

# **Geologic Factors Promoting Ground Subsidence and Coastal Land Loss in the Mississippi Delta and the Great Debate About What to Do About It**

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**for symposium on**

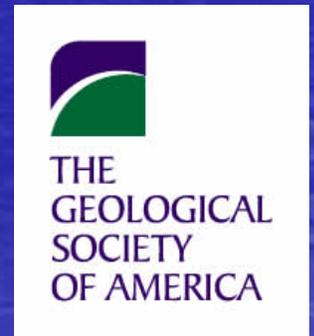
**The Role of Geology in Planning and Mitigation of Natural  
Hazards**

**Annual Meeting**

**Geological Society of America**

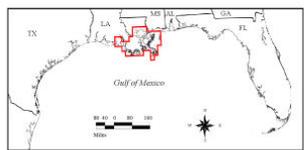
**Denver, Colorado**

**October 31, 2007**



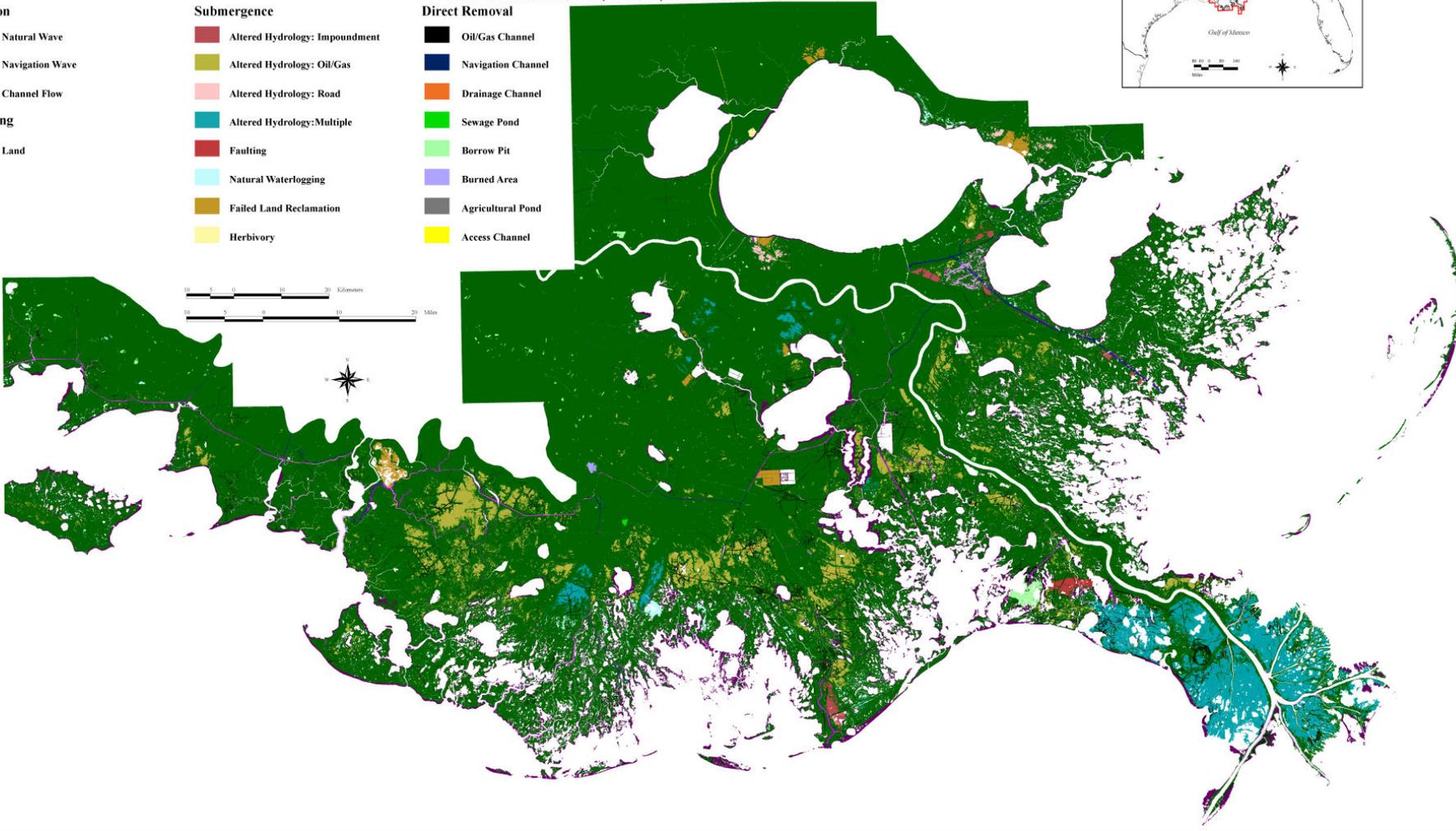
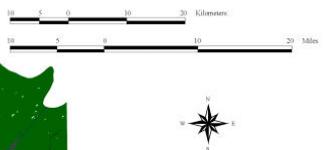
# PROCESS CLASSIFICATION OF COASTAL LAND LOSS BETWEEN 1932 AND 1990 IN THE MISSISSIPPI RIVER DELTA PLAIN, SOUTHEASTERN LOUISIANA

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## Legend

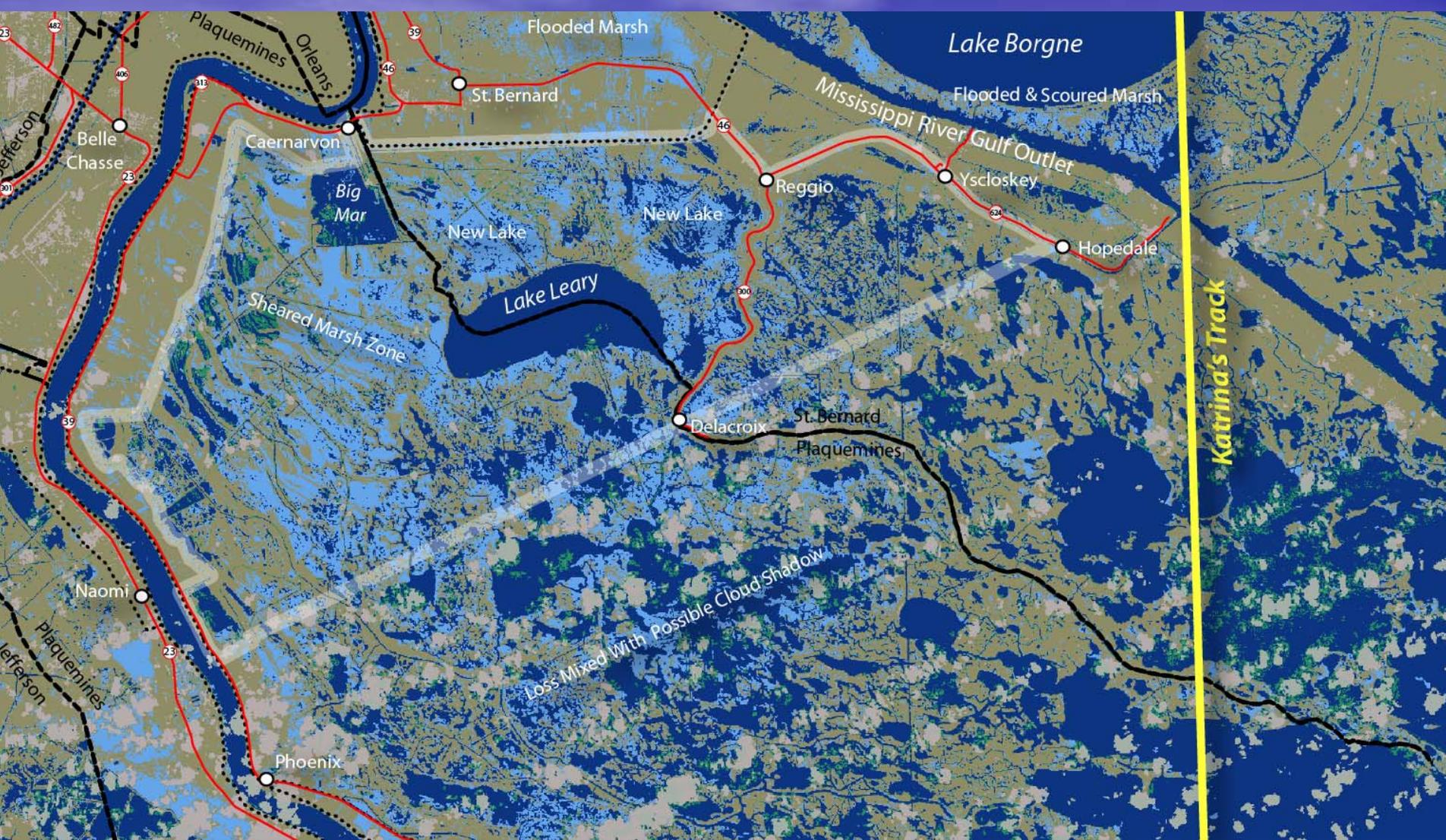
- |                   |                                  |                       |
|-------------------|----------------------------------|-----------------------|
| <b>Erosion</b>    | <b>Submergence</b>               | <b>Direct Removal</b> |
| ■ Natural Wave    | ■ Altered Hydrology: Impoundment | ■ Oil/Gas Channel     |
| ■ Navigation Wave | ■ Altered Hydrology: Oil/Gas     | ■ Navigation Channel  |
| ■ Channel Flow    | ■ Altered Hydrology: Road        | ■ Drainage Channel    |
| <b>Existing</b>   | ■ Altered Hydrology: Multiple    | ■ Sewage Pond         |
| ■ Land            | ■ Faulting                       | ■ Borrow Pit          |
|                   | ■ Natural Waterlogging           | ■ Burned Area         |
|                   | ■ Failed Land Reclamation        | ■ Agricultural Pond   |
|                   | ■ Herbivory                      | ■ Access Channel      |



- Between 1932-1990 an average of 35 square miles of land was being lost to the sea each year in the Mississippi Delta; and an average loss of 44 square miles/year of wetlands.



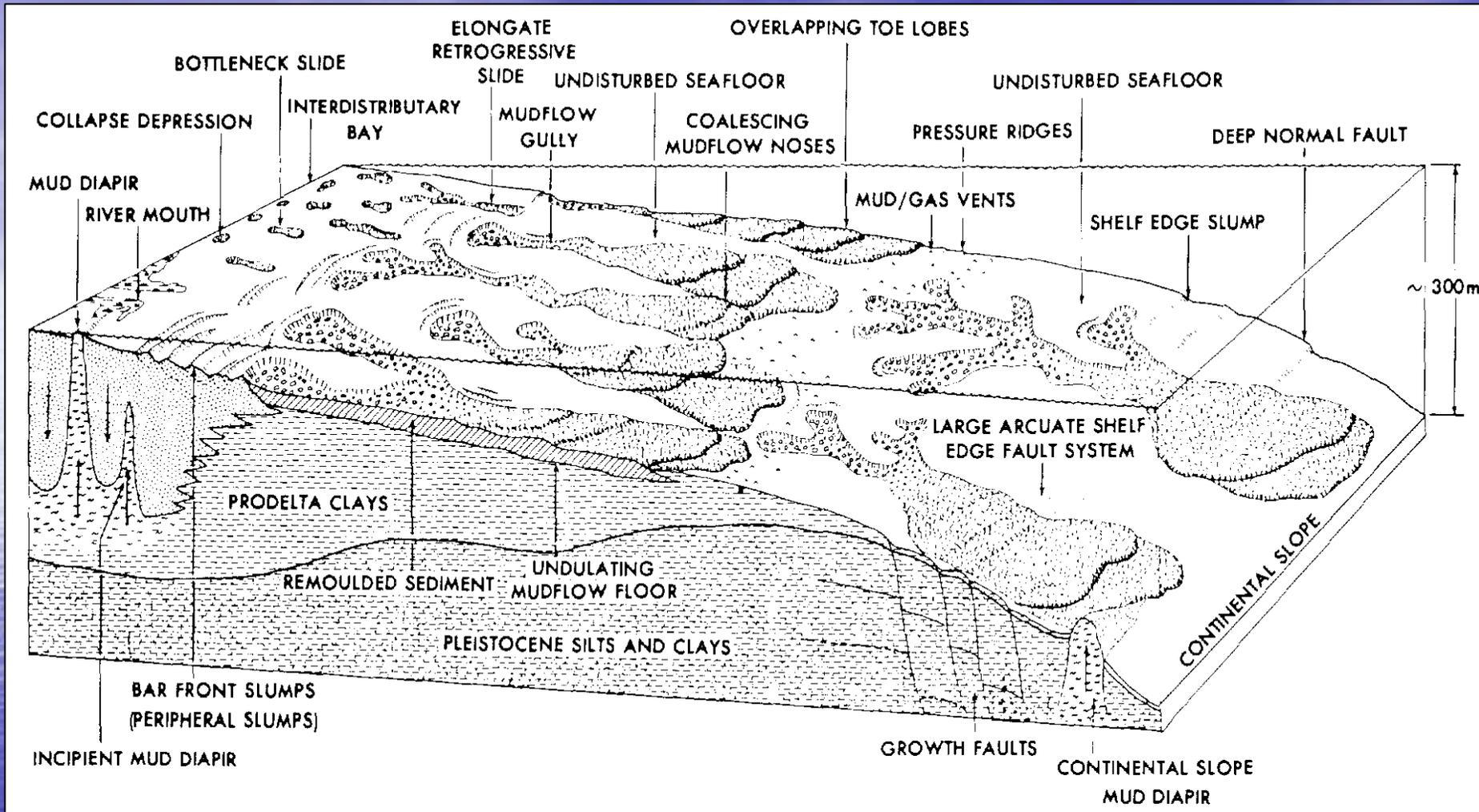
- Acute wind shear from Hurricane Katrina stripped off large tracts of floating marsh across the Mississippi Delta. *Can we construct sustainable levees on these kinds of materials?*



- During Hurricane Katrina, 115 square miles of land area was lost. This shows "land loss" in Breton Sound (in light blue) after the 2005 hurricane season.

# **MECHANISMS DRIVING GROUND SETTLEMENT**

- **The causes of ground settlement are a contentious issue in coastal Louisiana**
- **There appear to be many different causes, briefly summarized in the following slides**



- Block diagram illustrating various types of **subaqueous sediment instabilities in the Mississippi River Delta**, taken from Coleman (1988).

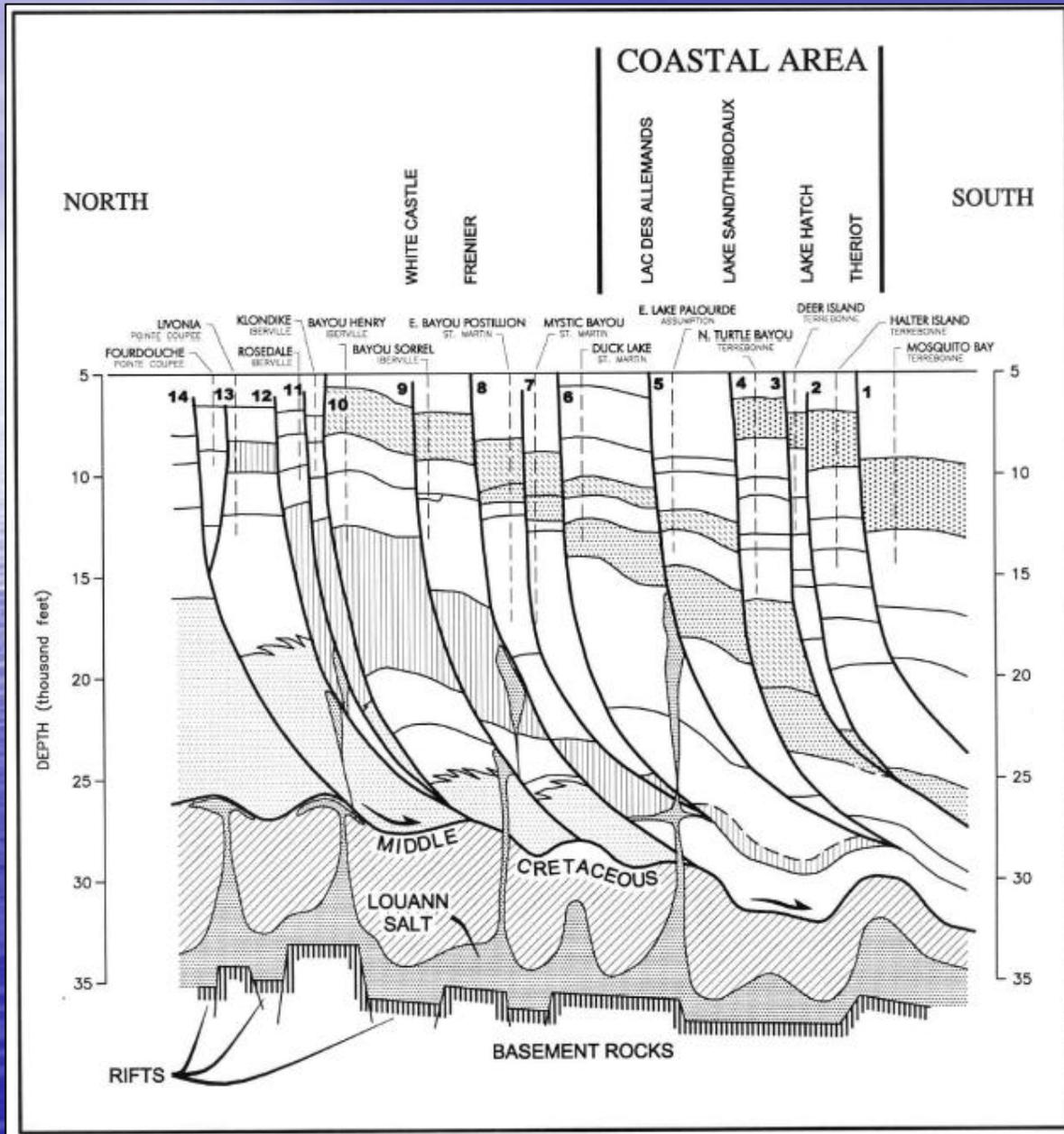


# FLUID EXTRACTION OF OIL, GAS, AND WATER

R.A. Morton of the USGS has blamed oil and gas extraction for the subsidence of the Mississippi Delta. Morton has constructed convincing correlations between petroleum withdrawal and

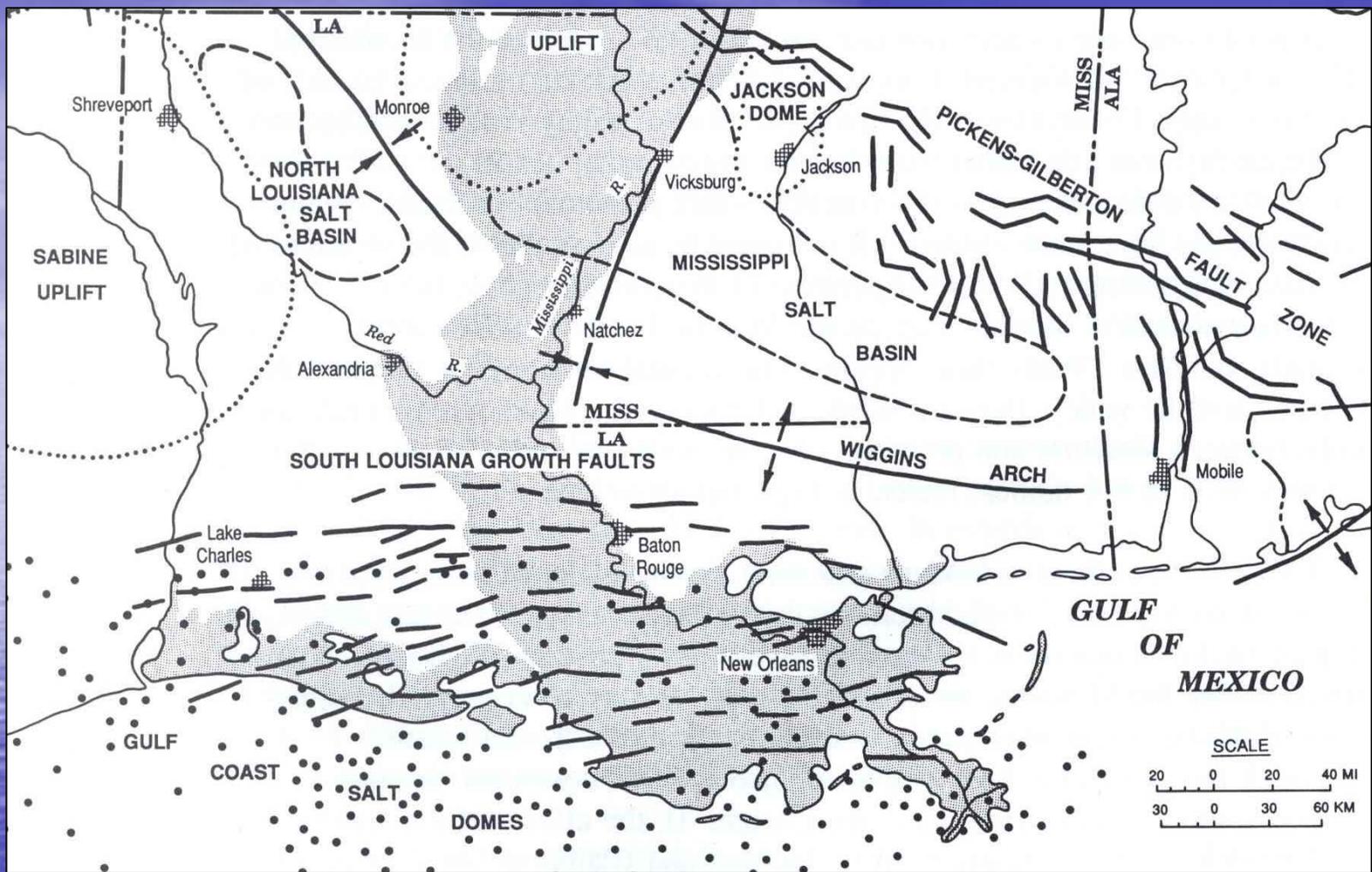
settlement rates on the southern fringes of the delta, near the mouth of the Mississippi, but this theory fails to account for marked settlement further north, where little or no deep withdrawal of oil or gas has been carried out.

# Growth Faults

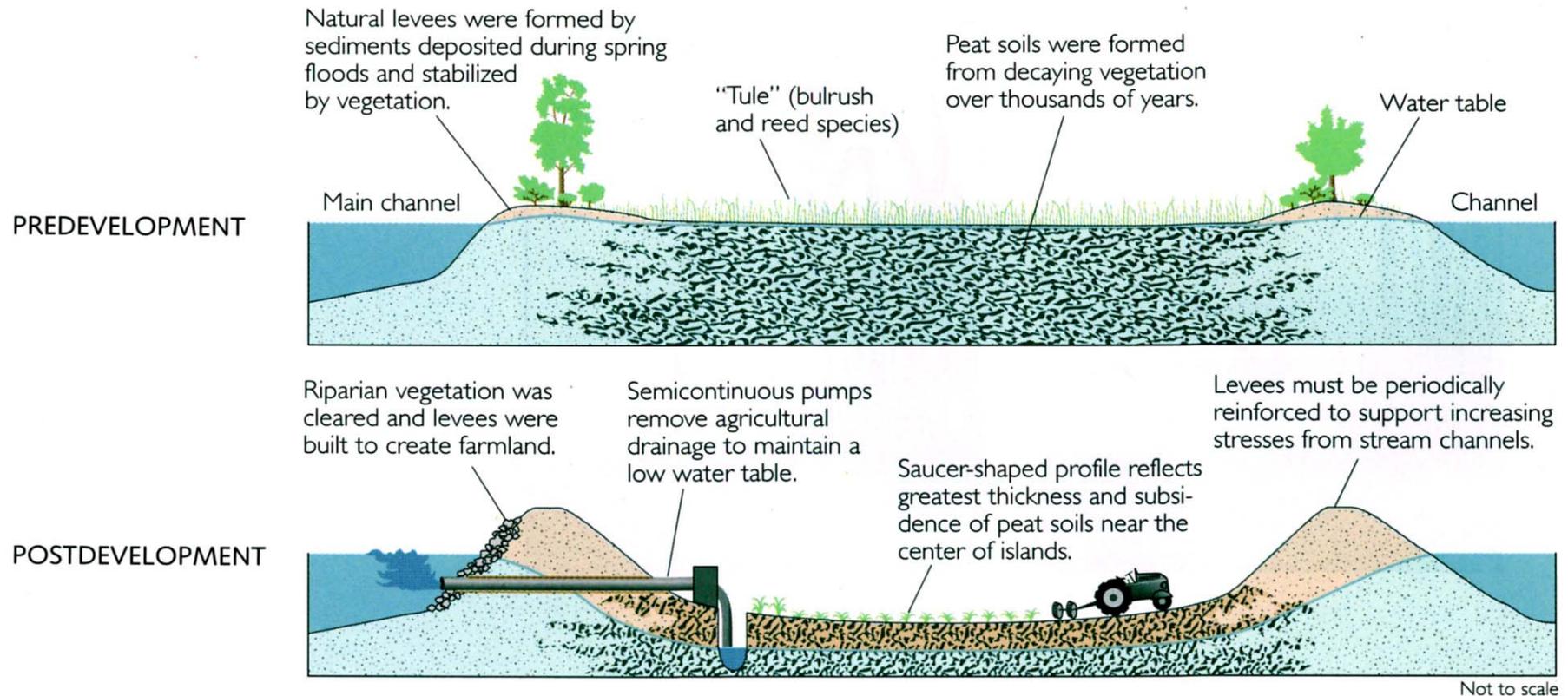


- Geologic cross section through the Gulf Coast Salt Dome Basin, taken from Adams (1997).
- This shows the retrogressive character of *lystric normal faults* cutting coastal Louisiana, from north to south.
- The faults foot in a basement-salt-decollement surface of middle Cretaceous age.

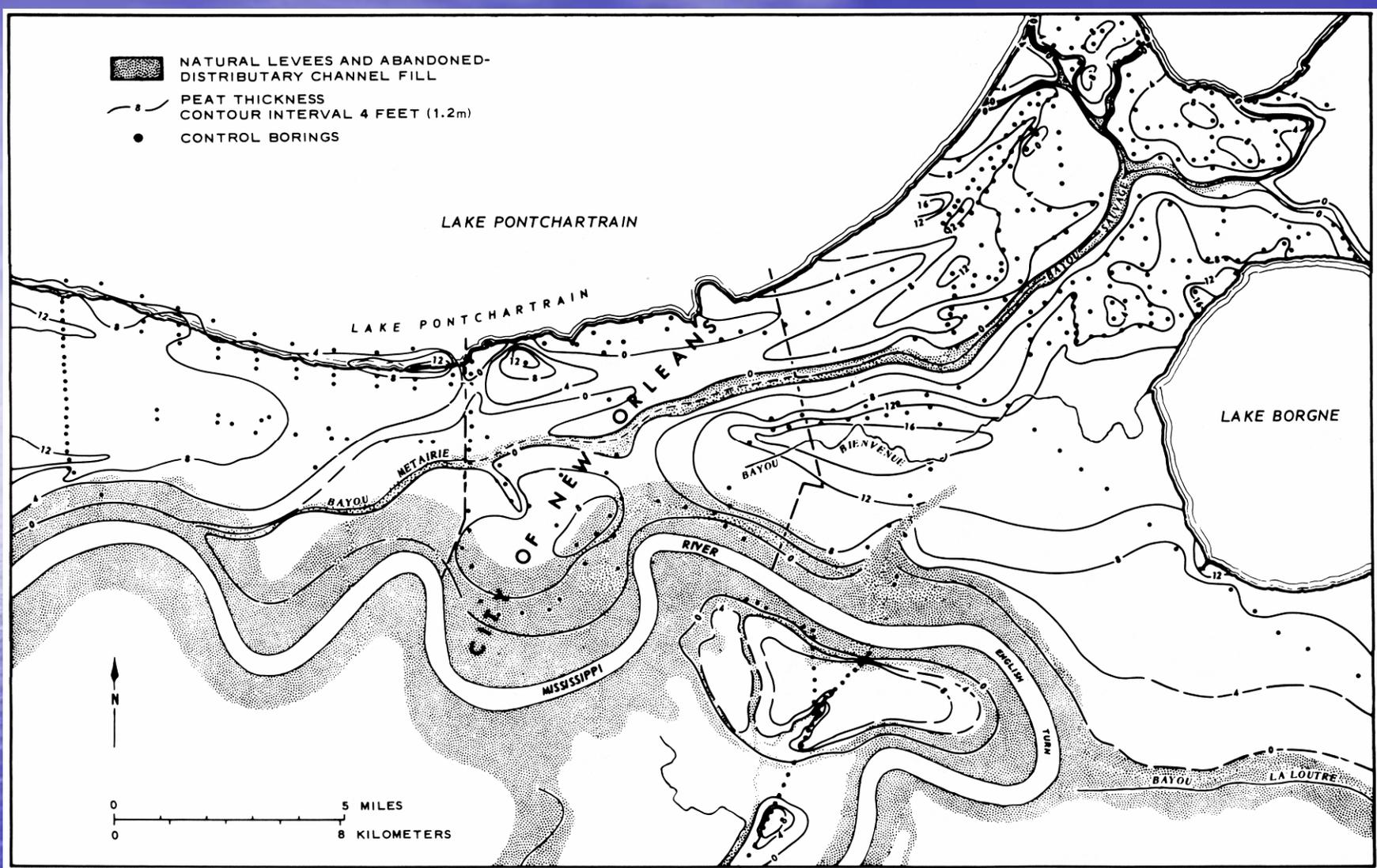




**Saucier's 1994 structural geology map of the Mississippi Delta, published by the Corps of Engineers. This shows *salt basins, salt domes, and active growth faults* that pervade the delta region.**



- Draining lowlands and backswamps** for agricultural or urban development increases the effective stress on underlying sediments and hastens rapid biochemical oxidation of organic materials, causing settlement of these surficial soils.



- New Orleans was built on **compressible peaty soils**. This isopach map shows the areal distribution of the surficial peaty soils (contour interval = 4 feet). From Gould and Morgan (1962) and Kolb and Saucier (1982).

# Compaction of Surficial Sediments



The interdistributary sediment package covering the old back swamps around New Orleans are under consolidated, and they exhibit gross settlements.

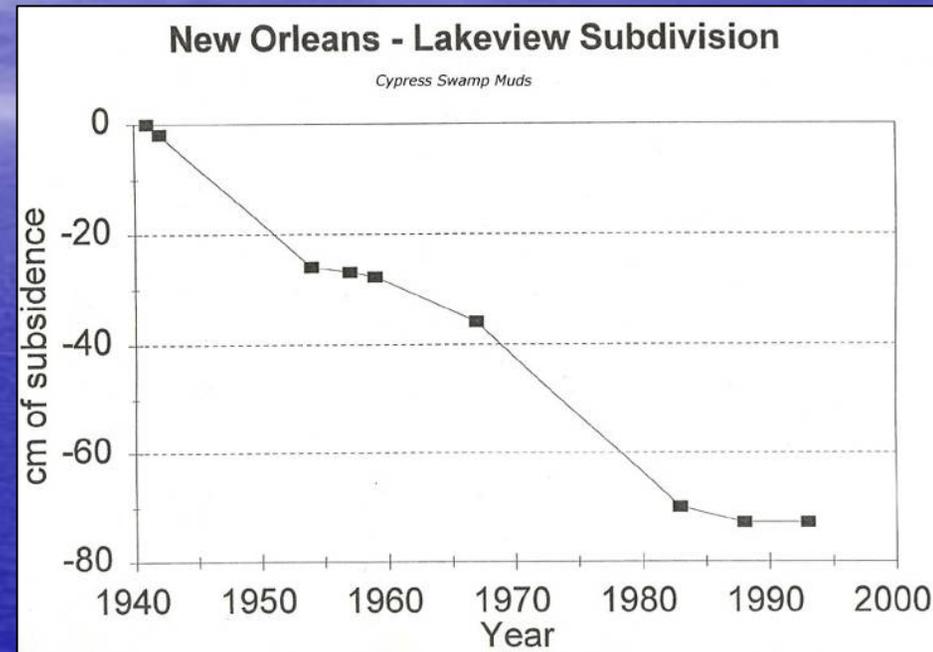
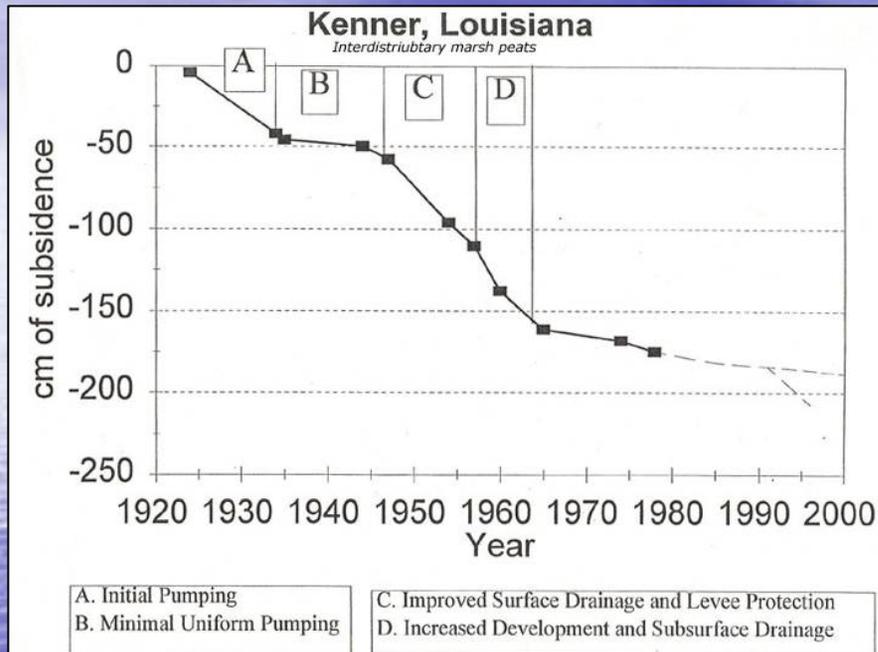
These examples are from the Lakeview area adjacent to the 17<sup>th</sup> St. Canal failure, where the ground appears to have settled 10 to 16 inches since 1956.



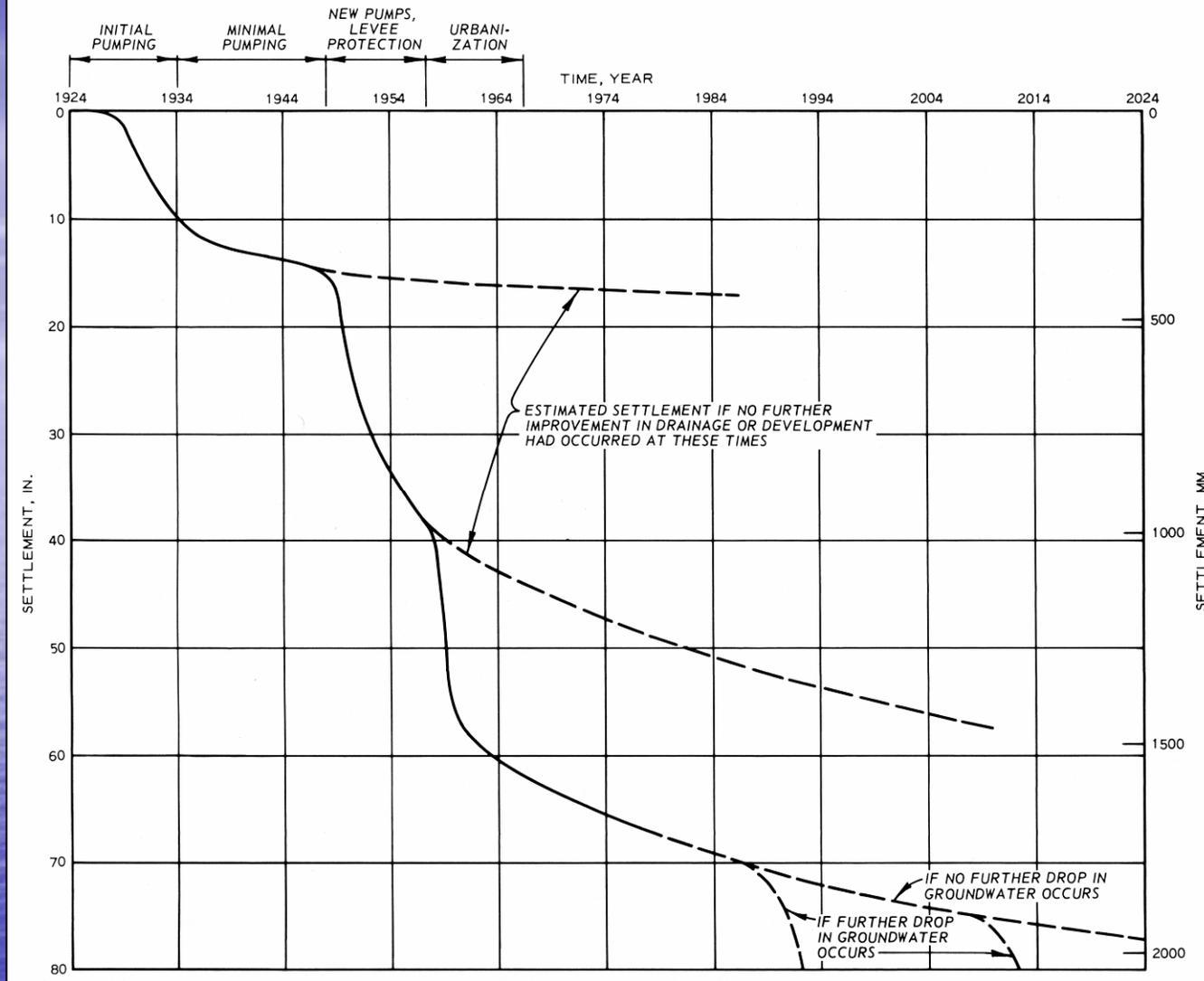
**Most residential structures in New Orleans are founded on wood pilings 6 to 8 inches in diameter, driven 30 feet deep. The ground beneath these post-1950 homes has settled 10 to 18 inches.**

**The mechanisms driving this settlement are likely drainage of near-surface soils, by dewatering and interception of storm water runoff, which is collected and conveyed to the city's pump stations.**

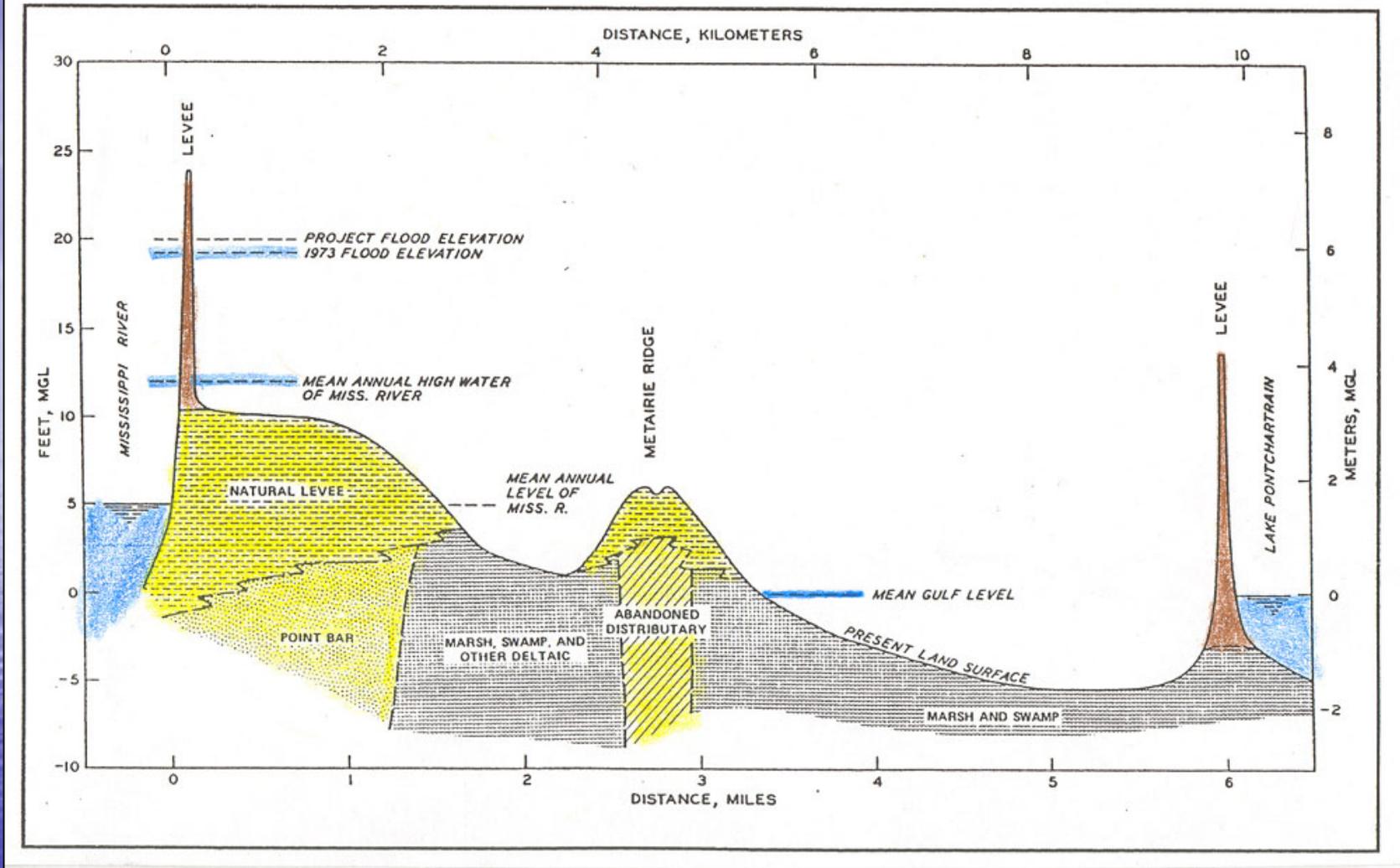
# Industrial and municipal groundwater withdrawal



As groundwater levels are depressed by withdrawal of groundwater, organic-rich peaty soils are oxidized, and the ground settles. This settlement creates depressed zones below the grade of adjacent watercourses, which creates challenges for providing flood control.

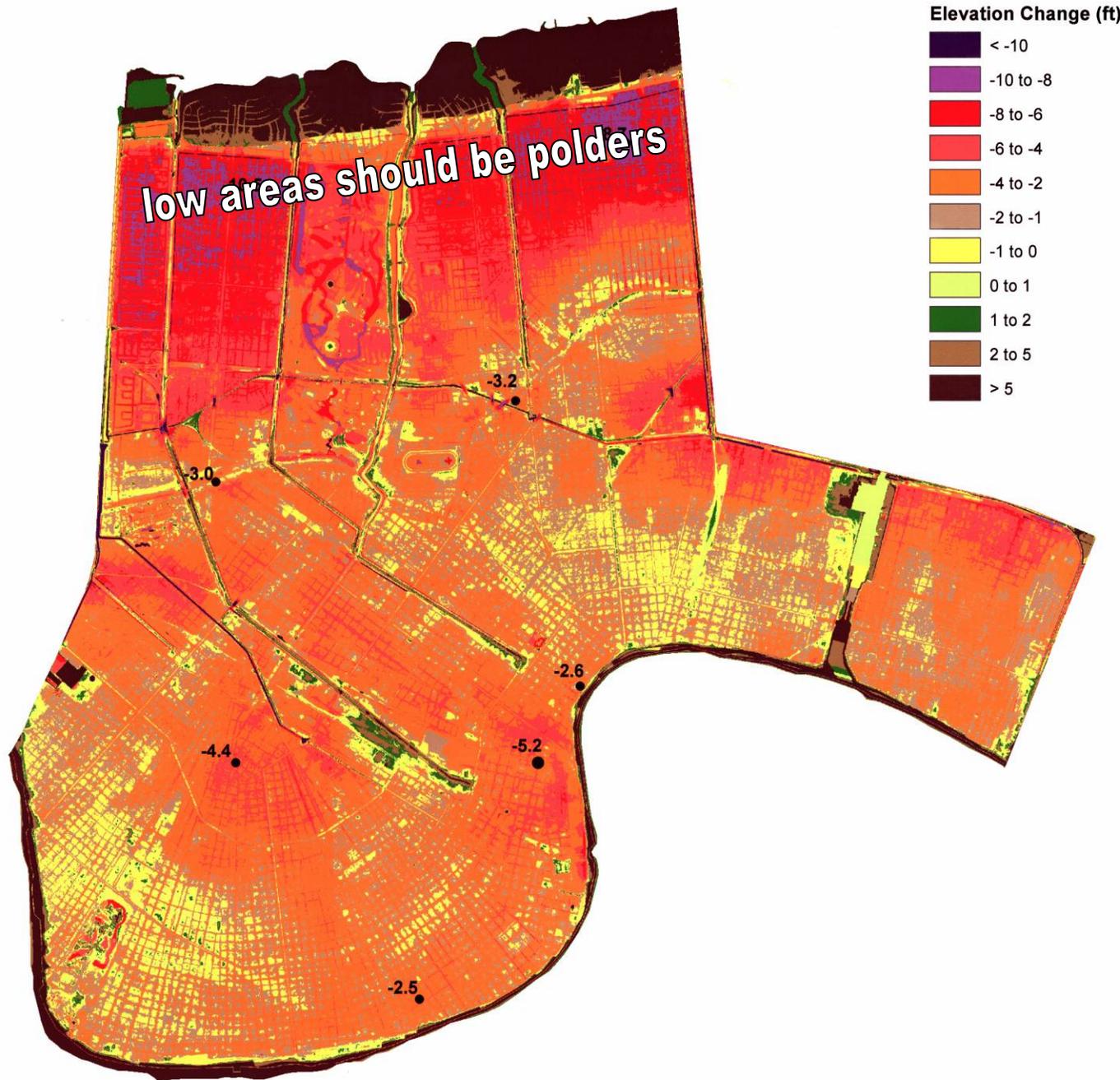


- Record of **historic settlement** in the town of Kenner, which is underlain by 6.5 to 8 feet of surficial peaty soils.
- The steps in these curves were triggered by **groundwater withdrawal for industrial use and urban development**. This area was covered by dense cypress swamps prior to development.



Much of New Orleans lies below sea level, Lake Pontchartrain, and the Mississippi River, making it particularly vulnerable to flooding. The Mississippi levee crest is 24.5 feet, while the Pontchartrain levee crest is 13.5 feet, above mean gulf level.





- Map showing relative elevation change between 1895 and 1999/2002, from URS (2006).
- The net subsidence was between 2 and 10+ feet, depending on location.



# STRUCTURAL SURCHARGING

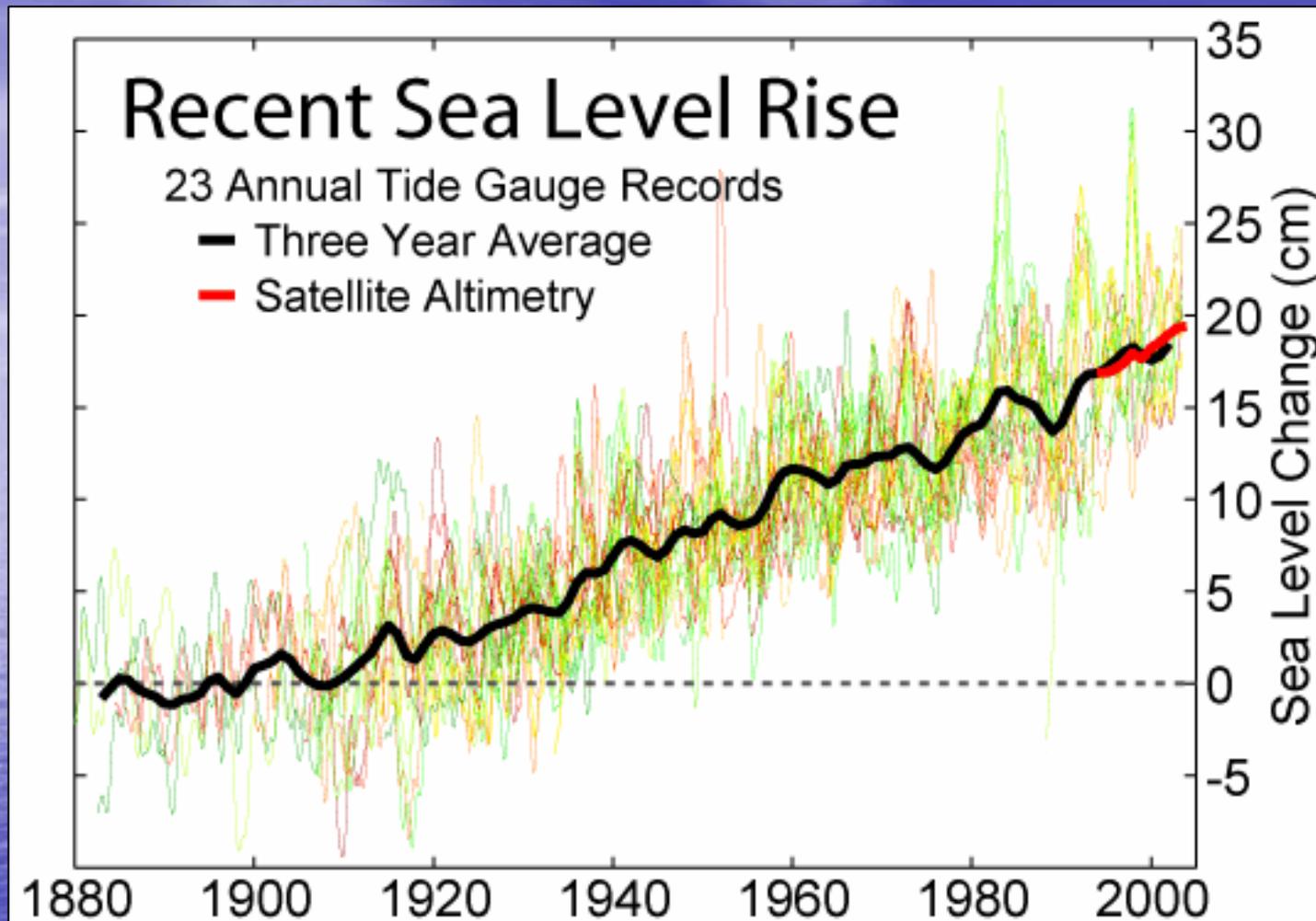
- An interesting aspect of the URS-FEMA settlement study is the marked increase in settlement in the Central Business District, where tall structures are founded on deep piles. This area settled 5 inches in 100 years, but the settlement was much less away from the heavy structures
- *Even the sandy river levees have settled 2 inches;* likely due to surcharging by MR&T levee heightening between 1928-60

# Mechanisms of Ground Settlement -1

- 1) **Elastic deformation** of Mississippi Delta from silt deposition (isostasy)
- 2) **Tectonic compaction** caused by formation of pressure ridges and folding
- 3) Subsidence on seaward side of **lystric growth faults**
- 4) **Drainage** of old swamp and marsh deposits increasing stress on underlying clays
- 5) **Biochemical oxidation** of peaty soils

# Mechanisms of Ground Settlement -2

- **6) Consolidation of compressible soils** caused by surcharging with fill
- **7) Surcharging** by structural improvements
- **8) Reduced groundwater recharge** in developed areas because of impermeable surfaces
- **9) Extraction of oil, gas, and water** causing pressure depletion
- **10) Solutioning** of salt domes and **seaward migration** of low density materials (salt and shale)



**Coastal land loss in Louisiana** is also exacerbated by **sea level rise**, which averaged about 1 foot during the last 100 years. This value could accelerate during the 21<sup>st</sup> Century, to as much as 3 feet.

# The National Debate that has erupted since Katrina....

- Can we build levees that won't fail?
- Should we, as a society, allow or encourage urban development of lands that are either: 1) below sea level; or, 2) barely above sea level?
- People who choose to live in high risk areas should pay greater insurance premiums for the privilege of living in those areas
- Should we bother trying to save the Mississippi Delta? Why? *New Orleans ships the greatest volume of exported goods from the USA, mostly wheat, corn, and soy.*

# Is it within the grasp of our society to save the Mississippi Delta?

- One modern analog – The Netherlands, following the 1953 floods; but this also involved a substantial investment, almost 30% of their GNP for 20 years.
- Can we apply 21<sup>st</sup> Century technology to help solve these immense challenges?
- Diverting sediments onto the land will require a much greater investment in operations and maintenance, several orders of magnitude more than we've spent heretofore.

# Earthen Levees are old technology

Levees are susceptible to erosion by *overtopping*, by *edified flow*, and by *undercutting*.

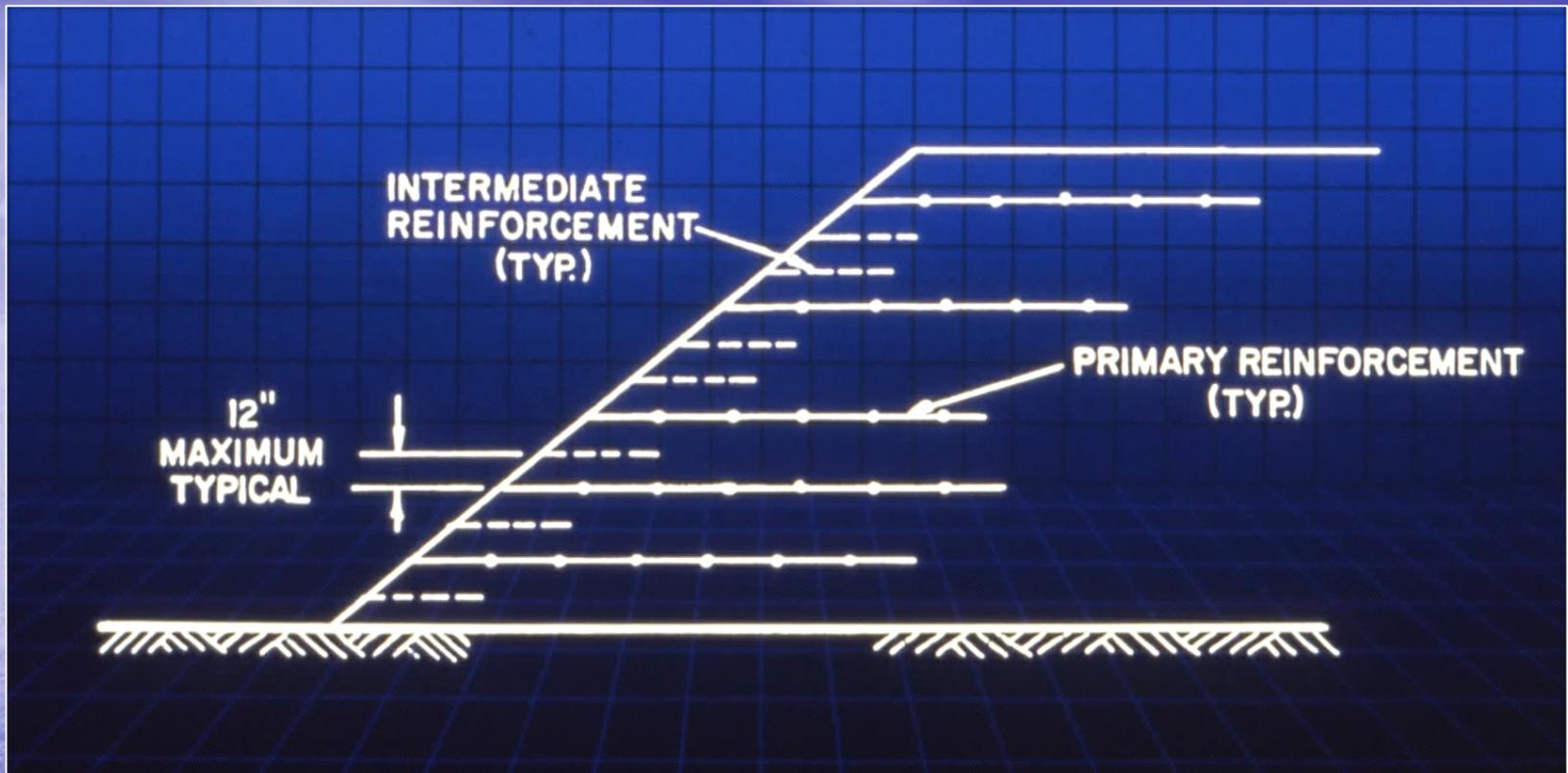
Once flood waters overtop an embankment they quickly scour the land-side toe of the embankment, and deep scour holes develop on either side of the “*hydraulic jump*” that forms at the point of overflowage, enlarging the breach, as shown here.



**COULD**  
***SOIL REINFORCEMENT***  
**TECHNOLOGIES**  
**BE APPLIED TO CREATE**  
**MORE ROBUST**  
**PROTECTION SYSTEMS ?**



- Geogrid-wrapped hay bales or gravel filled HDPE baskets can be used as facing elements for **mechanically-stabilized embankments**.
- These materials do not corrode and plants and trees can take root in them, so they are more "environmentally friendly"



- We can make embankments slopes as steep as we desire by using "false layers," of geotextiles, between primary reinforcement layers of mechanically stabilized embankments (MSE).
- These false layers restrict slope raveling and erosion

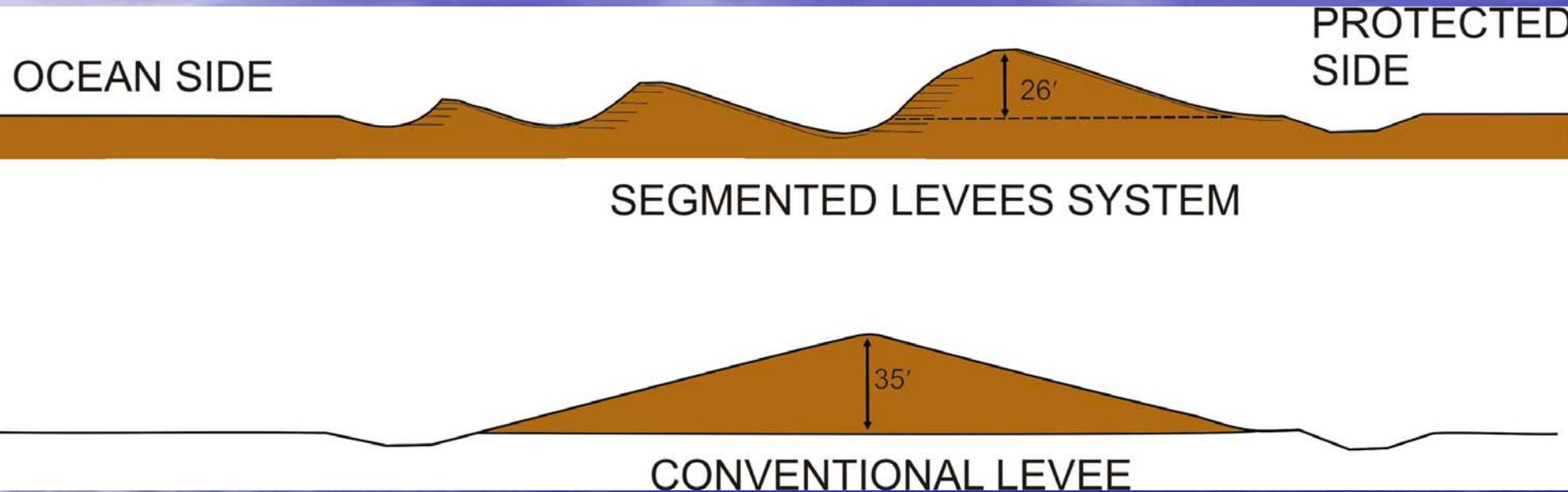


- **Example of a 45 degree fill face supporting a shopping center complex adjacent to a line of mature trees. The embankment was constructed using false layers of geotextiles spaced 1 foot apart (from Rogers, 1992)**



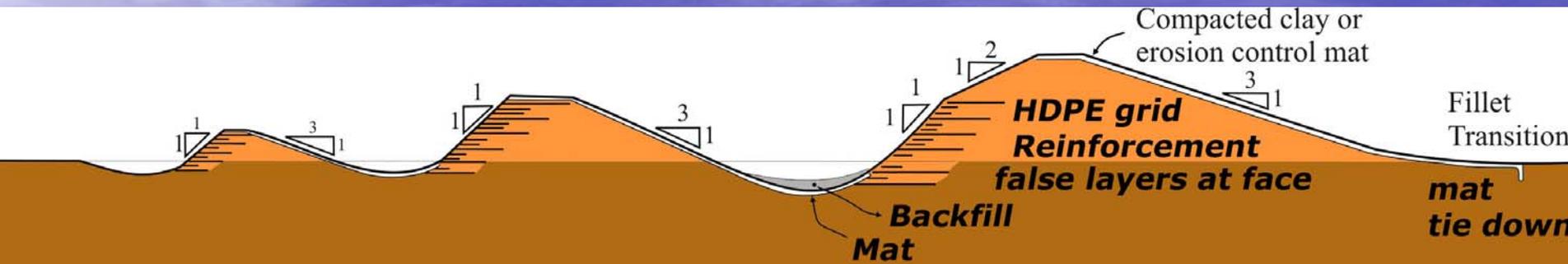
- Same 45 degree fill slope after hydroseeding and sprouting of fescue grass mix (from Rogers, 1992).

# Segmental Levee Systems

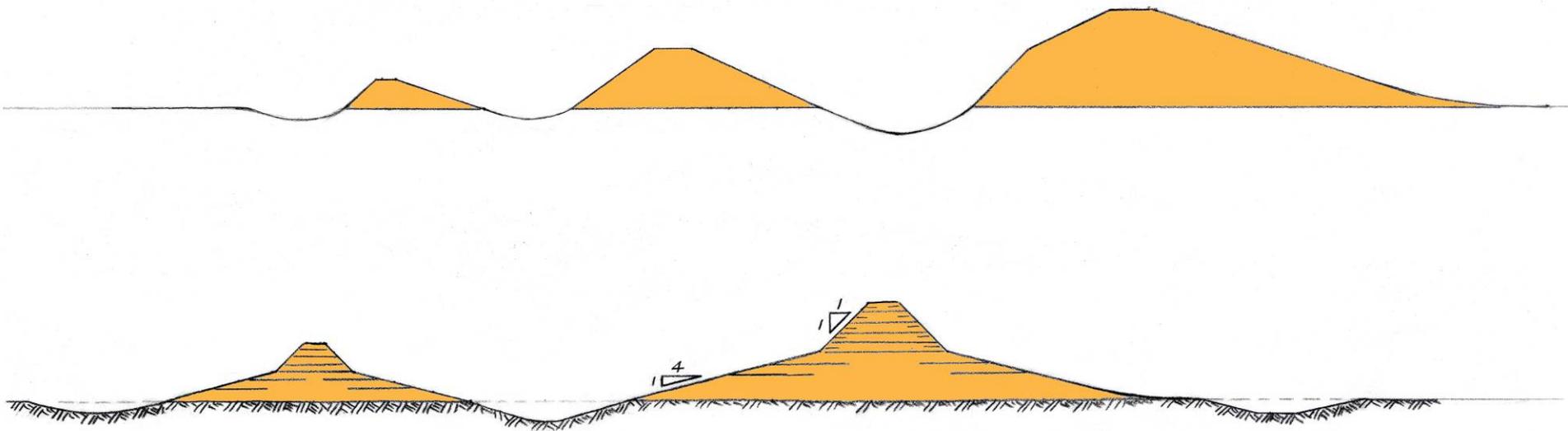


- In areas exposed to storm surge some thought might be given to equipping levees to be more efficient *energy dissipation systems*; and not just simple barriers. *Though more complicated, they might not have to be as high.*

# Soil Reinforcement



- Soil reinforcement could be applied to engender greater shear strength, allowing much steeper cross sections
- Steeper side slopes form more efficient barriers to dissipate forward wave energy
- Note curved troughs between the embankments.



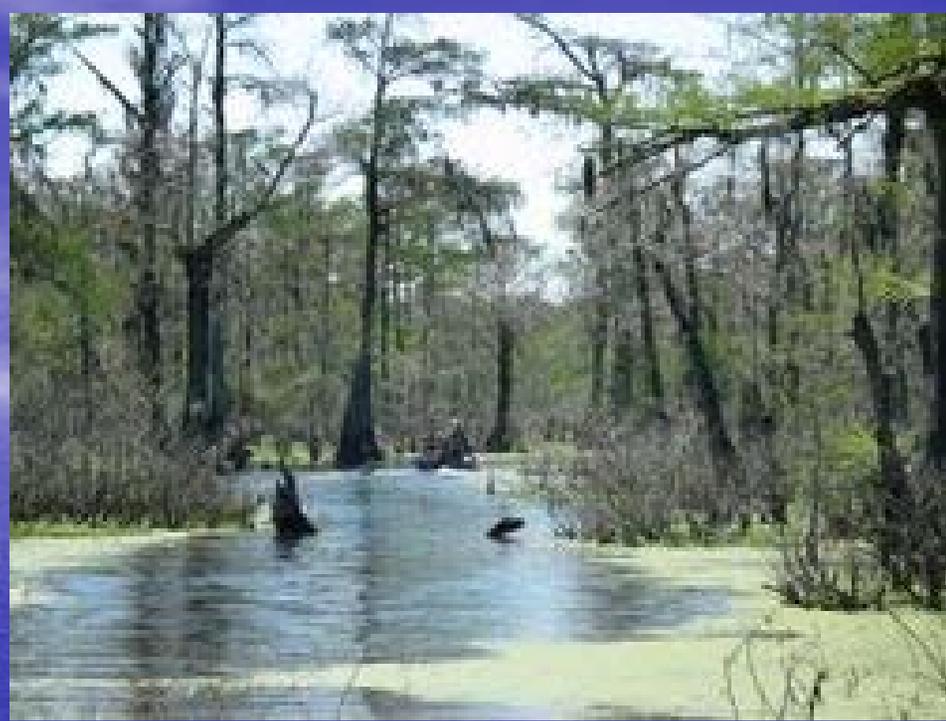
- **HDPE geogrid soil reinforcement** could be also be employed to engender *greater flexibility* in levee profiles, as suggested here.
- Levees could be molded into more efficient barriers to retard and survive storm surge
- The lower sketch shows how bearing loads could be reduced by employing soil reinforcement, allowing a **greatly reduced cross sections**.

# Cypress Swamp die-off



The entire delta is slowly subsiding. If new sources of sediment do not replenish the swamp, the **young cypress shoots cannot germinate in water > 2 feet deep**; and Cypress forests die off all at once, becoming a treeless, grassy marsh, with a forest of dead tree trunks.

# Mature Cypress swamps retard storm surges by mechanically dissipating incoming wave energy

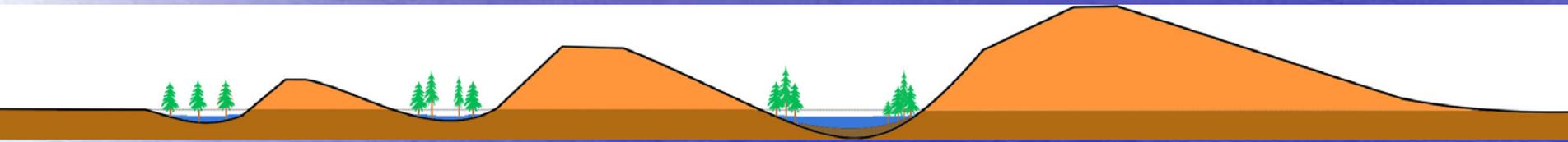


Much propaganda has been circulated concerning the potential mollifying effects of cypress forest dispelling wave energy, when hurricanes make landfall along the Louisiana Coast.

The most common-cited figure is 1 foot of storm surge reduction for every 2.4 miles of mature cypress swamp.

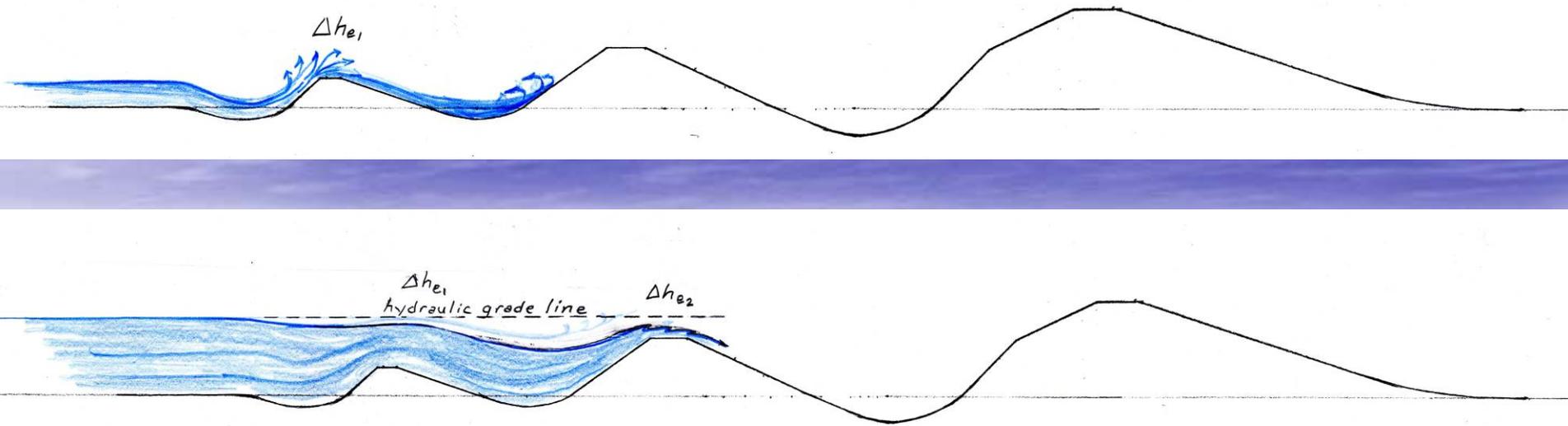
This value is not valid for the entire coastline. The actual impact depends on a number of physical factors.

# Green Levees: Create troughs to promote growth of cypress trees as mechanical barriers

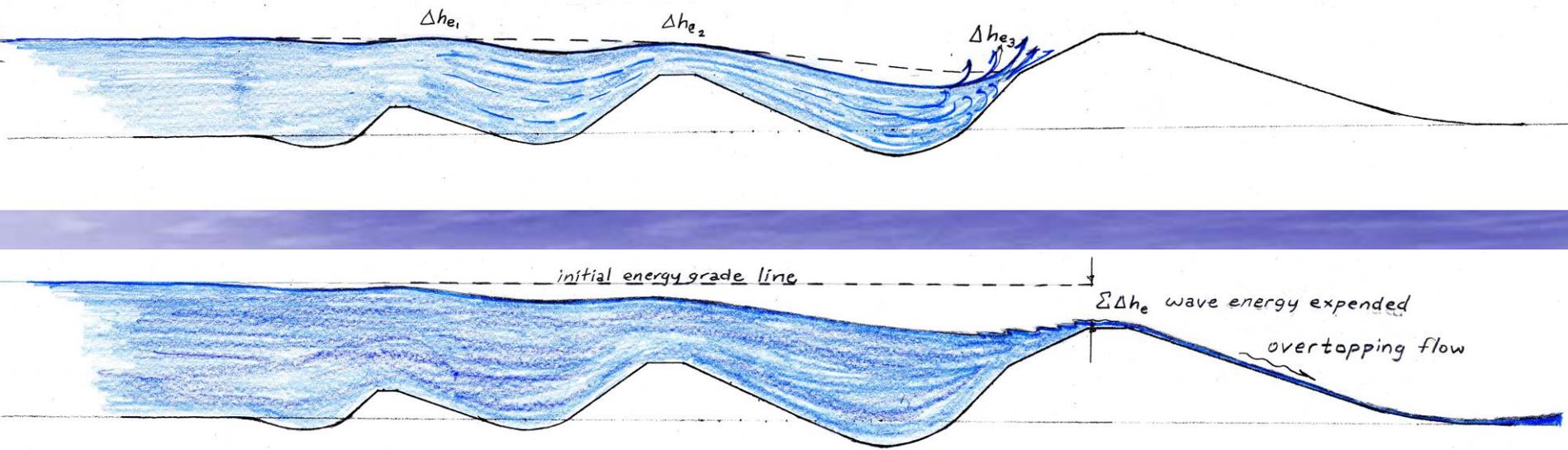


- Segmental levee systems could be crafted into “green” systems, which would employ swamp troughs between the embankments
- As the **cypress trees** mature, their impact on storm surge dissipation would increase, helping to offset freeboard losses caused by regional settlement

ENERGY DISSIPATION  
AT THE FIRST DIKE

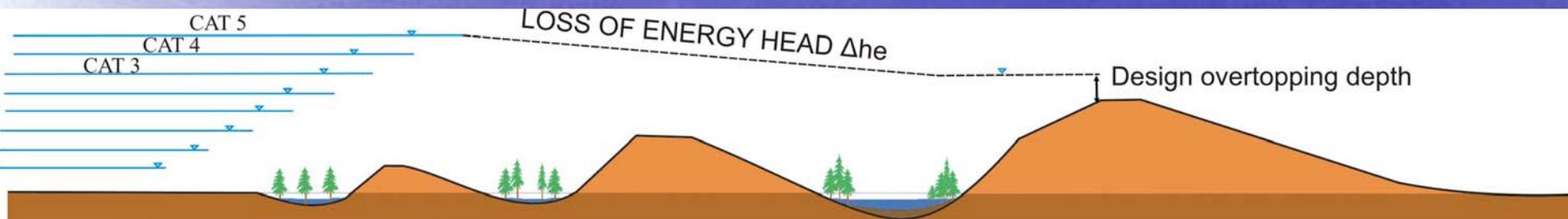


- Each flow obstruction will drain energy head from the advancing storm surge.
- Troughs with steep faces are some of the most efficient energy dissipaters, because they deflect forward energy upward.



- As the obstructions get larger, more and more wave energy is bled off and expended
- This might allow for a LOWER crest elevation for the highest embankment
- The system should be designed to survive short-term overtopping (e.g. 12 hours)

# Maximum Flexibility, with Innumerable Design Options

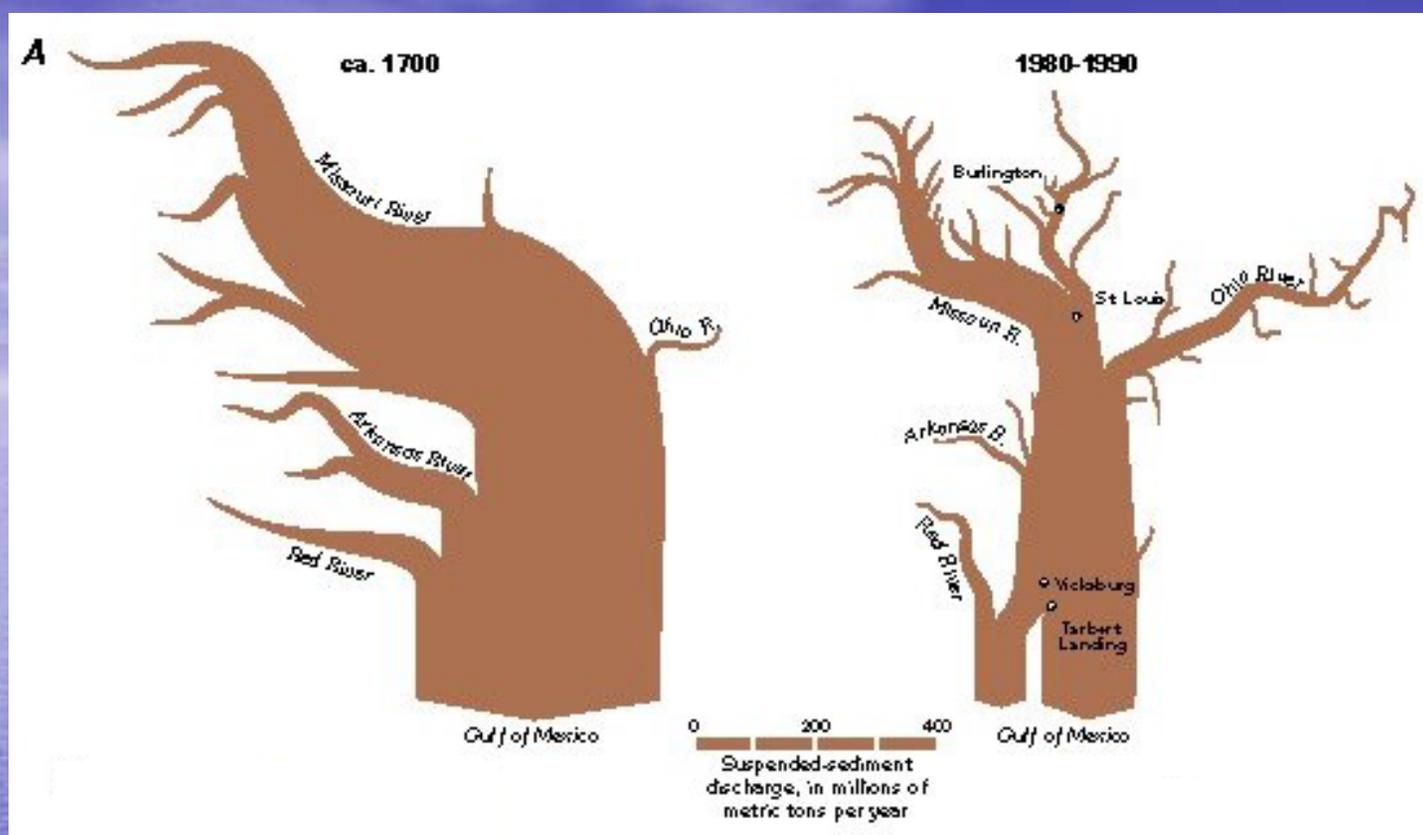


- Green segmented levee protection systems could be tweaked for any number of variables; including a *design overtopping depth* to accommodate low frequency events; without using as much earth fill as conventional embankments.

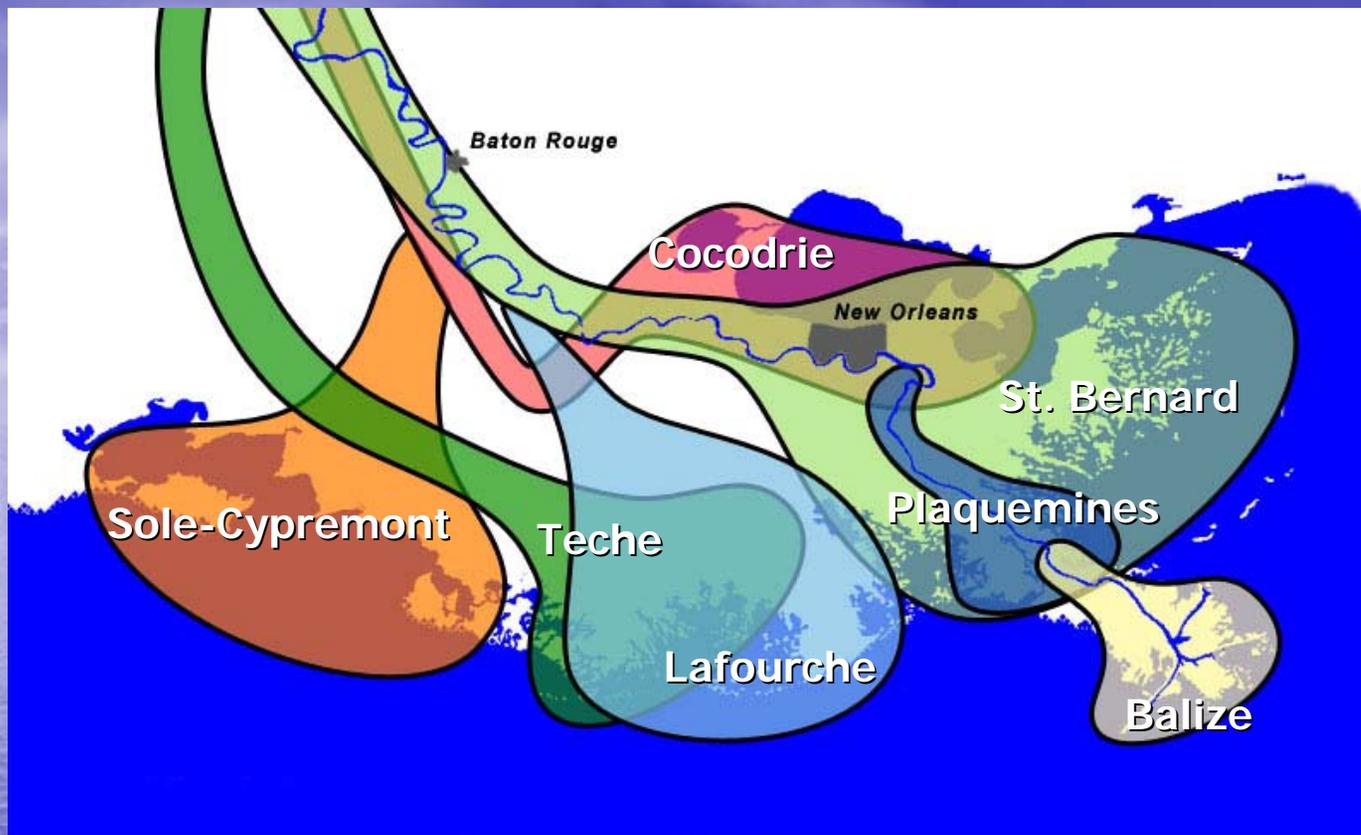
**CAN WE DO A BETTER  
JOB OF RETARDING  
LAND LOSS  
FOSTERED BY  
DIMINISHED  
SILTATION IN THE  
DELTA?**



- The Mississippi River drains approximately 41% of the continental United States, discharging about 580 km<sup>3</sup> of water each year (420 billion gpd).
- Almost 50% of the water comes from the Ohio River, which has 1/6<sup>th</sup> of the watershed.
- The Missouri River encompasses 43% of total watershed area, but only contributes 12% of the discharge.



- Prior to 1700, the average sediment discharge was about 440 million tons/year, mostly from the Missouri River watershed.
- This figure has decreased about 50% since 1950, because of dams constructed on Missouri and Arkansas Rivers.
- This loss somewhat compensated by 5 to 10 fold increase in sediment load carried down the Ohio River, because of row farming and deforestation.

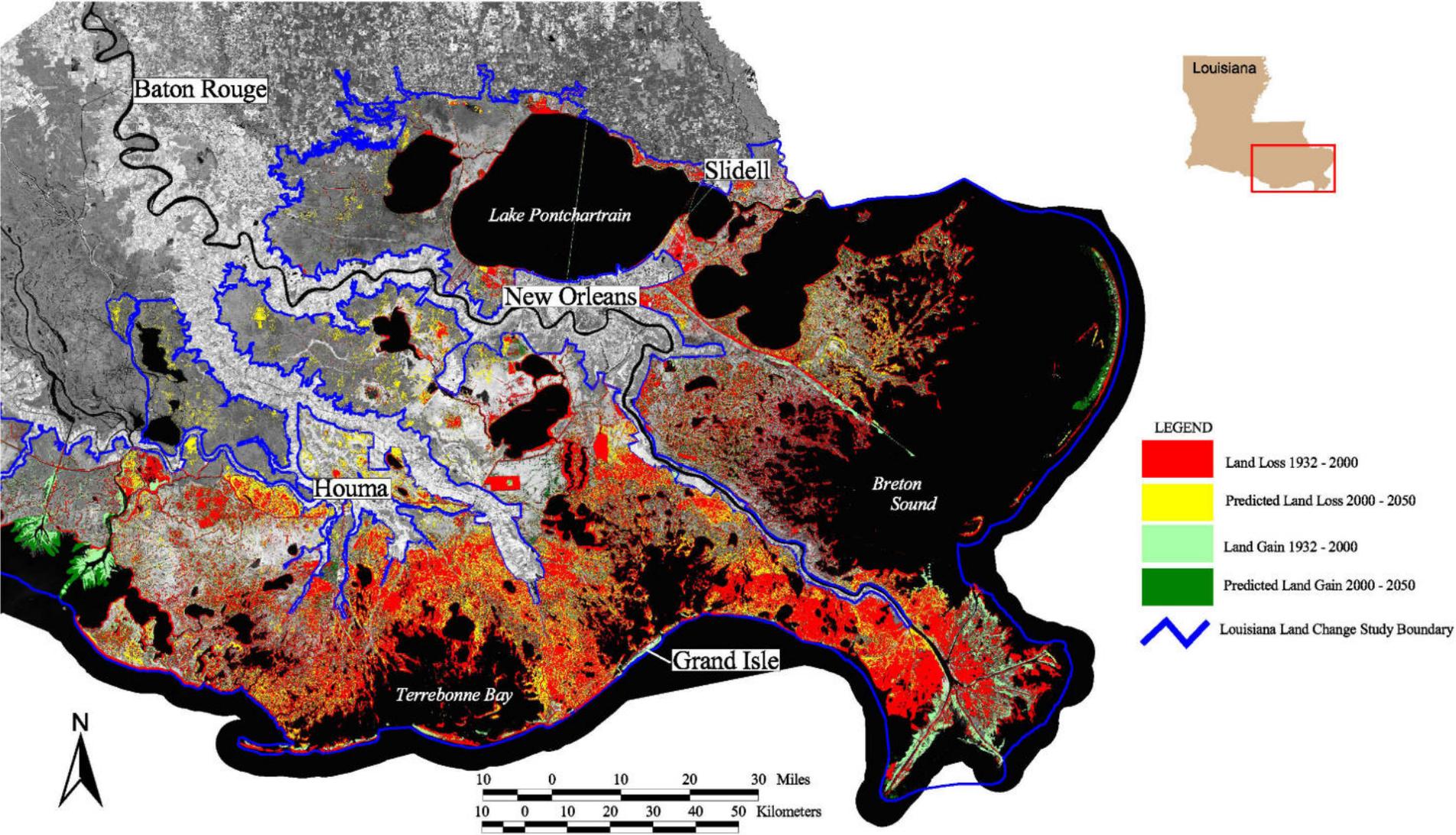


- The river has deposited enormous deltaic lobes during the late Holocene: Balize (550 yrs); Plaquemines (750-500); Lafourche (1000-3000); St. Bernard (2500-1000); Teche (3500-2800); Cocodrie (4600-3500); and Sole-Cypremont (>4600).



# Dynamic Environment: Chandelier Islands; before and after Katrina

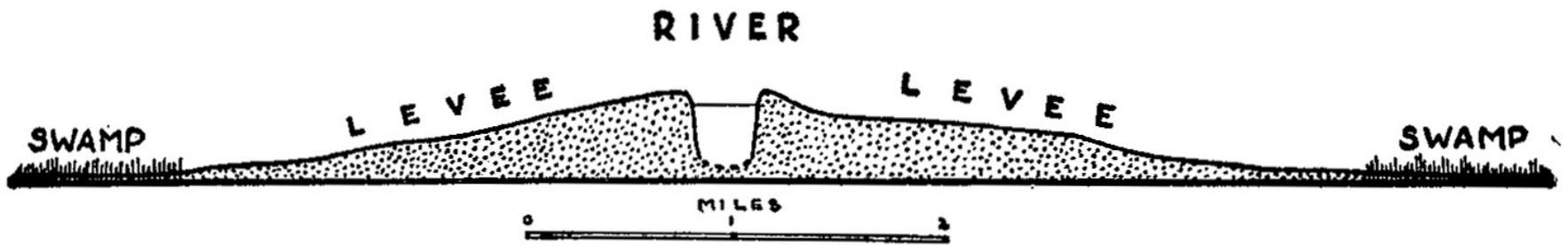
- Wave erosion stripped off sandy cohesionless deposits during Hurricane Katrina
- 4000 people were killed in this area in the 1915 hurricane



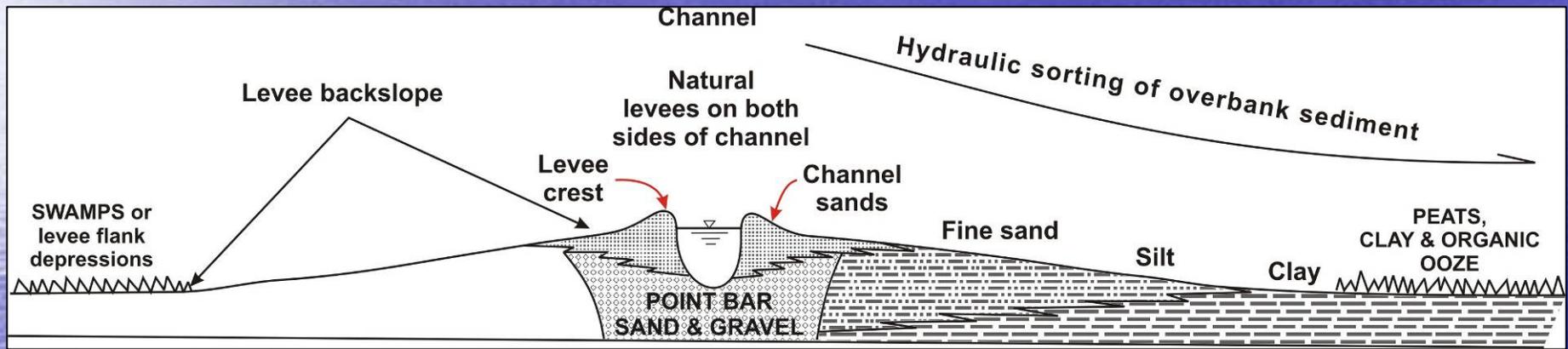
• Coastal Land Loss since 1932 (red) and land gain (green). We are losing about 50X more land mass than we are saving at present, even with the 2050 plan. (data from Ray Dokka at LSU).

The physical situation:  
*the river runs down in  
a deep hole...*

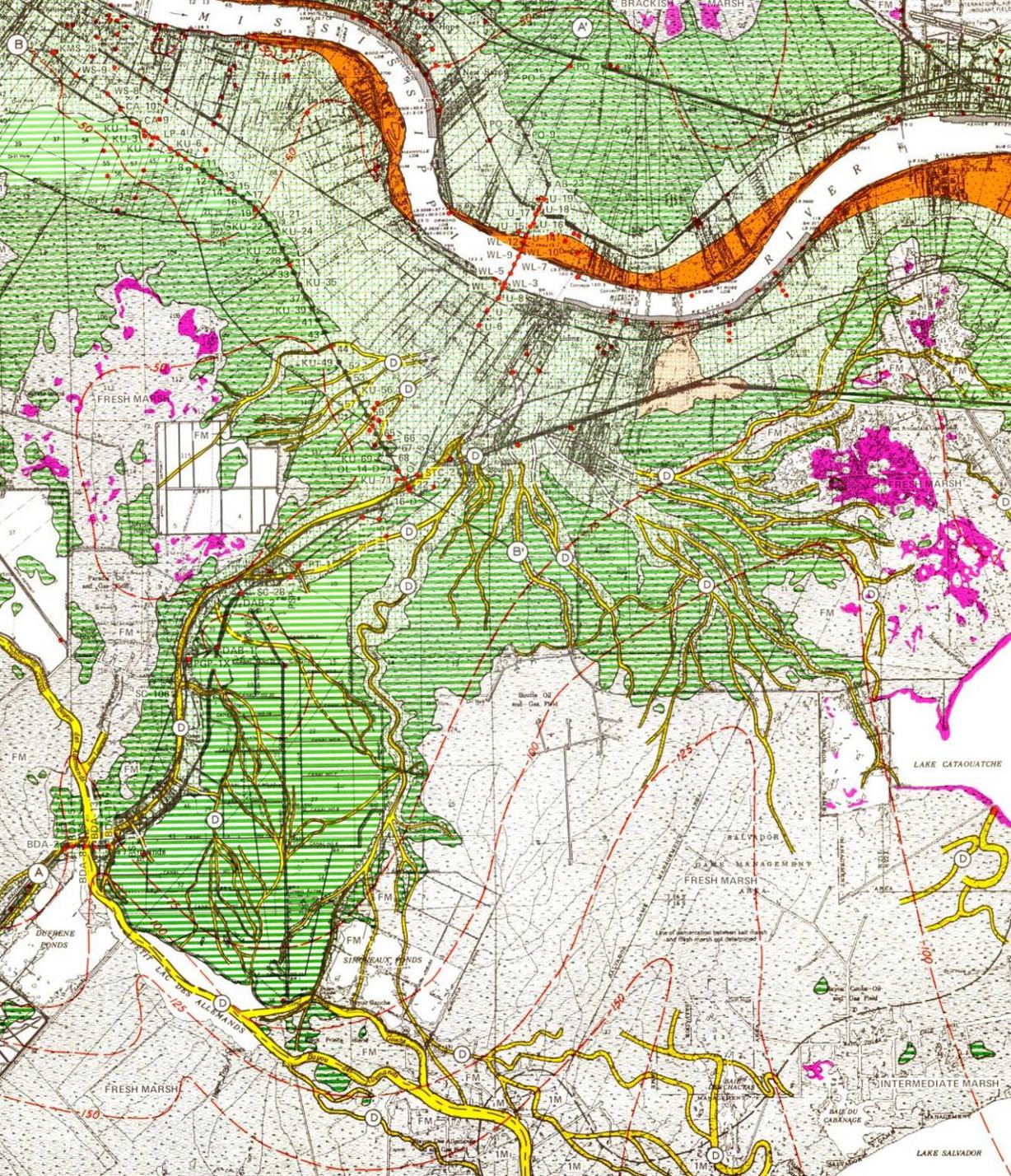
The design problem:  
*how can we extract its  
sediment?*



PROFILE OF THE MISSISSIPPI RIVER AT BELLE POINT



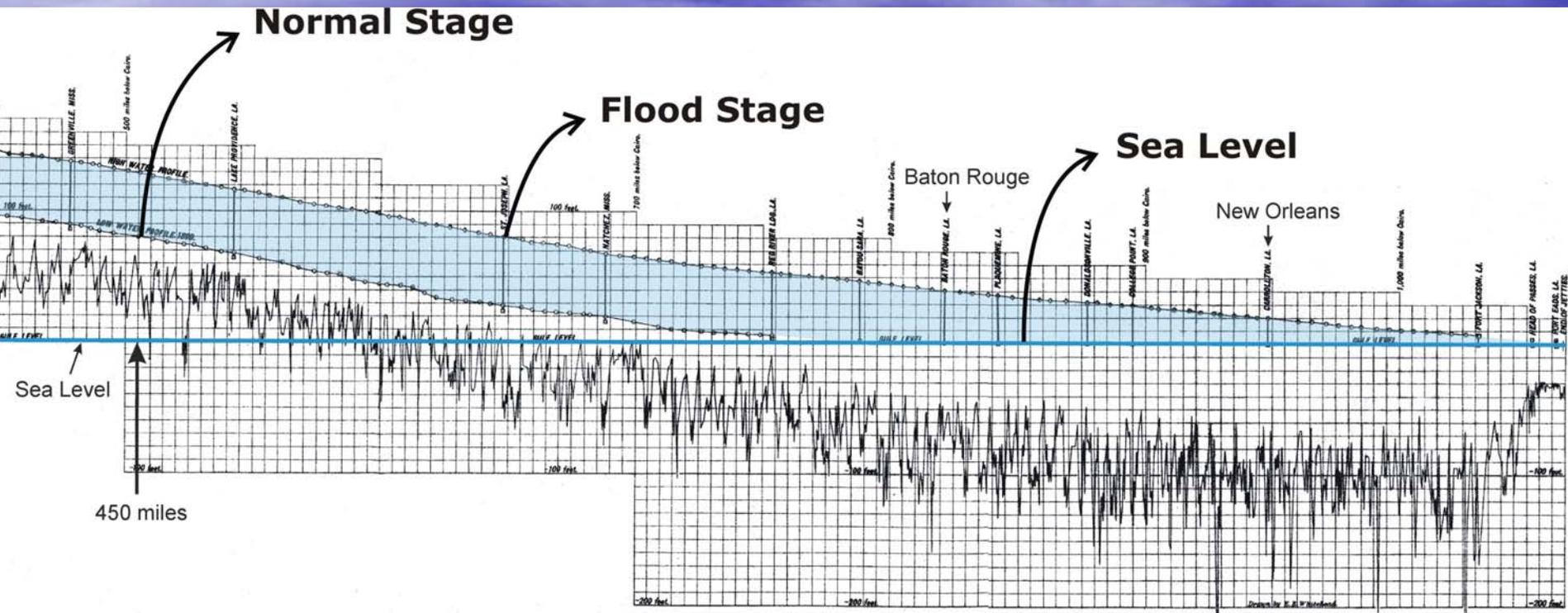
- Typical cross section through the sandy bank levees of the Mississippi River, illustrating how the river's main channel lies above the surrounding flood plain, which were poorly drained swamp lands prior to reclamation.
- There is significant hydraulic sorting of materials deposited on either side of these levees, as sketched below.



# Hahnville is just upstream of New Orleans

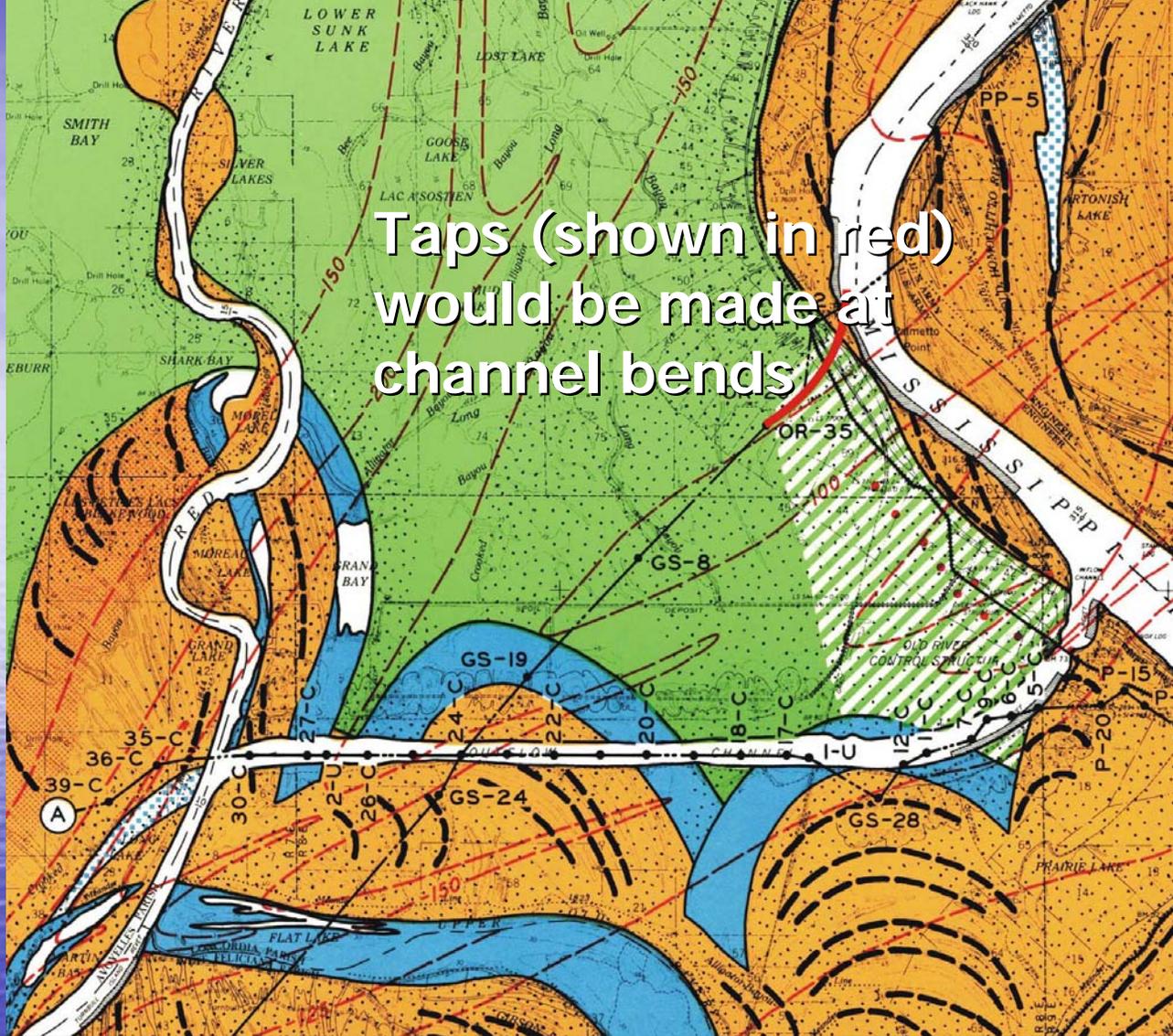
- Note classic birdfoot pattern of sand-filled distributary channels, shown in yellow
- Note development

# Profile of the Lower Mississippi



The bed of the Mississippi River is below sea level during the last 450 miles of its course, up to Greenville, Mississippi. We can only extract meaningful amounts of sediment during short-lived periods of high flow.

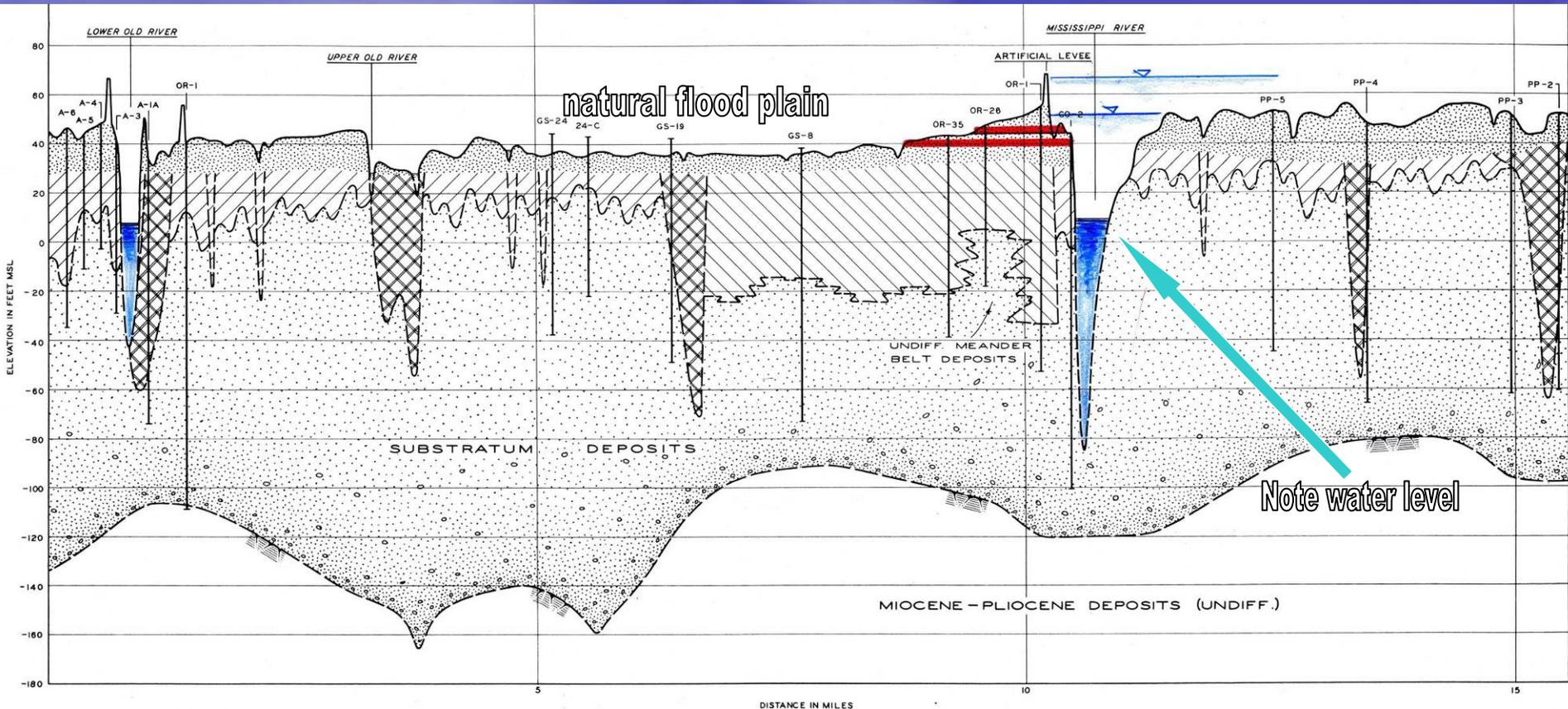
**Can we come up with a  
viable scheme for  
diverting silt-laden  
waters during high flow  
periods?**



Taps (shown in red)  
would be made at  
channel bends

One idea is  
to divert  
the flow of  
the river  
during  
high flows  
This map  
shows  
Artonish,  
Louisiana

- Artonish is typical of the Mississippi River's flood plain upstream of Baton Rouge
- Note multiple meander belts



**LEGEND**

**ENVIRONMENTS OF DEPOSITION**

- |            |  |                                  |
|------------|--|----------------------------------|
|            |  | NATURAL LEVEE                    |
|            |  | POINT BAR                        |
| TOPSTRATUM |  | BACKSWAMP                        |
|            |  | ABANDONED CHANNEL OR "CLAY PLUG" |
| SUBSTRATUM |  | UNDIFFERENTIATED SAND AND GRAVEL |
|            |  | TERTIARY SURFACE                 |

GEOLOGICAL INVESTIGATION  
BOEUF-TENSAS BASIN

SECTIONS A-A' AND B-B'  
ARTONISH, MISS.-LA.

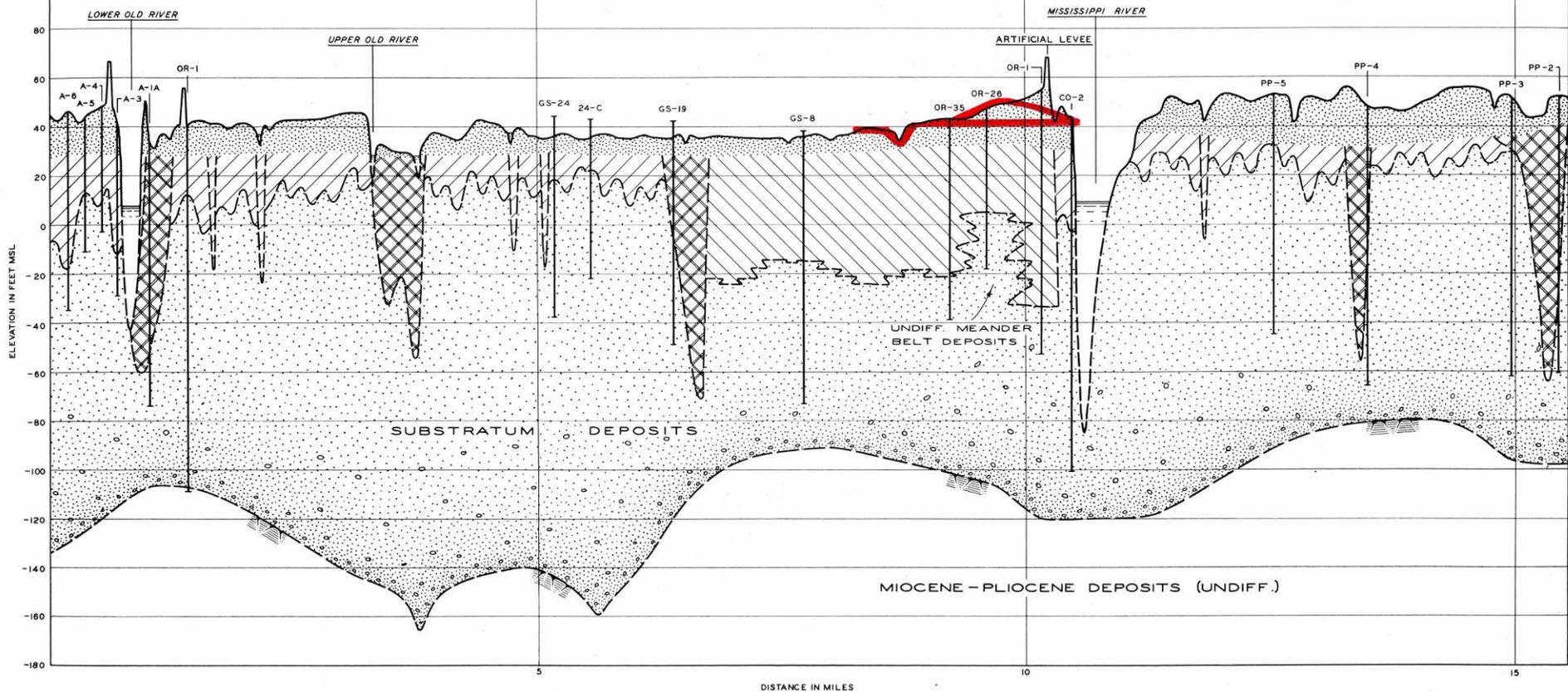
• This section shows "tunnel taps" 1 and 1.8 miles long that could be jacked through the overbank sediments, beneath the river's levee.



# Could we employ jacking of precast concrete tunnel boxes?

- During the Boston Big Dig, the world's largest precast concrete box tunnel section, for Interstate 90, was hydraulically jacked into position, beneath existing rail lines and bridges





**LEGEND**

**ENVIRONMENTS OF DEPOSITION**

|            |  |                                  |
|------------|--|----------------------------------|
|            |  | NATURAL LEVEE                    |
|            |  | POINT BAR                        |
| TOPSTRATUM |  | BACKSWAMP                        |
|            |  | ABANDONED CHANNEL OR "CLAY PLUG" |
| SUBSTRATUM |  | UNDIFFERENTIATED SAND AND GRAVEL |
|            |  | TERTIARY SURFACE                 |

GEOLOGICAL INVESTIGATION  
BOEUF-TENSAS BASIN  
SECTIONS A-A' AND B-B'  
ARTONISH, MISS.-LA.

- Tunnel taps could also be combined with siphons, in conventional or inverted form.

# Distributors



Ability to shift lines

Distributor alignments would need to be flexible, to accommodate even

distribution of sediment

Flexibility will be key aspect

**So, what portion of the  
lower Mississippi River  
could be targeted for  
massive flow diversions  
and be a receptacle for  
new sediment ?**

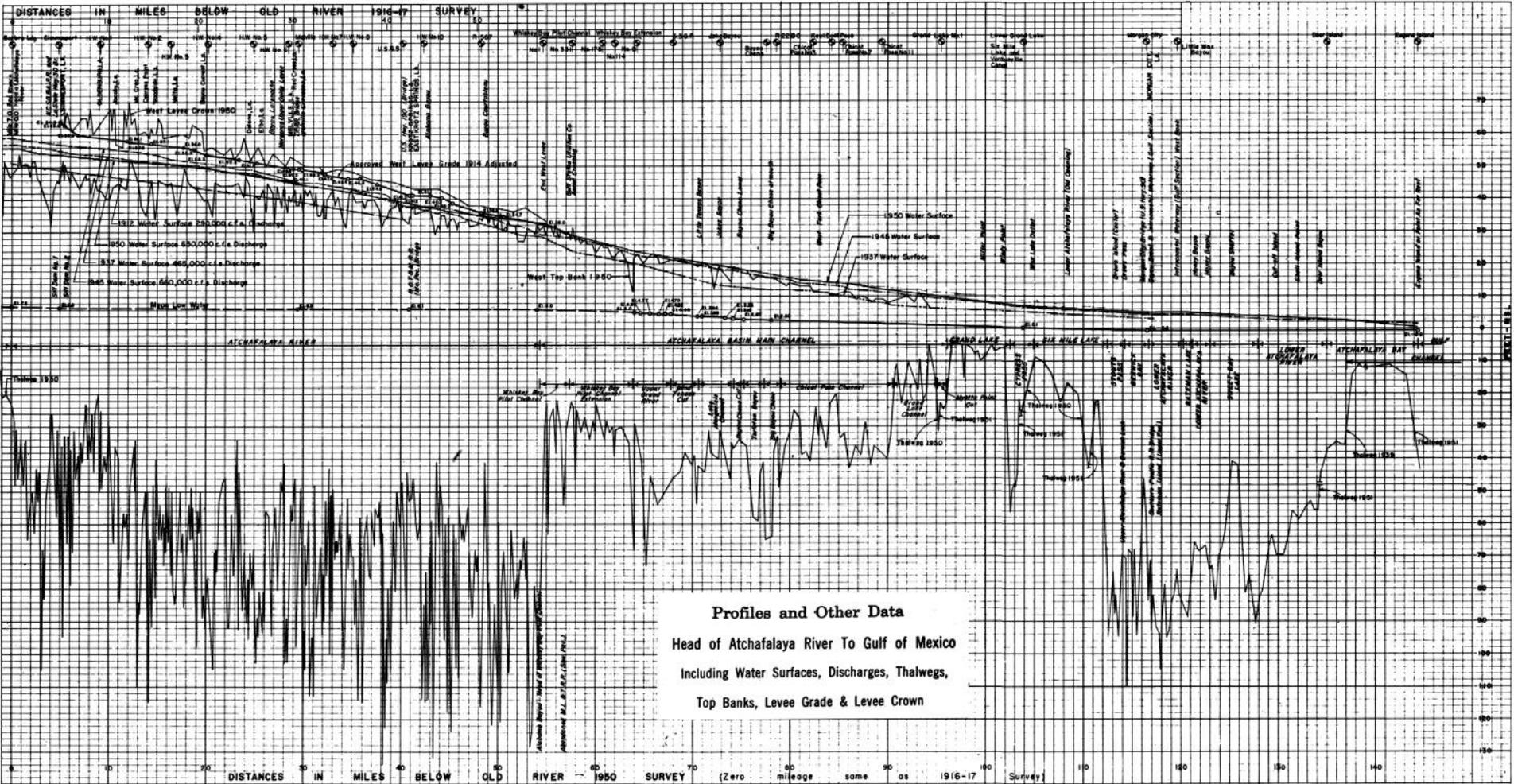


# Atchafalaya River

The Atchafalaya River is both steeper than the Mississippi (3:1 ratio in bed slope) and shorter (225 kilometers to the Gulf of Mexico from the

Red River entrance versus 480 kilometers for the Mississippi).

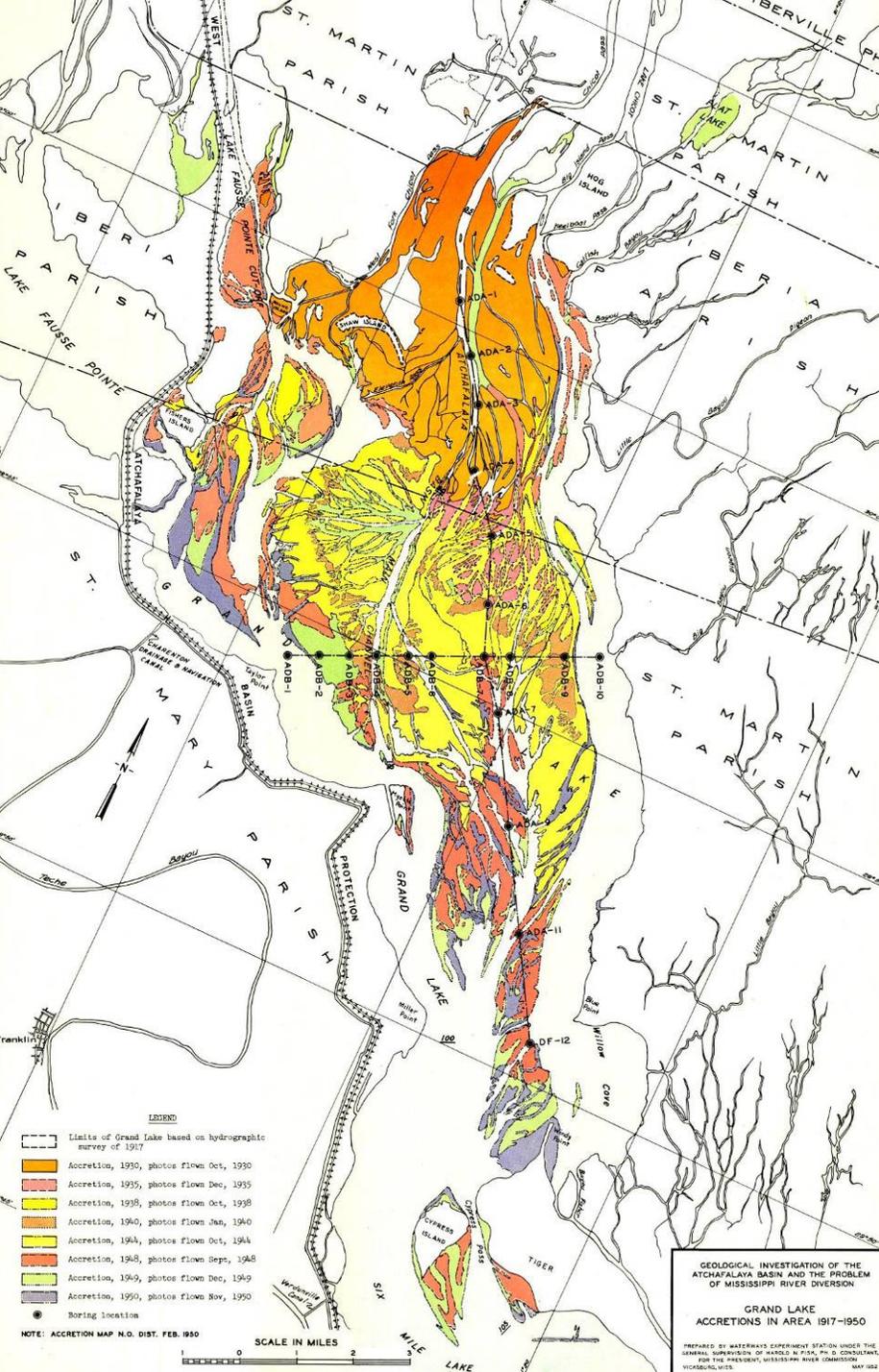
- Under natural conditions, the Mississippi River would probably have switched its course to the Gulf of Mexico via the Atchafalaya distributary between 1965 and 1975, if not for the levees.
- The Atchafalaya now drains about 30% of the combined flows of the Mississippi and Red rivers to the Gulf of Mexico.



- Profiles of the Atchafalaya River. Its steeper gradient would be much more efficient for sediment diversion, transport, and distribution than the lower Mississippi River.

# Sediment Accretion at Grand Lake 1917-1950

- The Atchafalaya Basin is our best analog model for sediment accretion in the delta
- Historic data on sediment accretion here needs to be analyzed and thoroughly understood



# The Likely Target

- Every physical factor save one, would seem to favor the Atchafalaya River for a prototype sediment deposition scheme involving the lower Mississippi River
- The sediment has be diverted from the Mississippi channel.
- We should probably begin by evaluating enhancements; options that would use existing facilities, like the Old River Diversion Structures

- This presentation will be posted in pdf format for easy downloading at:  
[www.umar.edu/~rogersda/levees](http://www.umar.edu/~rogersda/levees)