Performance of the Levee System in Hurricane Katrina

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Member, ASCE Inter-Institute Committee on Levees

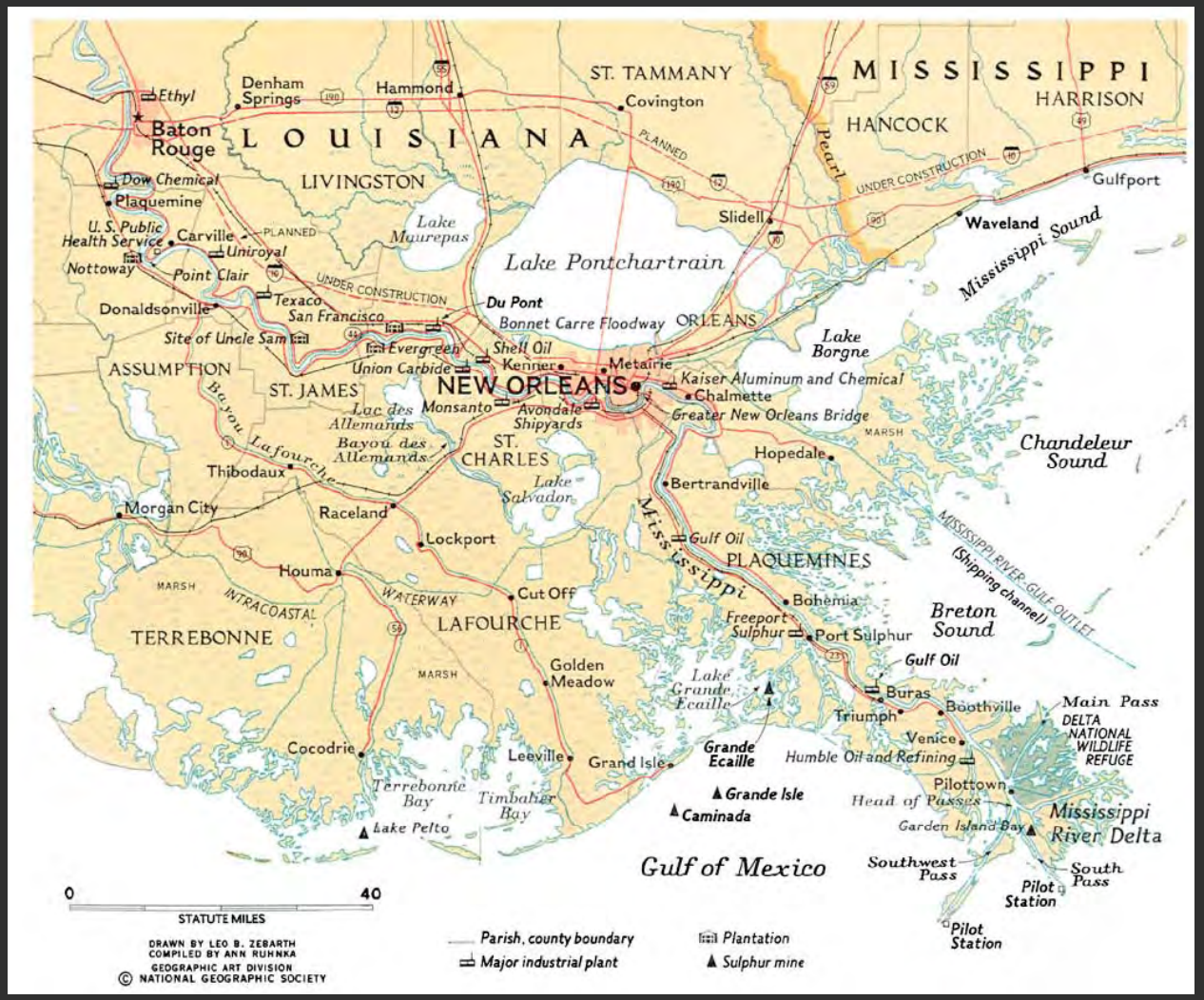
UNIVERSITY of WASHINGTON

Background

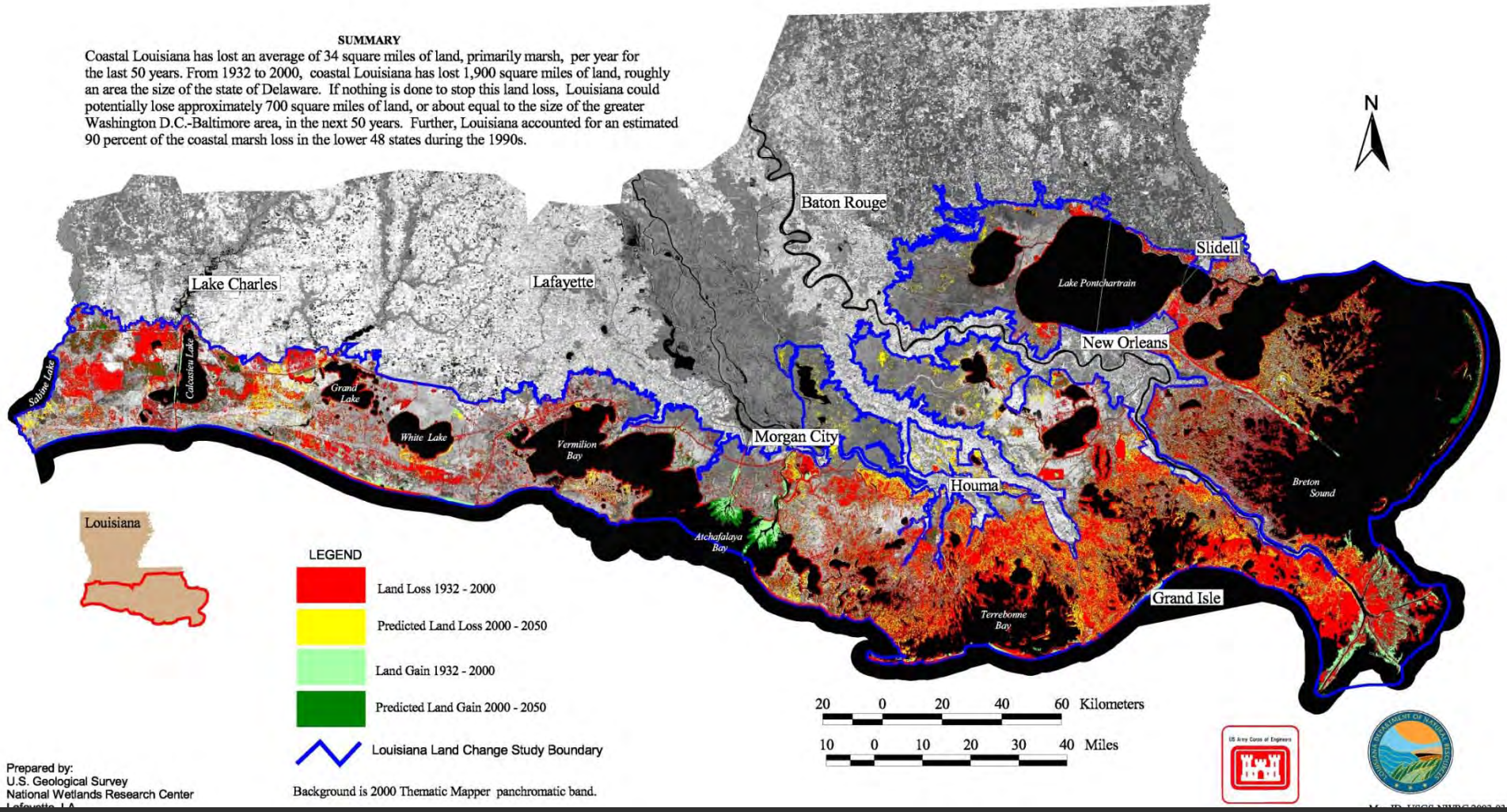
New Orleans:

"An impossible,

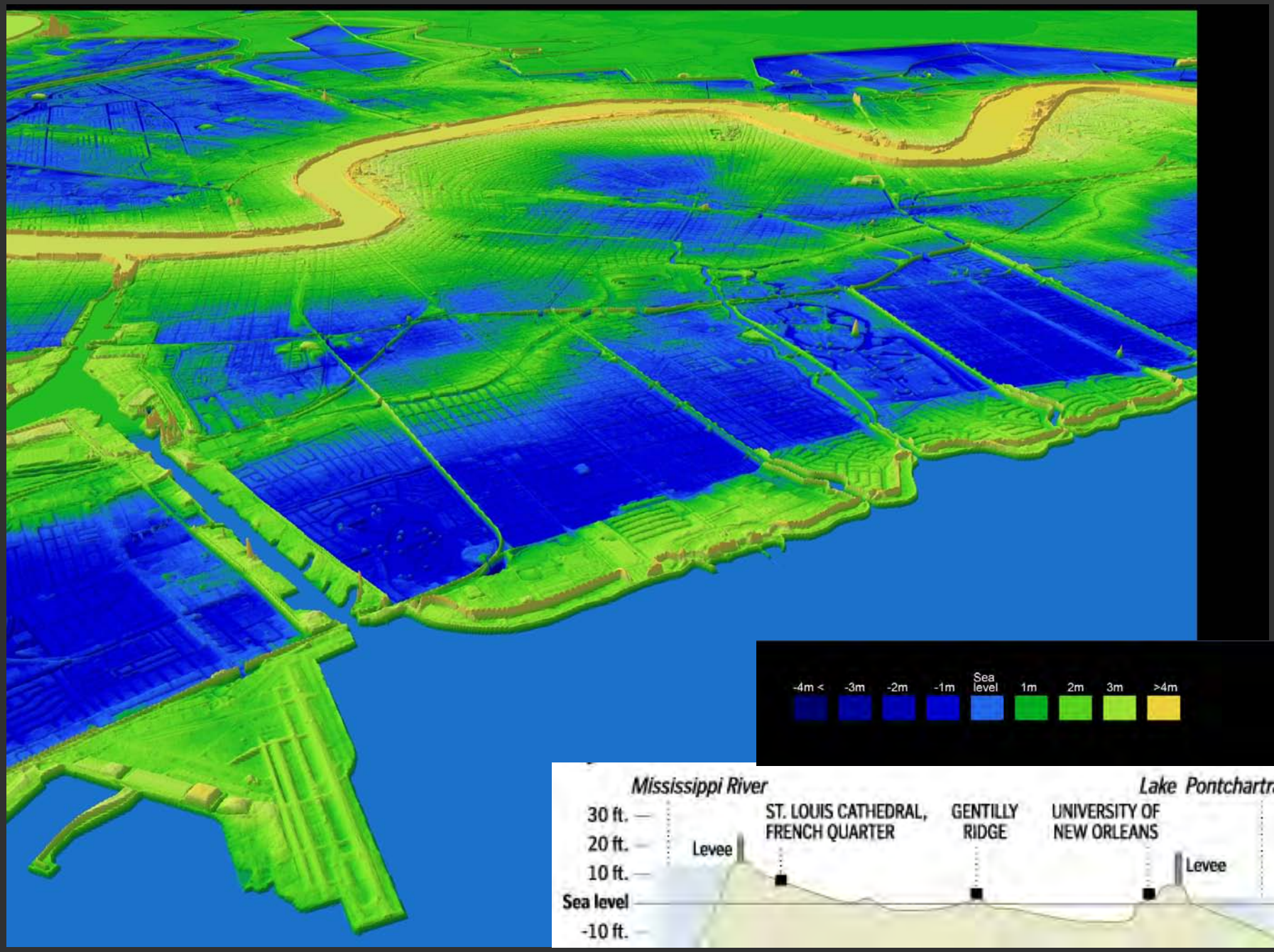
but inevitable city..."



Southern Louisiana: Subsidence and associated land loss



New Orleans: Topography



New Orleans: Levee system

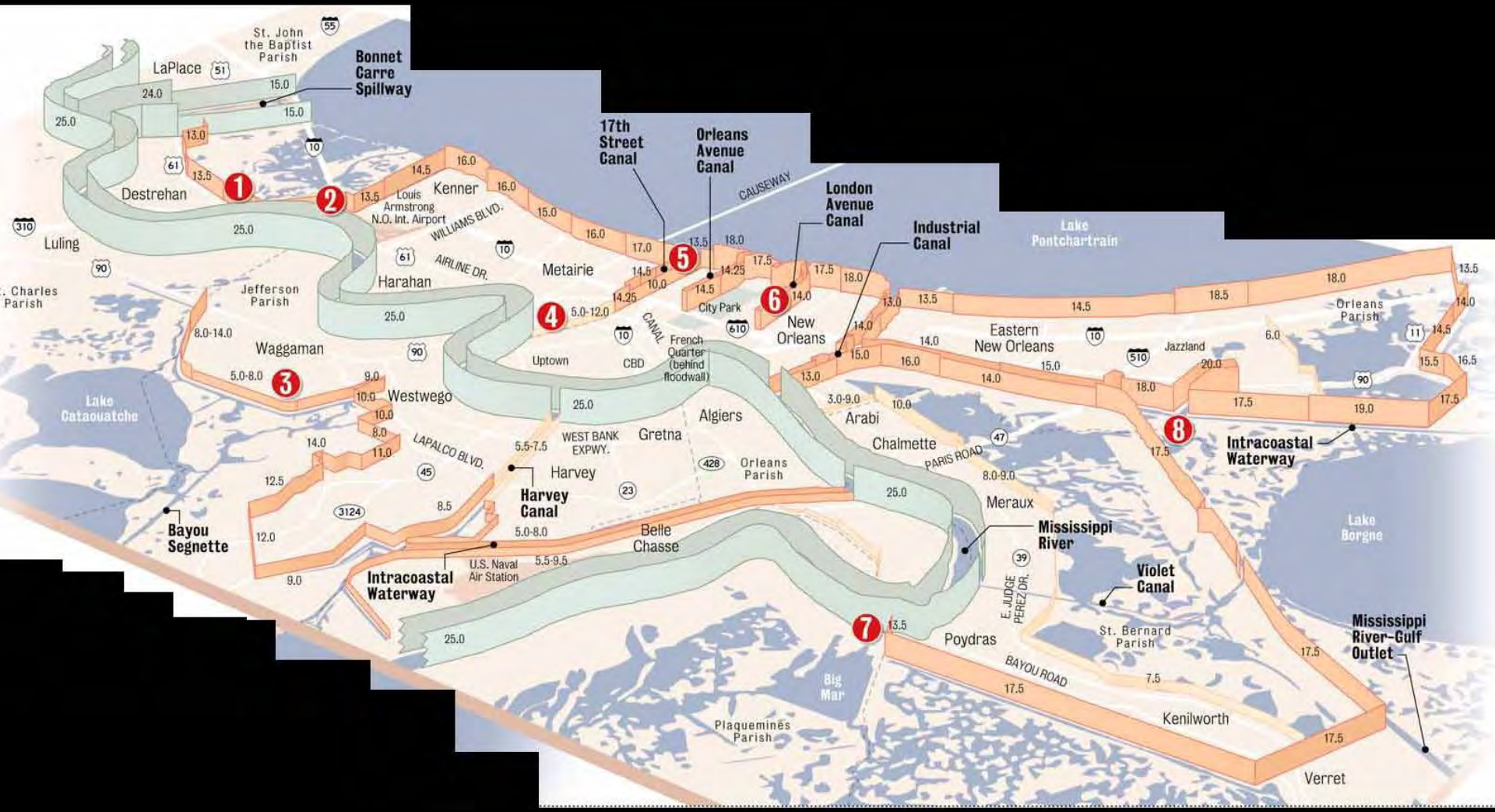
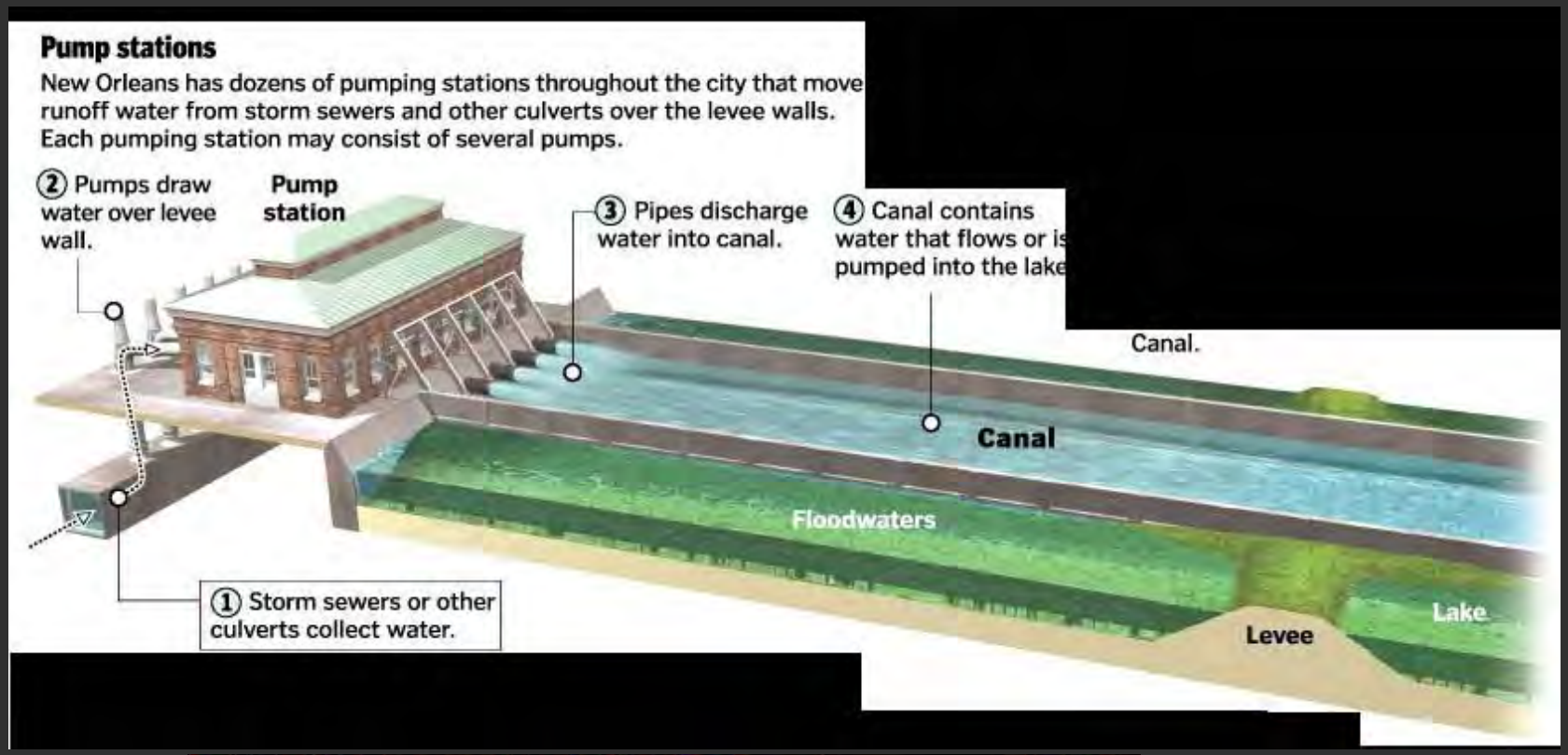


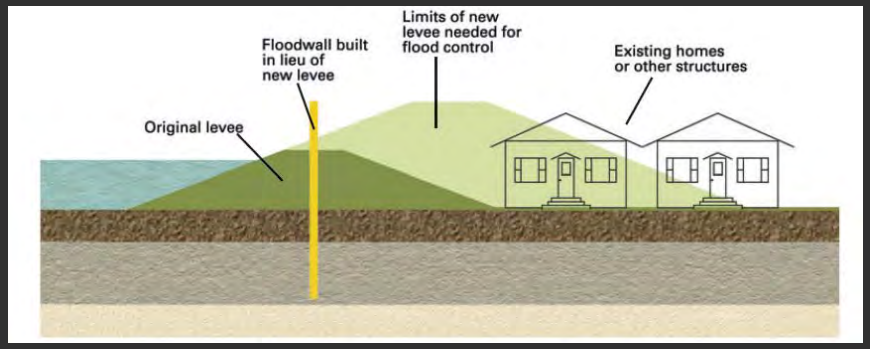
Figure courtesy of the *Times Picayune*

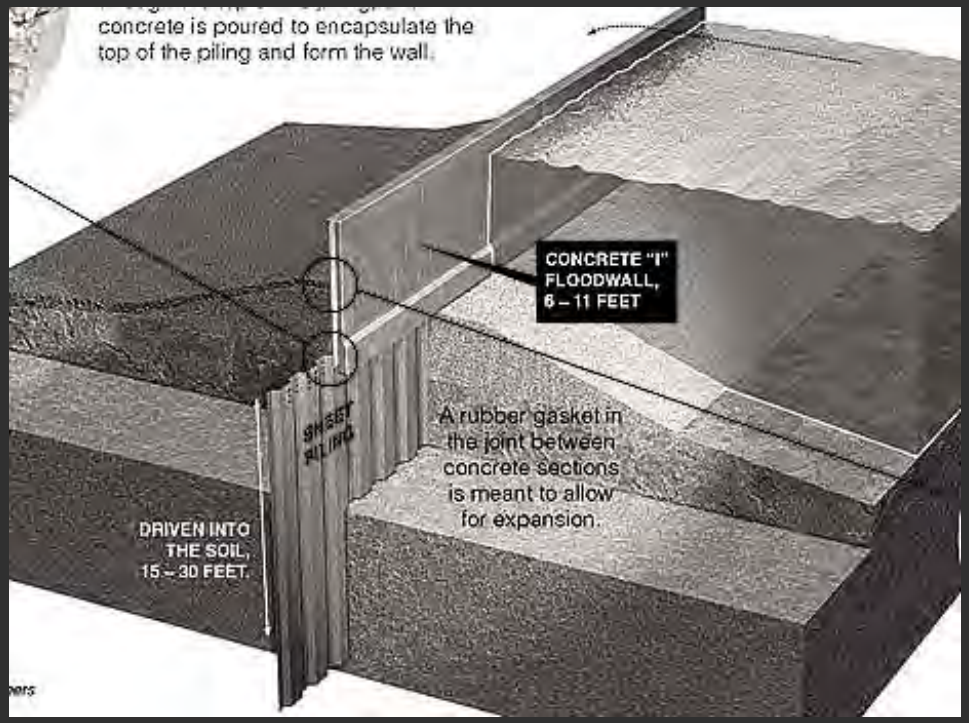
Pump Stations



Figures courtesy of the Wash. Post and NY Times

Levee and floodwall systems





Dams vs. Levees?

Dams

- Tall in height and limited in length

Levees

- Long (many miles) and relatively short in height

Dams vs. Levees?

Dams

- Tall in height and limited in length

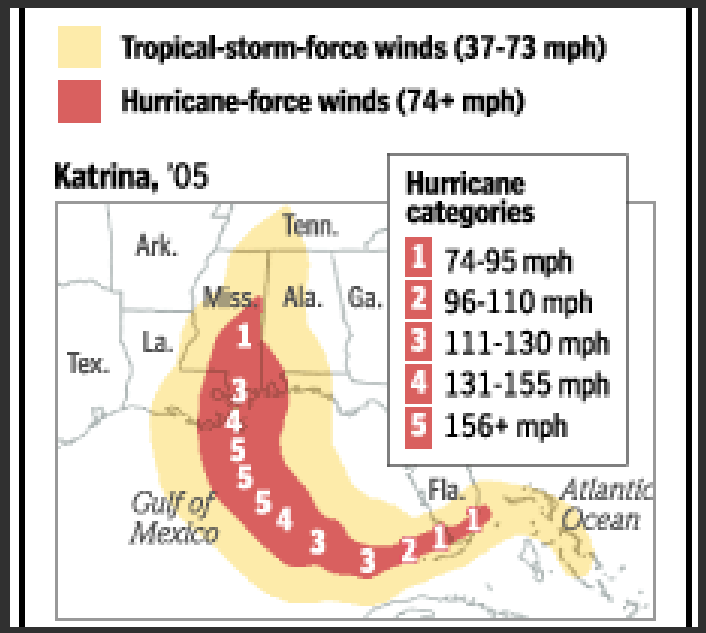
- Location is selected based on subsurface conditions

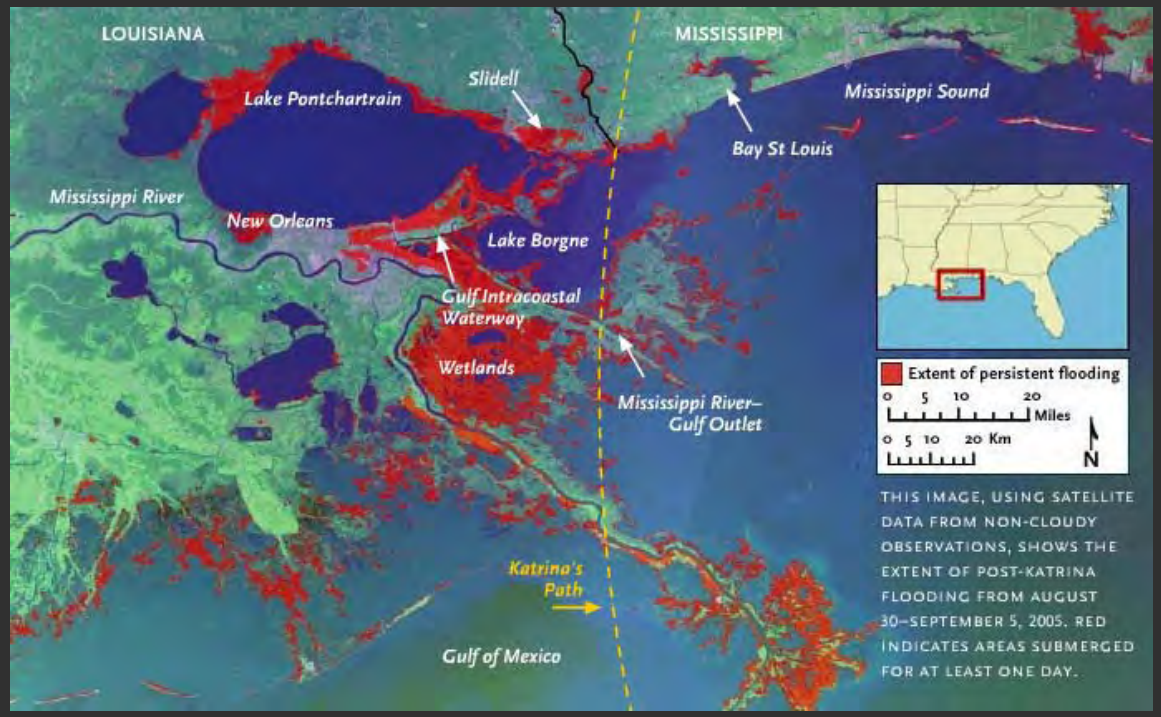
Levees

- Long (many miles) and relatively short in height

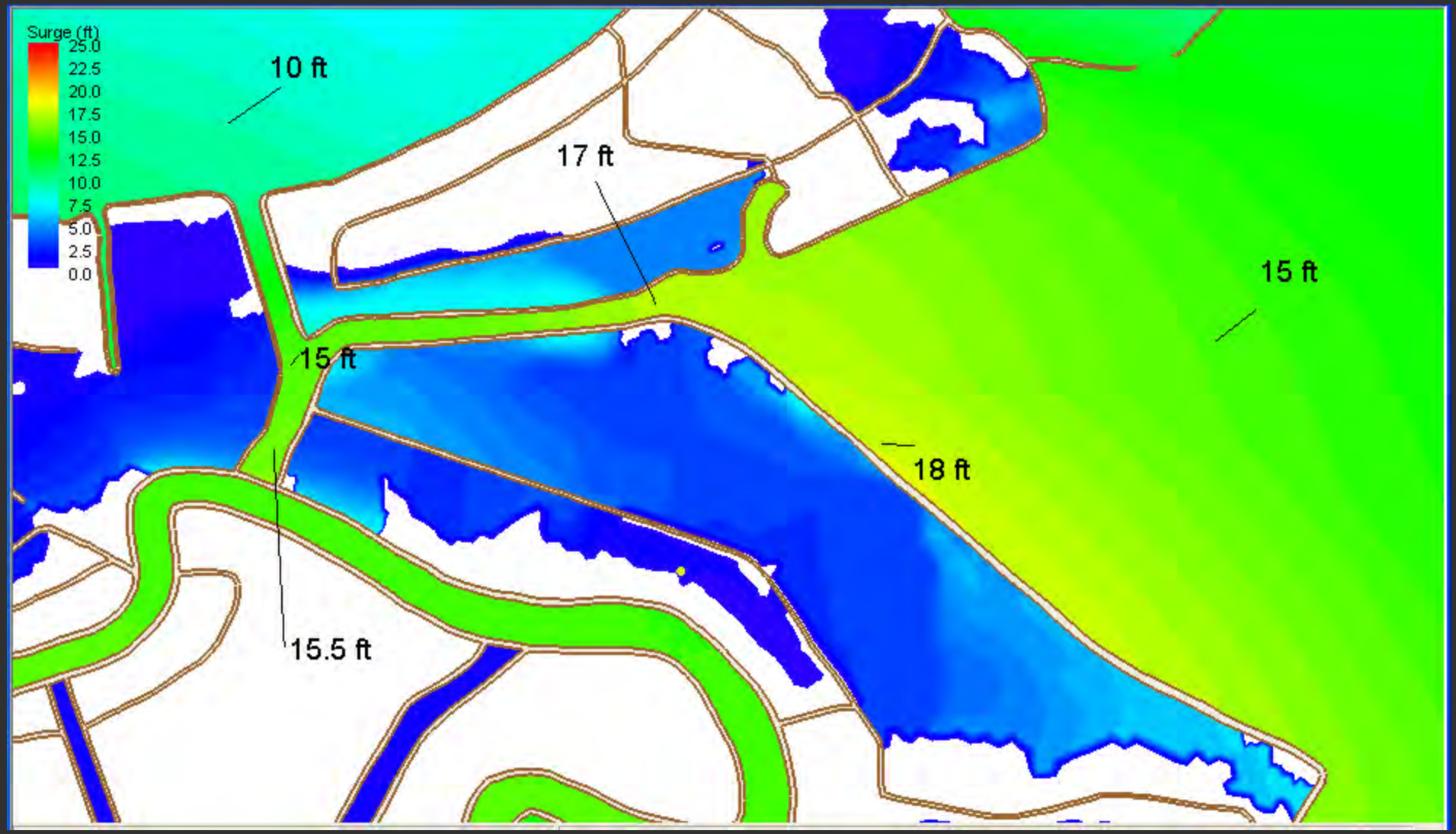
- Location is not selected, and is inherently poor
- Series systems that are costly to build and maintain

Hurricane Katrina



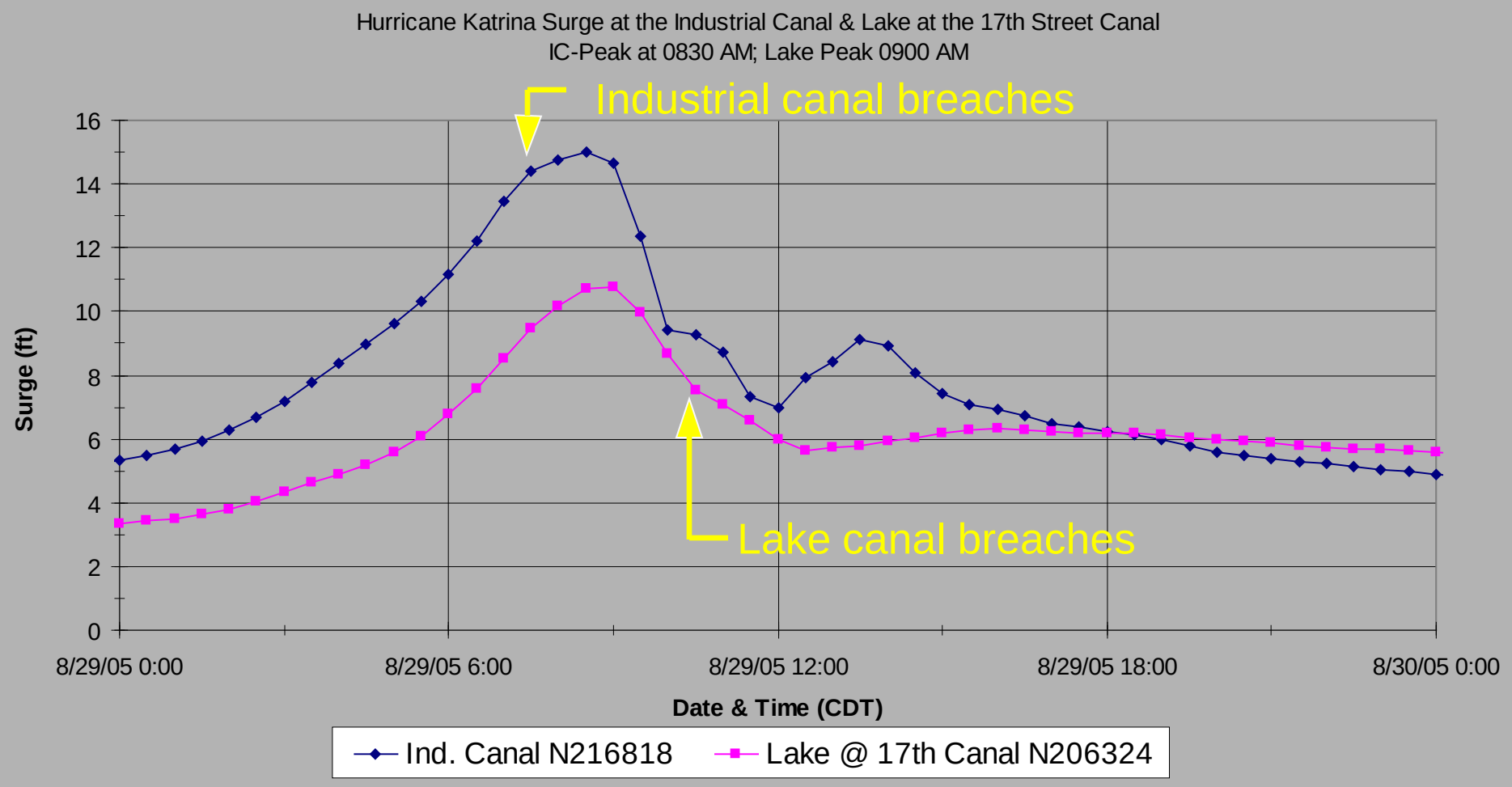


Hurricane Katrina storm surge (LSU simulation)



Hurricane Katrina Storm Surge Hydrograph Simulations

(LSU Hurricane Center)



Hurricane Katrina flooding

Figure Courtesy of the LSU Hurricane Center

Hurricane Katrina impacts on levee system

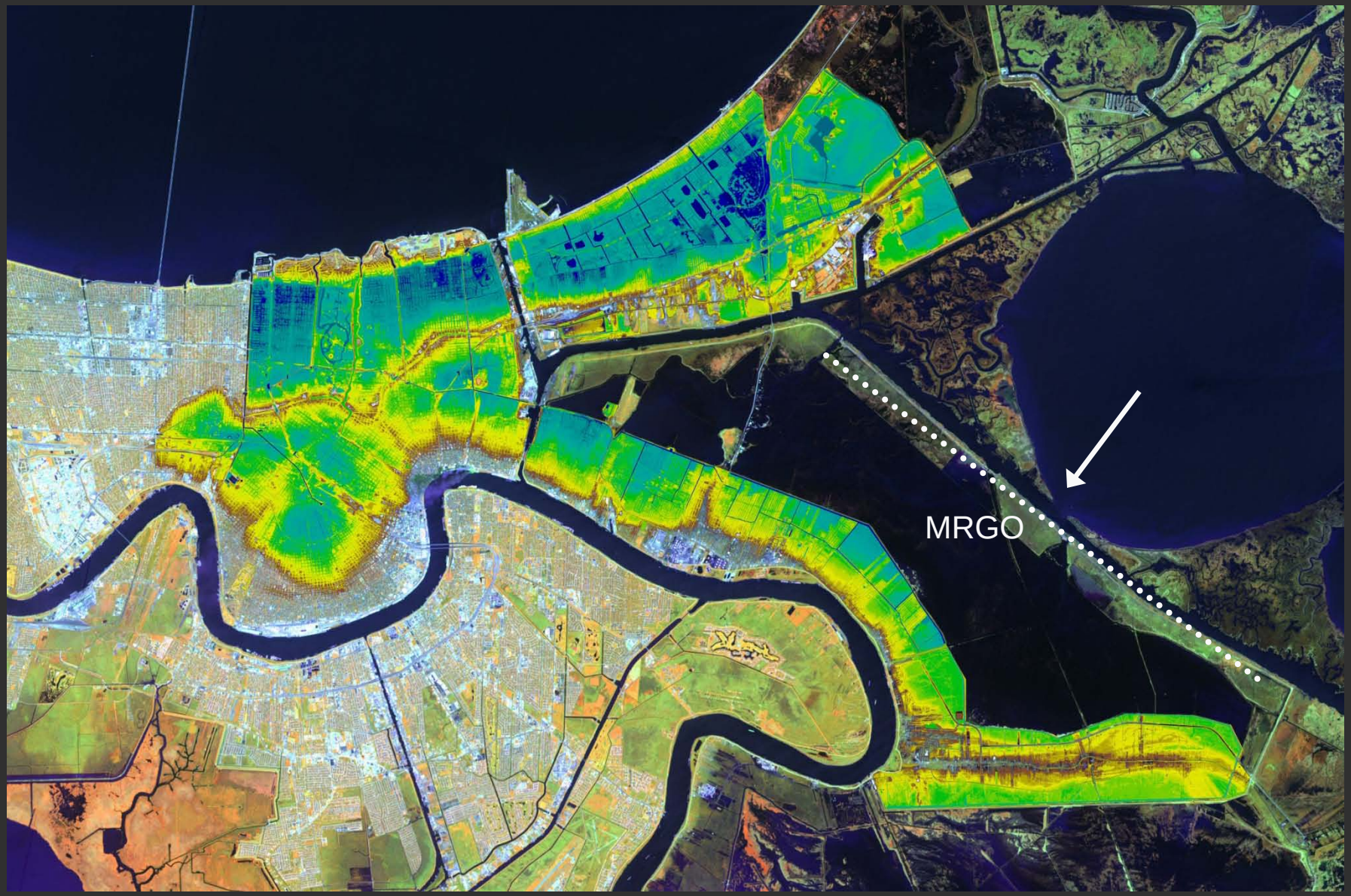


Figure Courtesy of the LSU Hurricane Center

Hurricane Katrina impacts on levee system

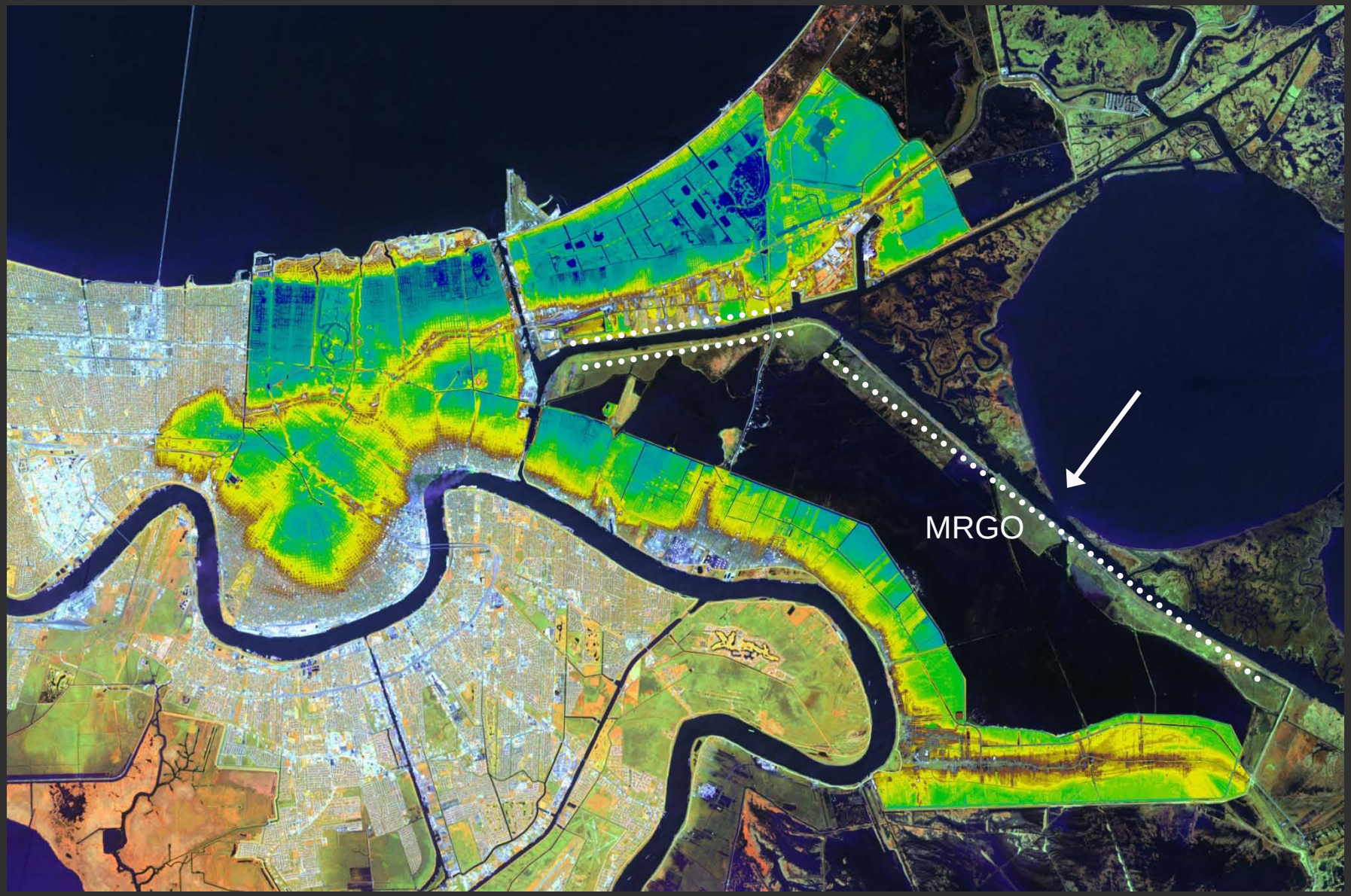


Figure Courtesy of the LSU Hurricane Center

Hurricane Katrina impacts on levee system

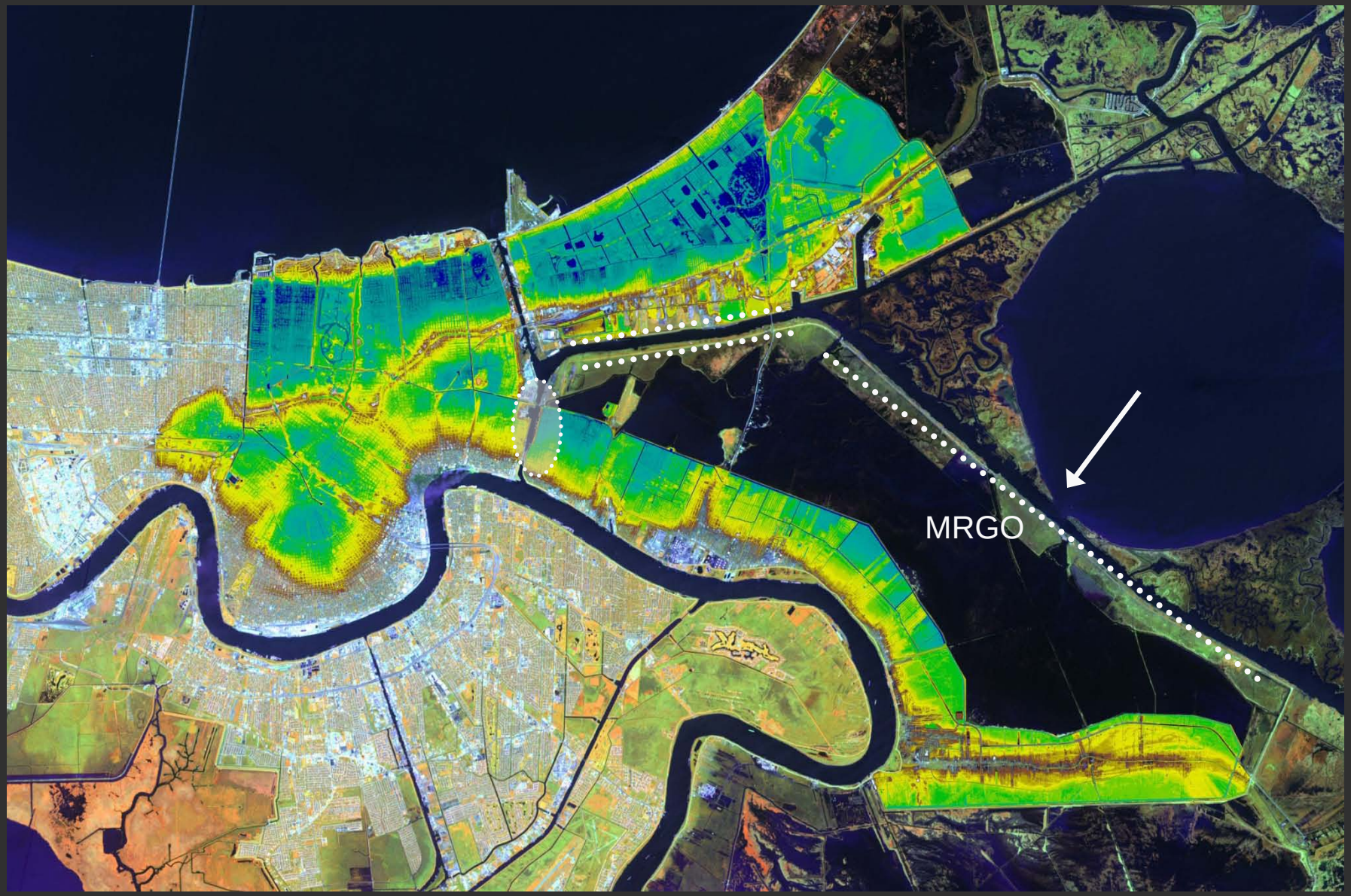


Figure Courtesy of the LSU Hurricane Center

Hurricane Katrina impacts on levee system

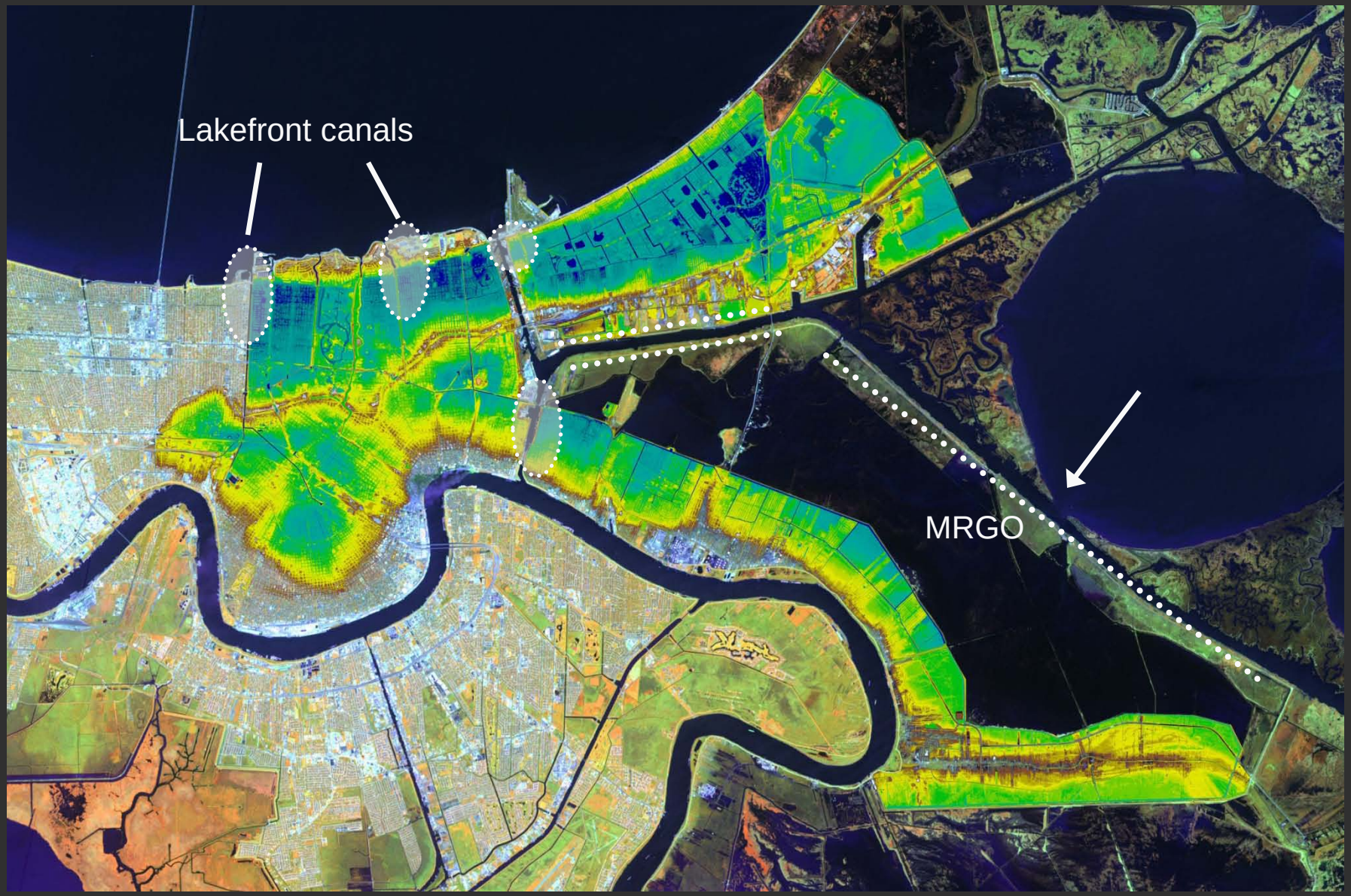
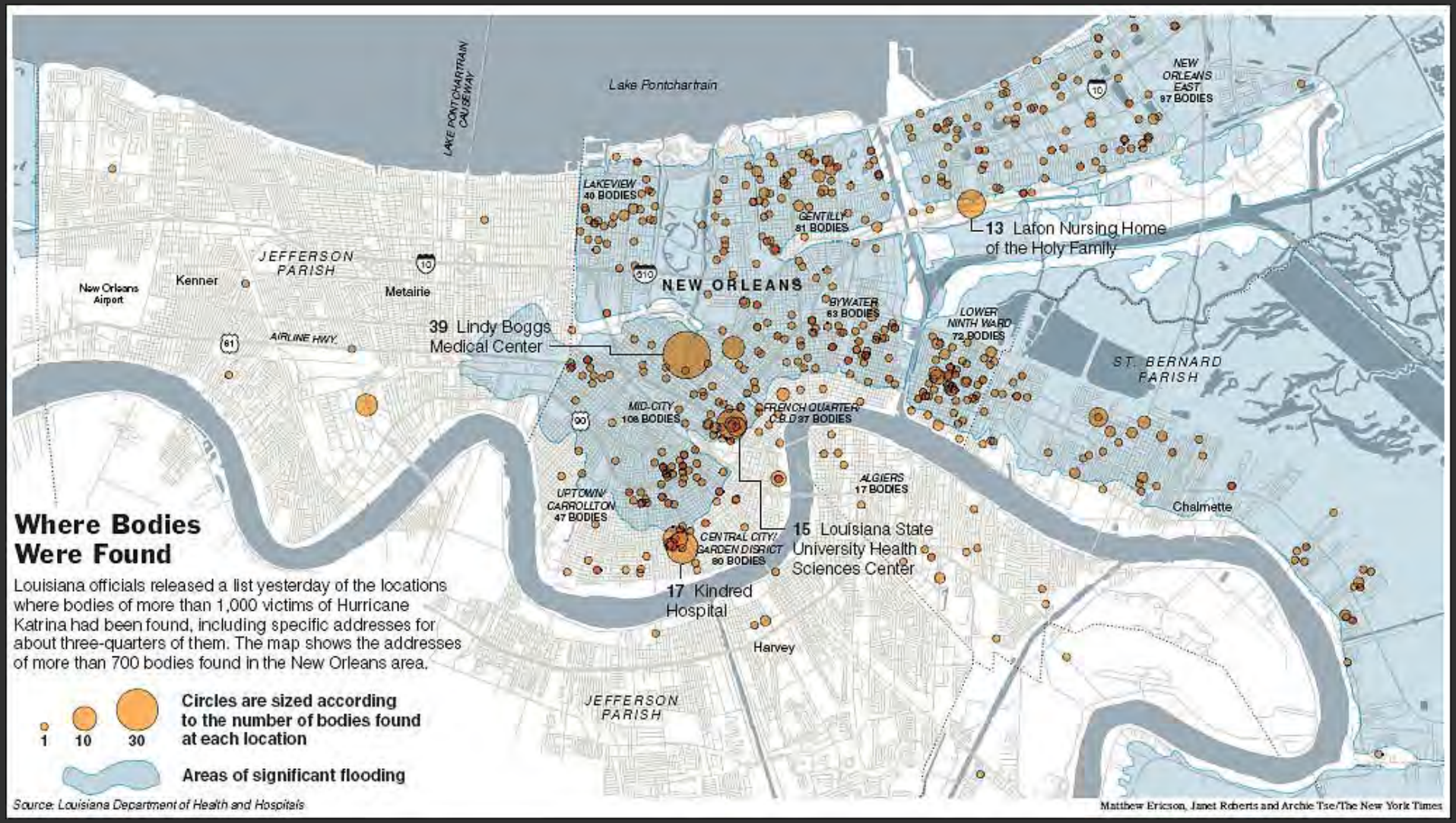


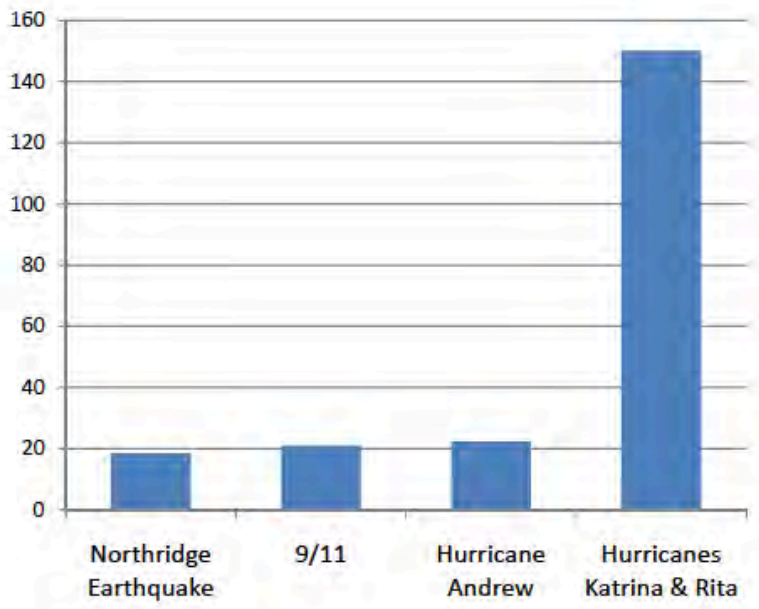
Figure Courtesy of the LSU Hurricane Center

Impact: ~1300 fatalities



Impact: ~$150 billion in capital losses

Hurricanes Katrina & Rita: $150 billion



Post-Katrina Repair

Preliminary findings

Multiple failures (breaches) throughout the regional levee system

Engineering, design, and/or construction played a key role in the catastrophe

White Sox Take 2-0 World Series Lead With Late Home Run | SPORTS A2

The Washington Post

DISTRICT & MARYLAND FINAL

Investigators Link Levee Failures to Design Flaws

Three Teams of Engineers Find Weakened Soil, Navigation Canal Contributed to La. Collapses

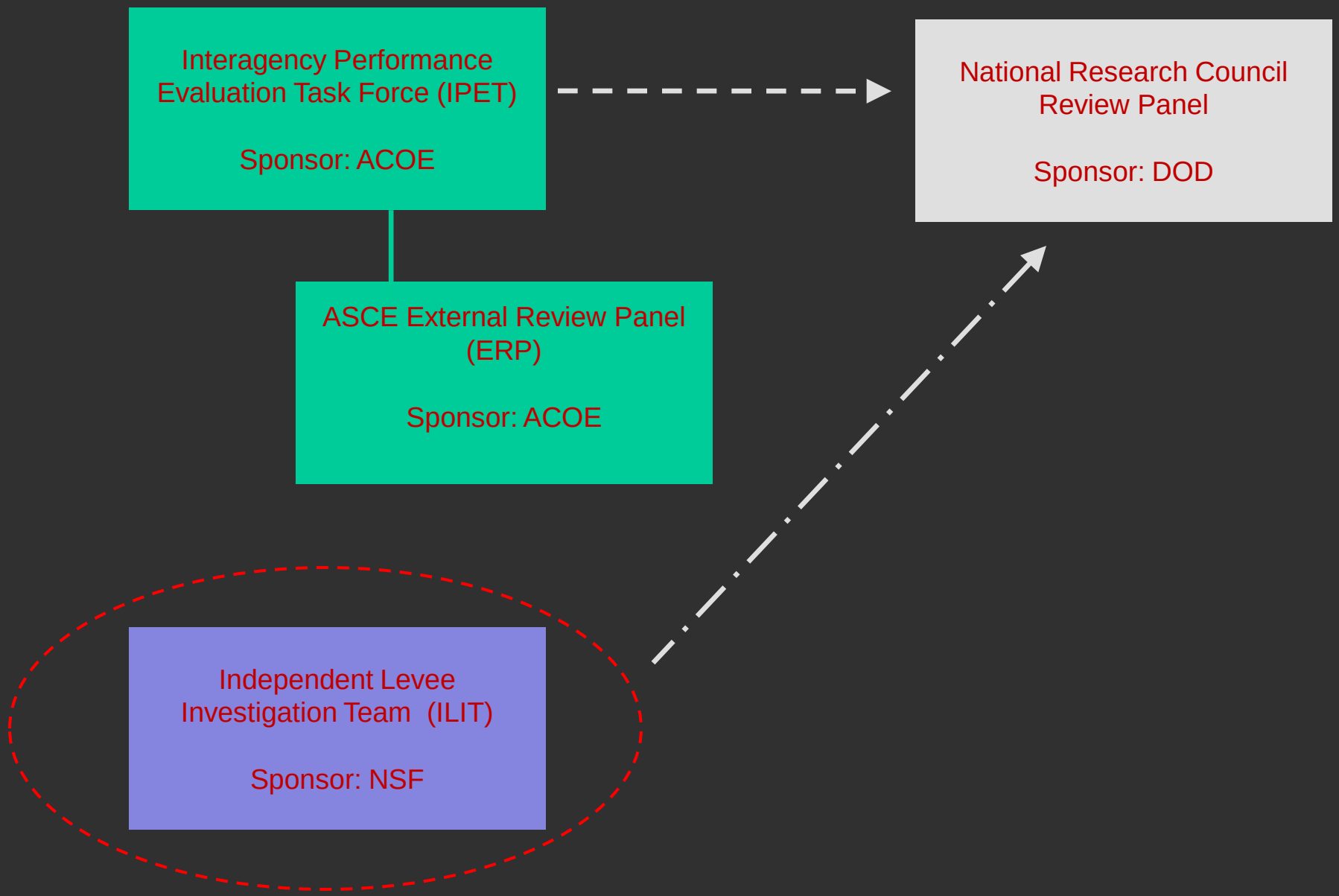
Enemy Body Counts Revived

U.S. Is Citing Toll to Show Success in Iraq

Letters Show Frist Notified Of Stocks in 'Blind' Trusts

Documents Contradict

Forensic investigations



Breach locations to be discussed

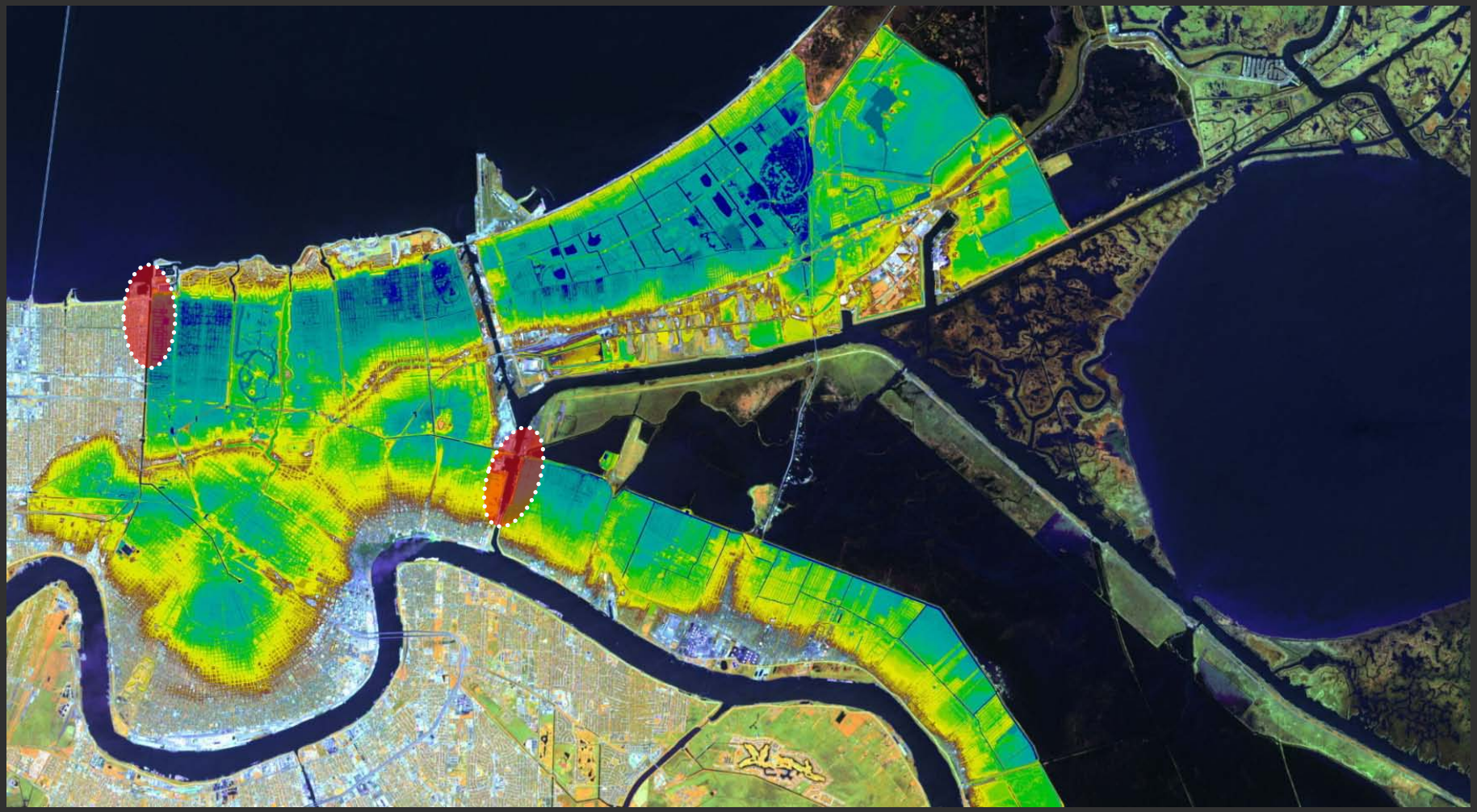
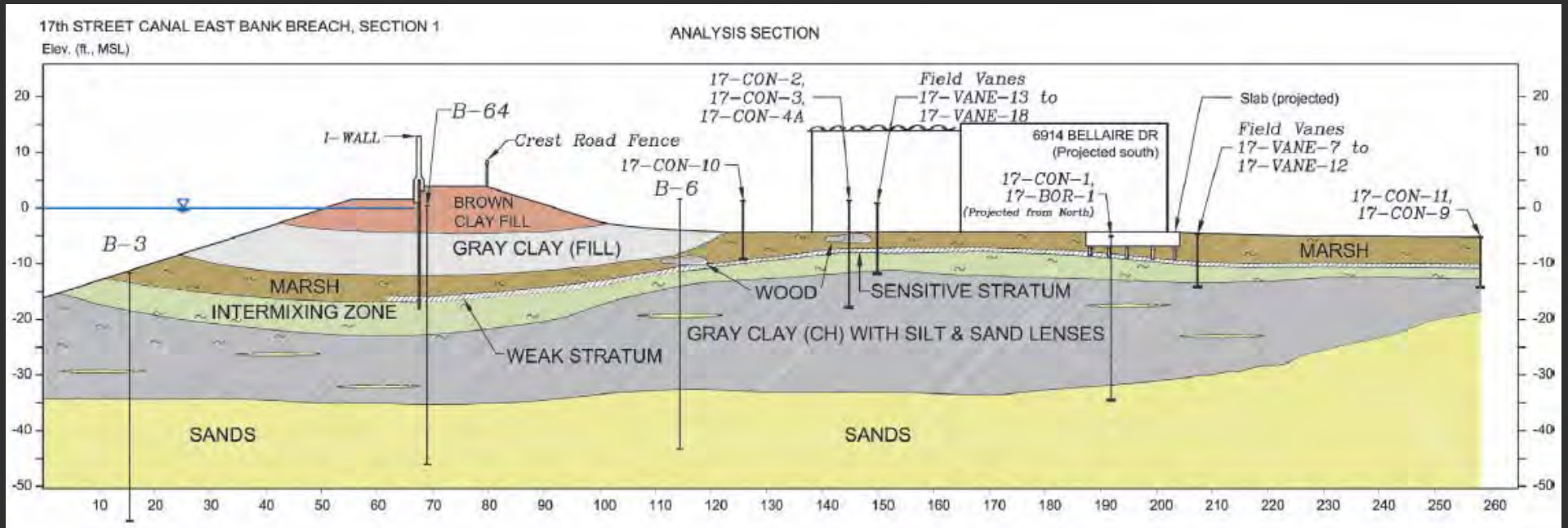
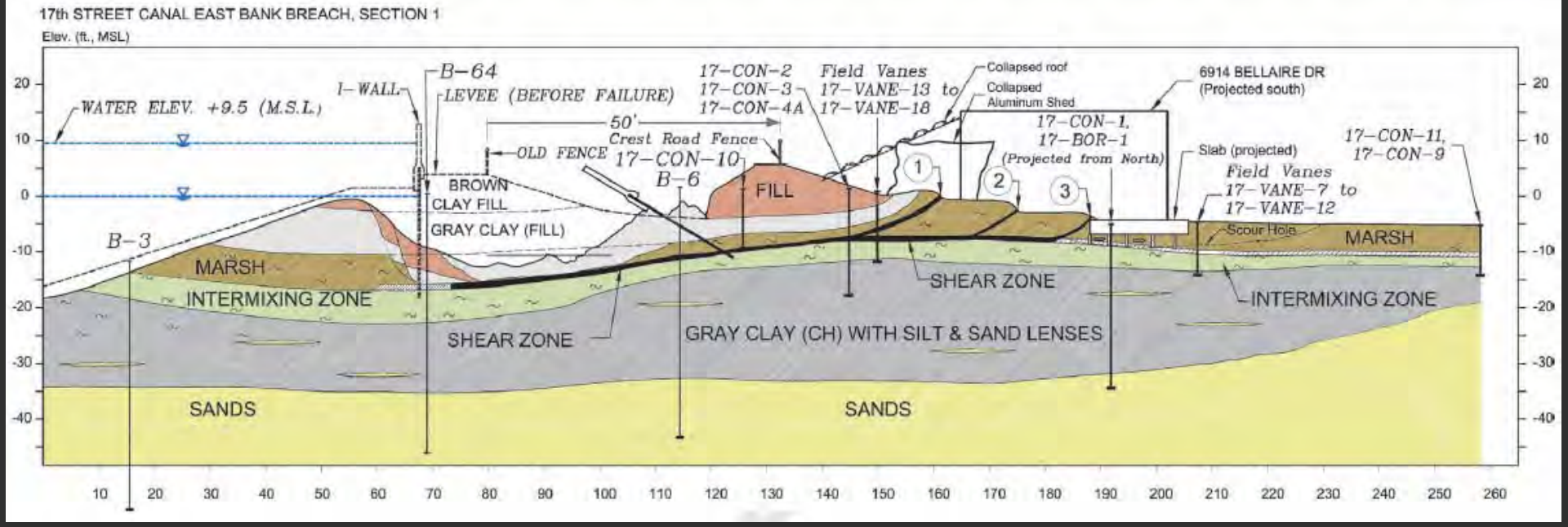


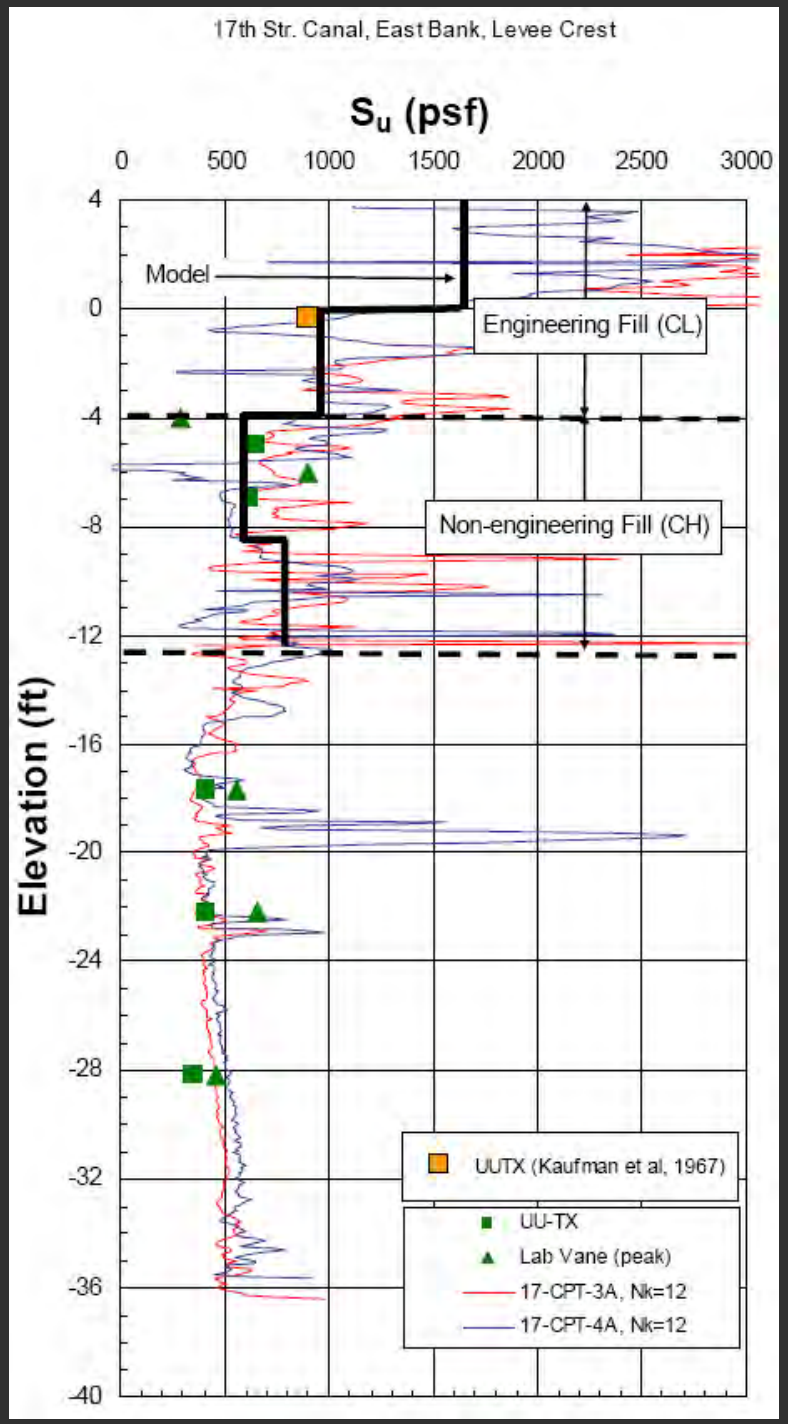
Figure Courtesy of the LSU Hurricane Center

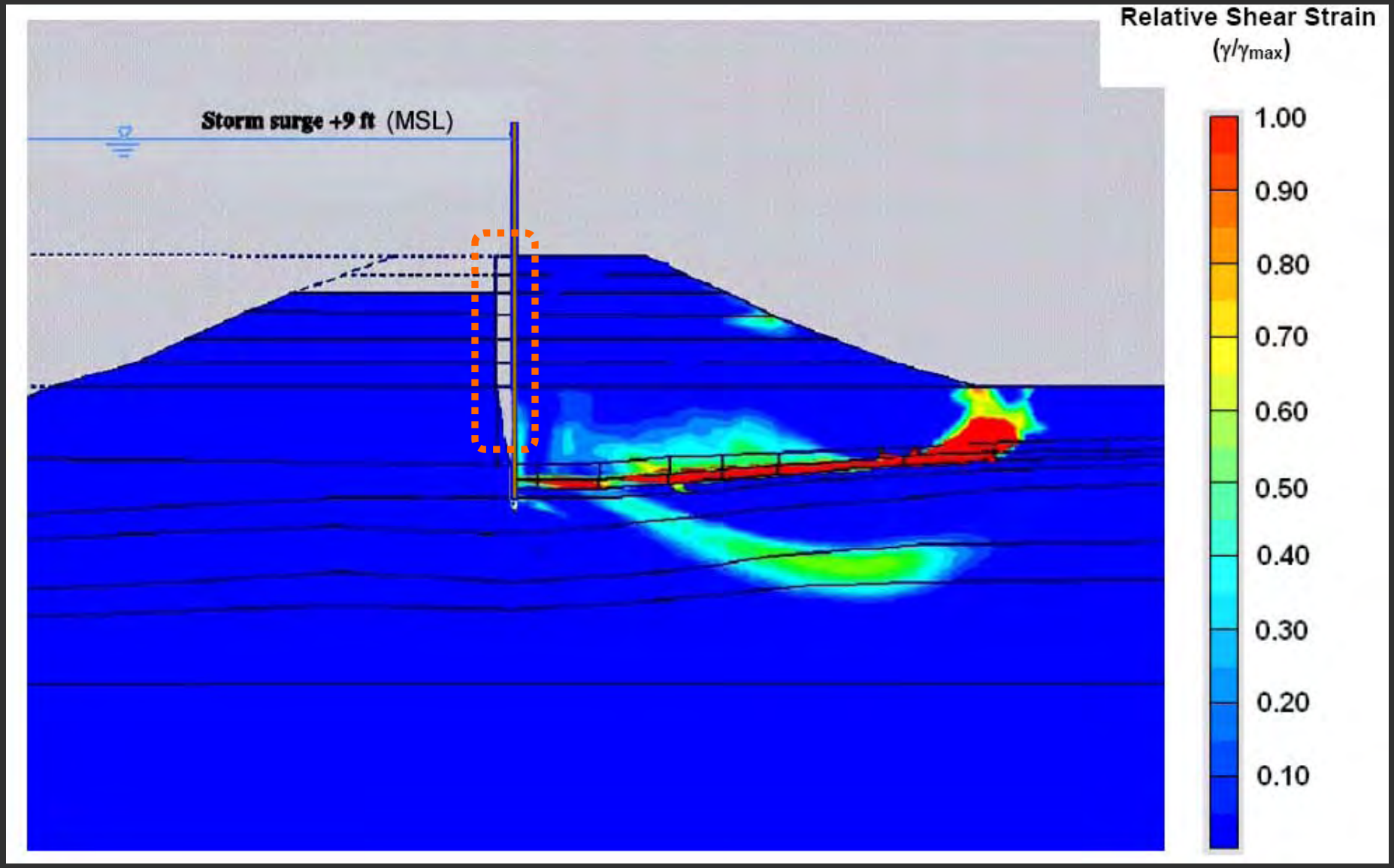
17th Street Canal


17th STREET CANAL EAST BANK BREACH, SECTION 1
Elev. (ft., MSL)
ANALYSIS SECTION
I-WALL
B-64
Crest Road Fence
17-CON-2,
17-CON-3,
17-CON-4A
Field Vanes
17-VANE-13 to
17-VANE-18
Slab (projected)
6914 BELLAIRE DR
(Projected south)
Field Vanes
17-VANE-7 to
17-VANE-12
17-CON-10
B-6
17-CON-1,
17-BOR-1
(Projected from North)
17-CON-11,
17-CON-9
B-3
BROWN
CLAY FILL
GRAY CLAY (FILL)
MARSH
MARSH
INTERMIXING ZONE
WOOD
SENSITIVE STRATUM
WEAK STRATUM
GRAY CLAY (CH) WITH SILT & SAND LENSES
SANDS
SANDS


17th STREET CANAL EAST BANK BREACH, SECTION 1
Elev. (ft., MSL)
WATER ELEV. +9.5 (M.S.L.)
I-WALL
B-64
LEVEE (BEFORE FAILURE)
50'
OLD FENCE
Crest Road Fence
17-CON-10
B-6
17-CON-2
17-CON-3
17-CON-4A
Field Vanes
17-VANE-13 to
17-VANE-18
Collapsed roof
Collapsed
Aluminum Shed
6914 BELLAIRE DR
(Projected south)
17-CON-1,
17-BOR-1
(Projected from North)
Slab (projected)
17-CON-11,
17-CON-9
Field Vanes
17-VANE-7 to
17-VANE-12
BROWN
CLAY FILL
GRAY CLAY (FILL)
FILL
1
2
3
Scour Hole
B-3
MARSH
MARSH
INTERMIXING ZONE
INTERMIXING ZONE
SHEAR ZONE
SHEAR ZONE
GRAY CLAY (CH) WITH SILT & SAND LENSES
SANDS
SANDS

Levee soils

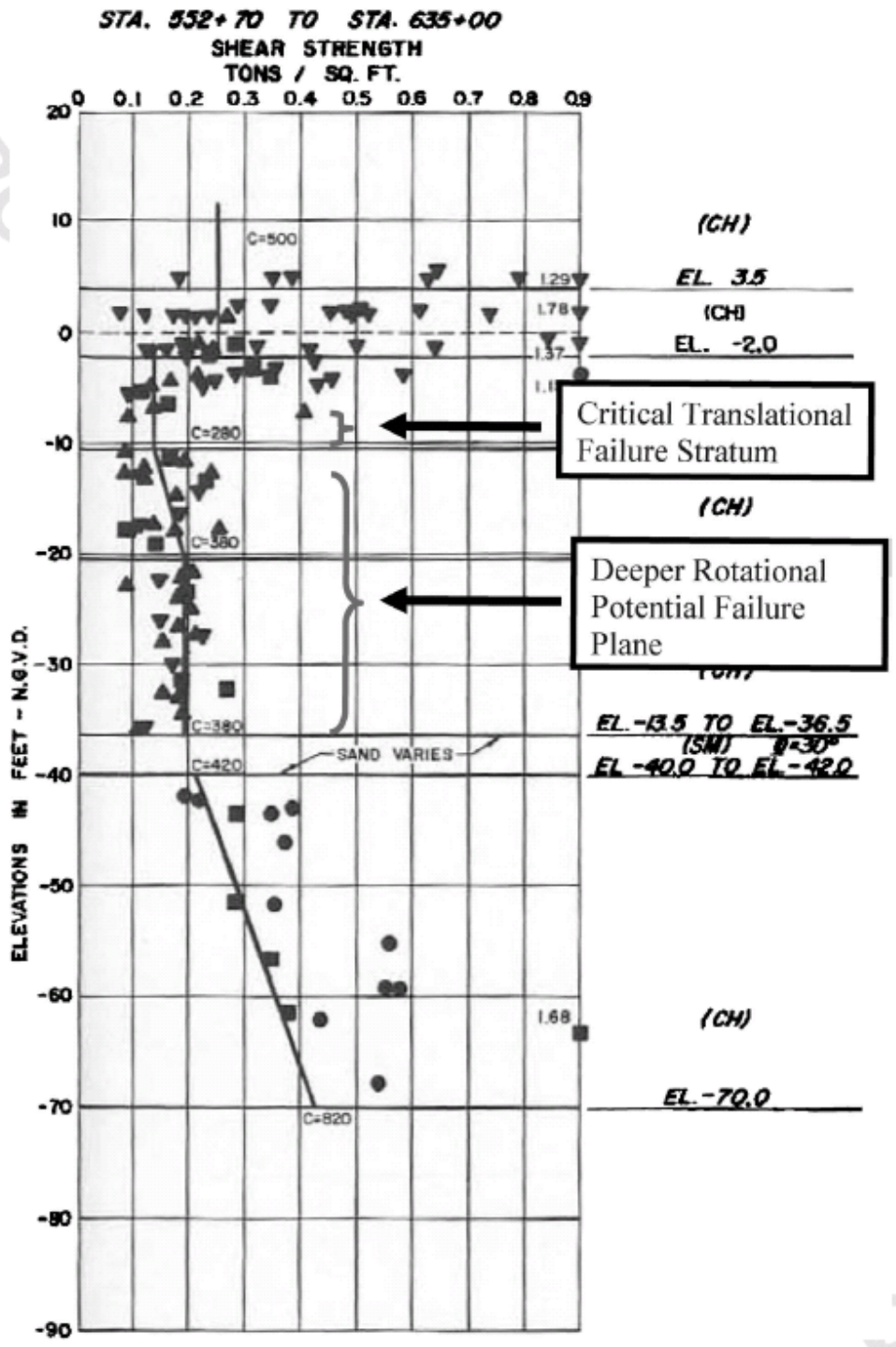

17th Str. Canal, East Bank, Levee Crest
S_u (psf)
0
500
1000
1500
2000
2500
3000
Elevation (ft)
4
0
-4
-8
-12
-16
-20
-24
-28
-32
-36
-40
Model
Engineering Fill (CL)
Non-engineering Fill (CH)
UUTX (Kaufman et al, 1967)
UU-TX
Lab Vane (peak)
17-CPT-3A, Nk=12
17-CPT-4A, Nk=12


Storm surge +9 ft (MSL)
Relative Shear Strain
(γ/γmax)
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10

Design issues

- Averaging of soil shear strength data
- "Water in the gap"

- Very low factor of safety (1.3)



Lower Ninth Ward (South breach)

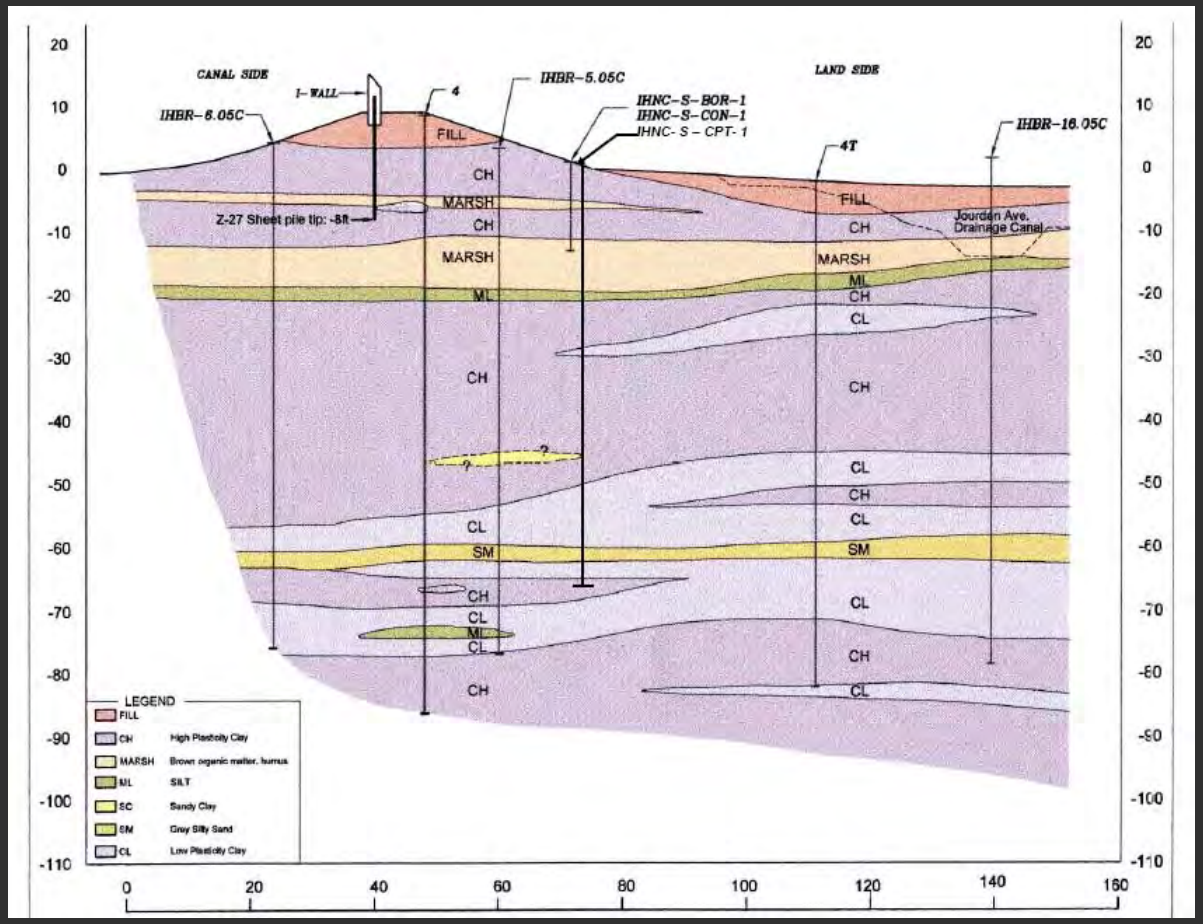
Hypotheses (4)

Semi-rotational Stability Failure through the Top of the Soft Gray Clays *(FOS > 1.3)*

Underseepage-Induced Piping *(clay too thick)*

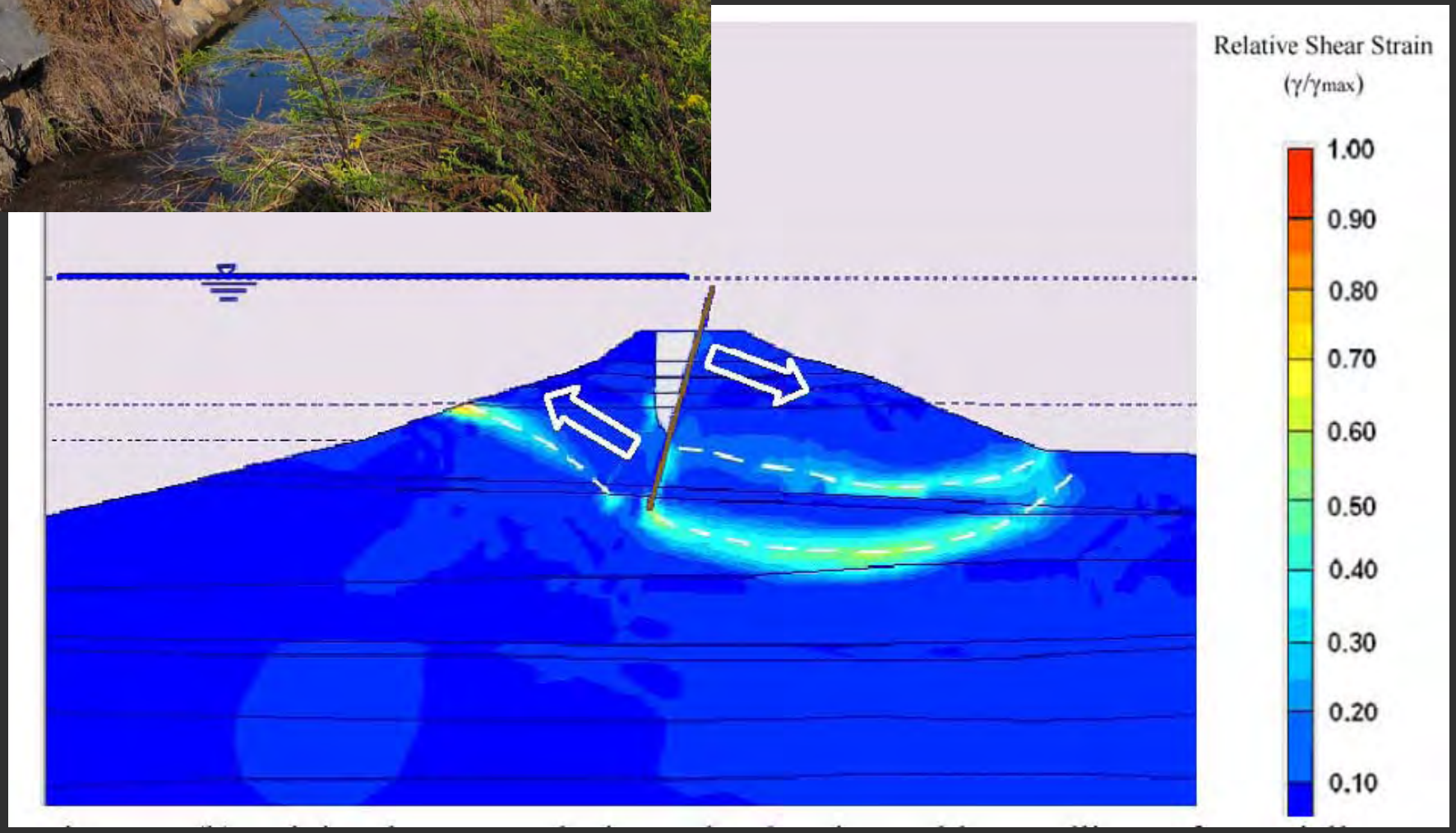
Overtopping, Trench Erosion, and Lateral Toppling of the I-Wall

Potential Underseepage-Induced Lateral Translational Instability



Overtopping hypothesis

- FEA: 6.5–8 ft of erosion to topple the I-wall
- Erosive trenching was observed to be 2.5 to 4 ft



Underseepage hypothesis

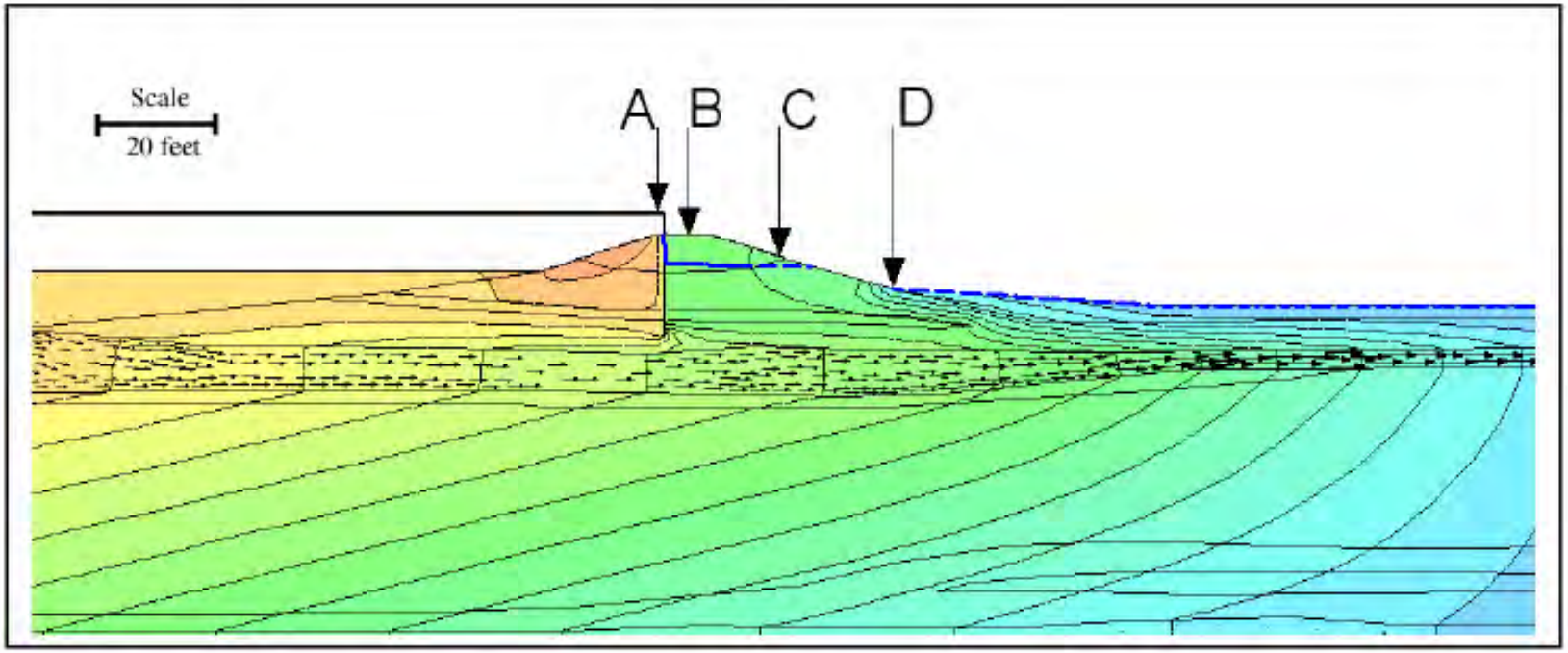
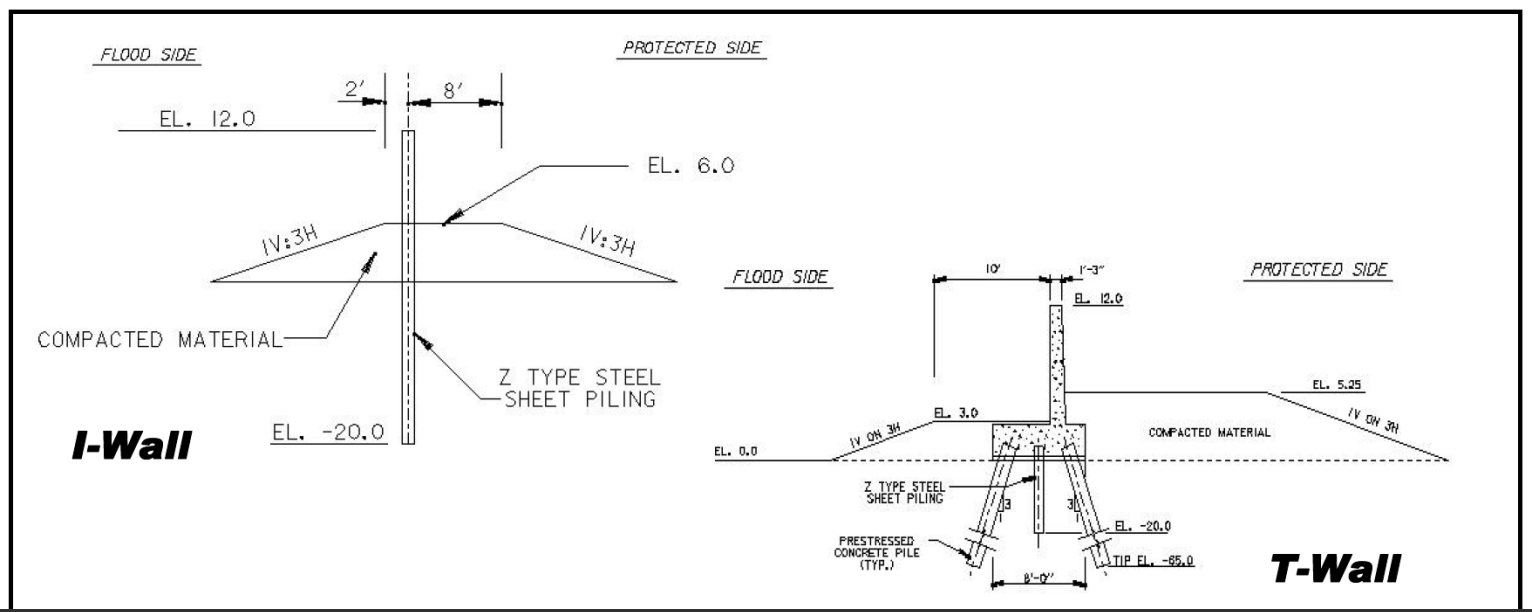


Figure 13(a): Equipotential contours at the time when canal water levels reached Elev. +14 feet (MSL). Contours are at 1-foot intervals.

Other issues: overtopping and scour



Other issues: transitions

Earthen levee performance

Earthen levee performance

Lessons learned and implications

Cognitive errors (due to lack of understanding)

-vs.-

Errors of omission (due to lapse in applying knowledge)

<u>Lessons Learned: 3 Categories</u>

- Technical
- Organizational
- Policy

Technical issues

- Water filled gap (ILIT, IPET, ERP, NRC)

- Soil erosion and levee stability during overtopping (ILIT, IPET, ERP)

    - cost savings = increased risk

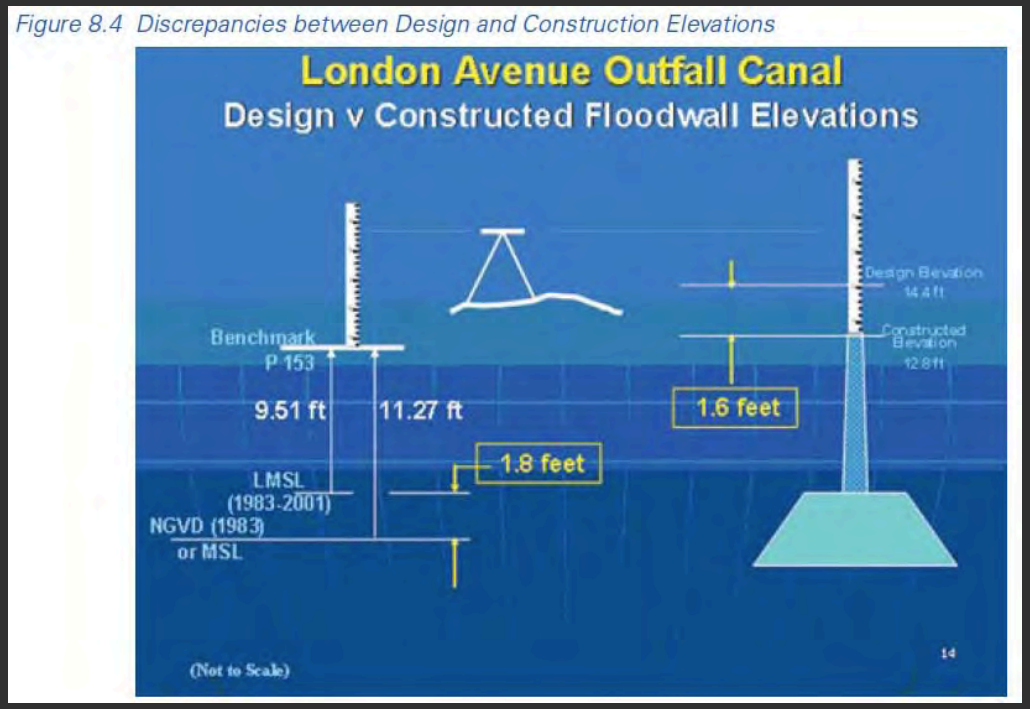
    - excellent erosion performance of cohesive levees

- Low FOS values (ILIT, IPET, ERP, NRC)

- Overly simplified technical models and analyses (ILIT, ERP)

Technical issues

- Some levees lower than designed (IPET, ERP)



- Standard Project Hurricane vs. Probable Maximum Hurricane (IPET, ERP, NRC)

Technical issues: Engineering “System”

- “The hurricane protection system was a system in name only”
(ILIT, IPET, ERP, NRC)

  - Many individual projects “patched” together
  - Transitions
  - Coupling of hurricane protection system and pumping stations
  - Role of wetlands
  - Consideration of social factors

Technical policy issues

- Peer review: “self-referential” decision making process (ILIT, IPET, ERP, NRC)

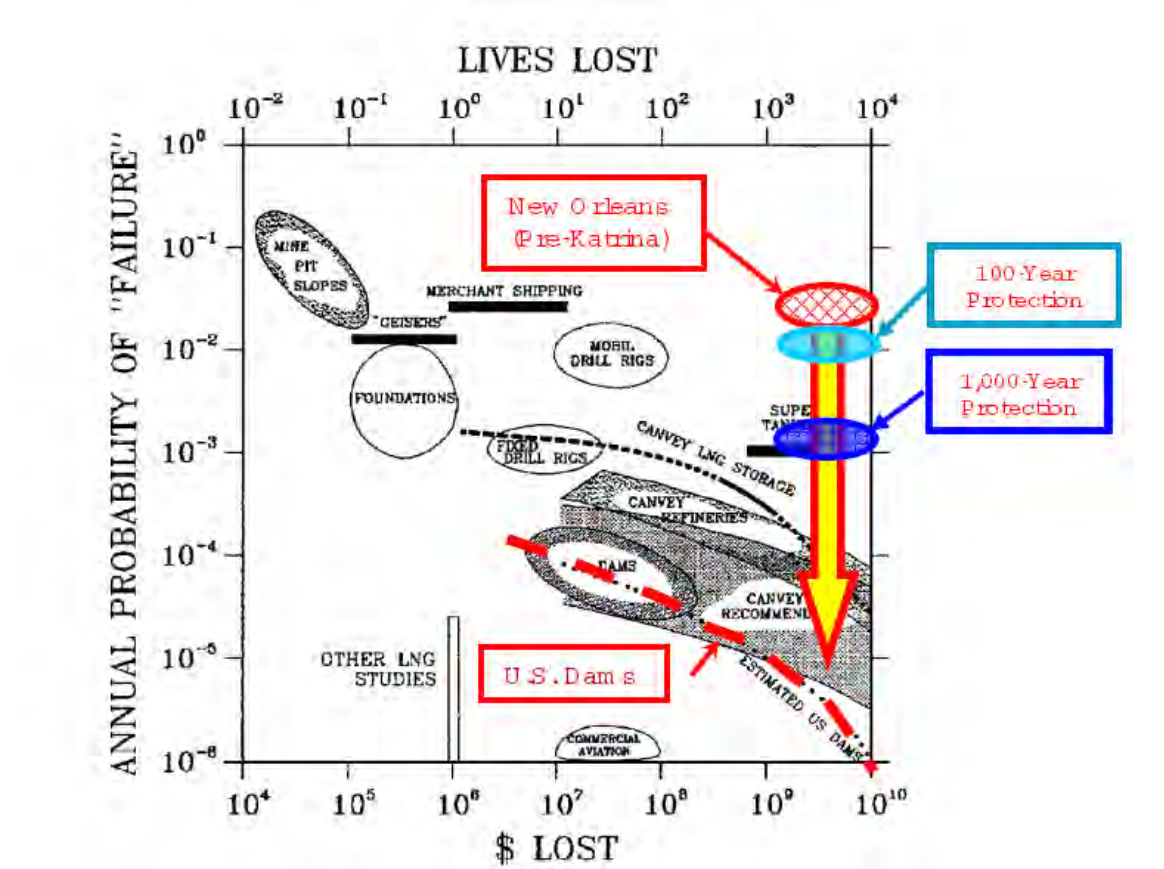
- Resiliency: “ductile” versus a brittle system, with consideration of “failure” (ILIT, IPET, ERP)

- Risk (ILIT, IPET, ERP, NRC)

  - not quantified, appreciated, nor communicated

  - residual risk still exists

  - acceptable risk level



Organizational Issues

- Many organizations "in charge" (ILIT, IPET, ERP, NRC)

- design
- construction
- maintenance
- operation

AGENCY	ROLE AND RESPONSIBILITY
UNITED STATES CONGRESS	Authorization and funding.
USACE HEADQUARTERS	USACE guidance and oversight.
USACE ENGINEER RESEARCH AND DEVELOPMENT CENTER	Research to support new design approaches.
USACE NEW ORLEANS DISTRICT	Design and construction oversight as the "Engineer" for each of the five independent levee districts in the New Orleans metropolitan area.
EAST JEFFERSON LEVEE DISTRICT	Maintenance and operation of the flood protection levee system around the east bank portion of Jefferson Parish to protect the citizens of East Jefferson from Lake Pontchartrain and Mississippi River flooding.
LAKE BORGNE BASIN LEVEE DISTRICT	Maintenance and operation of 13 miles of the Mississippi River Levee, 26 miles of back protection levee, 23 miles of the Lake Pontchartrain and Vicinity Hurricane Protection Levee, the Bayou Dupre Control Structure, 12 flood gates, the Violet Freshwater Siphon, 55 miles of drainage canals, and eight major drainage pumping stations.
ORLEANS LEVEE DISTRICT	Maintenance and operation of the hurricane and flood protection improvements for the City of New Orleans on the southern shores of Lake Pontchartrain and along the Mississippi River, including inspection and maintenance of 129 miles of levees and floodwalls, 189 floodgates, 97 flood valves, and two flood control structures.

Organizational Issues

- One-way relationship between the U.S. Congress and the USACOE (ILIT, IPET, ERP, NRC)

  - Congress sets design levels
  - Congress allocates funds, often in a piecemeal fashion
  - No feedback loop or mechanism for dialog
  - Funding less than originally anticipated

Planning

- Rebuilding New Orleans (ILIT, IPET, ERP, NRC)

  - will require out-of-scale resources to protect some areas
  - incentives to discourage re-settlement

New Orleans 7 years after Katrina

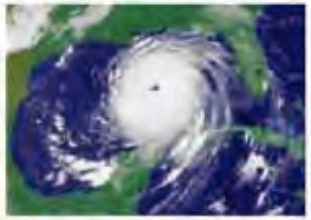
Positive changes

- More resilient system
- Peer review
- Better quantifaction of risk
- Agency consolidation
- Systems thinking
- Mapping and inventories

Less progress

- Levee policy: factors-of-safety, seismic design standards, etc.
- Funding
- Interactions with congress
- Risk communication
- Continuous loss of wetlands
- Other ongoing issues: vegetation on levees, FEMA "certification"

Risk-based evaluations

Chance of Hazard	X	System Performance	=	Vulnerability to Flooding	X	Consequences	=	Risk
								
Surge & Wave levels estimated at 138 locations from 76 possible hurricanes Producing storm water elevation events with 20 to 4,000-year return periods		Performance of entire 350 mile HSDRR system 1) Pre-Katrina 2) 2007 3) 2011 138 Reaches, 350+ Features and Transitions		Chance of Flooding and Flood Depth By location and HPS Scenario With and Without Pumping		Potential Loss of Life by Flood Depth Potential Property Damage by Flood depth Based on Pre-Katrina population and property data		Expected Loss of Life by Return Period Expected Property Damage by Return Period Based on Pre-Katrina population and property data

Risk-based evaluations

pump capacity →

time ↓

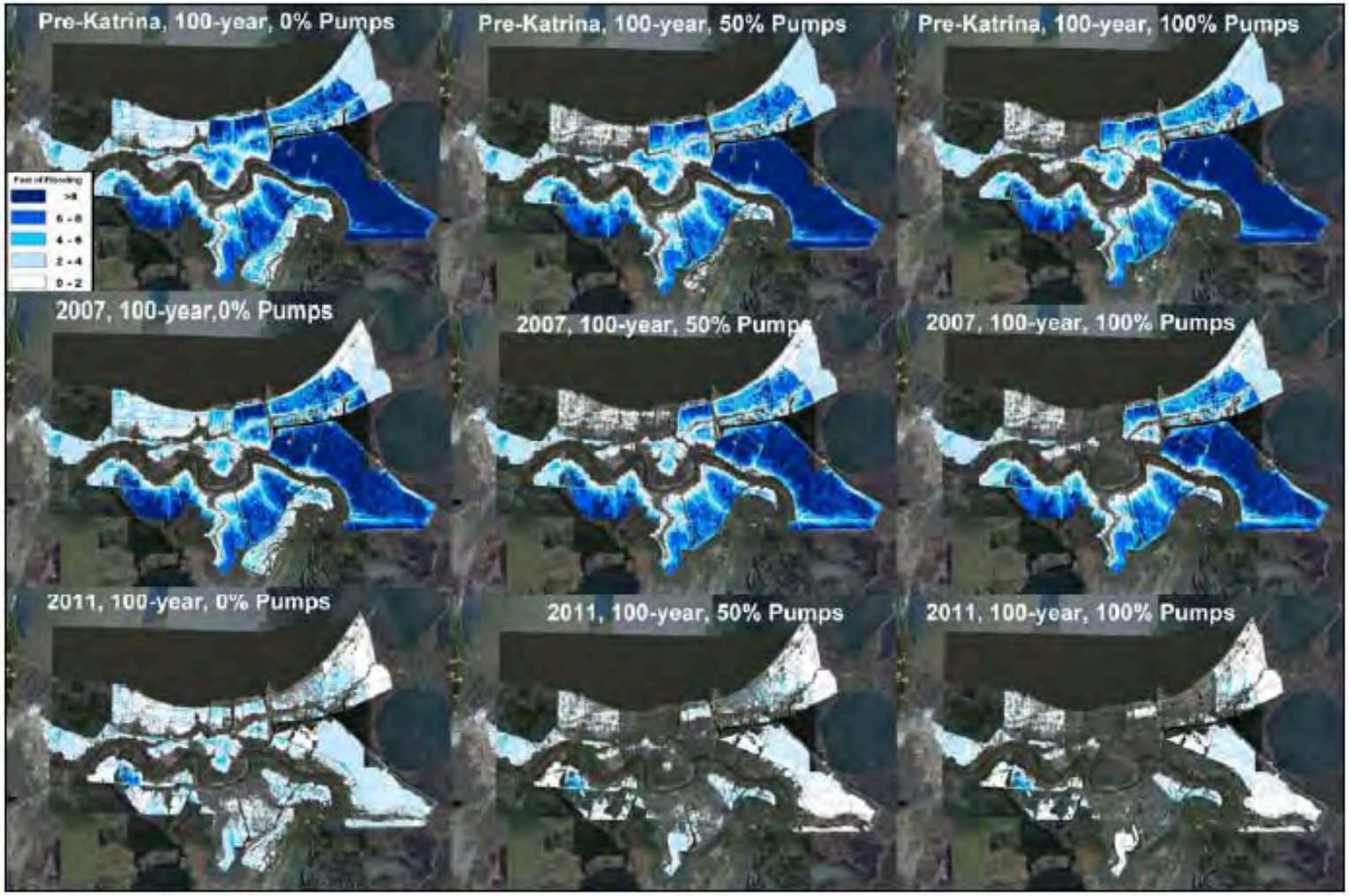


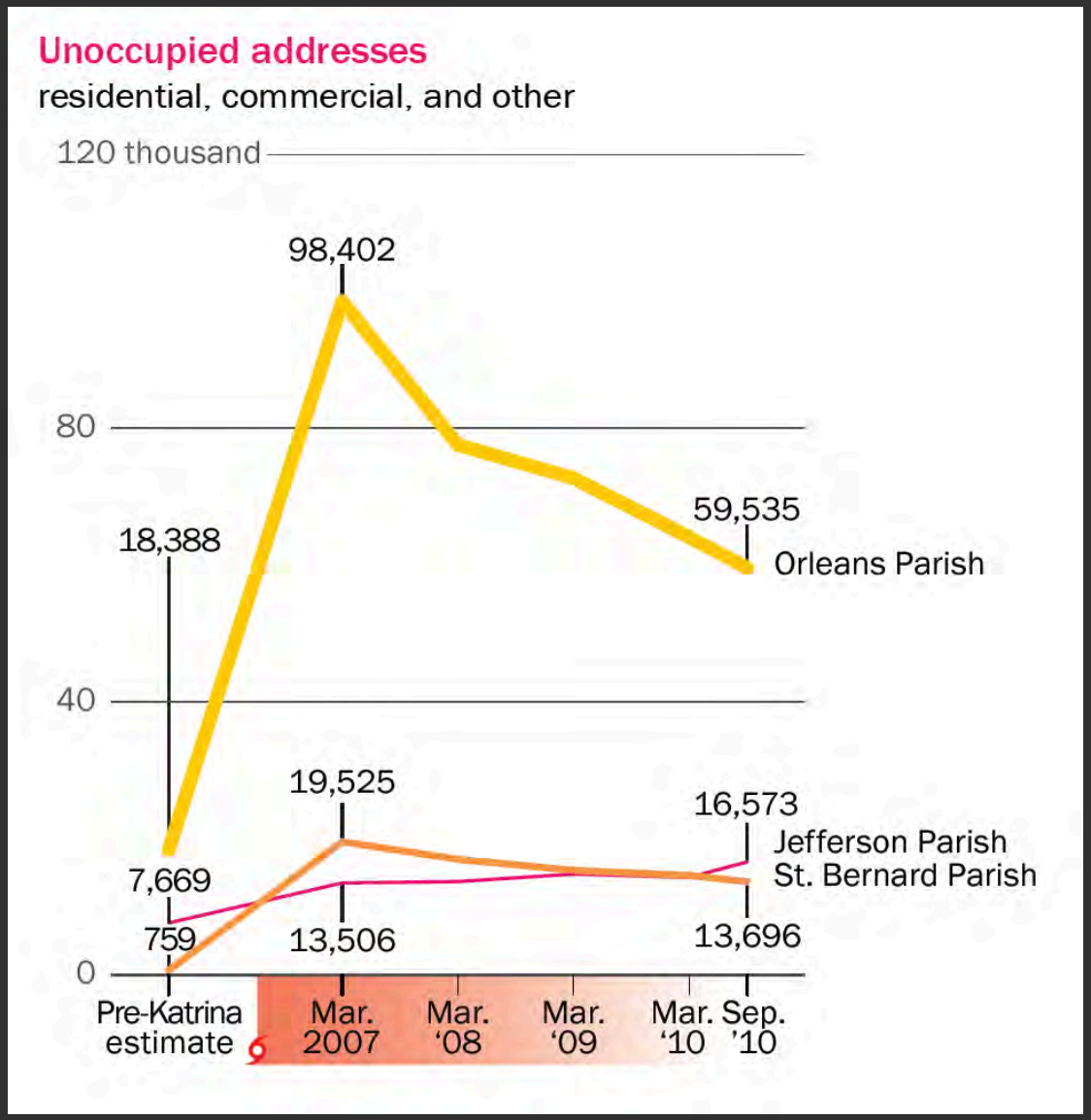
Figure 16. Flood Depth Frequency Maps for 100-Year (1%) Hurricane Floodplain. The label on each map indicates the HSDRRS infrastructure, flood frequency and percent pumping capacity modeled.

Post-Katrina Recovery

- Disasters generally accelerate longer-term trends; however, it is possible to break with the past

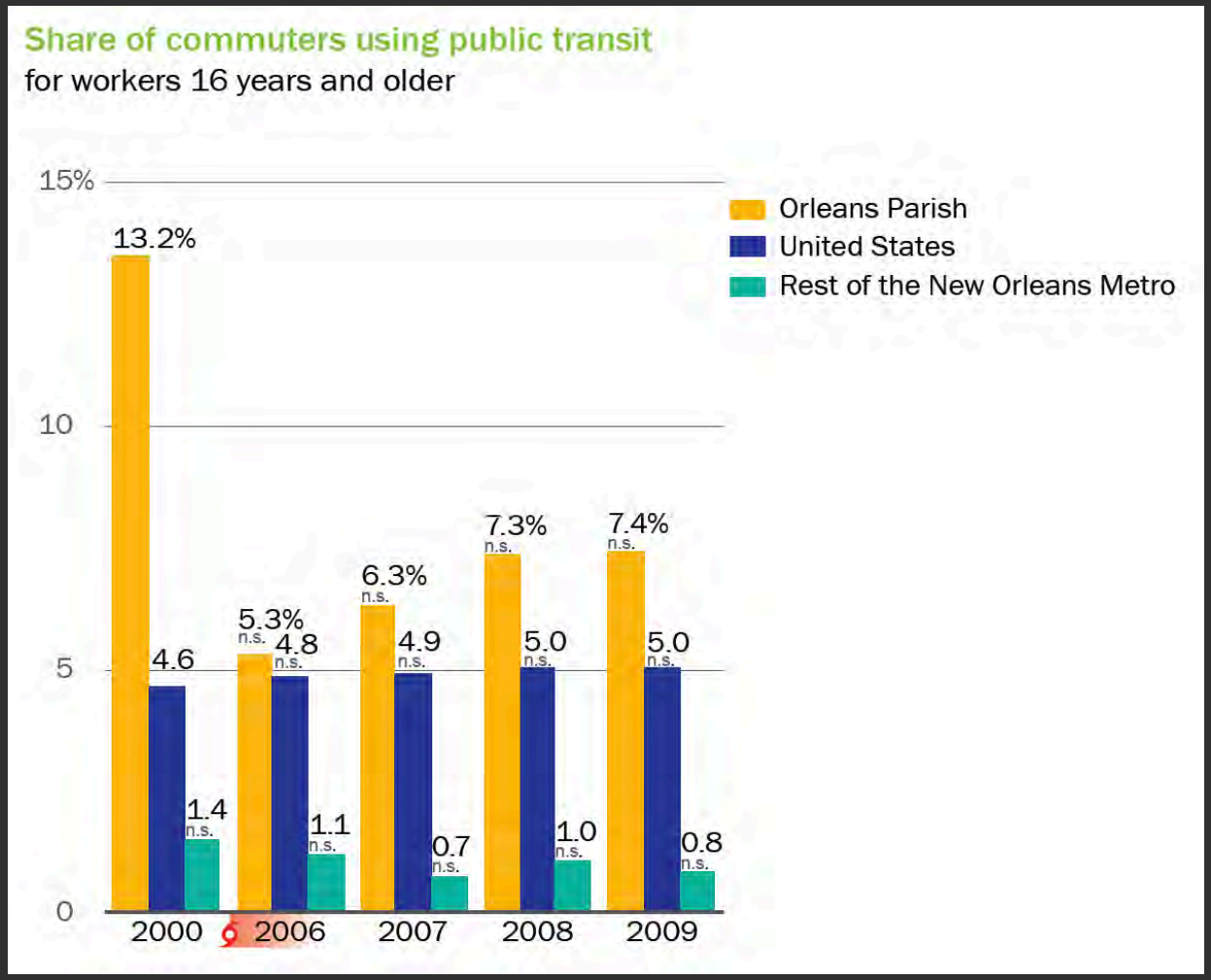
- New Orleans 10 year population loss: 29%

- Metro: 11% population loss



Data and graphics from: Greater New Orleans Community Data Center

Post-Katrina Recovery

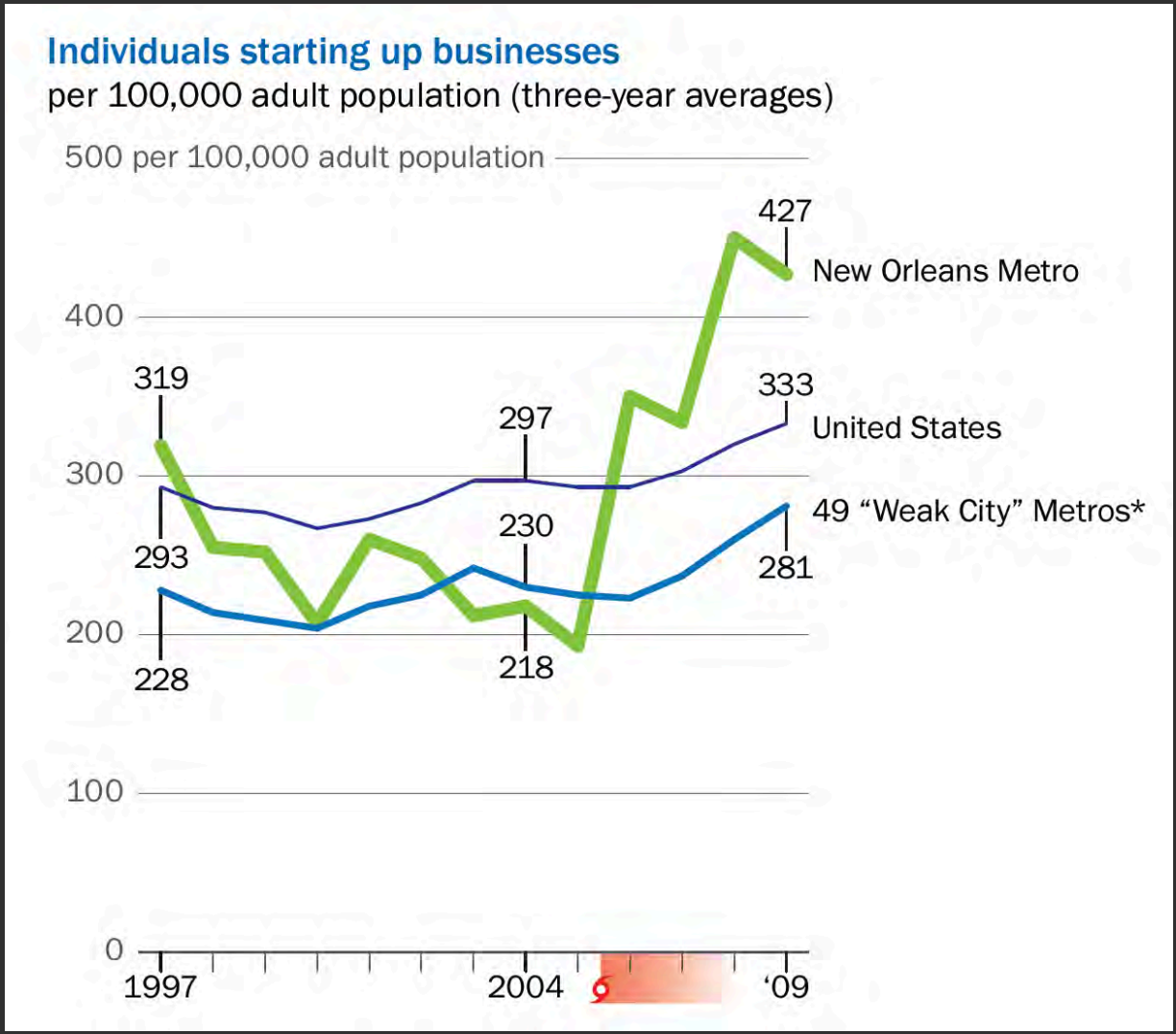


Data and graphics from: Greater New Orleans Community Data Center

Closing thoughts

- “What’s past is prologue”
- Event has been a catalyst for change, New Orleans and elsewhere
- Natural hazards are recurring events

Post-Katrina Recovery



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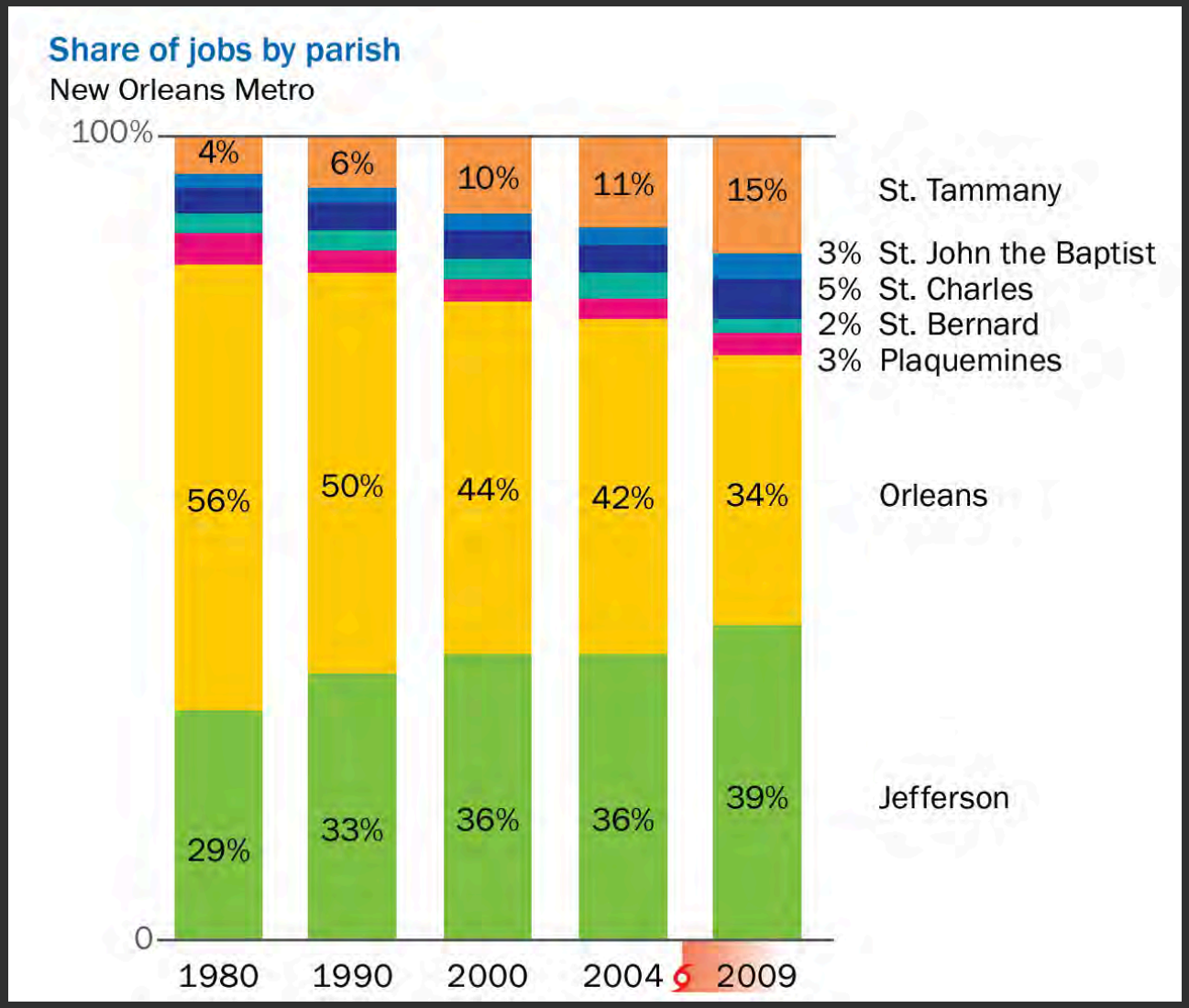
Post-Katrina Recovery



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