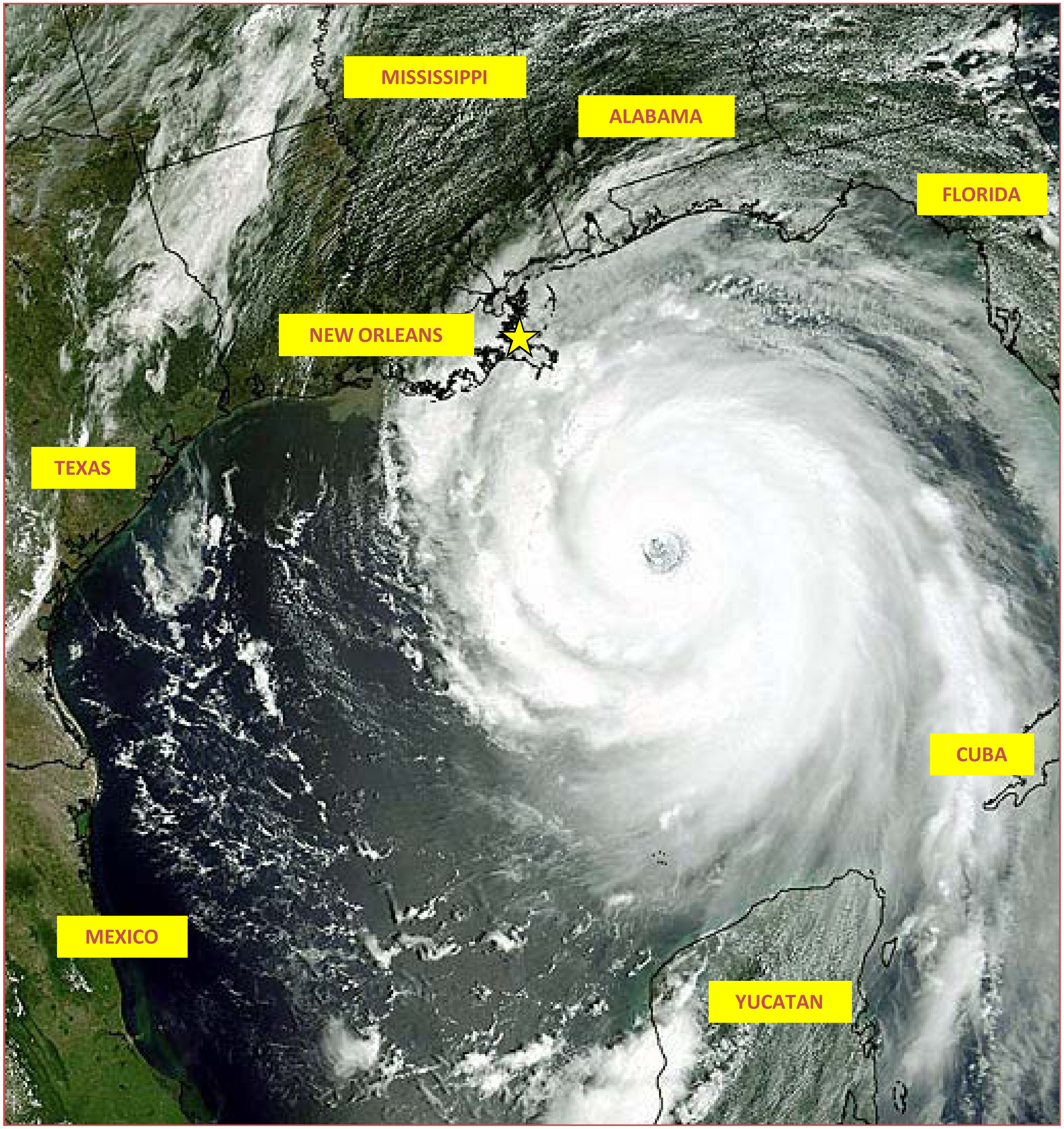


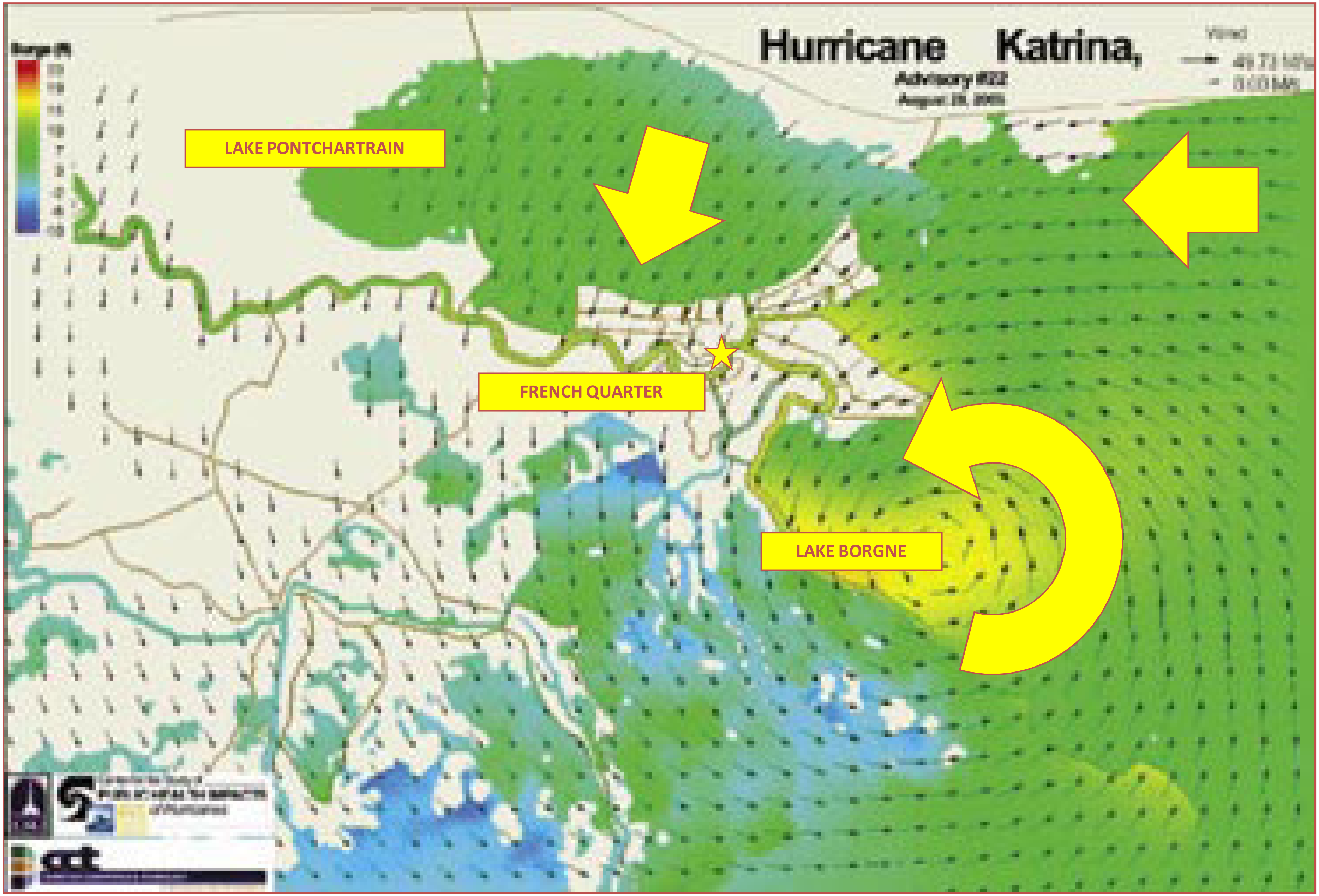
- 284 miles of federal levees
- 66 miles of non-federal levees
- 56 miles of I-wall
- 2 miles of T-wall



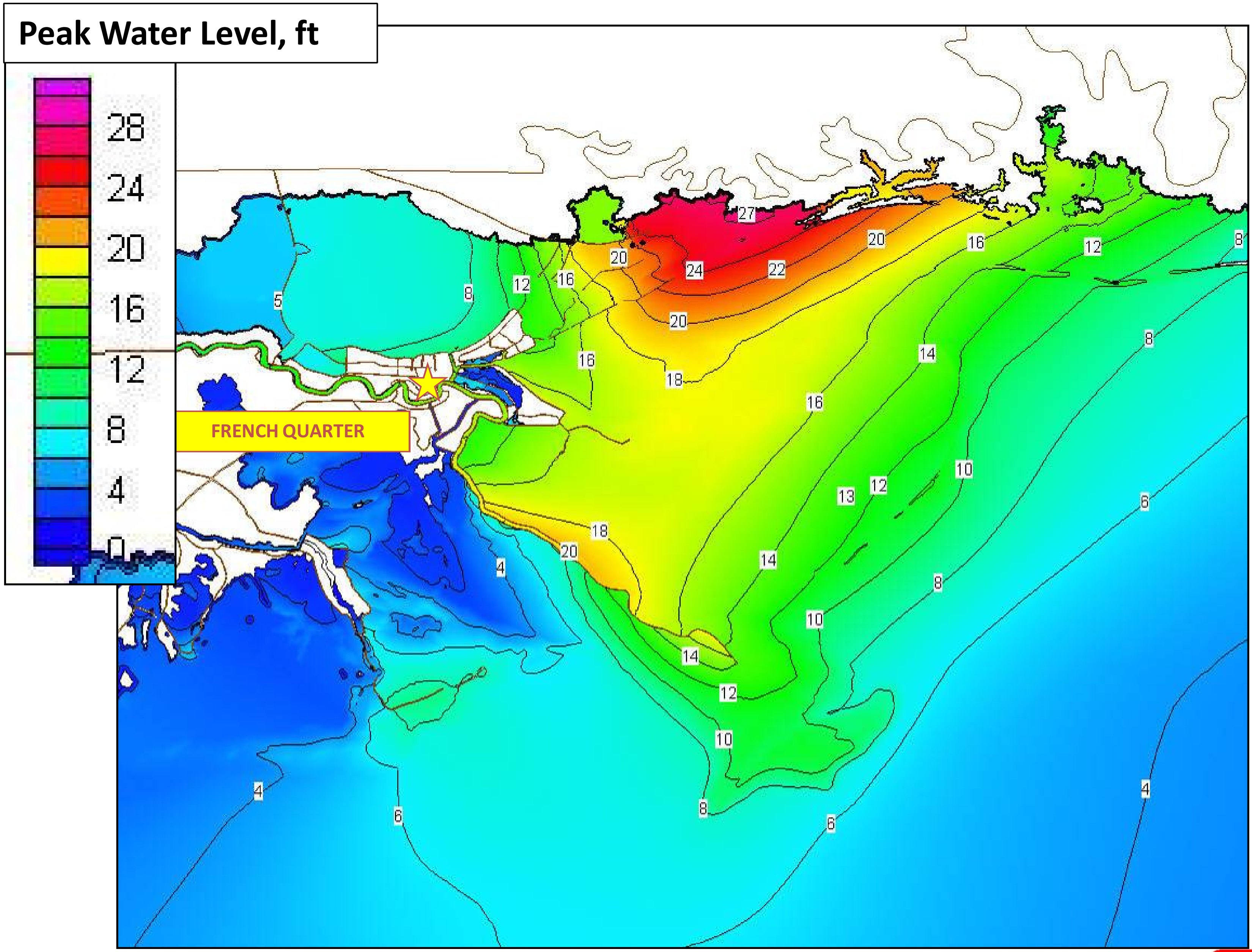
Raising the height of an earth levee

Hurricane Katrina

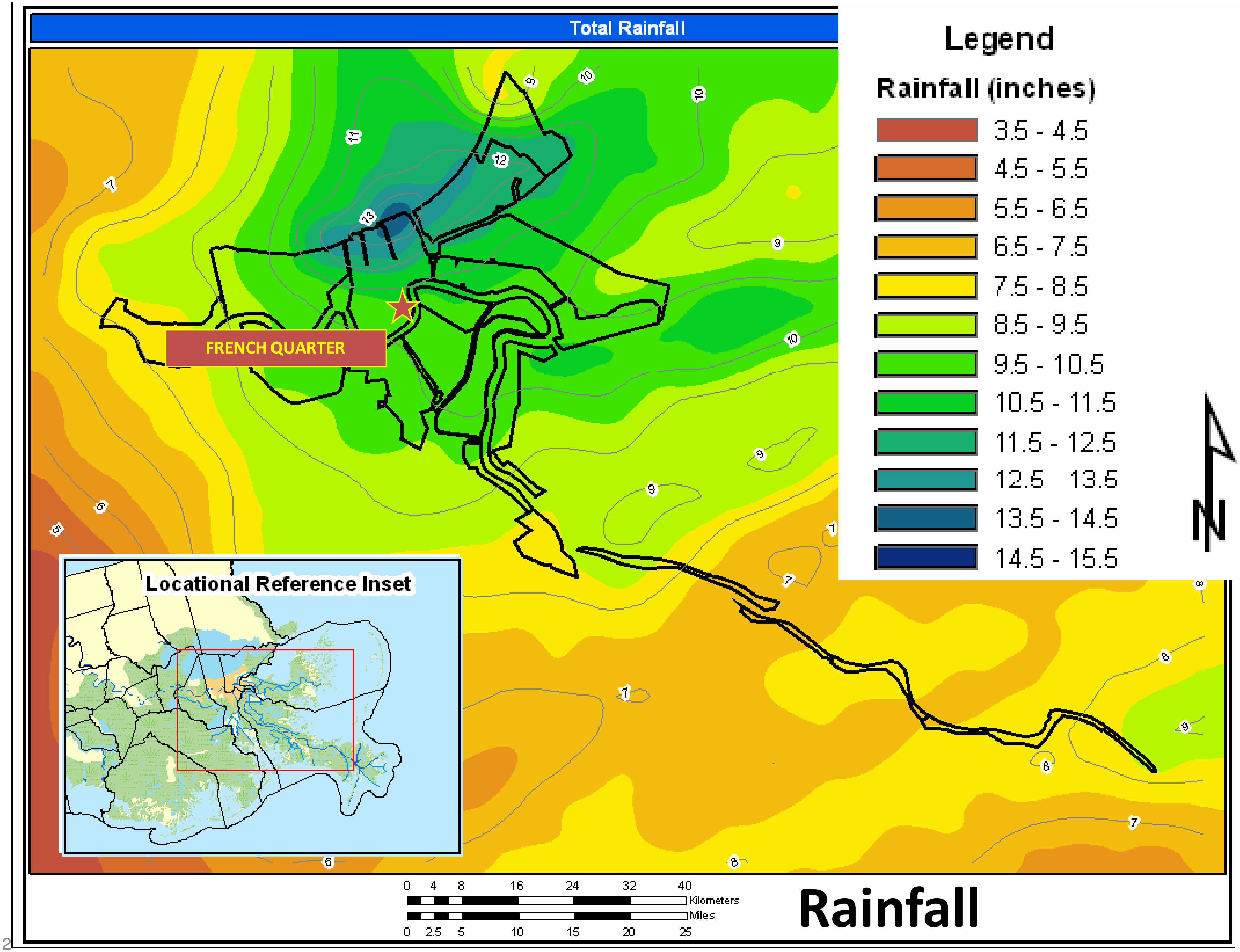




Wind vectors



Storm surge

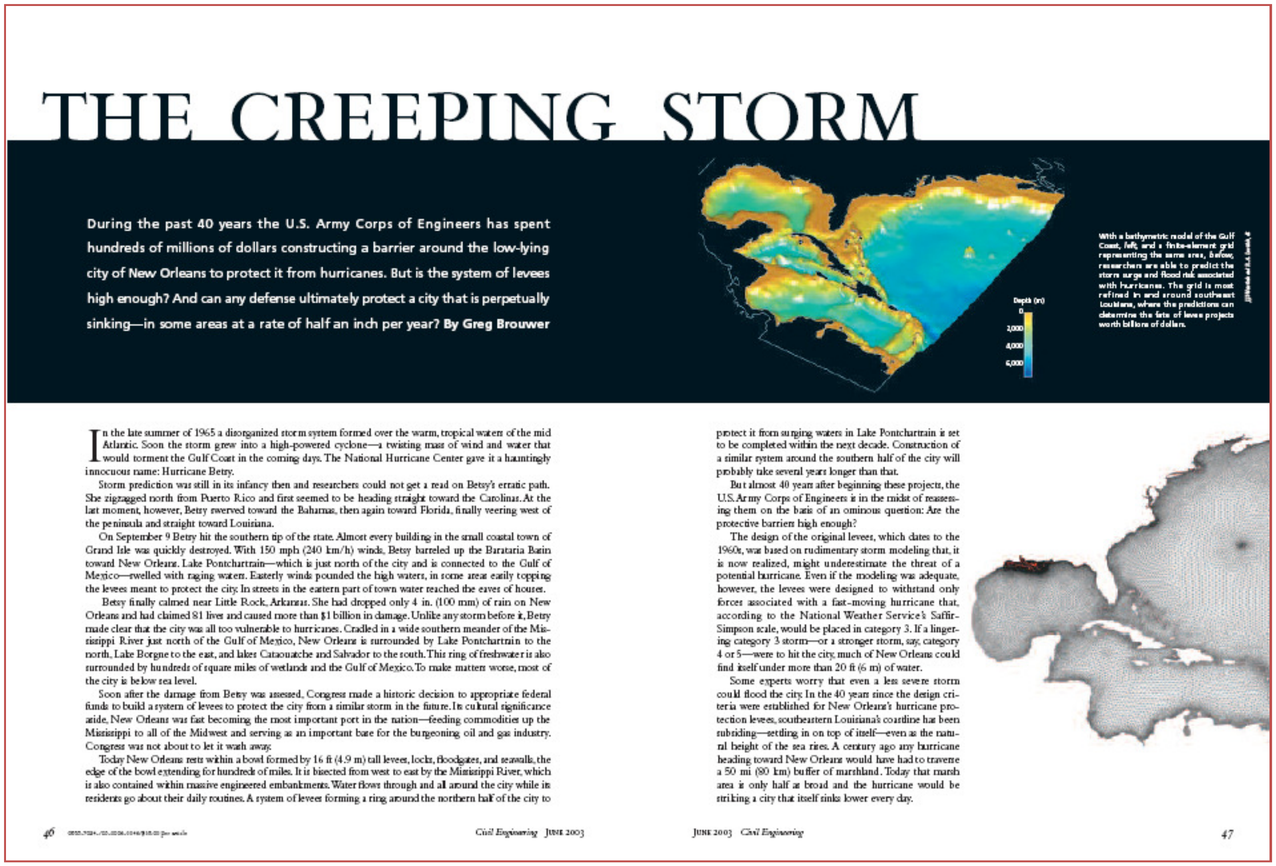

Total Rainfall
Legend
Rainfall (inches)
3.5 - 4.5
4.5 - 5.5
5.5 - 6.5
6.5 - 7.5
7.5 - 8.5
8.5 - 9.5
9.5 - 10.5
10.5 - 11.5
11.5 - 12.5
12.5 13.5
13.5 - 14.5
14.5 - 15.5
N
FRENCH QUARTER
Locational Reference Inset
0 4 8 16 24 32 40 Kilometers
0 2.5 5 10 15 20 25 Miles

Rainfall

What Went Wrong

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

Depth (m)
0
2,000
4,000
6,000

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. Its 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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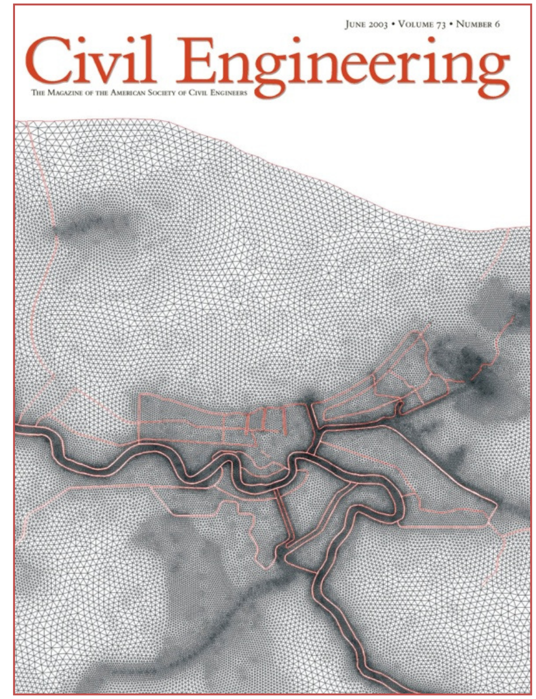
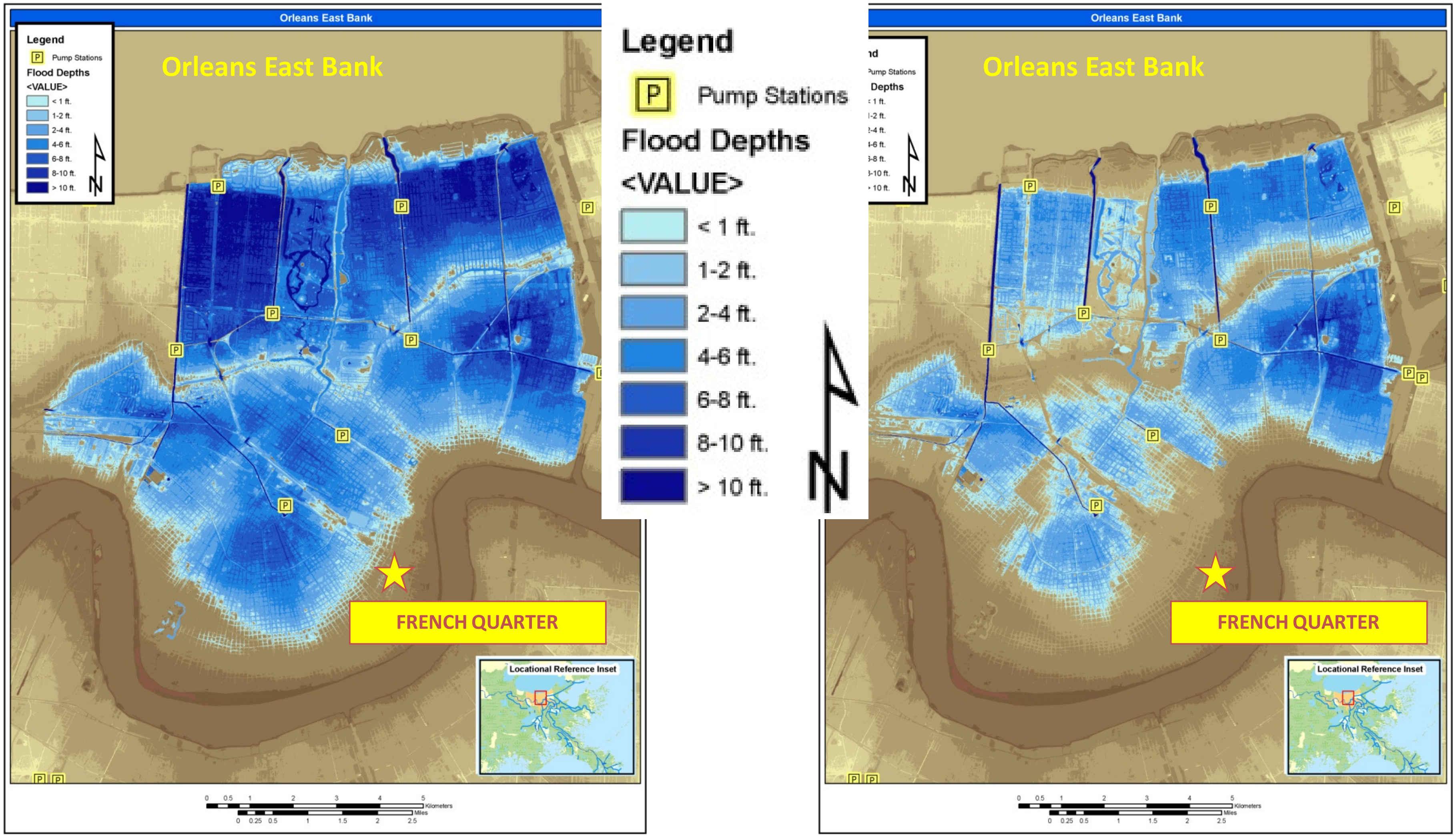


The catastrophe was borne out of a failure to recognize:

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

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 <u>300 percent</u>



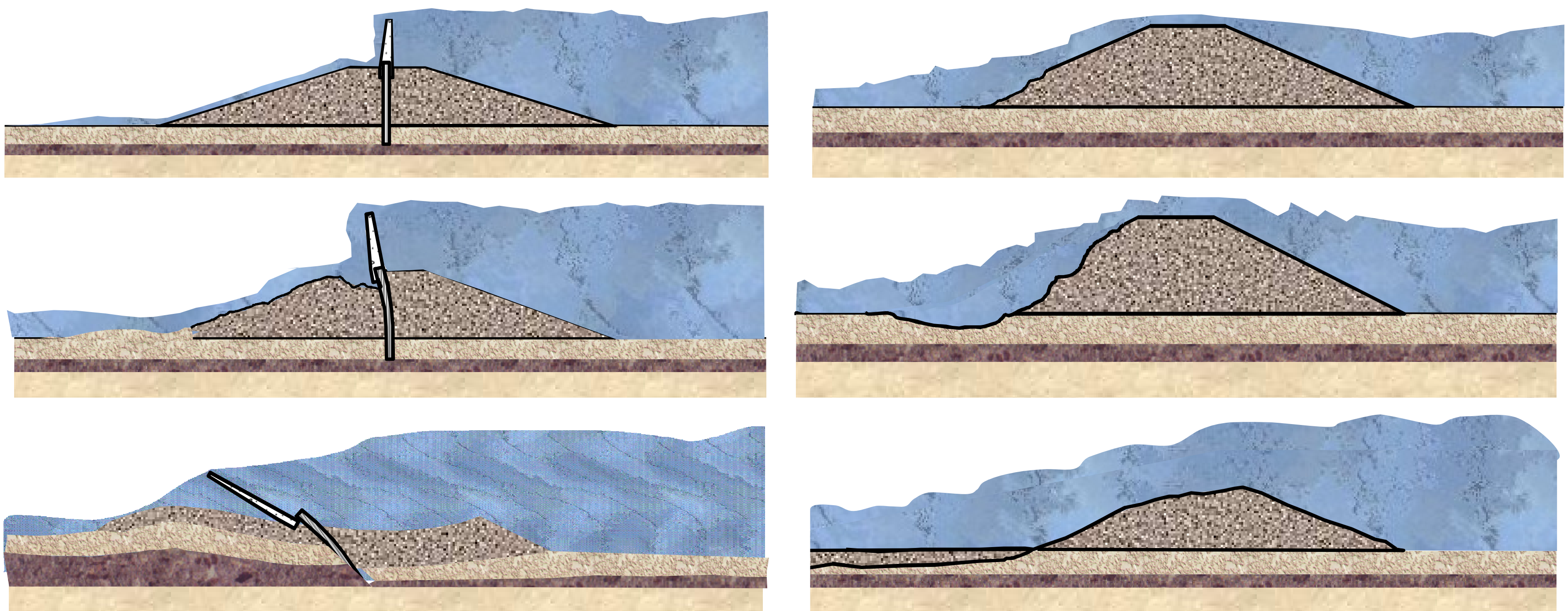
- Breaching
- No breaching

Two direct causes of breaching

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

2. Four I-walls collapsed before water reached design levels

1. **Uncontrolled overtopping and ensuing erosion led to catastrophic failure of levees and floodwalls**



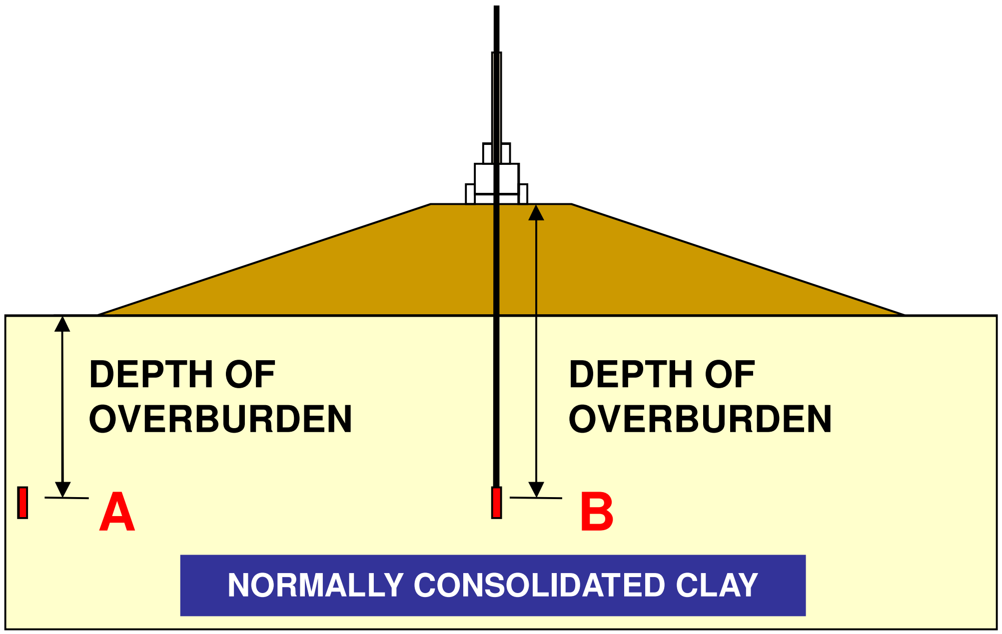
Katrina's Surge in East Orleans (Location: Near Power Plant)

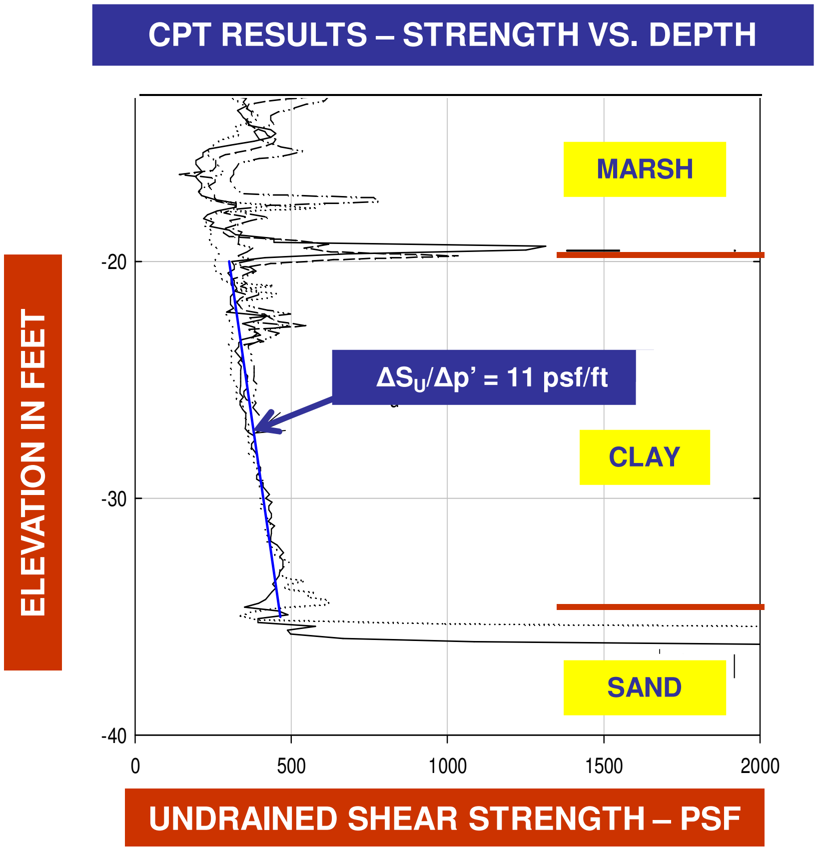
Location: Near Power Plant

London Avenue

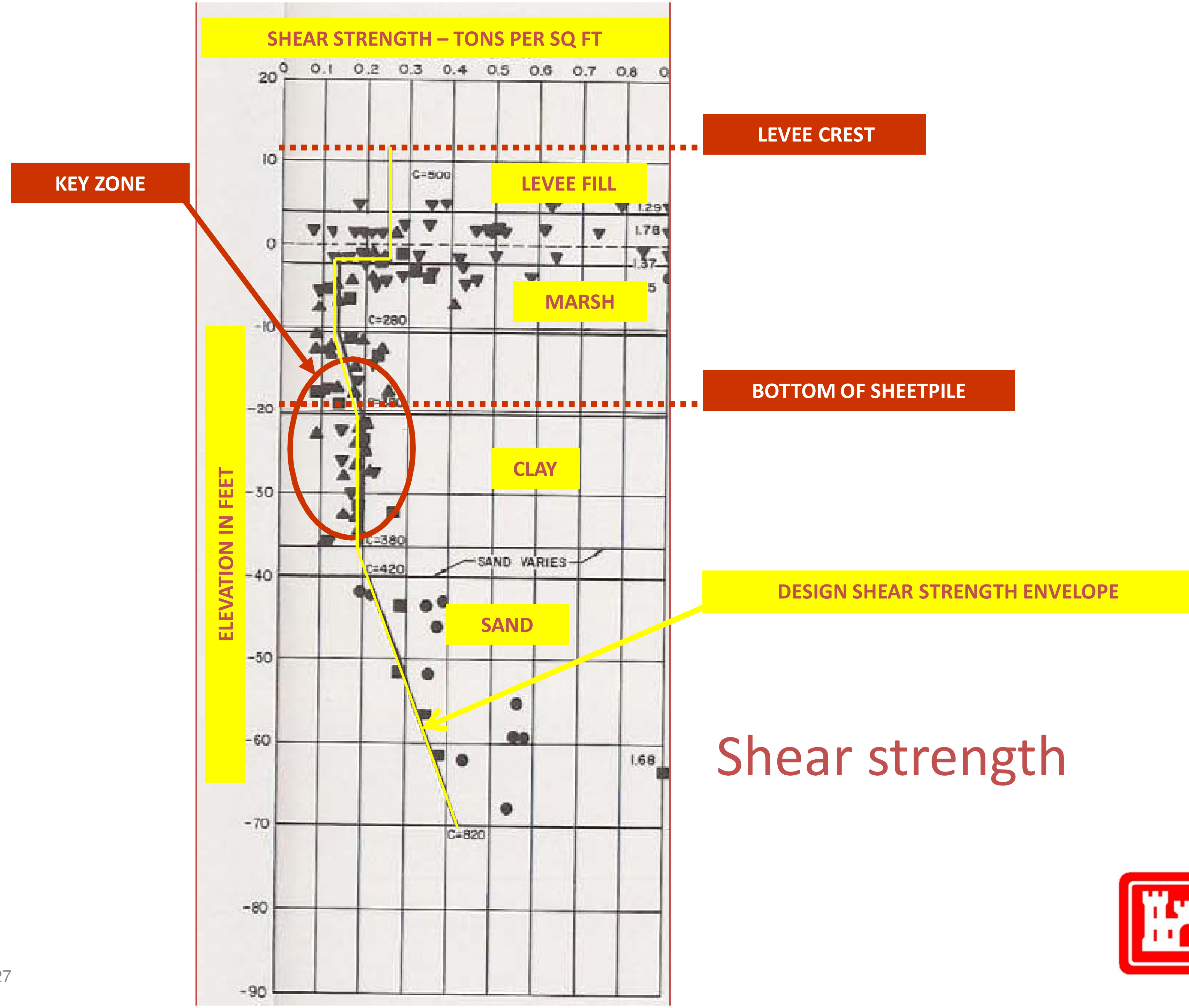
17th Street Canal

2. **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**



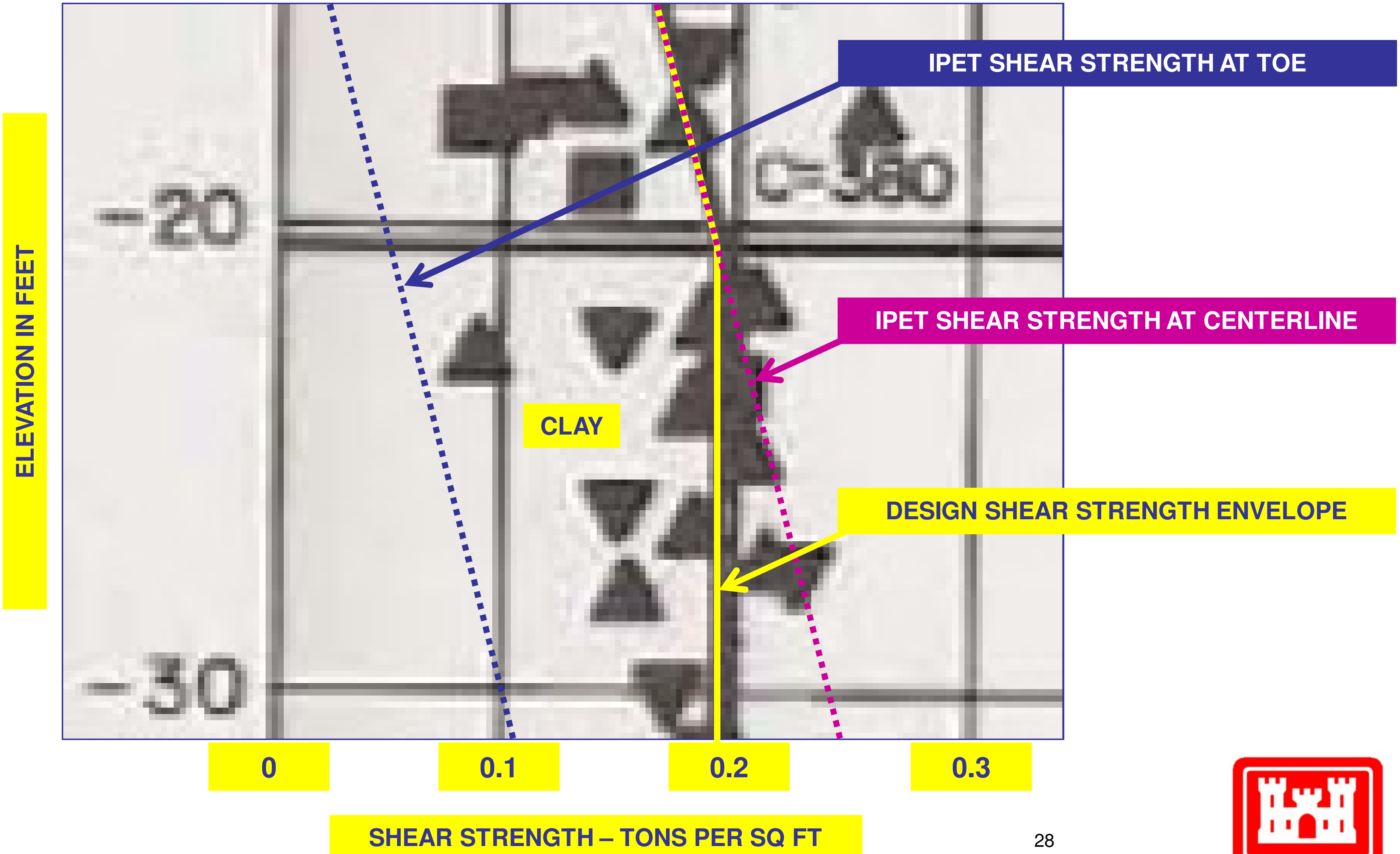


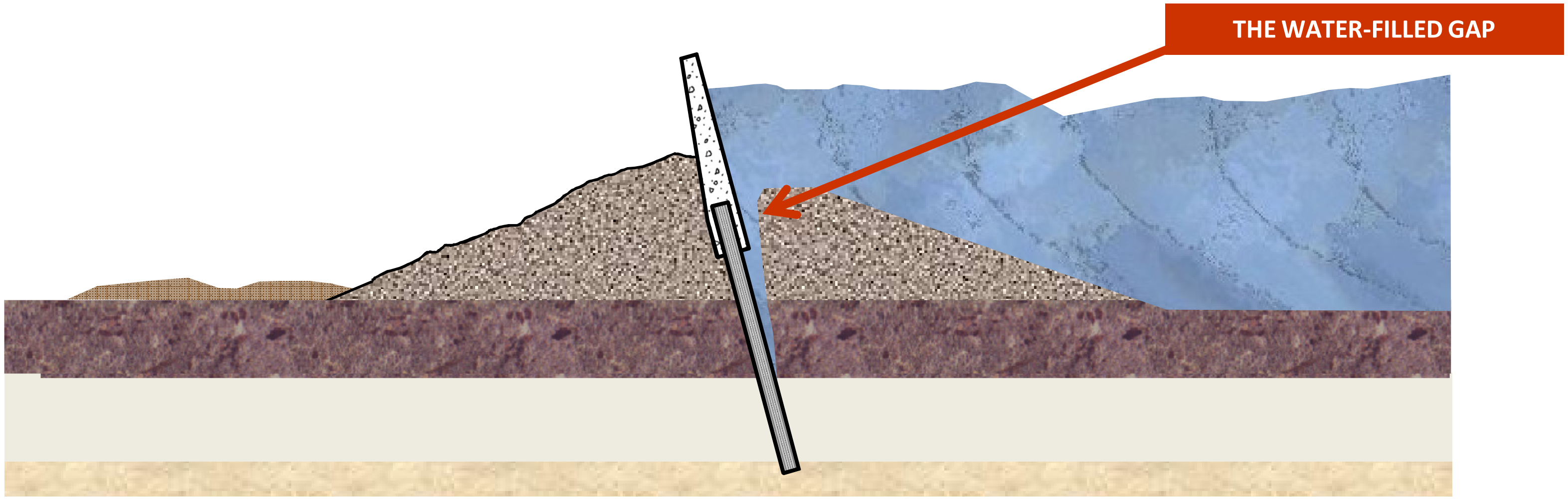
- Borings made at levee centerline
- Designer assumed A and B to have equal strength
- But, strength = *fn* (depth of overburden) for a normally consolidated clay
- So, the strength at A << strength at B

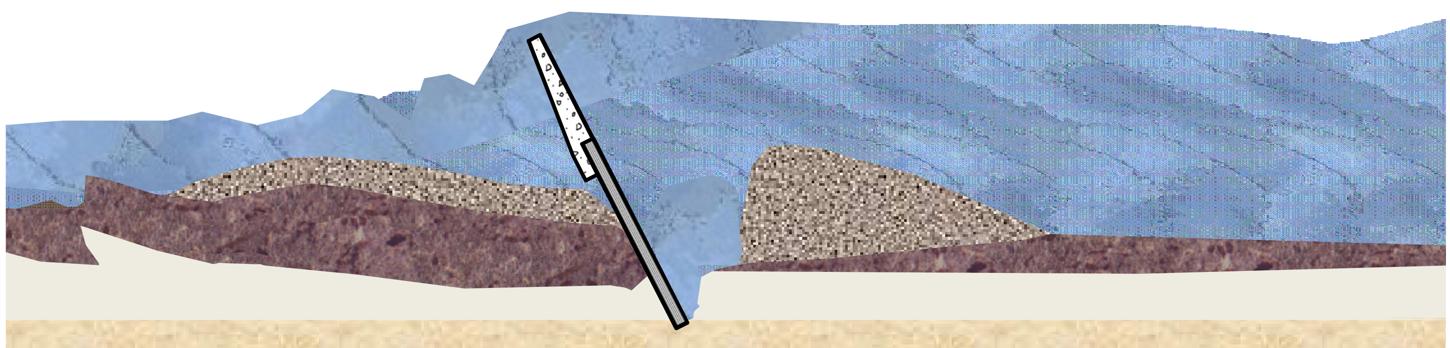


Shear strength

Un-Conservative Estimate of Soil Strength

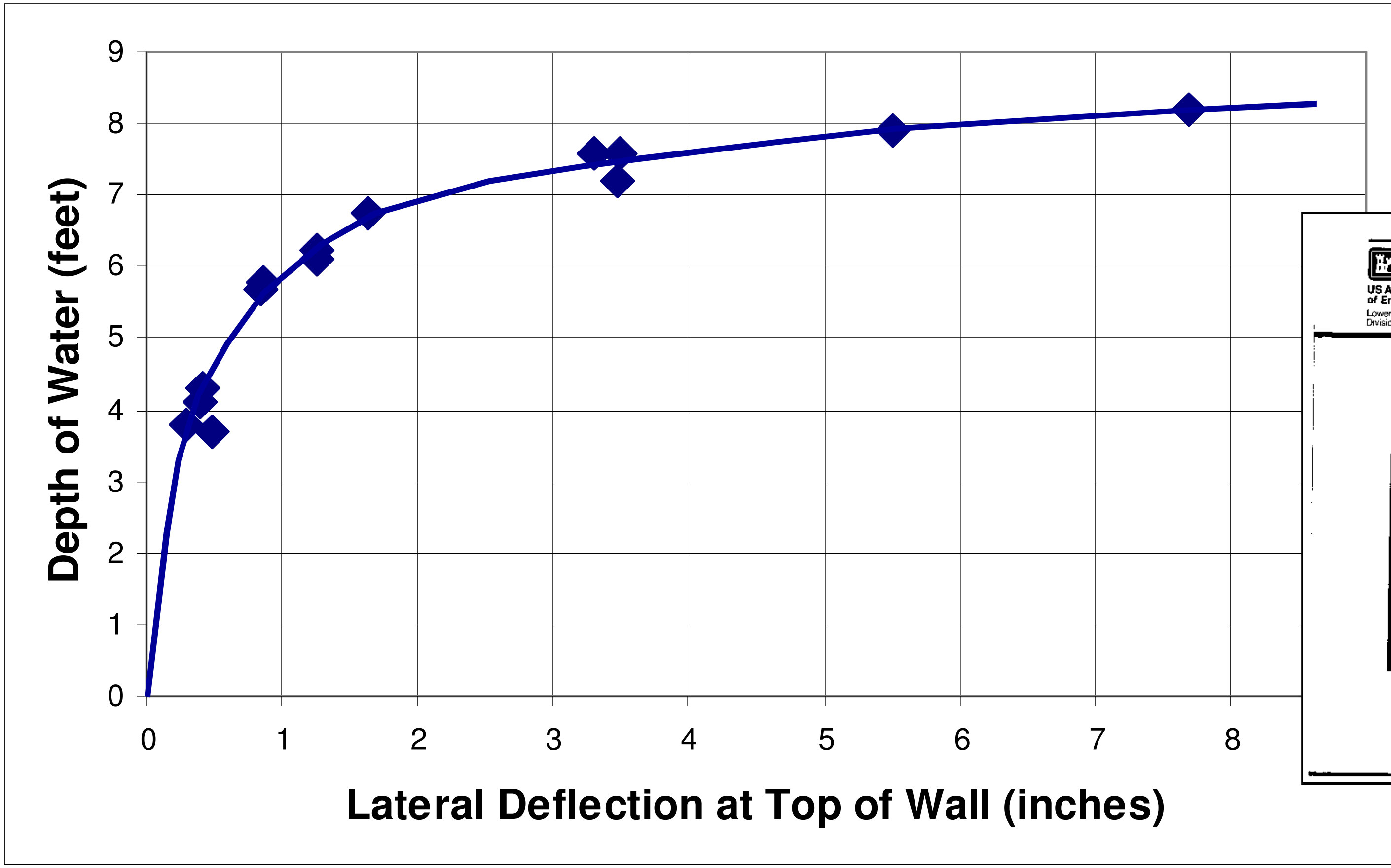


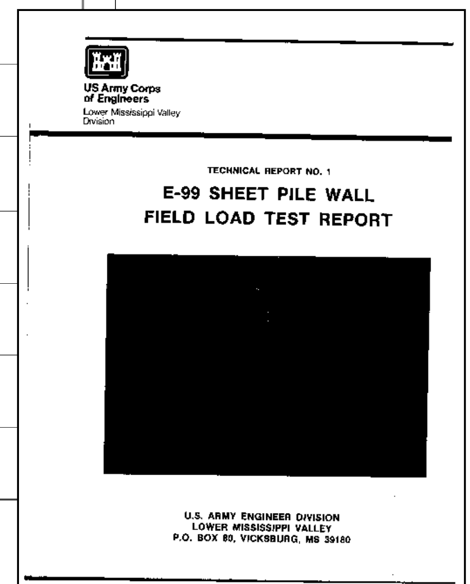

THE WATER-FILLED GAP



THE WATER-FILLED GAP

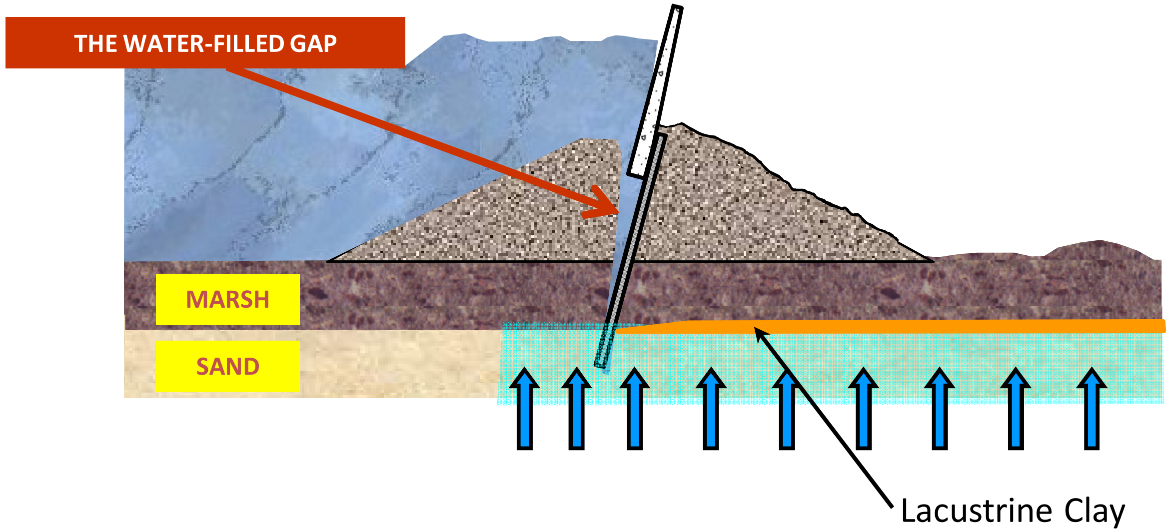
~~The Corps ignored its own research on I-walls~~ **RUMOR**

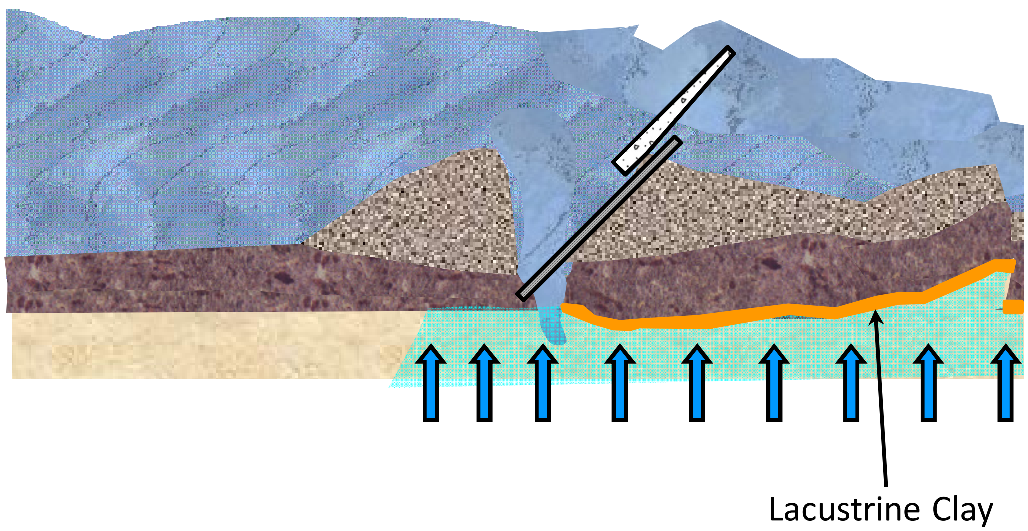




- From the E-99 report: “Although the test wall was not loaded to ‘failure,’…failure may have been imminent.”

LONDON AVENUE

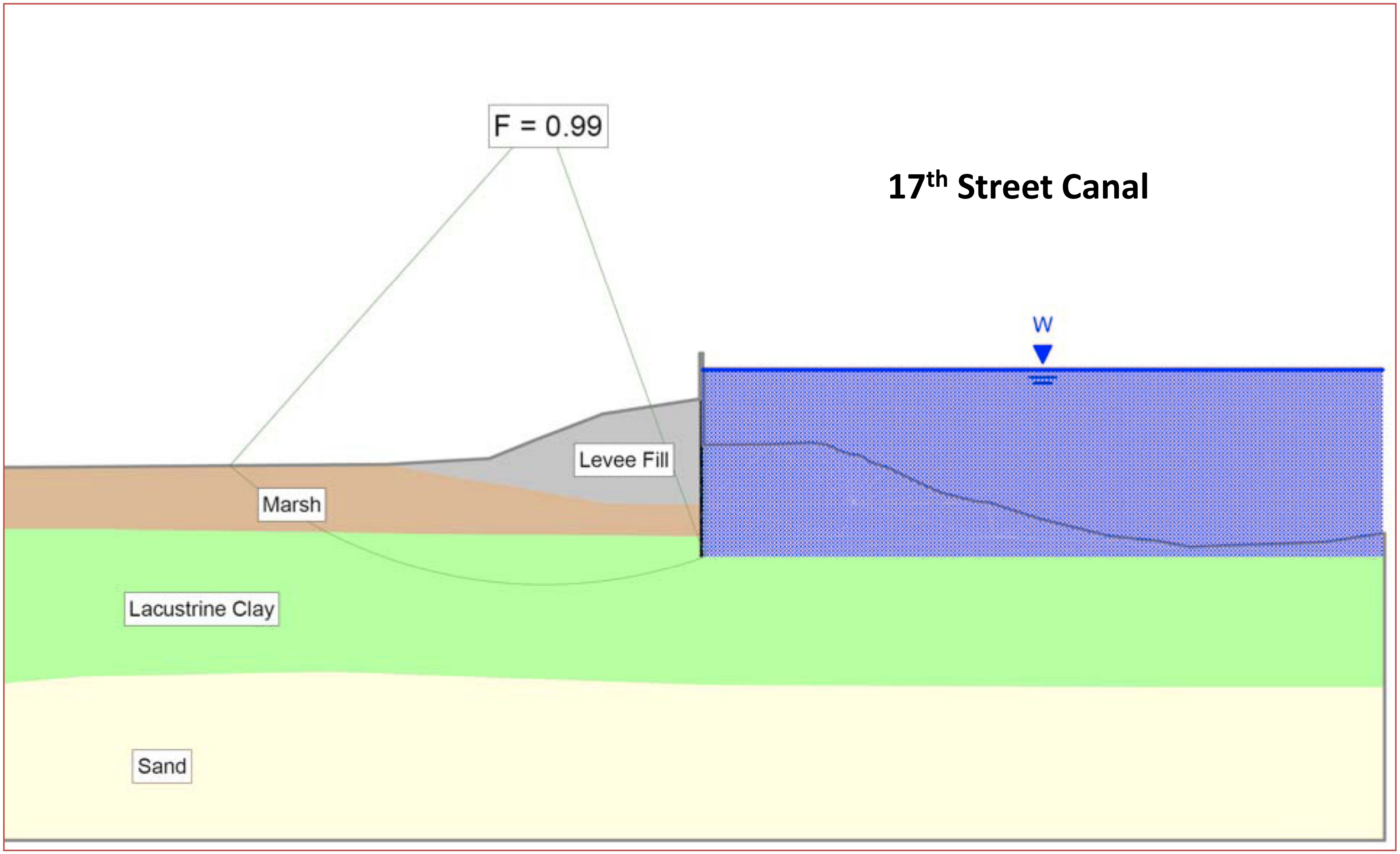




South Breach

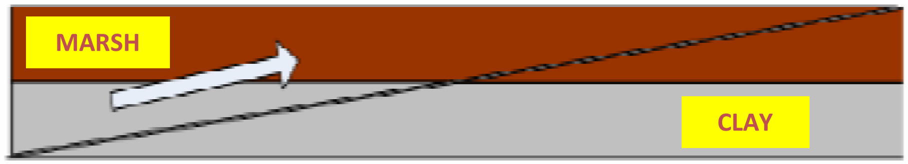
** Courtesy of Professor James M. Duncan, VA Tech*

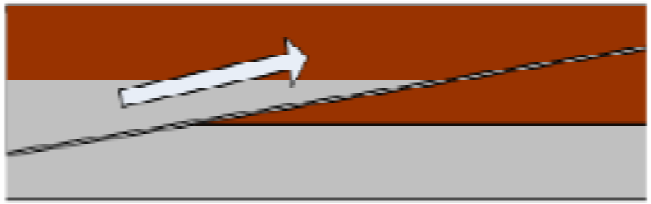
17th Street Canal

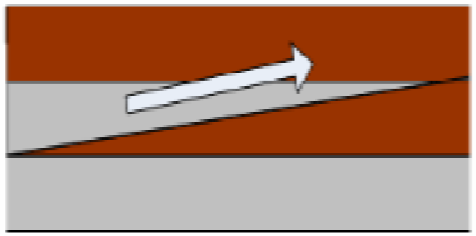


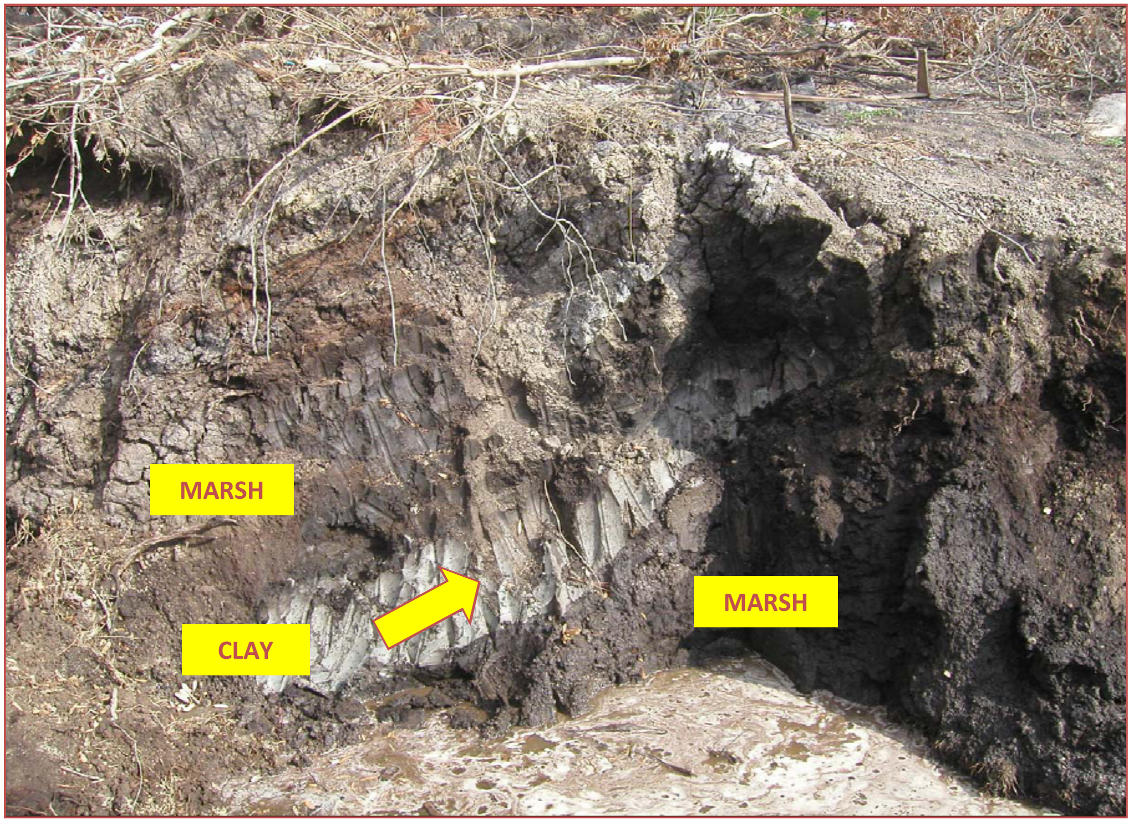
- Strengths over-estimated
- Loads under-estimated
- F < 1

Failure plane









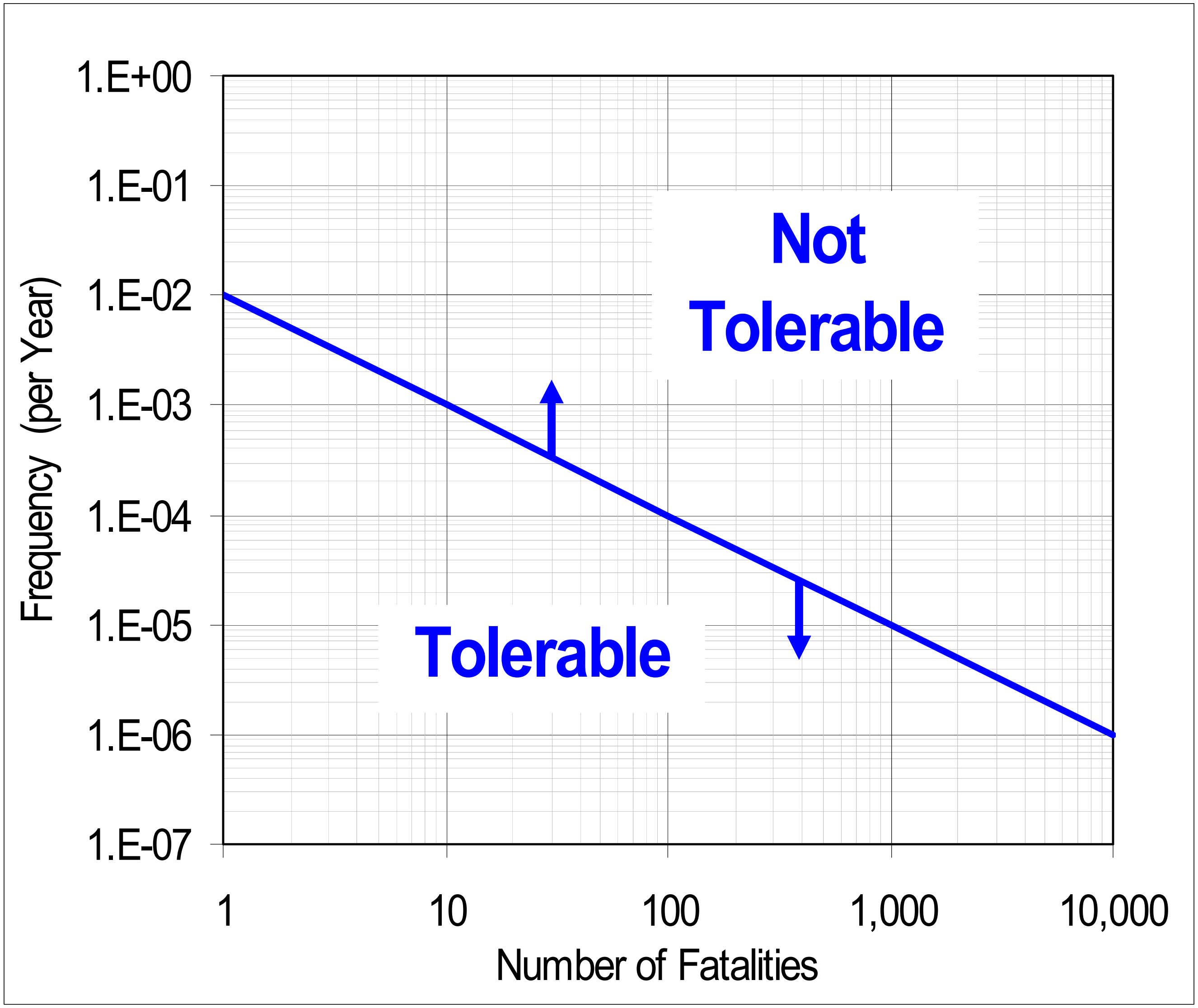
- "Stability of I-Walls in New Orleans during Hurricane Katrina" by J. Michael Duncan, Thomas L. Brandon, Stephen G. Wright, and Noah Vroman.
- "Analysis of the Stability of I-Walls with Gaps between the I-Wall and the Levee Fill" by Thomas L. Brandon, Stephen G. Wright, and J. Michael Duncan
- Both published in Journal of Geotechnical and Geoenvironmental Engineering, ASCE, May 2008.


Risk

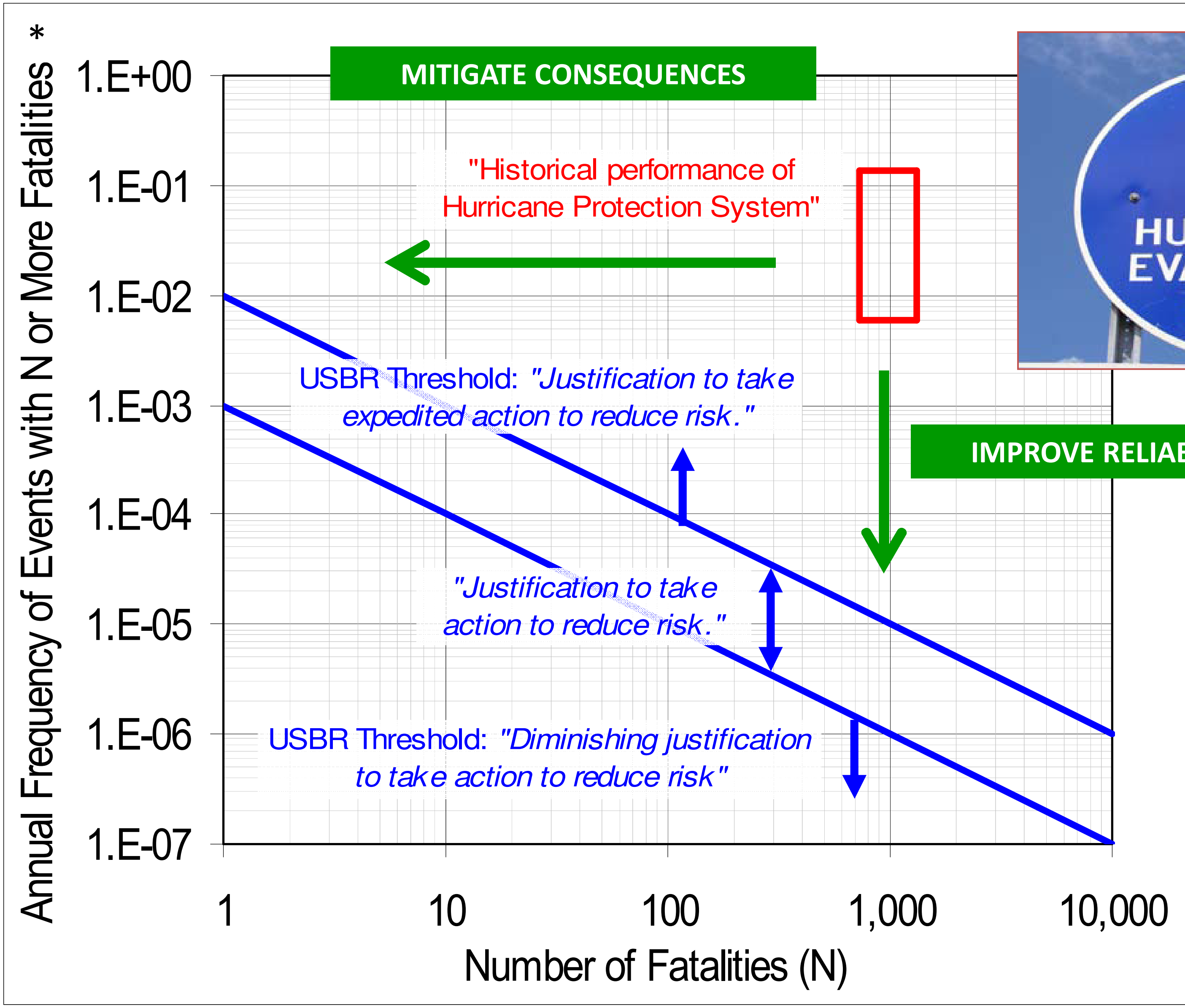
Eric Holdeman's Four Stages of Denial

- 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

The Risk to People was Misunderstood*

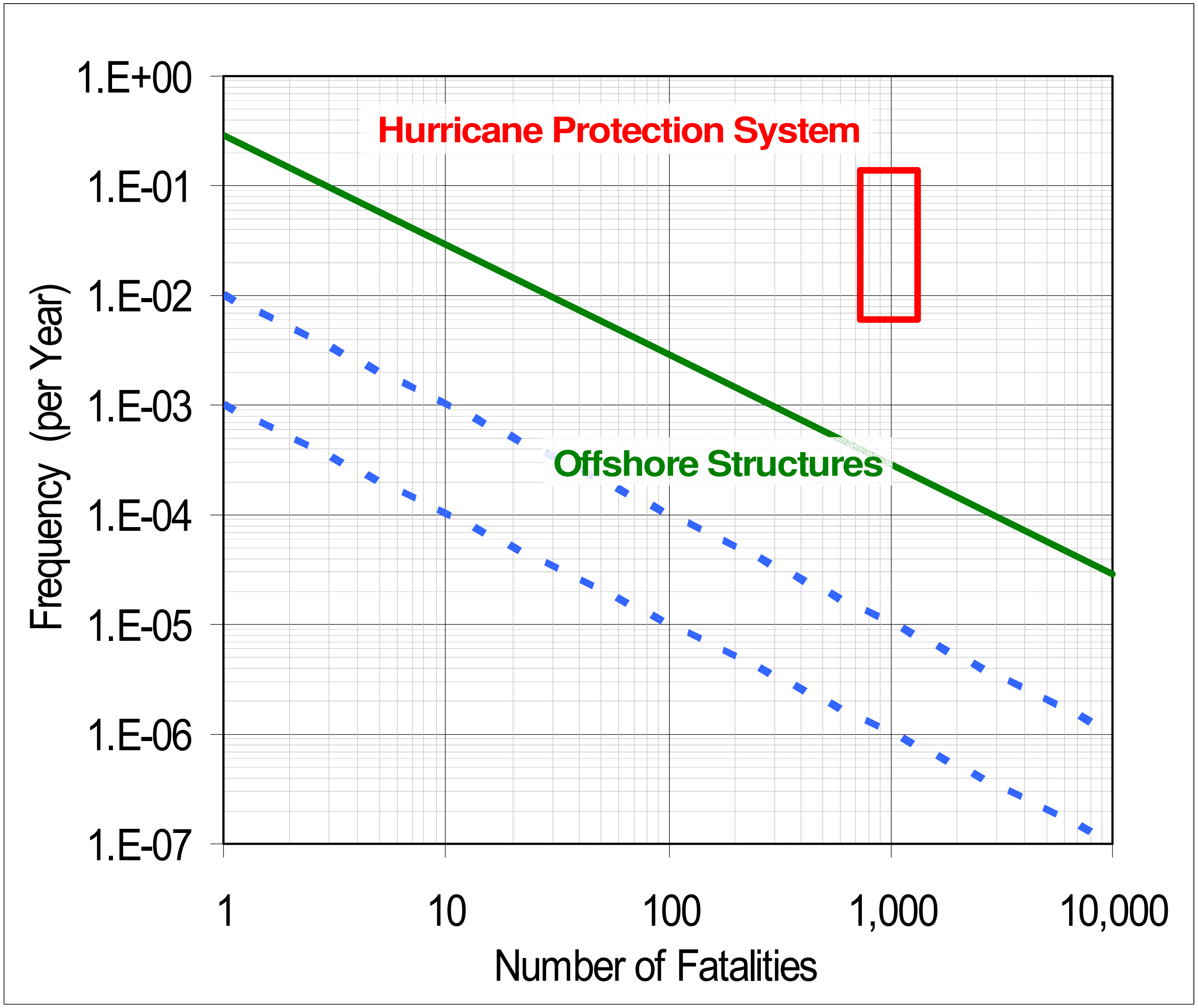


** Courtesy of Robert B. Gilbert, Univ. of Texas, Austin*



** Courtesy of Robert B. Gilbert, Univ. of Texas, Austin*

Guidance for offshore structures in the Gulf*



** Courtesy of Robert B. Gilbert, Univ. of Texas, Austin*

Offshore structures

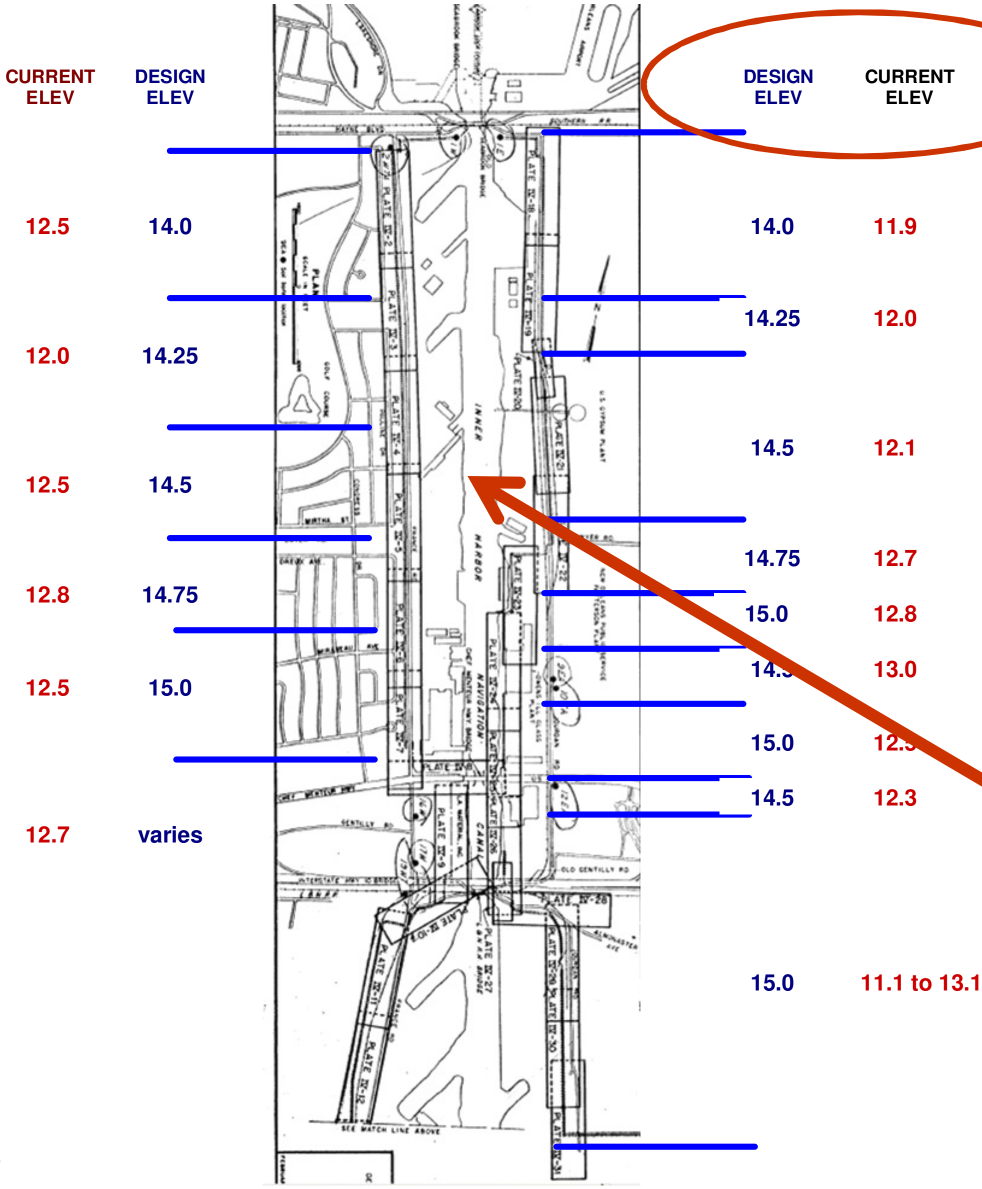
NOLA HPS

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

- $30 billion in damages
- 80 percent evacuation
- >1100 fatalities

Lessons Learned

Failure to think globally, act locally



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

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. A flood-side water-filled gap should always be assumed.

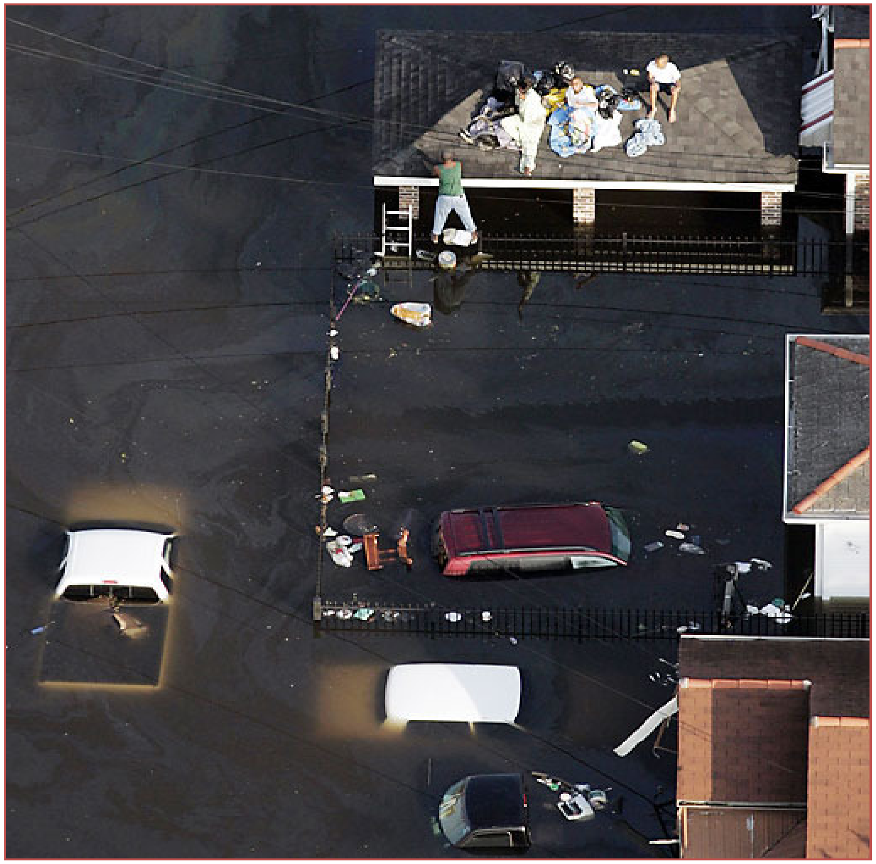
Failure to build in quality

- 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

Conclusions

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



Demand engineering quality

- Upgrade engineering design procedures
- Bring in independent experts
- Engineers <u>*must*</u> place safety first

Acknowledgements

- Lawrence H. Roth, P.E., G.E., F.ASCE
- U.S. Army Engineer Research and Development Center
- Corps' Interagency Performance Evaluation Taskforce
  - Levee and Wall Performance Group: Reed L. Mosher and James Michael Duncan
- Professor Robert B. Gilbert
- Tracey Waddell, ERDC


Questions?