BRIEF OVERVIEW OF THE 2011 MISSISSIPPI RIVER FLOODS

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for the
Society of American Military Engineers
Ft Wood Chapter Meeting
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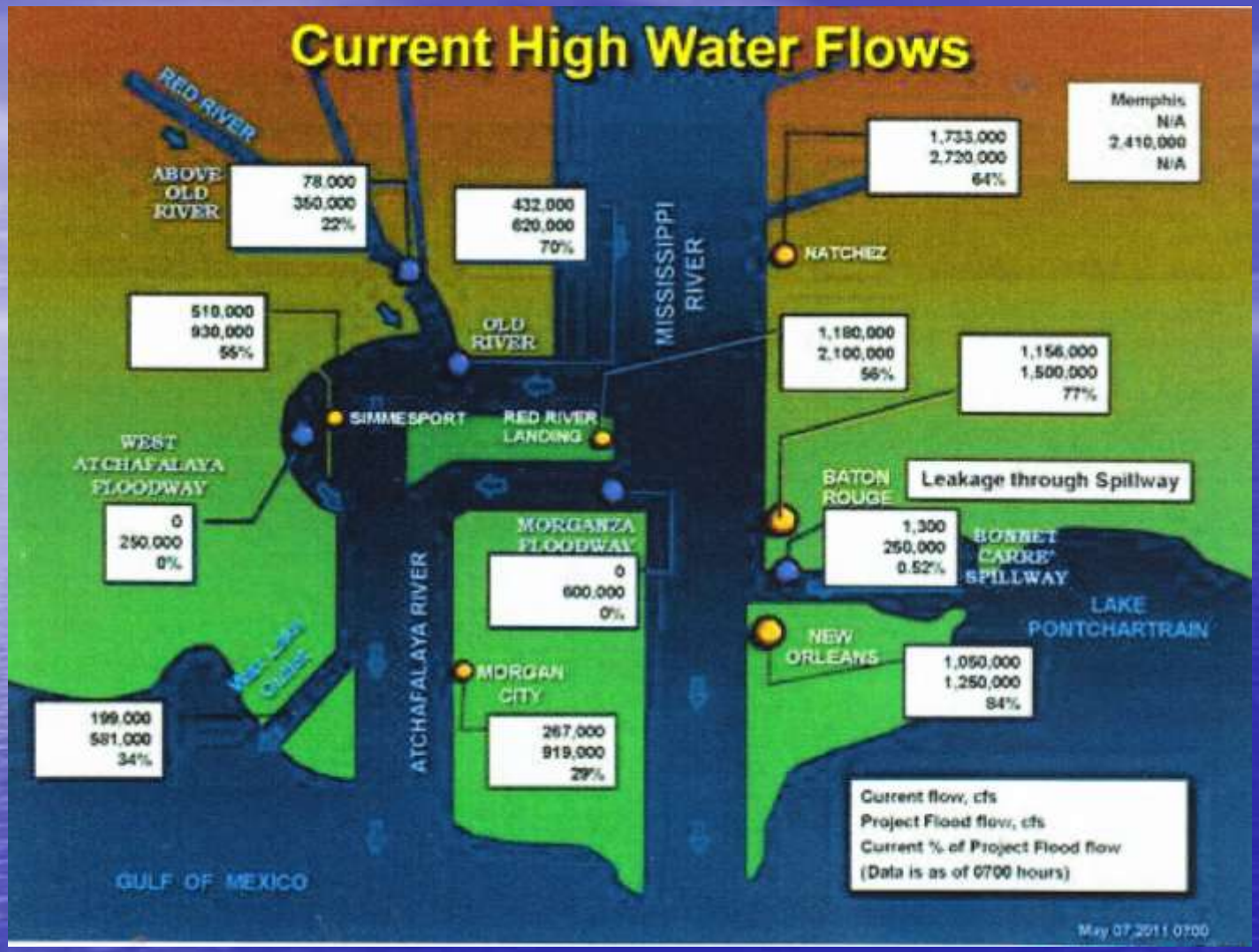
MISSOURI S&T
University of Science & Technology

2011 Flood

- We're witnessing a peak flood flow of ~2,330,000 cfs (at Natchez on May 20th); about 86% of the design capacity of 2.71 million cfs
- We're seeing record stage levels everywhere, downstream of Cairo. e.g. The Natchez gage hit 62.5 ft, 4.5 ft above the previous record
- The Bird's Point-New Madrid floodway was opened for the first time since 1937
- The Morganza floodway was opened only the second time since it was constructed in 1954



- **Flood Routing situation in the Mississippi Delta on May 7, 2011**

- About 1300 cfs was leaking through the needle logs prior to their being lifted at Bonnet Carre for the 10th time since 1932, on May 9th. The spillway is 7000 ft long.

- Bystanders gather to view the opening of the needle log gates at the southern end of the Bonnet Carre Spillway, constructed in 1929-32. 330 of the 350 spillway bays were opened in May 2011, discharging up to 316,000 cfs.

- The design capacity of the spillway is 250,000 cfs, about one-fifth of the channel's capacity. It was completed in 1932 and the railroad and highway relocations completed in 1936. The spillway was opened in 1937, 1945, 1950, 1973, 1975, 1979, 1983, 1997, 2008, and in 2011. Not statistically significant…yet e.g. 3X 1st 20 yrs; 7X next 40 yrs

- The **Bonnet Carre Bypass Spillway** diverts flow 6 miles, into Lake Pontchartrain, which is at sea level. It was constructed a few miles downstream of a natural crevasse, which had breeched 6 times in the previous 120 years.
- Four million cubic yards of sediment was mucked from the spillway channel after the 1997 overflows, increasing the spillway capacity.

The Morganza Spillway was constructed in 1953-56, to retard the flow passing Baton Rouge to 1,500,000 cfs. It was only opened once previous to 2011, during the 1973 flood. This shows the first bay being opened on May 11th, 2011 and the structure discharged a peak flow of 172,000 cfs on May 17th.

Explosives Barge

The explosives barge carry the ANFO components was parked at this location throughout the memorable 1993 flood of the lower Missouri and middle Mississippi Rivers

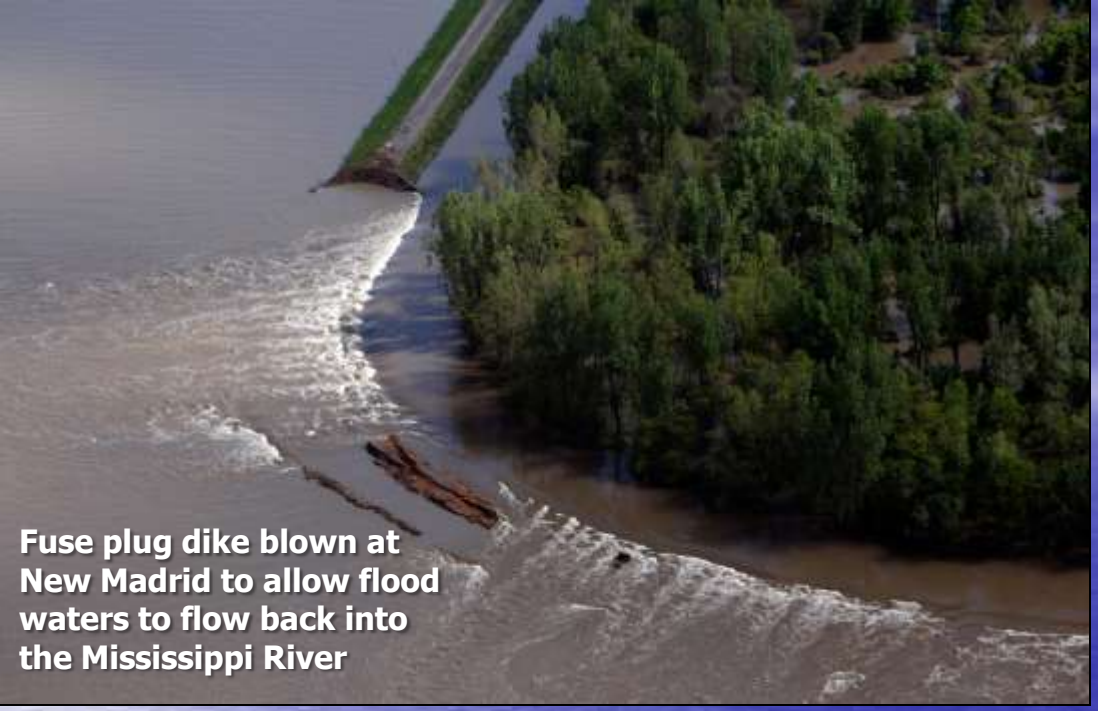
- Several thousand lineal feet of hollow PVC pipe was embedded in the *fuse plug levee* at Bird's Point. When the time came to blow the dike, the pipes were filled with a mixture of ammonium nitrate fertilizer and diesel fuel (ANFO)

Detonation at Bird's Point

- The middle-of-the-night detonation on May 2-3, 2011 created an artificial crevasse 11,000 feet long, diverting 335,000 to 375,000 cfs of the river's flow

- Approximately 200,000 acres of essentially level flood plain within the **Bird's Point-New Madrid Floodway** was inundated within 36 hours of the detonation.
- The USGS deployed 40 hurricane ***storm surge sensors*** to monitor excavation of the crevasse scour hole and flow velocities, every 30 seconds.

Bird's Point-New Madrid Floodway



Fuse plug dike blown at New Madrid to allow flood waters to flow back into the Mississippi River

- The State of Missouri appealed to the US Supreme Court to prevent the Bird's Point diversion, on basis of economic cost-benefit
- The U.S. Government maintains flowage rights in the four designated floodways, regardless of their post-1928 development

‘Hard points’ and backwater flooding in Memphis

- Some of the high-value developments in Memphis were afforded increased protection
- Older neighborhoods bereft of any recent flood protection were inundated for the first time, under *record high gage flows*

Tailwater Effects

- The areas initially impacted by high flows are often those inundated by low gradient tributaries to the Mississippi River

Flood Preparations

- An engineer from the Corps of Engineers Louisville District inspects the troubled floodwall at Hickman, Kentucky.
- The downtown area was destroyed by high groundwater in 1993 because of the sheetpile cutoff beneath this floodwall
- Volunteers unpack and assemble Hesco Bastion concertainers in Memphis. These can be filled with rock to create more substantial barricades than using sandbags.

The Waterways Experiment Station and the Mississippi River & Tributaries Project

Long duration floods transport enormous volumes of sediment

Funnel-shaped basin drains 41% of the continental United States

1st Lt Herbert D. Vogel

West Point Class of 1924
MS Univ California Berkeley '28
DEng Berlin Technical Univ '29
MEng Univ Michigan '34
First Director of the Waterways Experiment Station at Vicksburg 1930-34

"Vog" Class of '24

Dr. Vogel

The **Waterways Experiment Station** was established by the Army Corps of Engineers in 1928, following the disastrous floods of 1927 along the lower Mississippi River. The Army chose 1st Lieutenant Herbert D. Vogel with standing up the facility, which he directed for five years, between late 1929 and mid-1934

BGEN Harley Ferguson (West Point '97) was President of the Mississippi River Commission from 1932-39, during the formative years of the Mississippi River & Tributaries Project

Vogel and Prof. Clarence Bardsley were the first engineers to ever construct outdoor earthen bed hydraulic models

The loess soils in Vicksburg were ideal for carving precise scale hydraulic models , with vertical exaggeration

Vogel and Prof. Clarence Bardsley, of the Missouri School of Mines

Vogel employed the principles of similitude that had been pioneered by hydraulic modelers in Europe to examine various means to make the Mississippi River channel more hydraulically efficient

Vogel observing results of an overflow test of a full-scale railroad right-of-way


Model of Birds Point-New Madrid floodway under test

- The **Birds Point-New Madrid Floodway** was located in Missouri and starting just below the confluence of the Mississippi and Ohio Rivers at Cairo, IL, covering about 206 square miles.
- In 1932 WES performed a model study to determine the effects of operating the floodway on the lands lying within it and to predict the draw-down on the Mississippi River with the floodway in use.
- With more than 100 miles of river to simulate, Vogel built an 80-foot-long outdoor concrete model of the river channel, the overbank between levees, backwater areas, and the floodway.
- Vog took special care to correctly place drainage ditches, levee borrow pits, and other details that would affect water levels, and raised miniature levees with soil taken from actual on-site levee borings. These tests indicated that the new levees were of sufficient height to contain any projected flood

Design Intent of the Bird's Point Floodway

The Corps of Engineers designed the floodway to save Cairo, IL, a key rail and highway junction They also designed a drainage system to reclaim floodway lands for agriculture

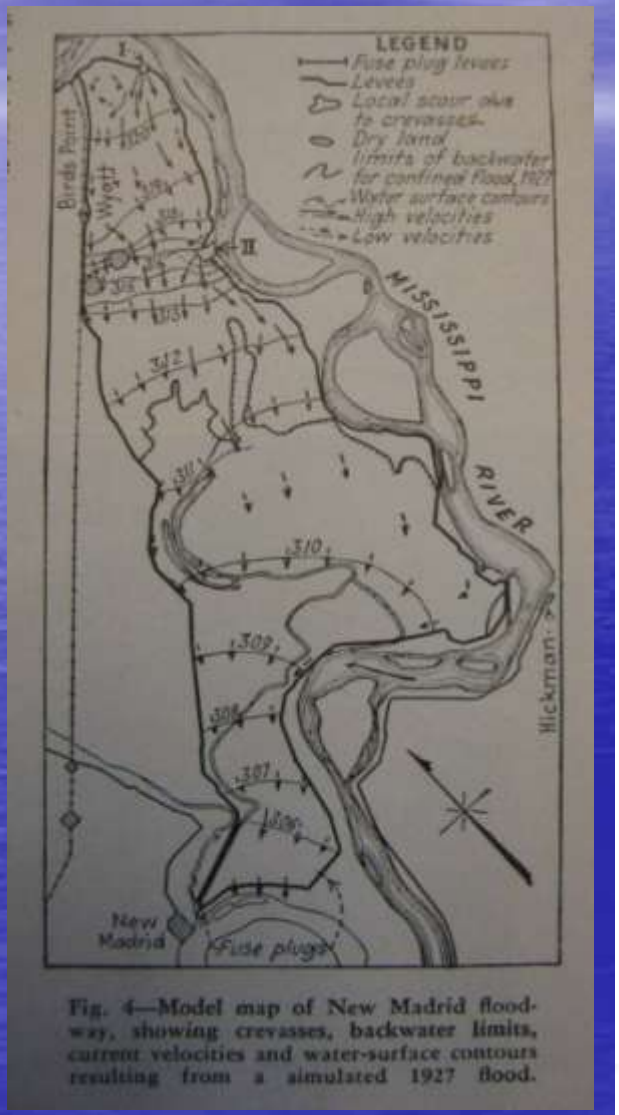


Fig. 4—Model map of New Madrid floodway, showing crevasses, backwater limits, current velocities and water-surface contours resulting from a simulated 1927 flood.

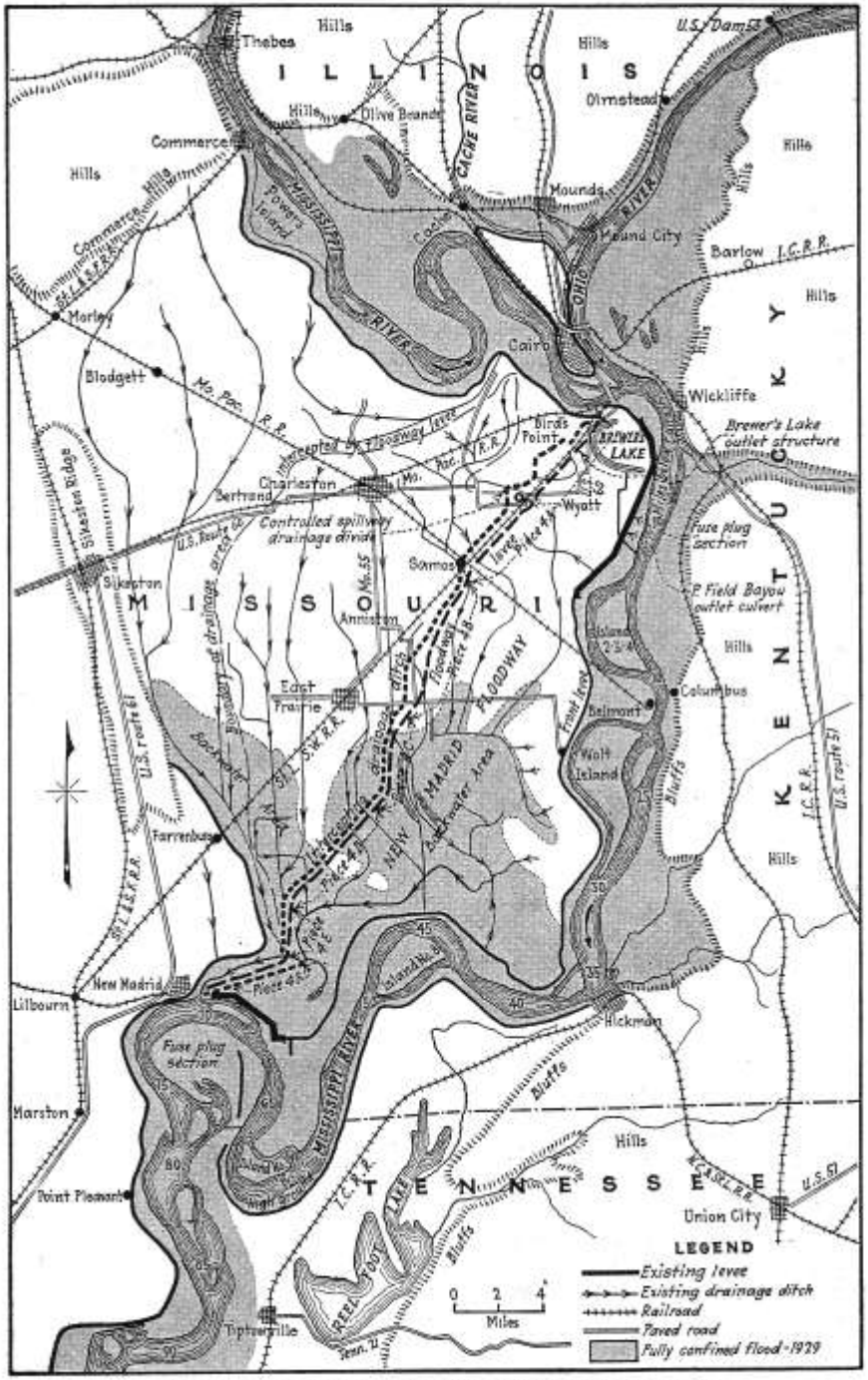
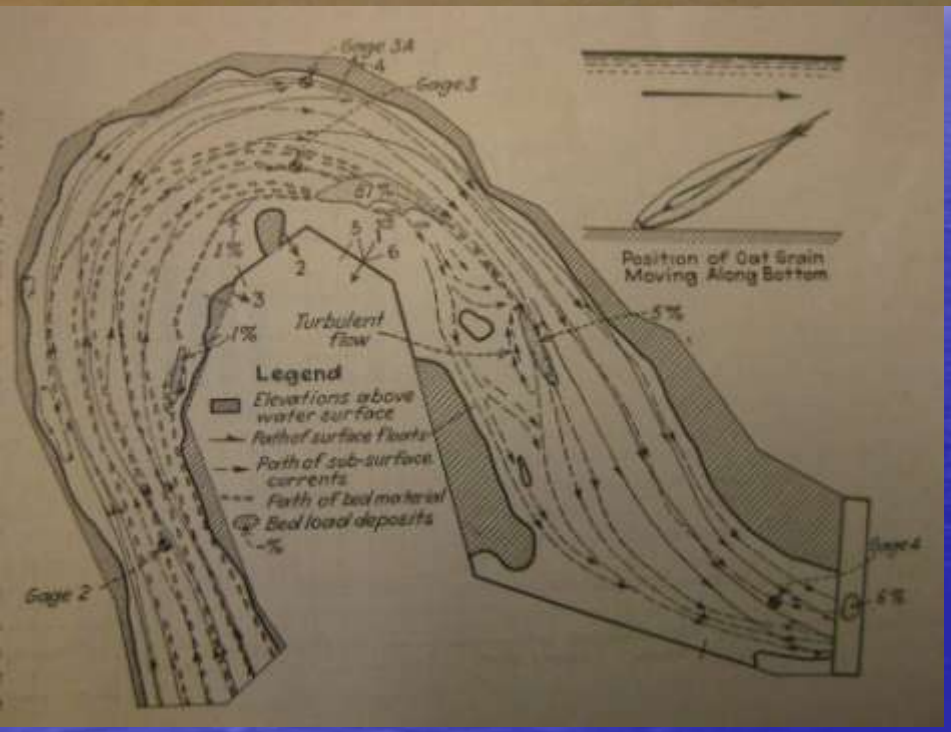


Fig. 1—Levee and drainage system of New Madrid floodway

Geometric Versus Hydraulic Similitude

Factors to Be Considered When Using Models to Study Flow in Open Channels

By Herbert D. Vogel
Director, U.S. Waterways Experiment Station, Vicksburg, Miss.
First Lieutenant, Corps of Engineers, U.S. Army
and John Paul Dean
Assistant to District Engineer, First Lieutenant, Corps of Engineers,
U.S. Army, New Orleans, La.



One aspect the hydraulic models could not predict were long-term bed and bank adjustments, made over many decades by dramatically different flow regimens (Herbert D. Vogel and Missouri Mines Professor Clarence Bardsley pictured at upper right).

Major Elements of the MR&T

- 2,200 miles of **levees and floodwalls** (avg 30 ft high) below Cape Girardeau
- **Bypass floodways**: Bird's Pt-New Madrid (1931); Bonne Carre (1931); Morganza Diversion (1954); Old River Diversion (1960/1977)
- **Channel improvements**; incl. 16 cutoffs and two major chutes; and bank revetments. Initially lowered flood stages 16 ft at Ark City and 10 ft at Vicksburg
- **Major tributary improvements**, 4 dams in Yazoo Basin (Enid, Arkabutla, Sardis, Grenada) and Wappapello on the St Francis River

Effects of Mississippi River Cut-Offs

By HARLEY B. FERGUSON
MEMBER AMERICAN SOCIETY OF CIVIL ENGINEERS
BRIGADIER GENERAL, CORPS OF ENGINEERS; PRESIDENT, MISSISSIPPI RIVER COMMISSION, VICKSBURG, MISS.

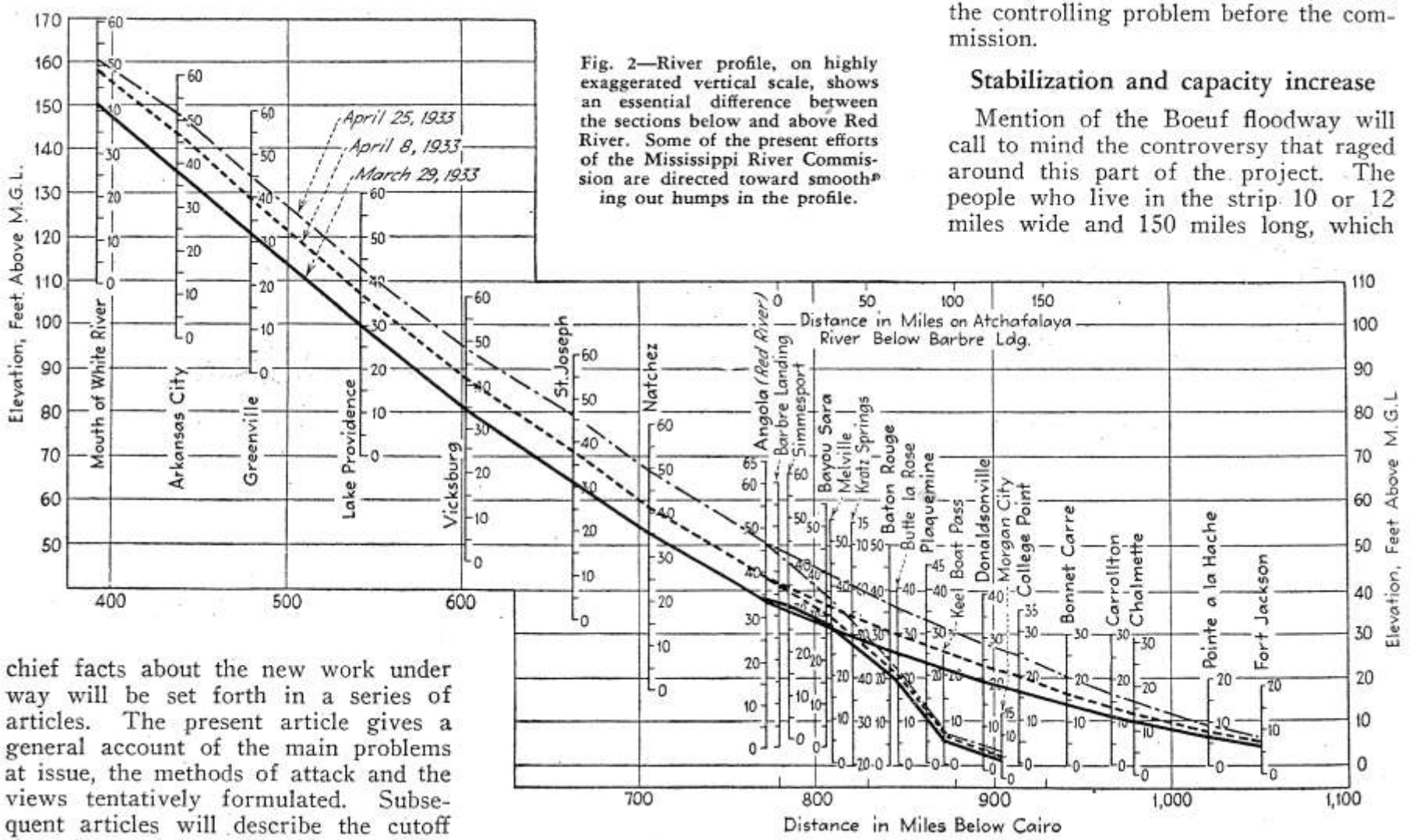


Fig. 2—River profile, on highly exaggerated vertical scale, shows an essential difference between the sections below and above Red River. Some of the present efforts of the Mississippi River Commission are directed toward smoothing out humps in the profile.

chief facts about the new work under way will be set forth in a series of articles. The present article gives a general account of the main problems at issue, the methods of attack and the views tentatively formulated. Subsequent articles will describe the cutoff operations, contraction works, new

the controlling problem before the commission.

Stabilization and capacity increase

Mention of the Boeuf floodway will call to mind the controversy that raged around this part of the project. The people who live in the strip 10 or 12 miles wide and 150 miles long, which

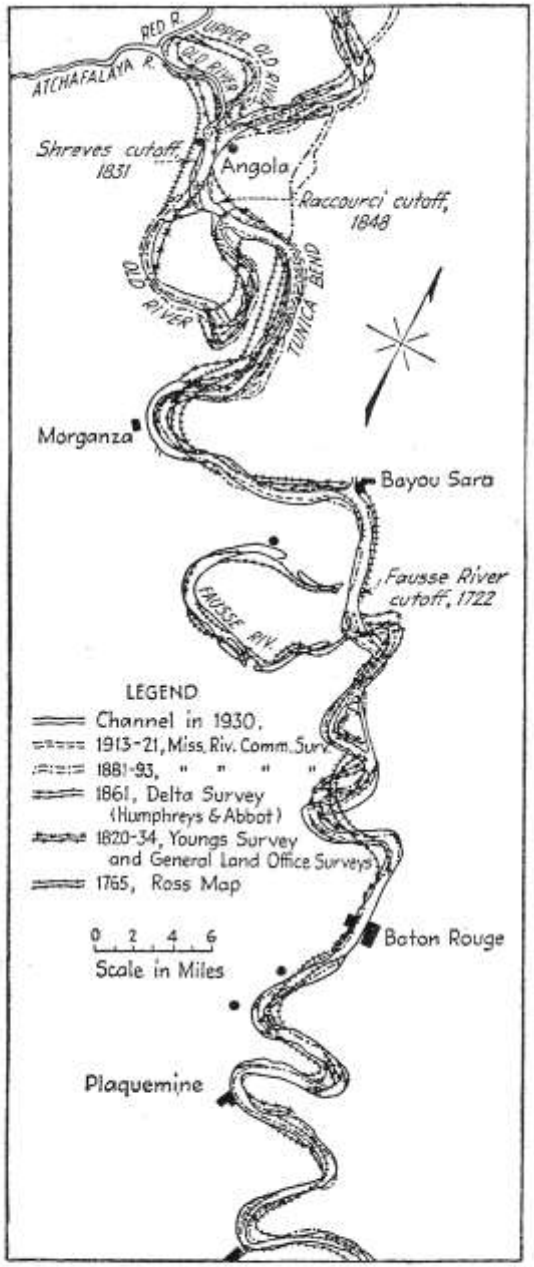


Fig. 5—Records of 165 years of channel changes below Baton Rouge reflect a high degree of stability. Compare with Fig. 4, which is typical above Red River.

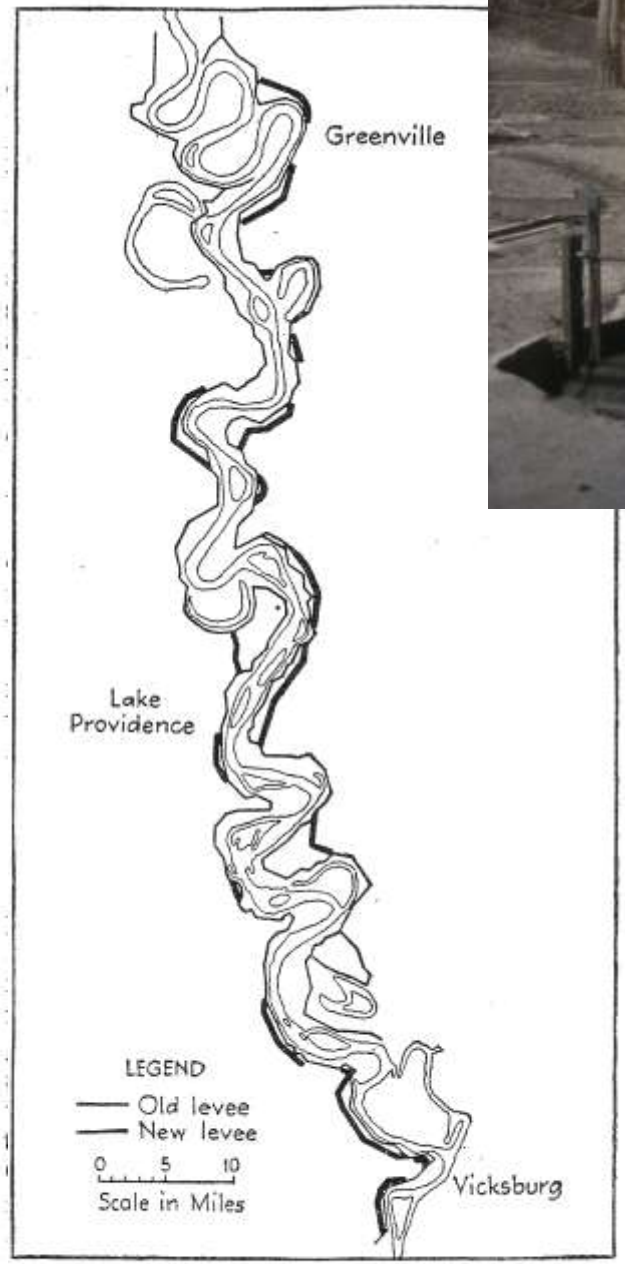


Fig. 6—Much rectification of the high-water channel has been accomplished by setting back the levee line at projecting points, as shown in this stretch between Greenville and Vicksburg.

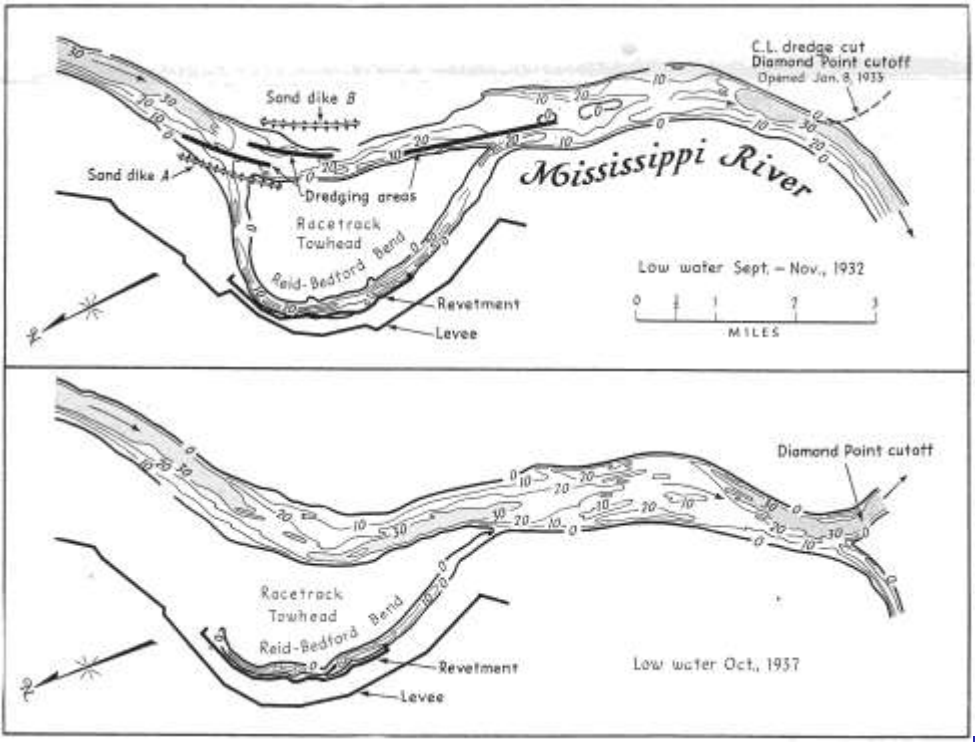
FIG. 1. INCREASING THE MISSISSIPPI'S CAPACITY: GILES CUTOFF IS BEING DREDGED AND VIDALIA POINT CUT BACK.

Mississippi River Cutoffs Effective

Cutoffs Lower Flood Crests

GEORGE R. CLEMENS
Mississippi River Commission, Vicksburg, Miss.

Fifteen cutoffs are rapidly redistributing the flow of the Mississippi River and have materially lowered flood crests above Red River Landing



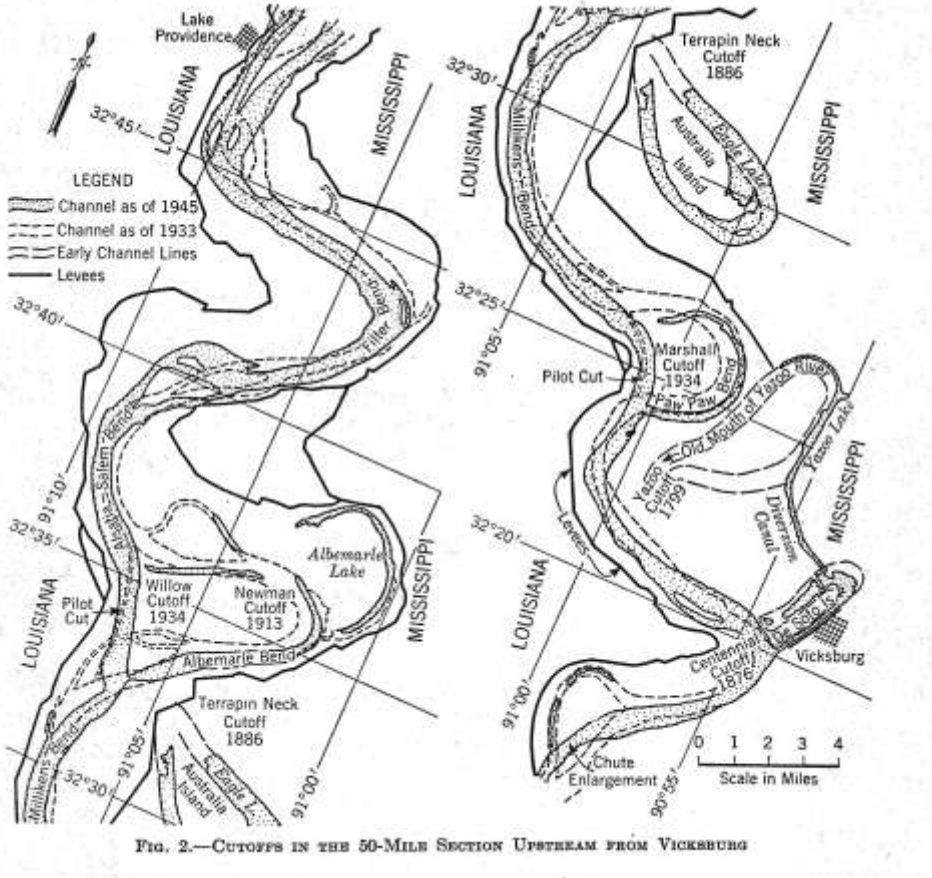


FIG. 2.—CUTOFFS IN THE 50-MILE SECTION UPSTREAM FROM VICKSBURG

Goal: reduce flood height thru increased channel efficiency: 16 cutoffs were made along the lower Mississippi River to increase grades and channel efficiency.

WES strove to improve channel efficiency

August 3, 1933 — Engineering News-Record 133

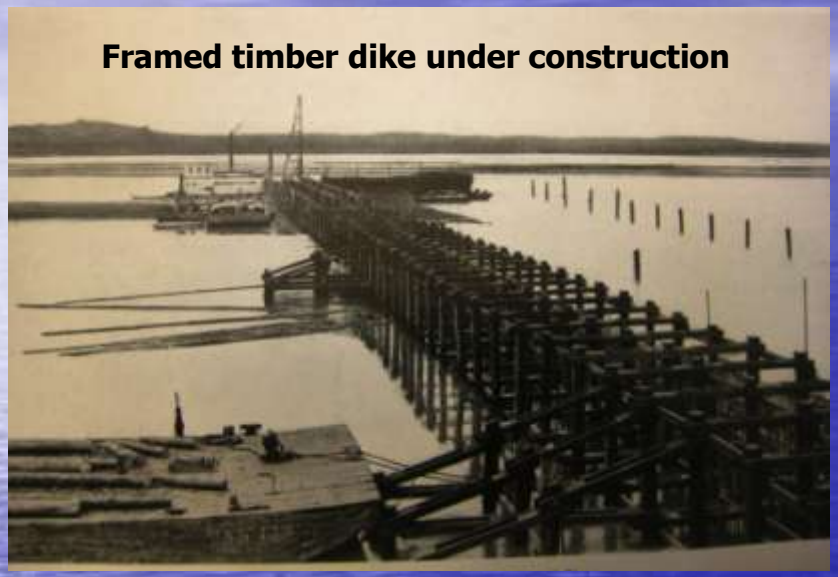
NEW PLANS FOR THE MISSISSIPPI

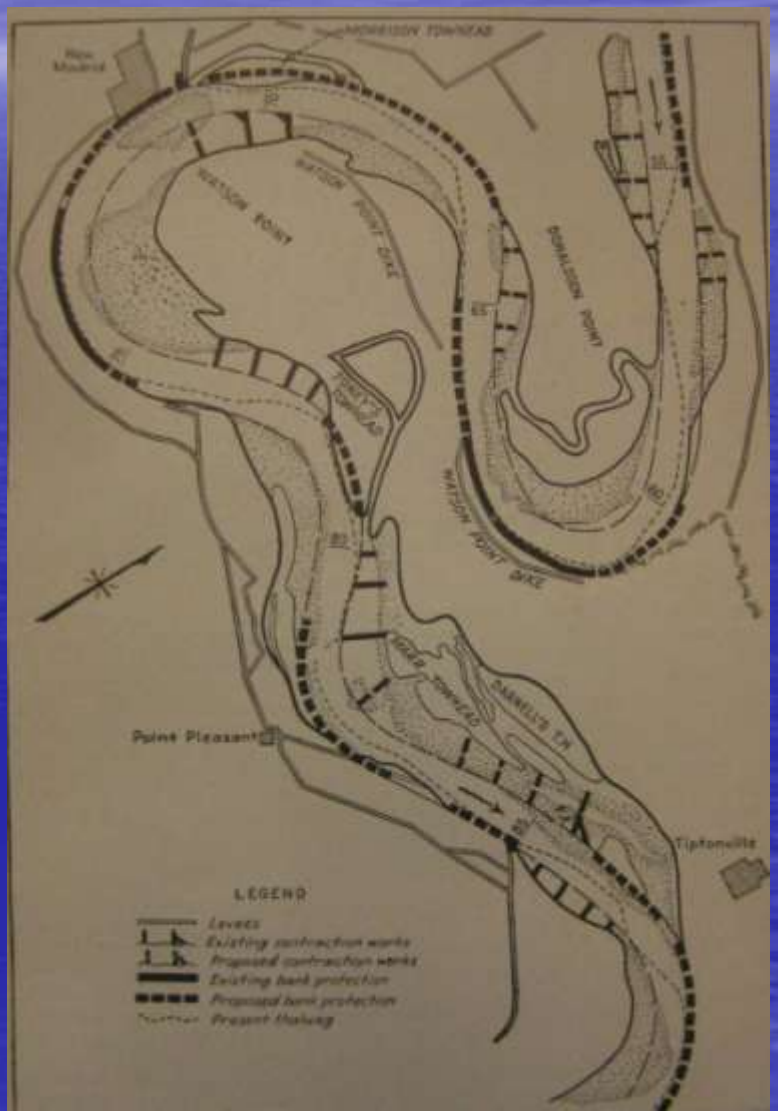
Contraction Works Stabilize Low-Water Channel

Seventh of a Series of Eight Articles

Shallow navigation depths between Cairo and Memphis are being increased by narrowing and stabilizing the low-water channel by means of spur dikes

Framed timber dike under construction





- **Timber dikes** were employed along the Mississippi River to confine flow and increase velocity along a preferred navigation channel. These dike caught organic debris which aided in their becoming backfilled with sediment.

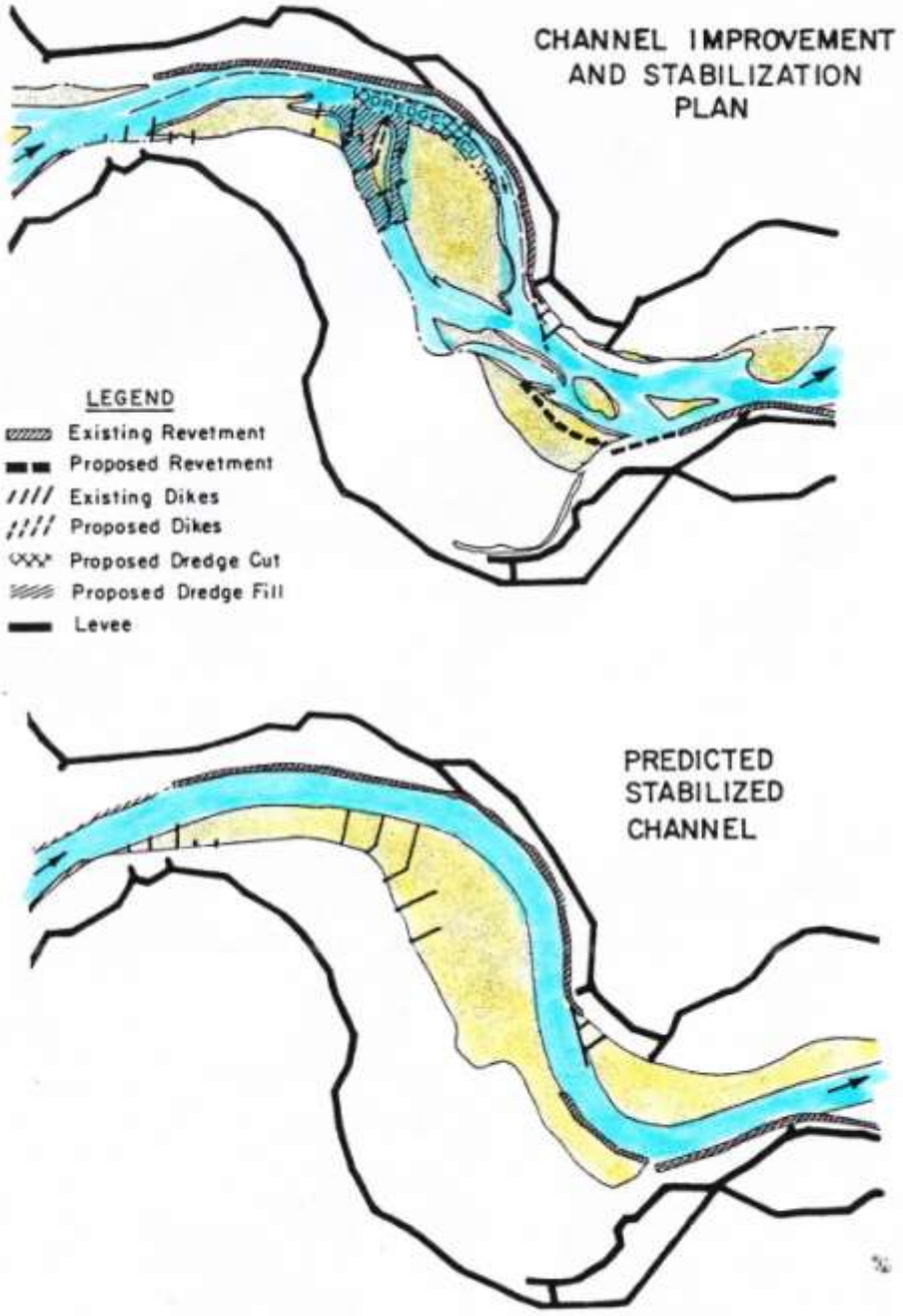
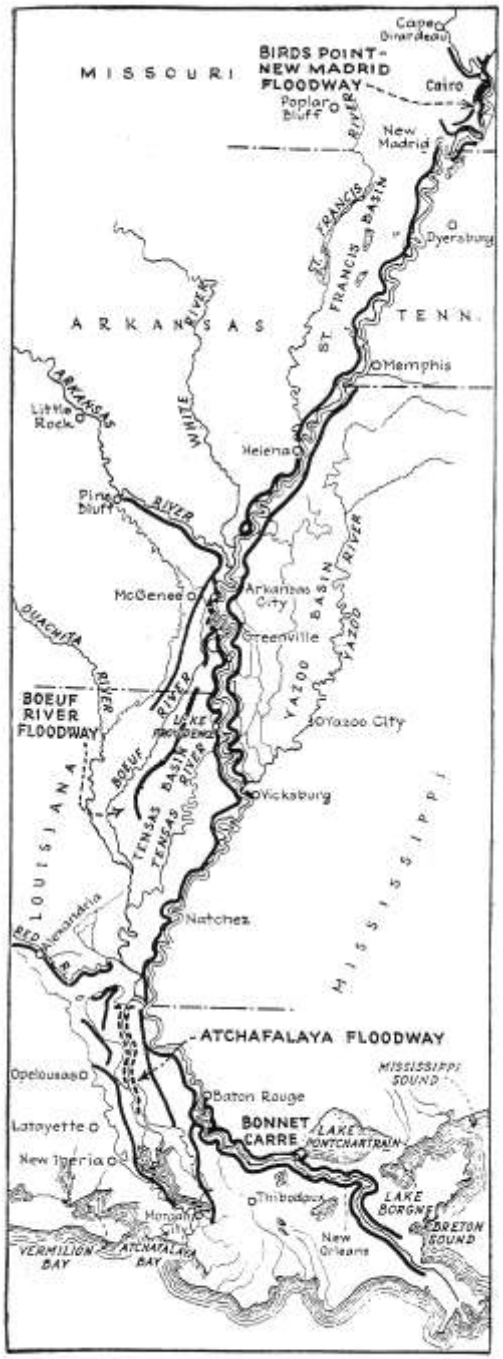


FIGURE 5 *Example of corrective works used to alleviate a troublesome divided-flow condition along a selected Mississippi River reach.*

Split Flow Conditions

- **Channel improvements; incl. 16 cutoffs and two major chutes; and bank revetments (damaged during high flows).**
- **These improvements initially lowered flood stages 16 ft at Ark City and 10 ft at Vicksburg**
- **Requires corrective dredging**

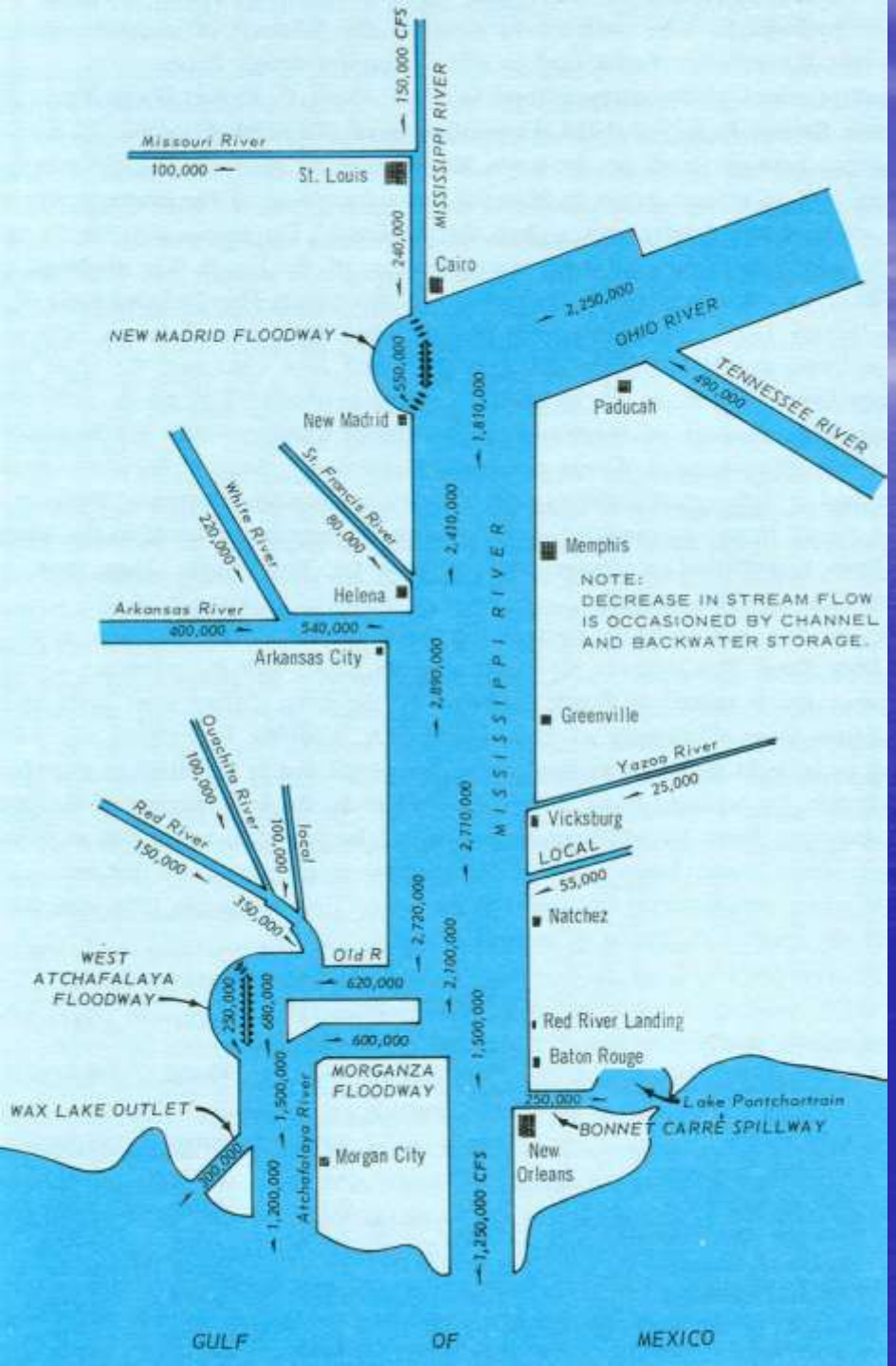
Levees, Floodwalls, and the Atchafalaya



Levee and diversion system of Mississippi flood control adopted by act of Congress approved May 15, 1928

Prof H. N. Fisk briefs BGEN Max C. Tyler, of the Mississippi River Commission in 1942

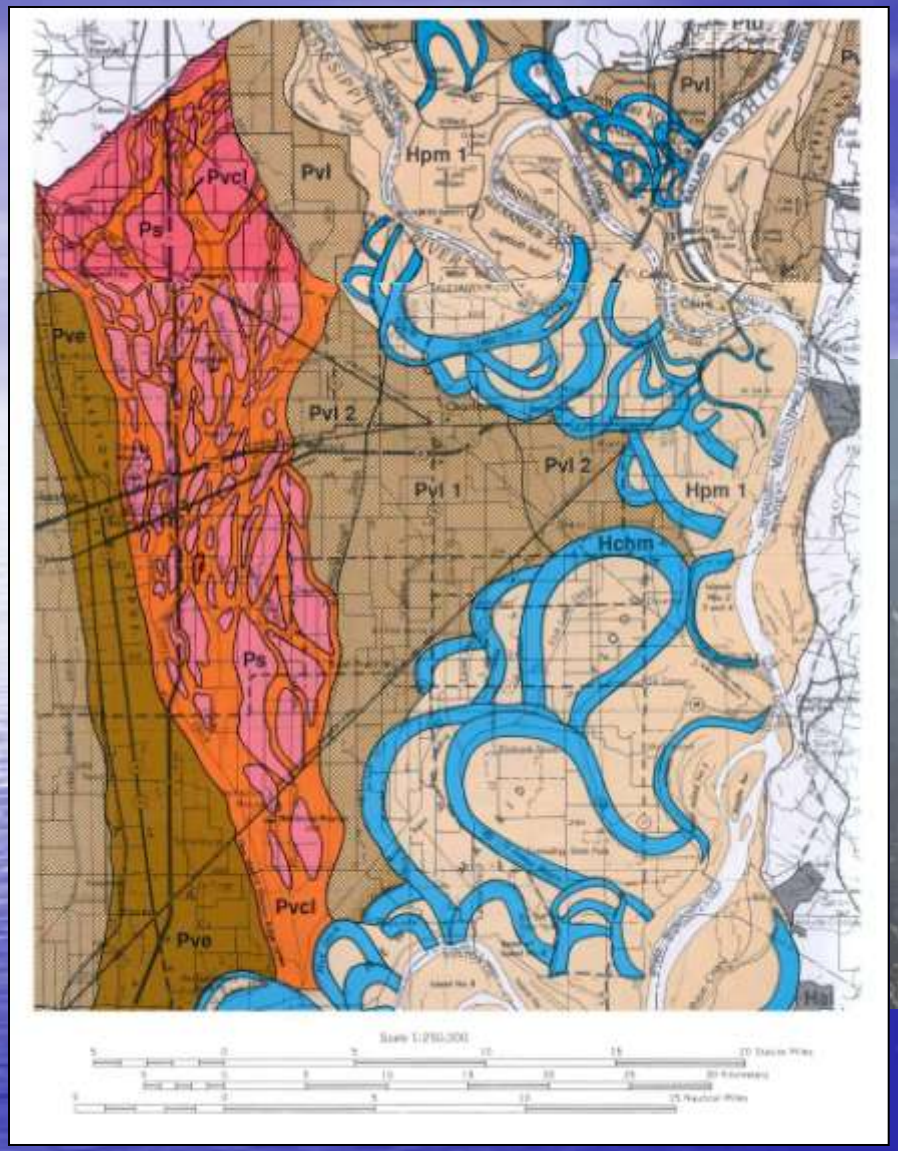
- The MR&T employs 2,200 miles of **levees and floodwalls** below Cape Girardeau, which average 30 ft high
- In 1952 Prof. Fisk told the Corps of Engineers that under natural conditions the Mississippi River would divert itself down the Atchafalaya River, sometime by 1973



MR&T Design Flood

- The **Project Flood** was developed in 1956. It combines Jan 1937, Jan 1950, and Feb 1938 storms over the Ohio and Mississippi Basins
- The peak flow of the Project Flood is **3,000,000 cfs** at Red River landing
- The MR & T was constructed by the Army Corps of Engineers between 1928-60 for $8 billion
- Numerous additions since 1960
- Major diversions at Old River, Morganza Floodway, and Bonne Carre; which siphon off 54% of the maximum flow

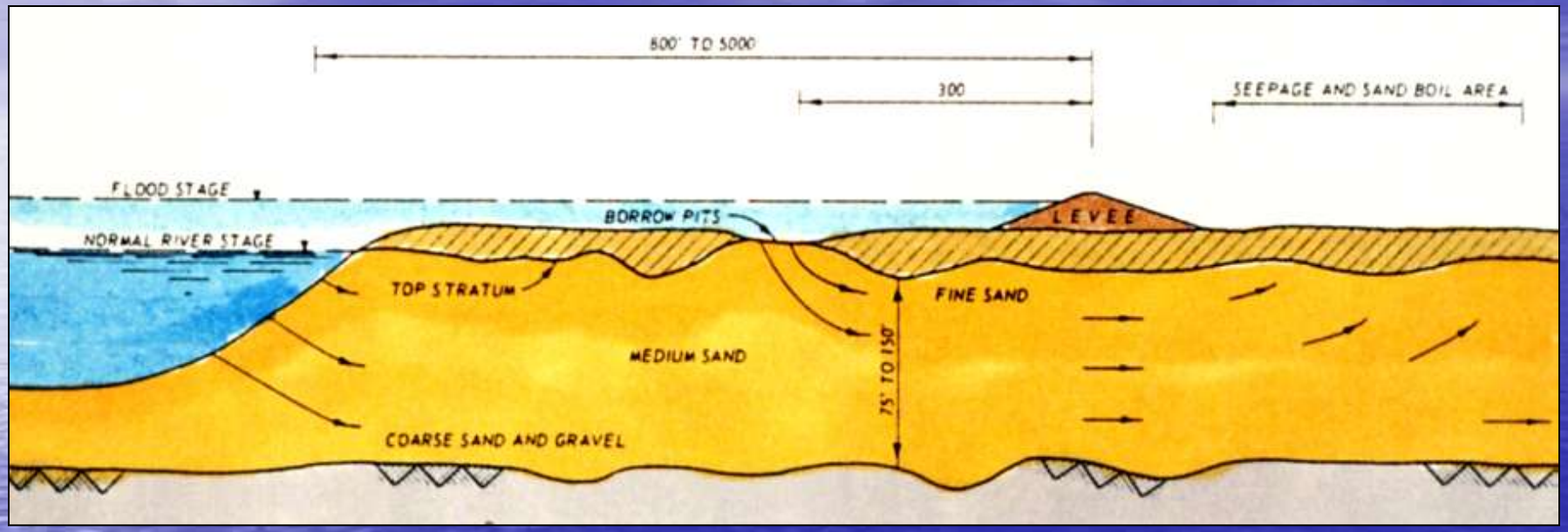
Why are levees 1000X more likely to fail than dams?



Map of Mississippi River Valley showing abandoned meanders.

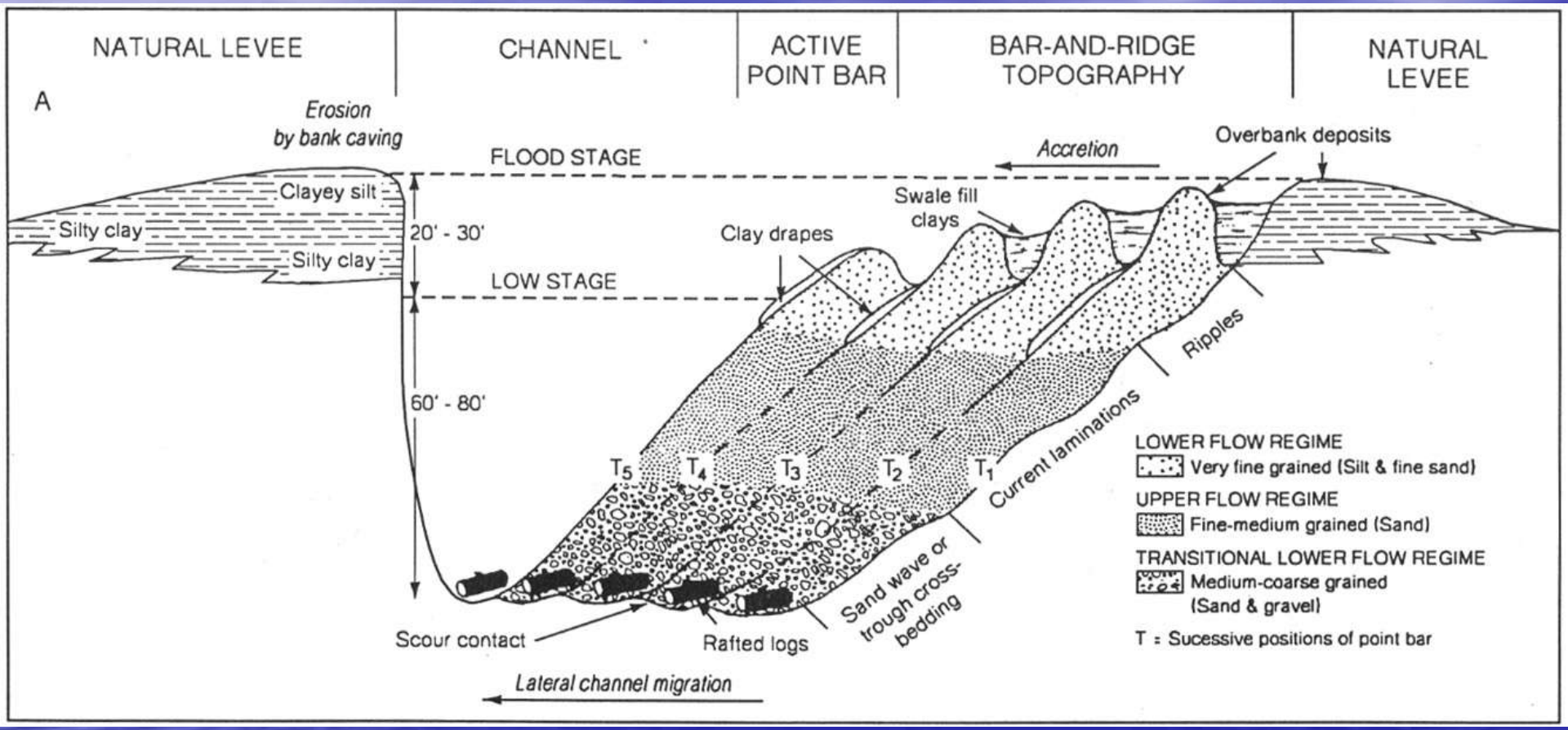
- A major shortcoming of levee is the differing foundation conditions upon which they are founded.

Underseepage problematic in permeable point bar sands



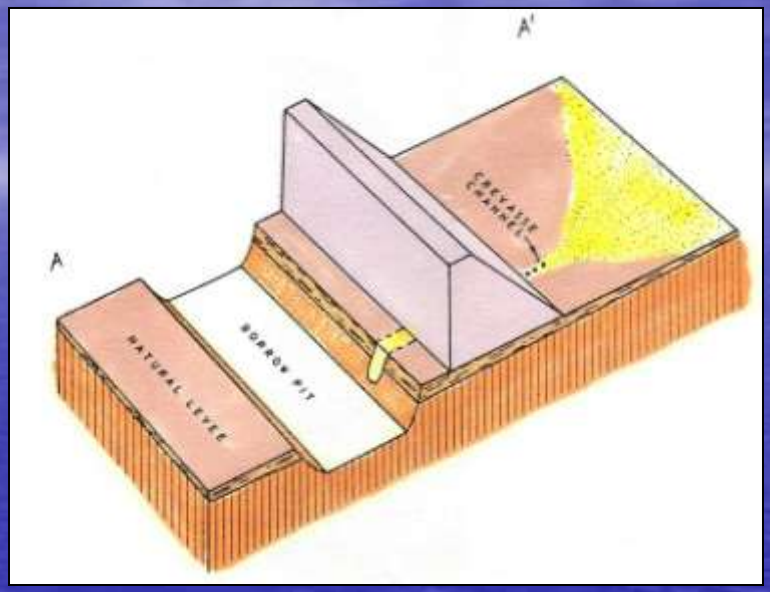
- Saturated pervious foundations respond quickly to increased hydraulic pressure, leading to development of sand boils.
- Site geology and flood duration two most important factors.

Danger of horizontal correlations



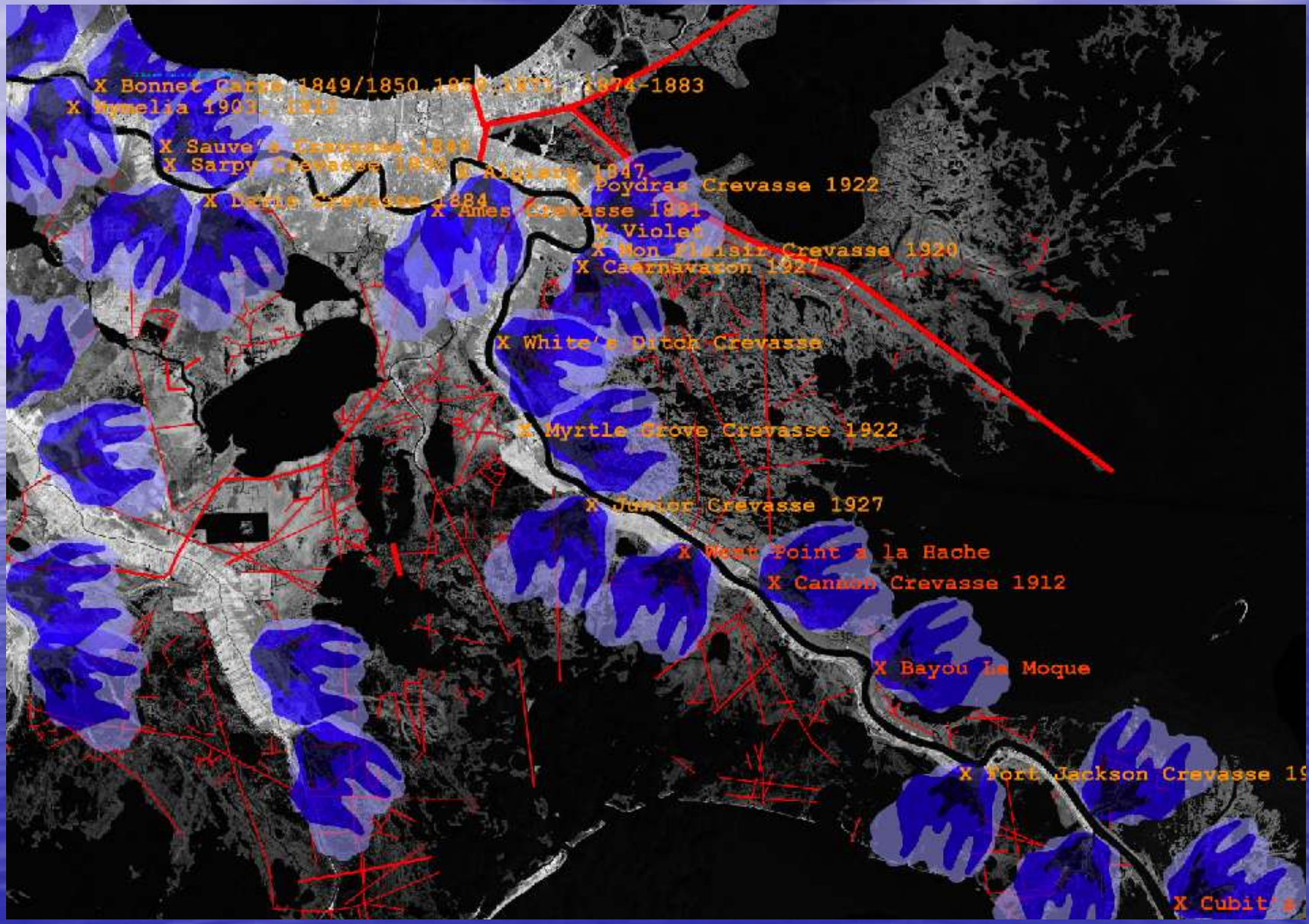
- **Inclined character of point bar deposits in a sinuous channel system. Note clay drapes; and how these might easily be mis-characterized by straight line correlations between adjacent borings.**

Natural crevasses beneath levees



Crevasses lie beneath earthen levees like *ticking time bombs*, waiting to explode.

Major crevasse splays along lower Mississippi River channel (from John Day, LSU)



Levee construction techniques for the MR&T in 1930s

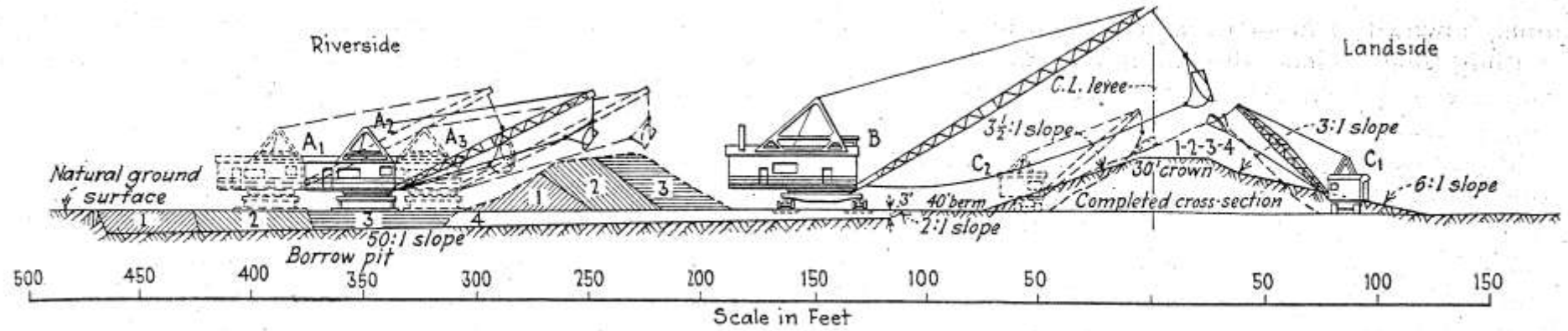


Fig. 3—Levee construction with draglines operated in series

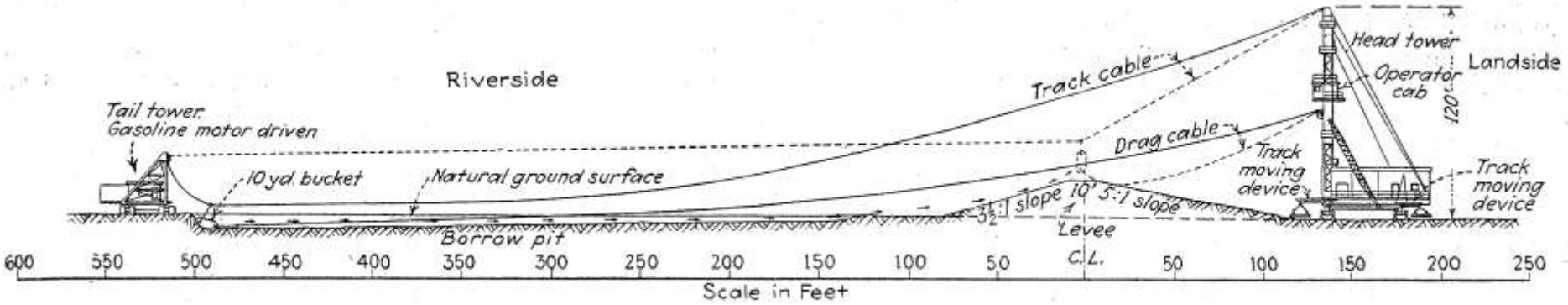


Fig. 4—Levee construction with electric tower excavator

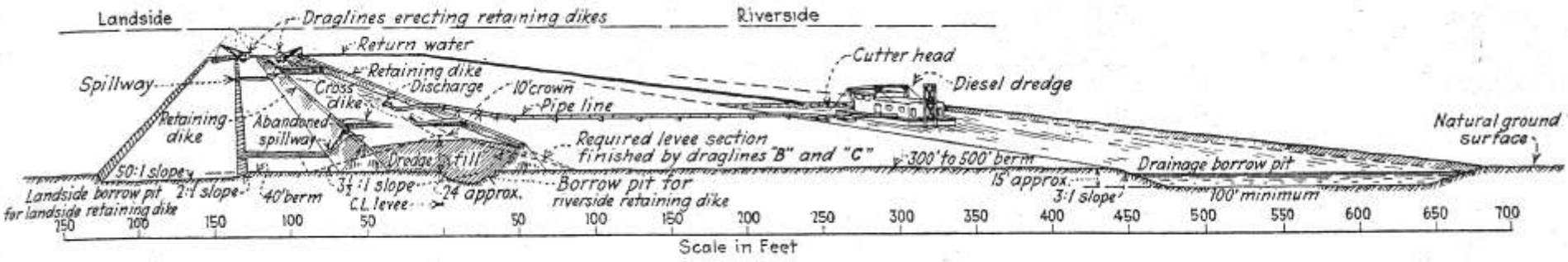
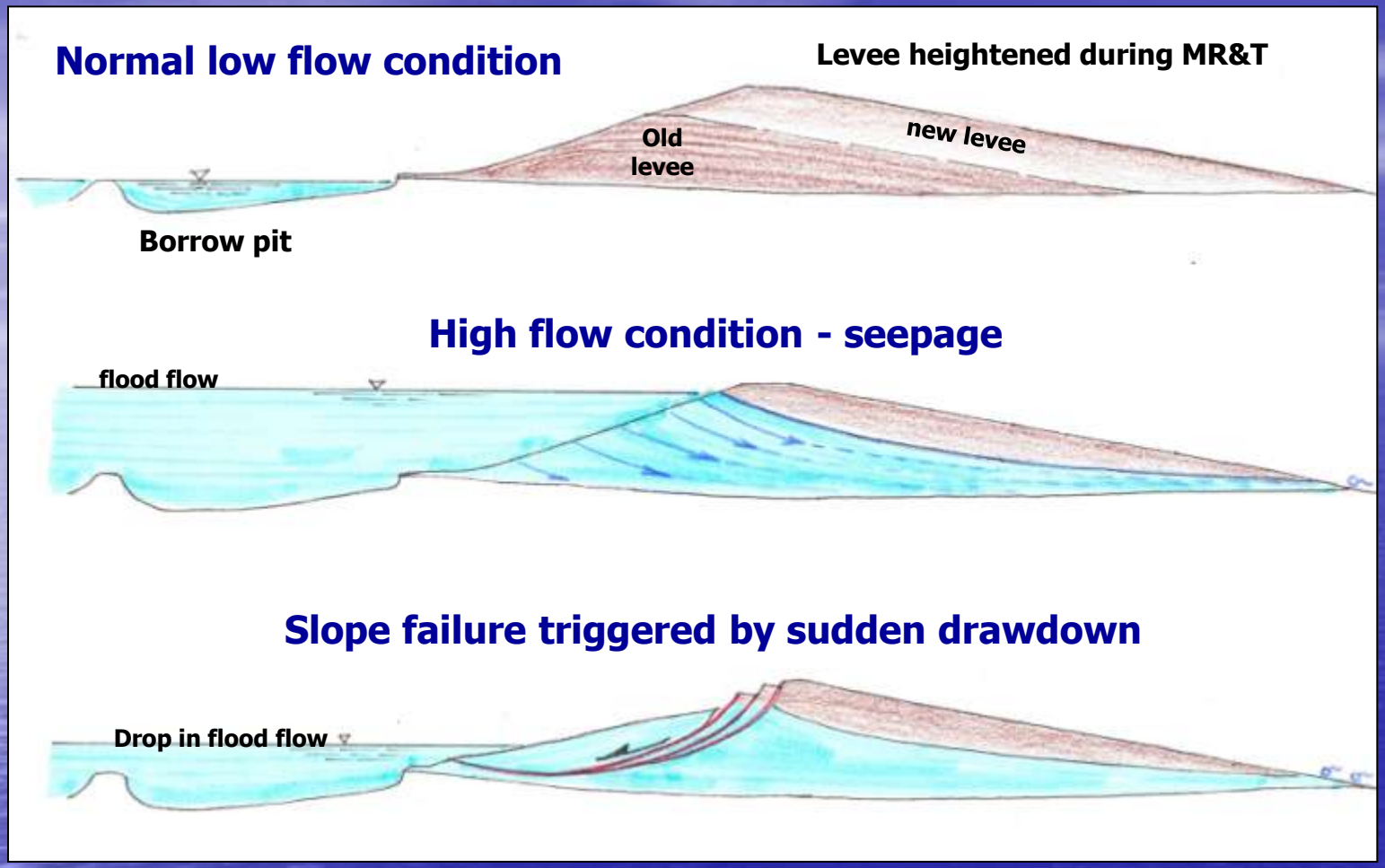
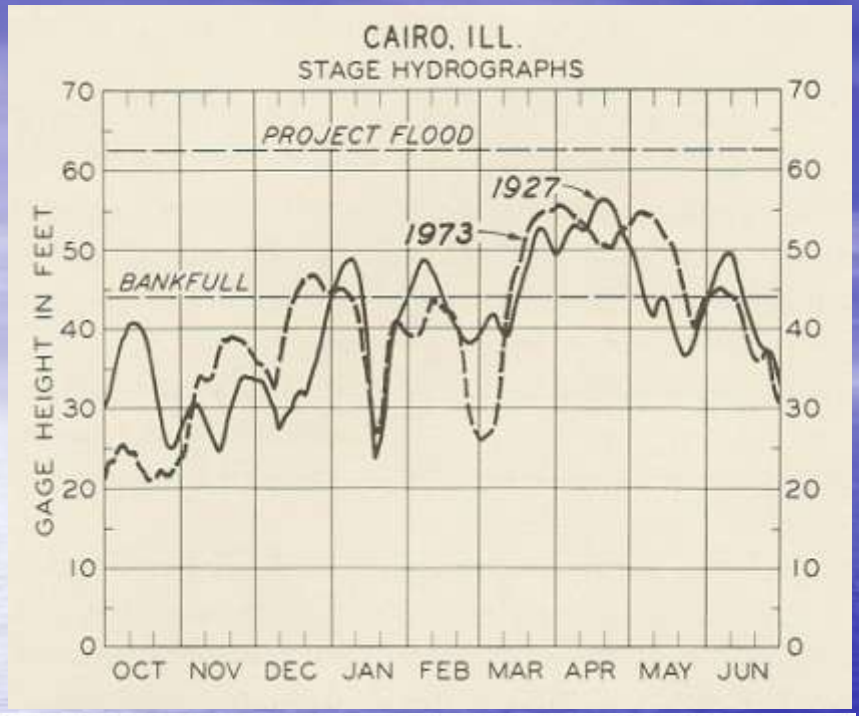


Fig. 7—Hydraulic-fill levee construction with pipe-line dredge



- ***Rapid drawdown*** **is generally the most severe loading condition for an earthen levee. The severity is a function of how many flood cycles and how rapidly the high flow cycles drop, after peaking. Rapid drawdown also impacts natural river banks in the same manner.**

The 1973 Flood – all sorts of surprises



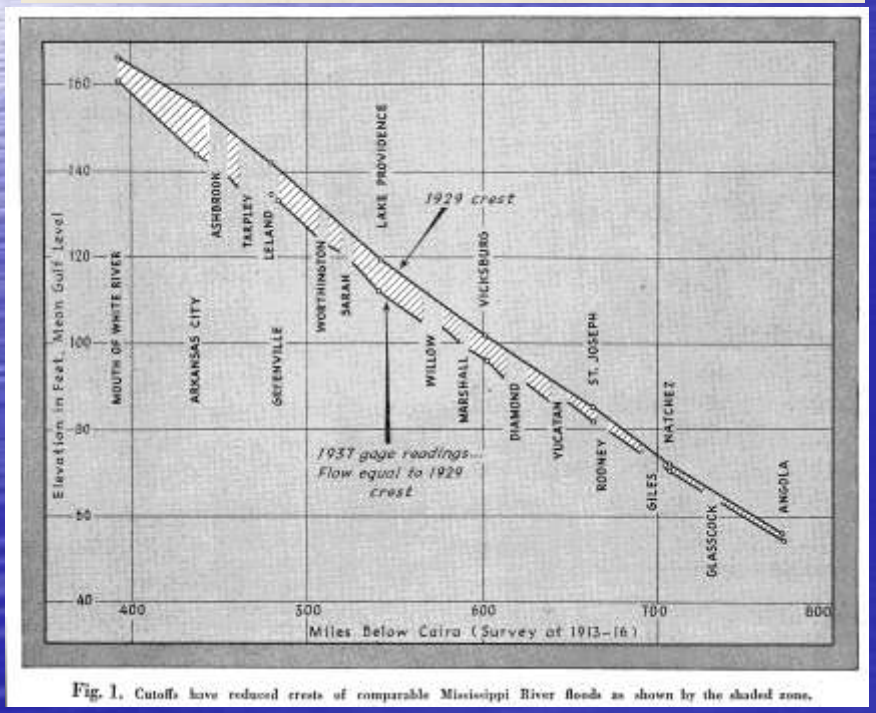
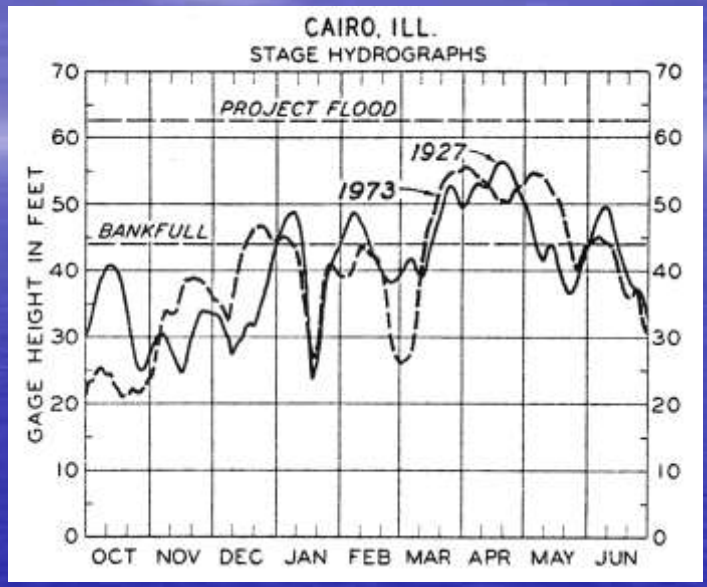


Fig. 1. Cutoffs have reduced crests of comparable Mississippi River floods as shown by the shaded zone.

Fallout from 1973 Mississippi River Flood

- MR&T only 41% complete when flood occurred
- Set a record for days-out-of-bank at 62
- Damages of $183,756,000 to the MR&T system; $1 billion overall
- Flow levels at Cairo similar to 1927, but much higher downstream
- *The carrying capacity of the river had decreased*; meaning the flow of water would now be at a higher elevation
- This realization necessitated raising 800 miles of levees

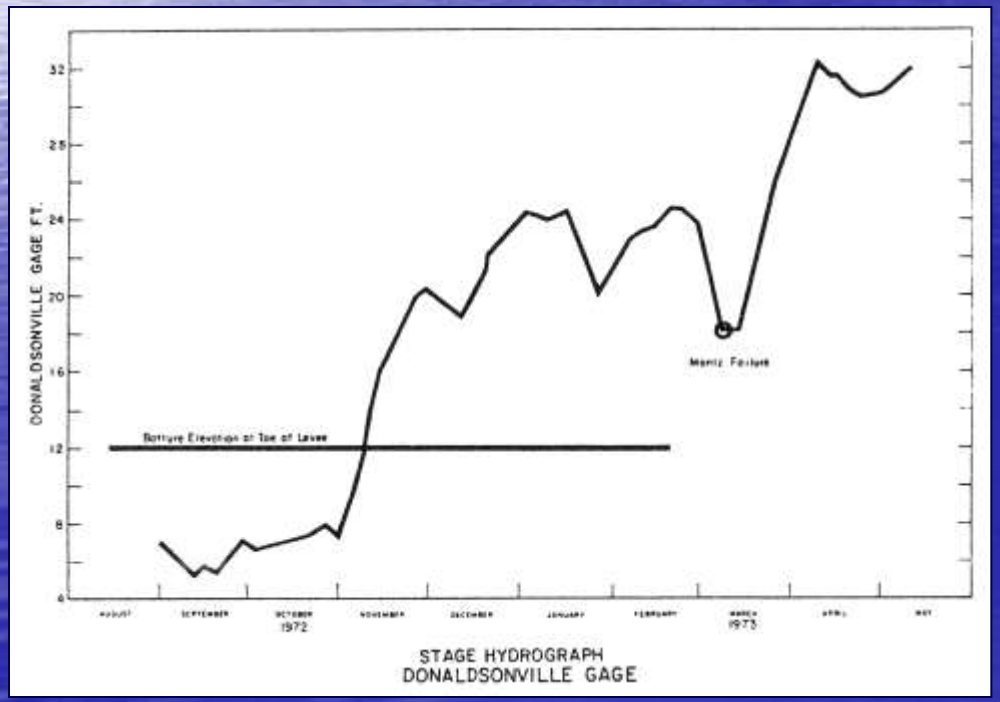
Rapid Drawdown induced failures



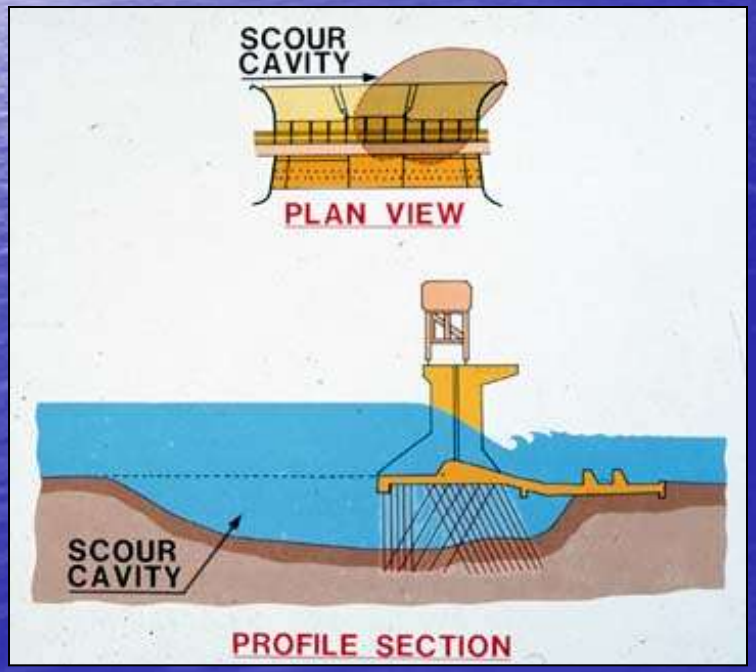
- The 1973 flood was unusual in its duration (62 to 90 days), and its multiple cycles (loop effect)
- Levees resisted peak flows, but many failed when the river dropped precipitously, after its initial early season peak, in January, February, and April

Bank Failures most sensitive to drawdown cycles

- 1973 flow hydrograph for Donaldsonville. River flowed between 20 and 25 ft for two months during the 1973 flood, then dropped 7 feet in 9 days, creating a severe *rapid drawdown* condition.



STAGE HYDROGRAPH
DONALDSONVILLE GAGE



Near Disaster at the Old River Control Structure

- During the '73 flood a large ***back-eddy scour hole*** developed on the up and downstream sides of the left abutment of the Low-Sill Diversion Structure

- Without the battered steel piles a new Mississippi River channel would have been carved down the Atchafalaya River to the Gulf !

Aftermath of the '73 Flood

- **Siltation** of the lower Mississippi and at the Passes was without precedent, because of double crests and loss of channel efficiency
- Near loss of the Old River Control Structure
- Underseepage beneath levees
- Bank failures along lower reaches of the river
- Channel deterioration and flood cycles rendered stage-discharge relationships invalid
- 800 miles of levees along lower Mississippi had to be raised 3 to 6 ft

Old River Control Structure Complex was completely rebuilt following the '73 flood

Why are the river's stage-discharge relationships on the rise ?

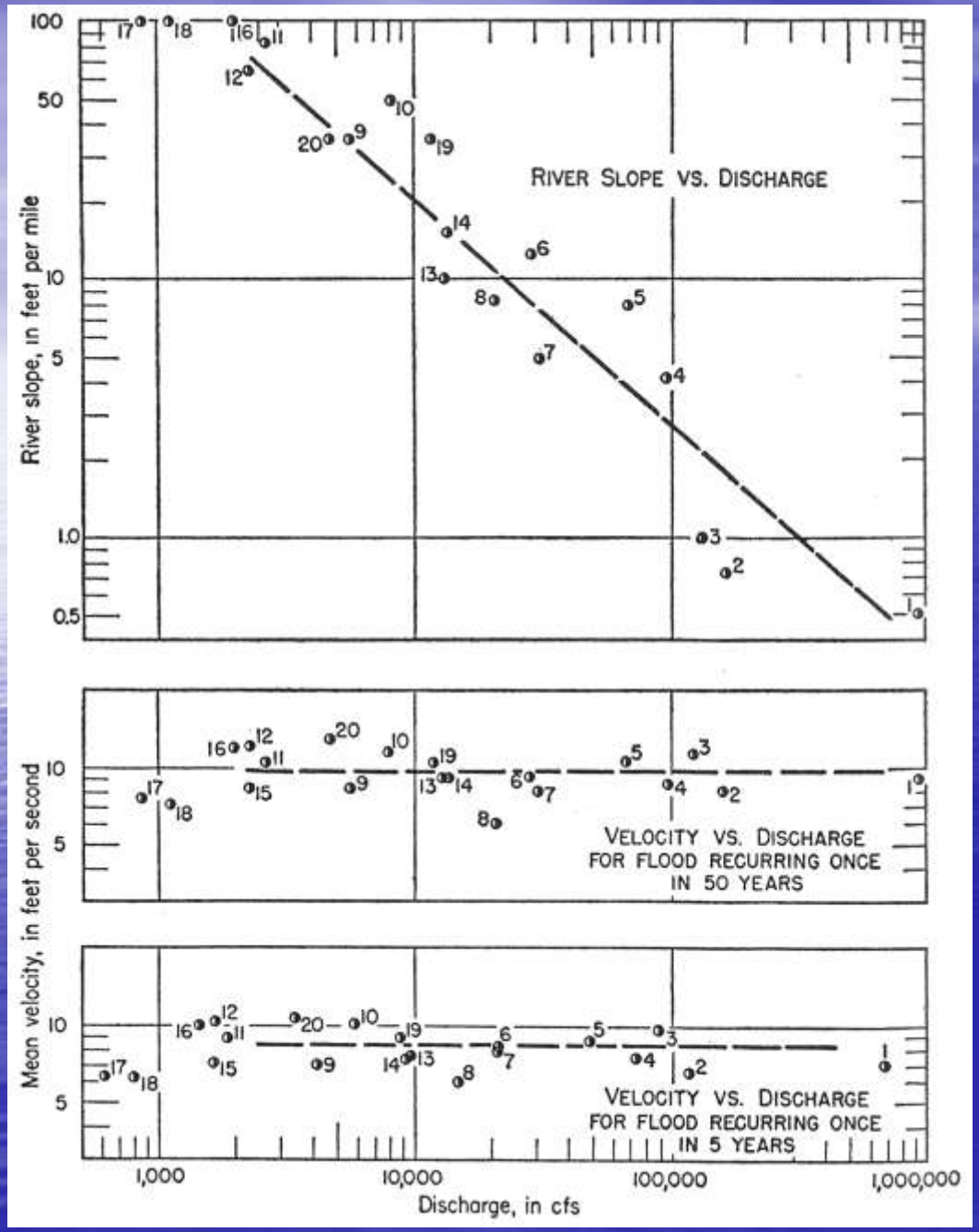
1933 THE MILITARY ENGINEER

Experiments with Movable Bed River Models

HERBERT D. VOGEL
First Lieutenant, Corps of Engineers; Director, U. S. Waterways Experiment Station

Examining transient bed effects at constant flow values

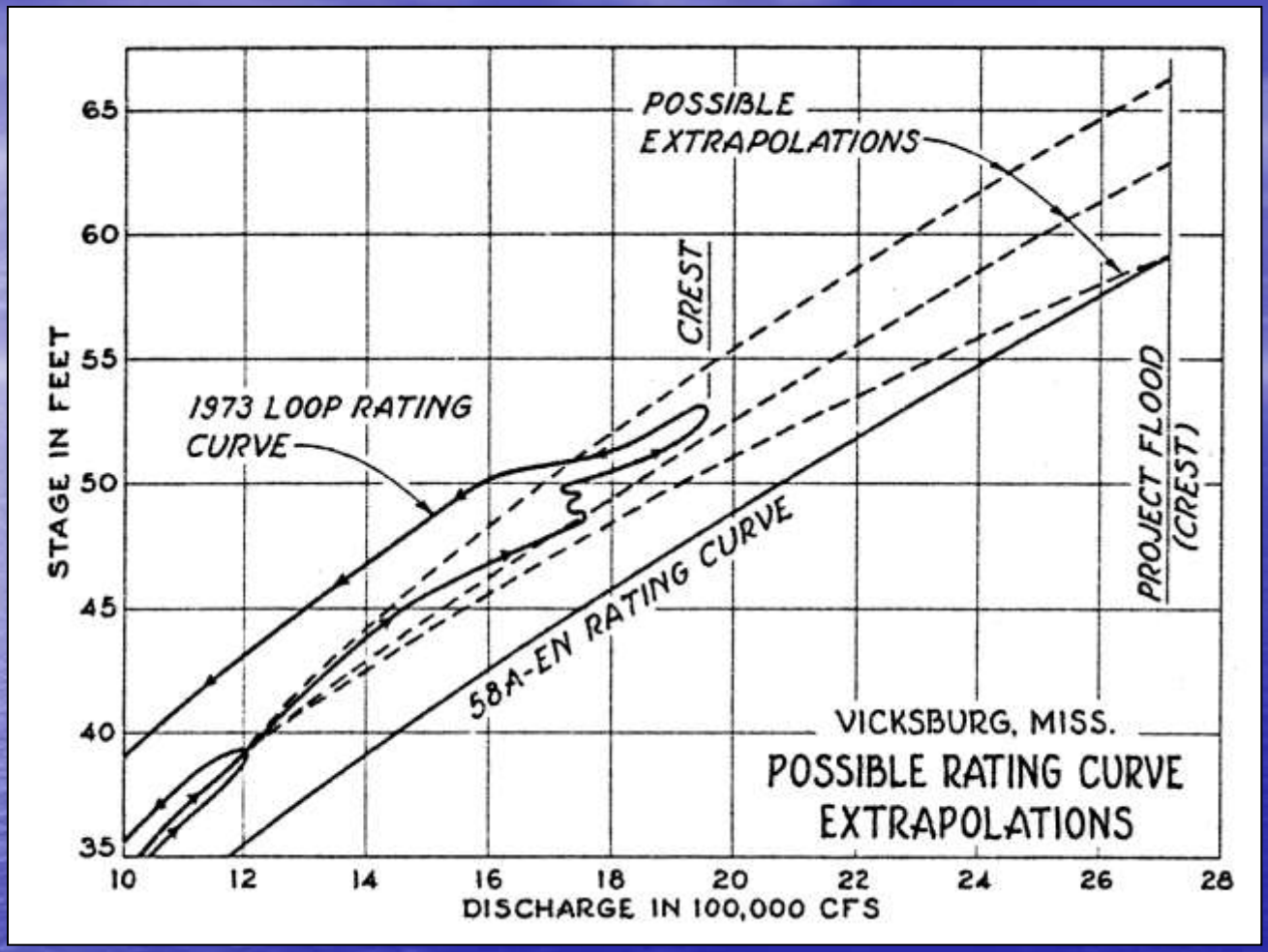
Natural sand bed channel (lower left); dredged channel (upper right); and impact of structural dikes (lower right)



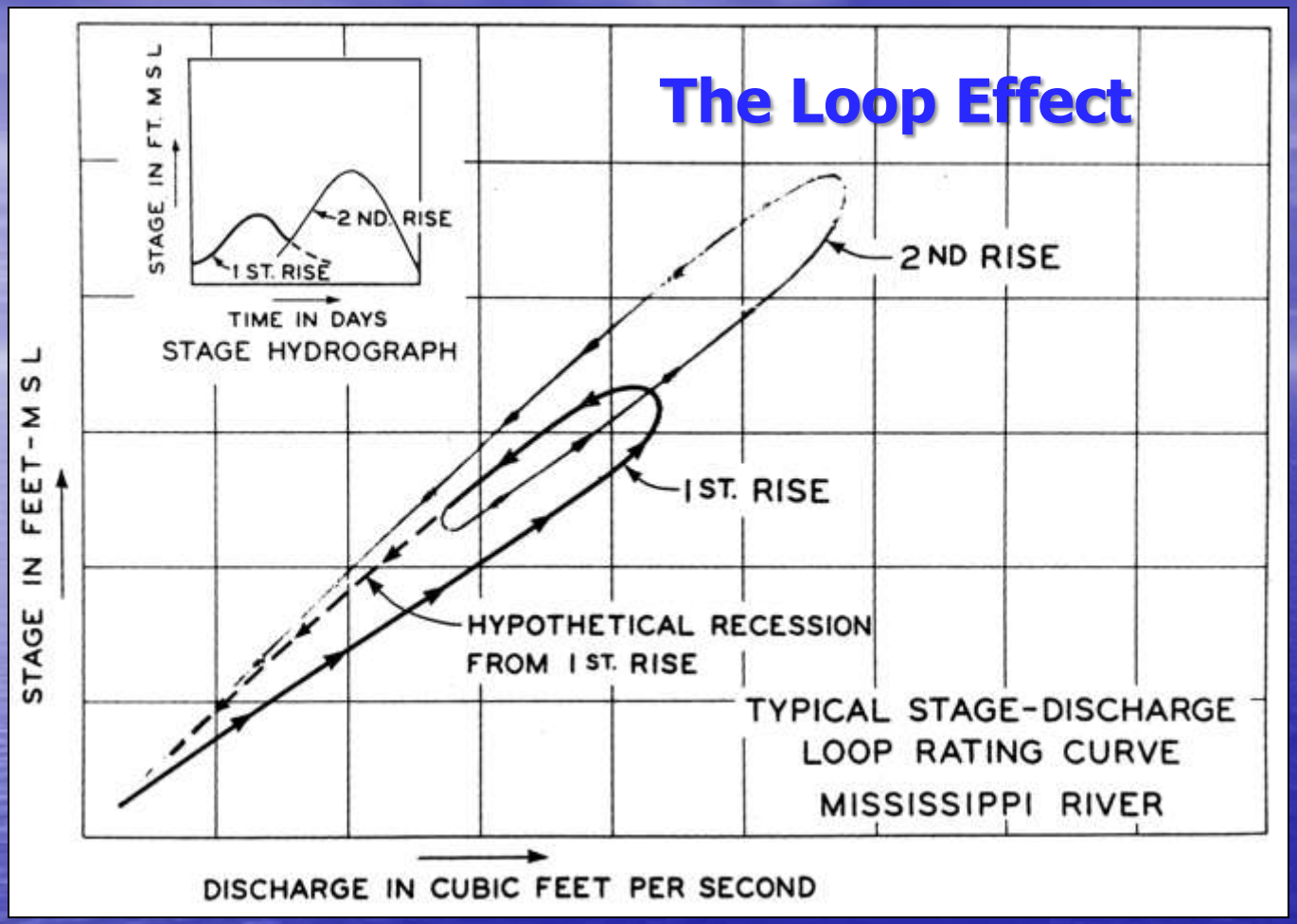
Luna B. Leopold, Ph.D., P.E.

Prophetic Revelations

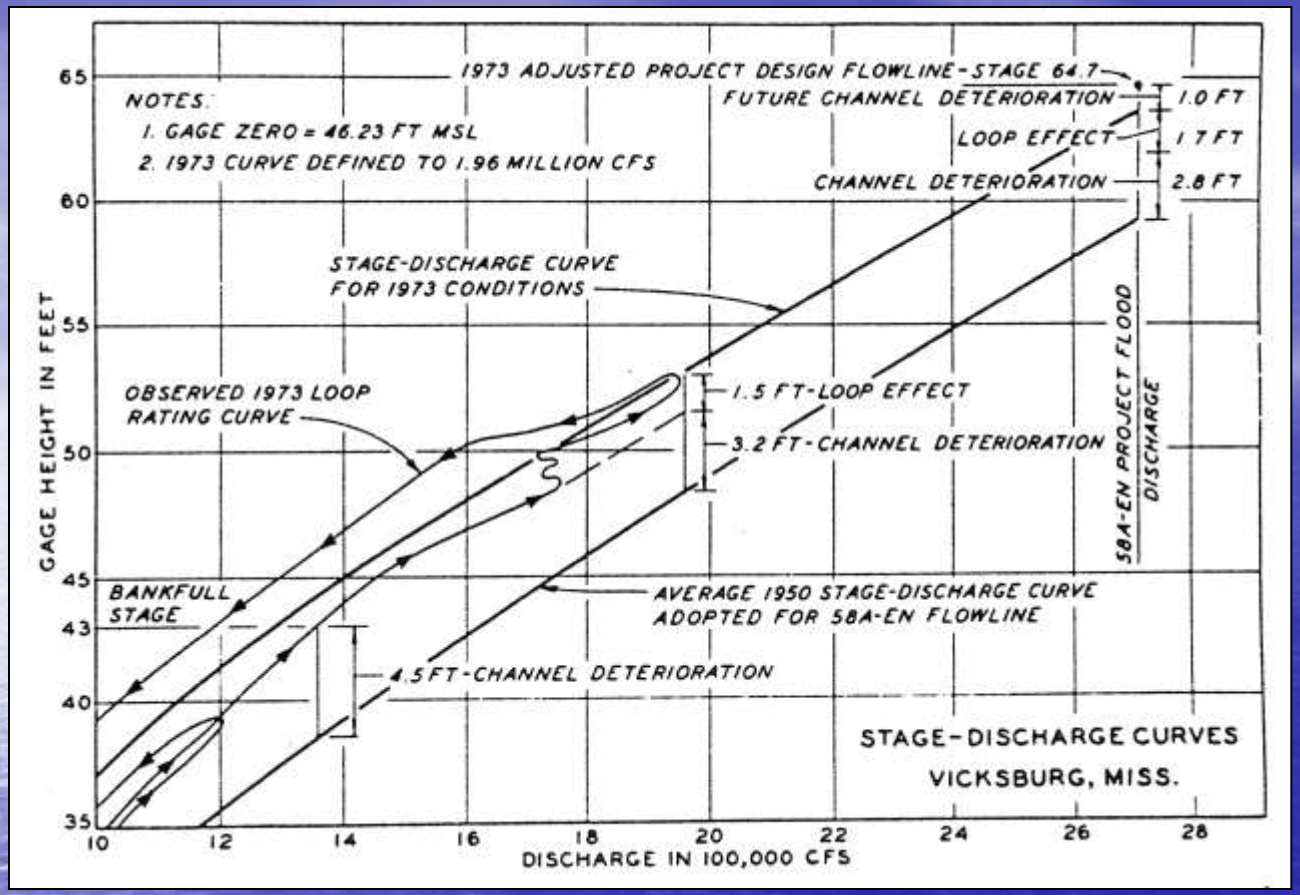
- **In the late 1950s Luna Leopold led the USGS-WRD team who discovered that *river depth* and *velocity* increase at predictable rates preceding downstream, counter to previously-held theorems.**



- **'Aging problems' with Stage-Discharge relationships.** River stages recorded in 1973 were far higher than assumed in design of the MR&T Project. At Vicksburg (shown here) the river was 8 ft higher than its design elevation.



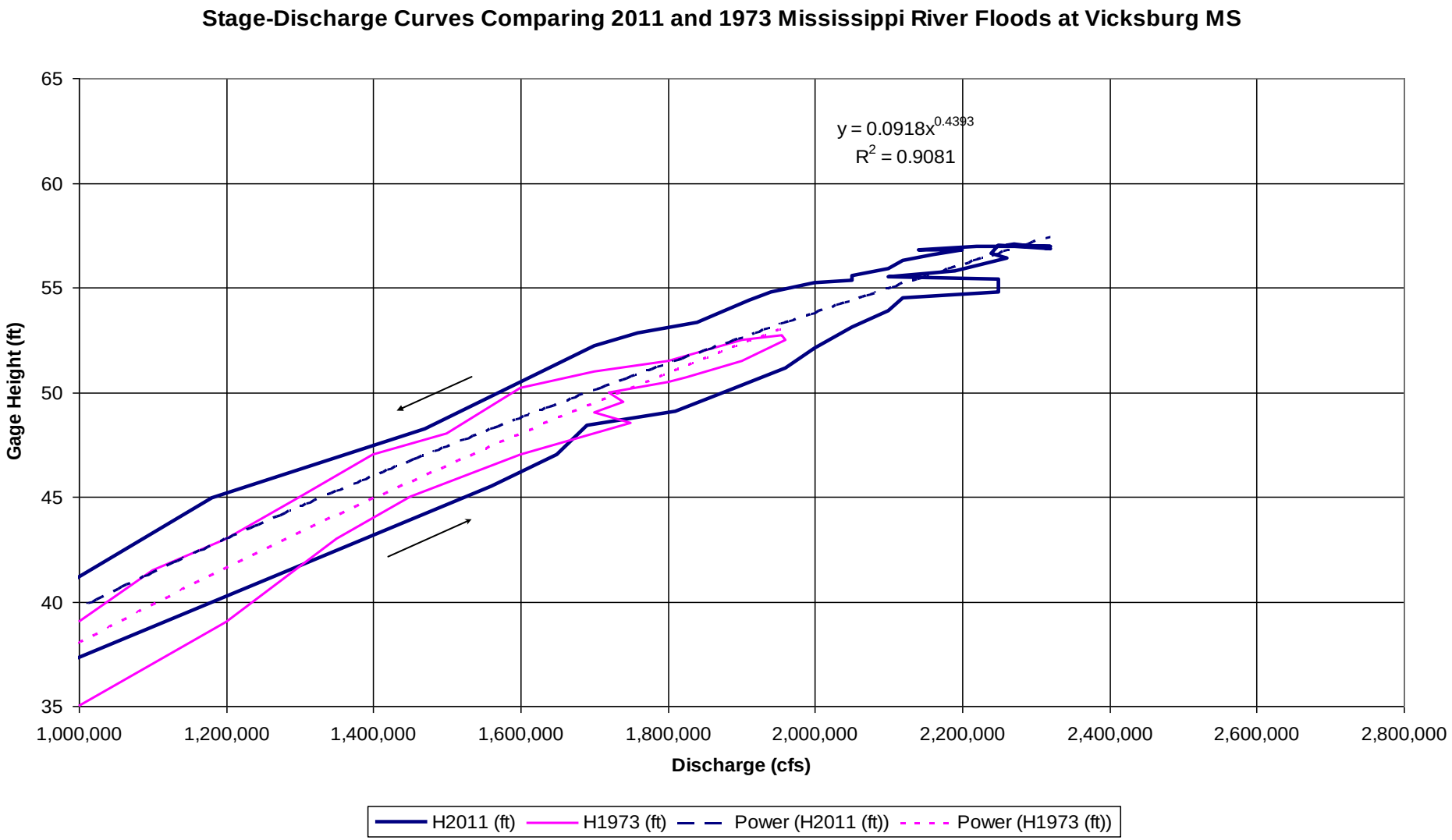
- **Stage-Discharge 'Loop Rating Curve:'** Typical increases in flow stage that accompanies successive peak flows, as observed in the 1973 Flood.



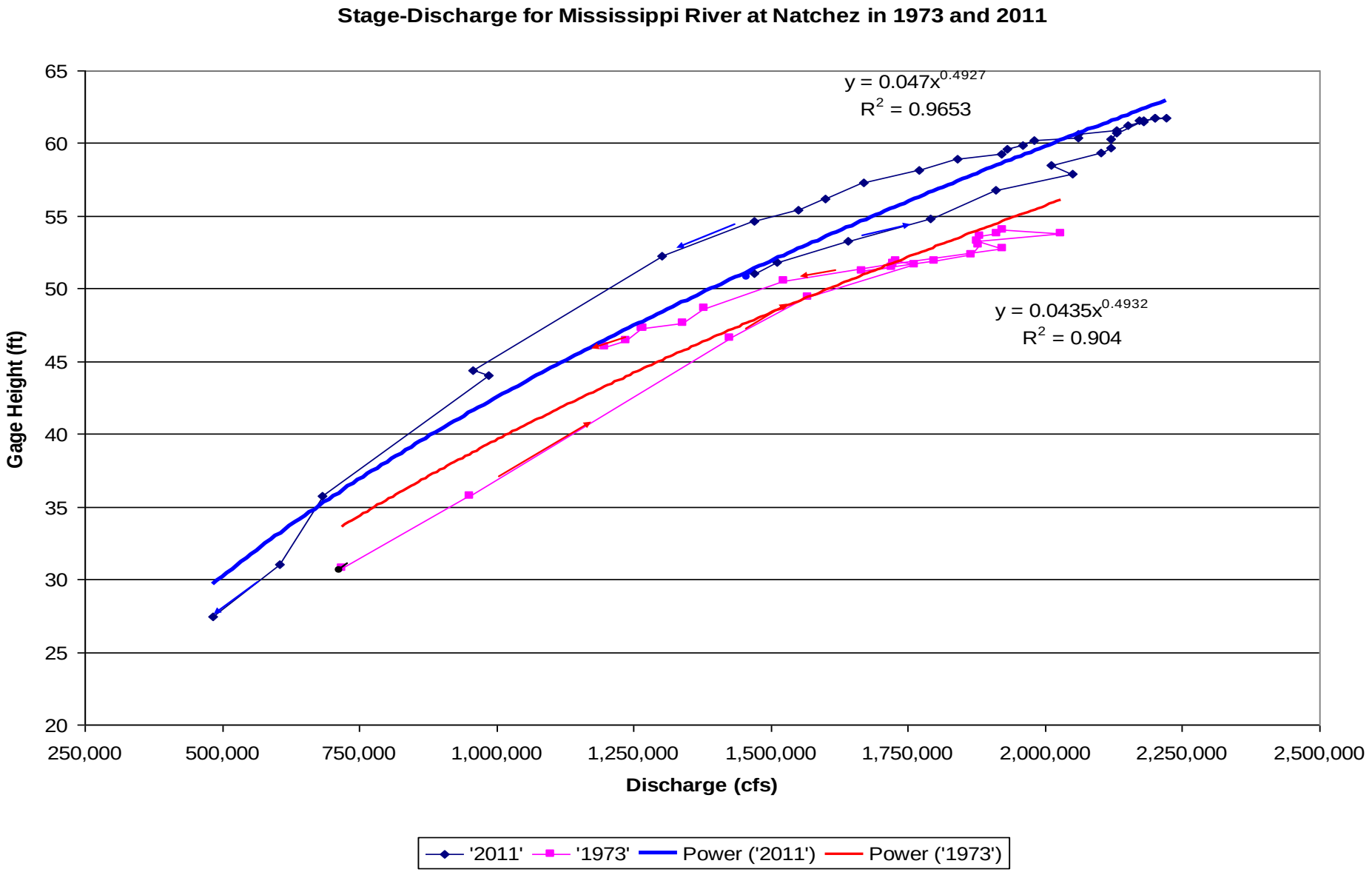
Sediment is deposited adjacent to and within most of the structural cutoffs when high flows drop rapidly. These deposits degrade channel efficiency.
Other complications: sediment starvation by reservoirs and submerged navigation training structures, such as groins.

- **Reasons for unstable stage-discharge relationships:** sand waves, bank migration, changing bed movements during successive high flow cycles during peak discharge years, like 1973, 1993, and 2011.
- Since 1950 the river has been working via entropy to *re-establish its original length*, losing some of the channel capacity gained by the streamlining carried out during the two previous decades.

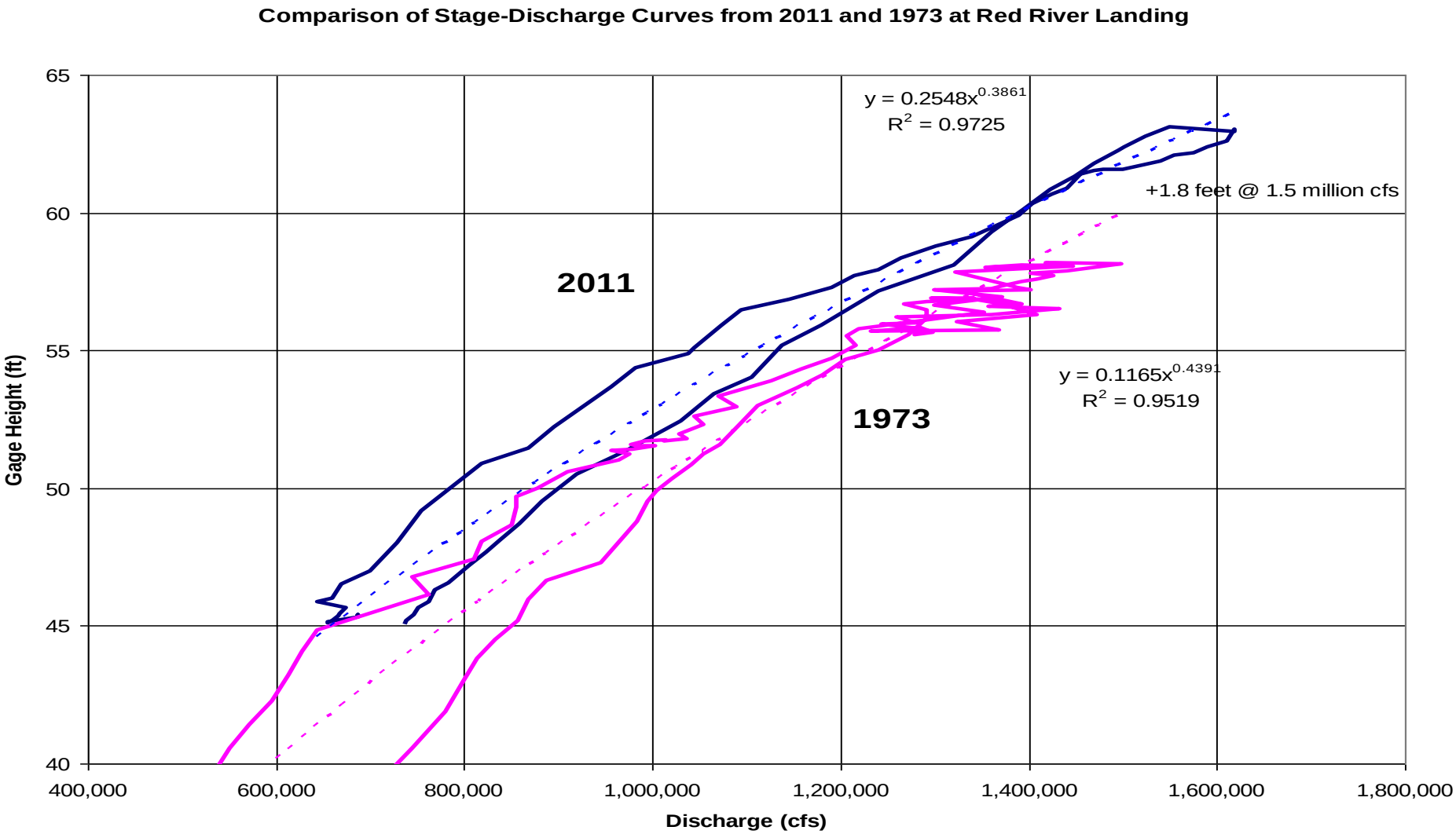
Comparison of 1973 & 2011 at Vicksburg



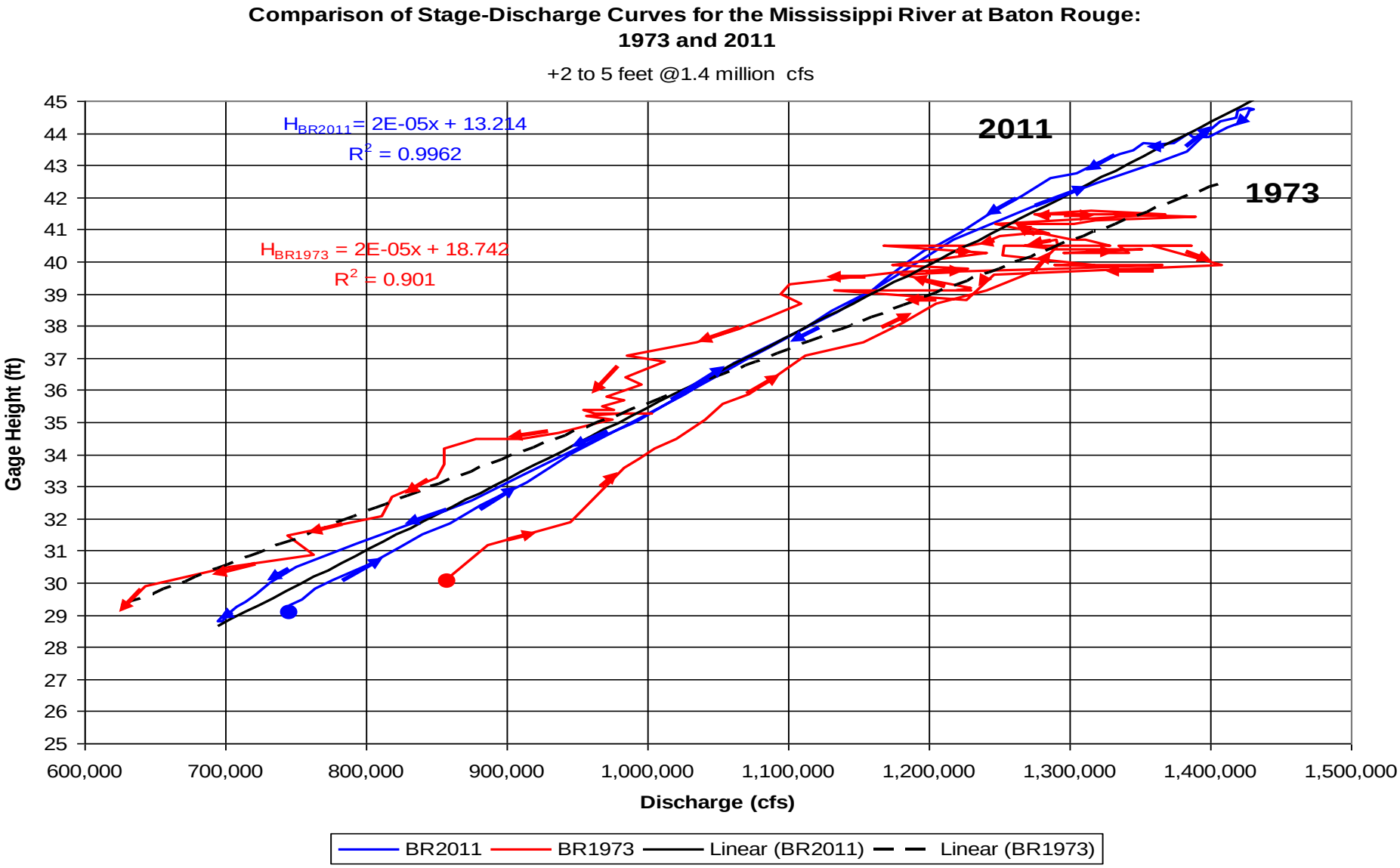
Comparison of 1973 & 2011 at Natchez



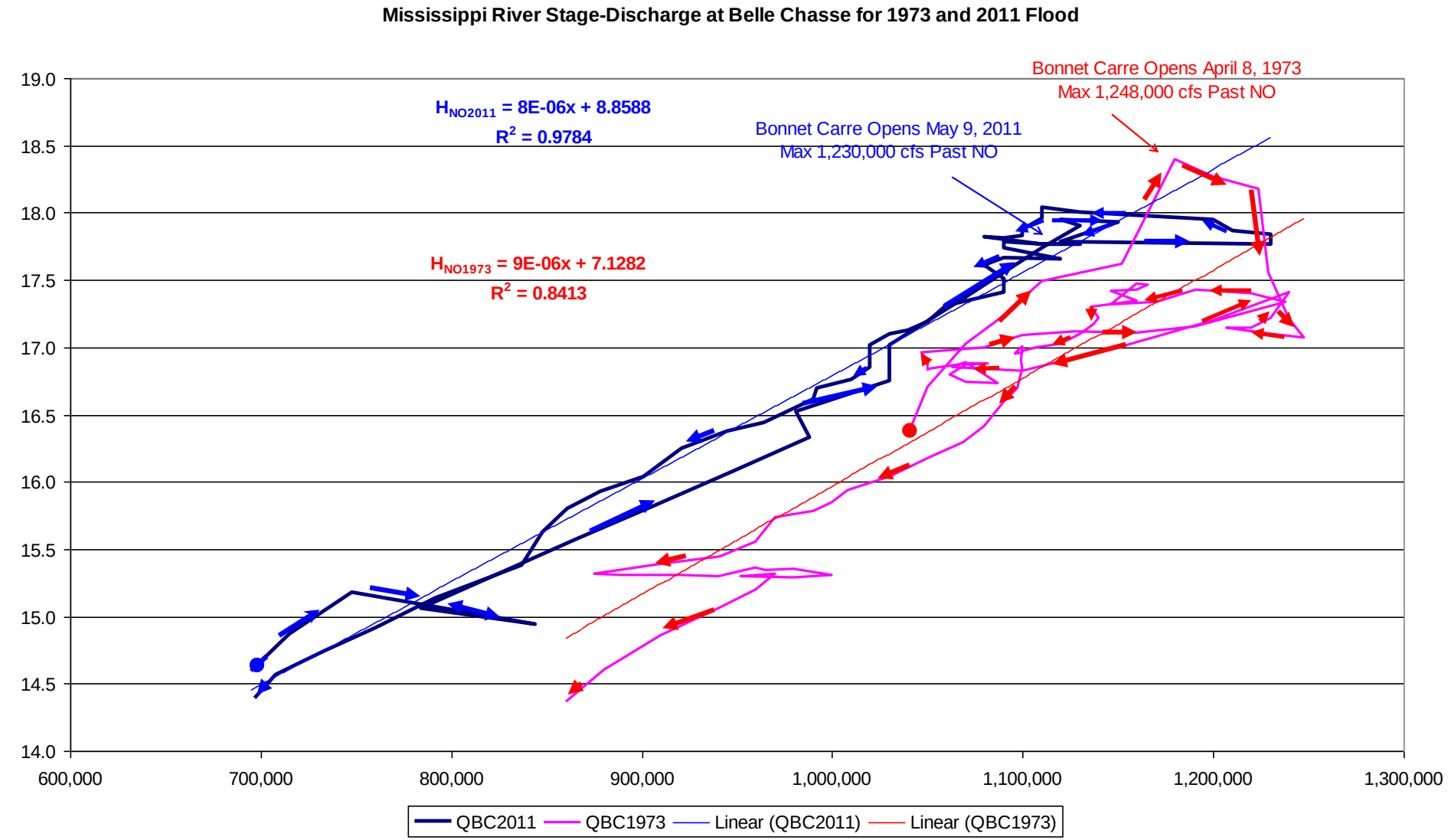
Comparison of 1973 & 2011 at Red River Landing

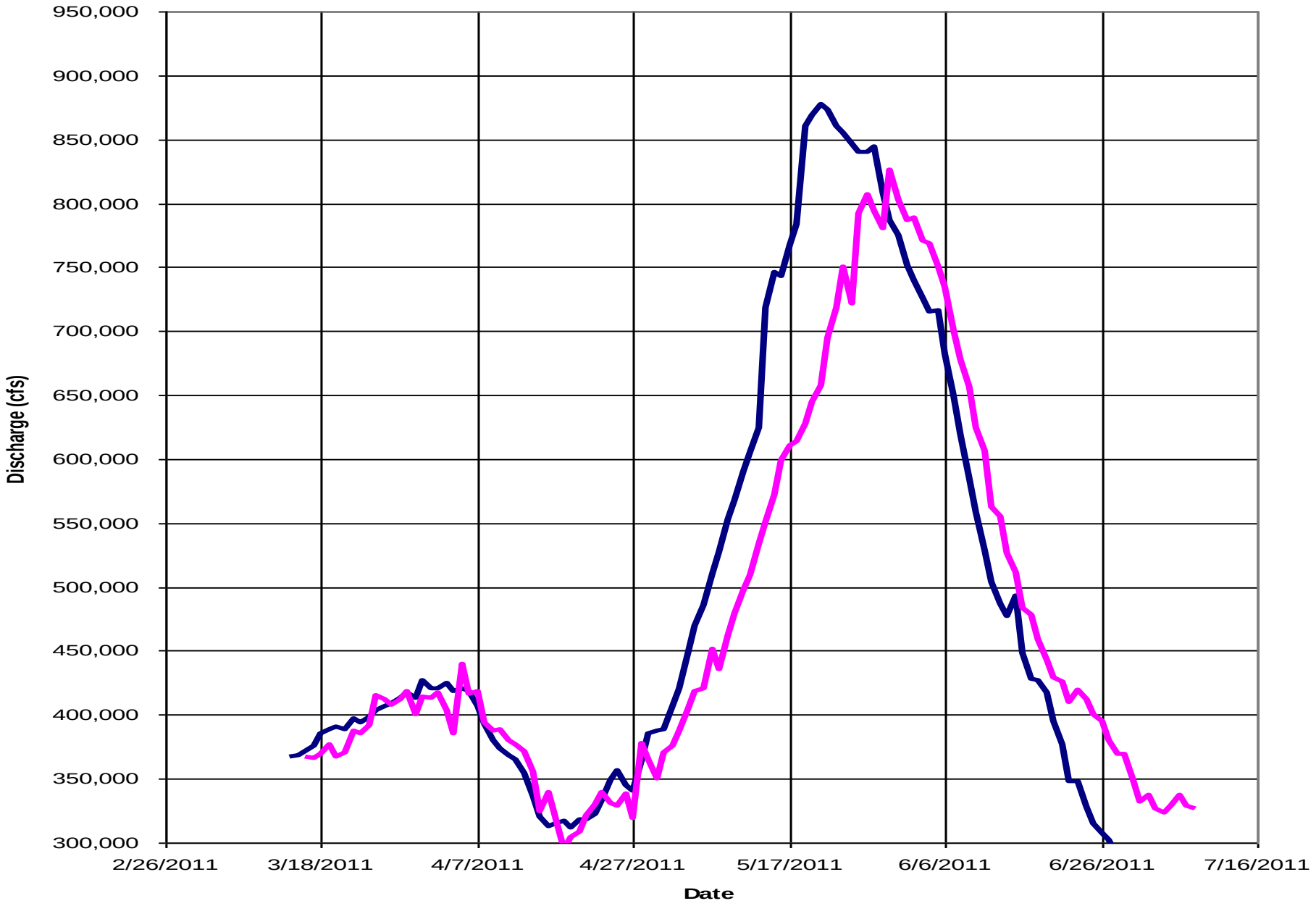


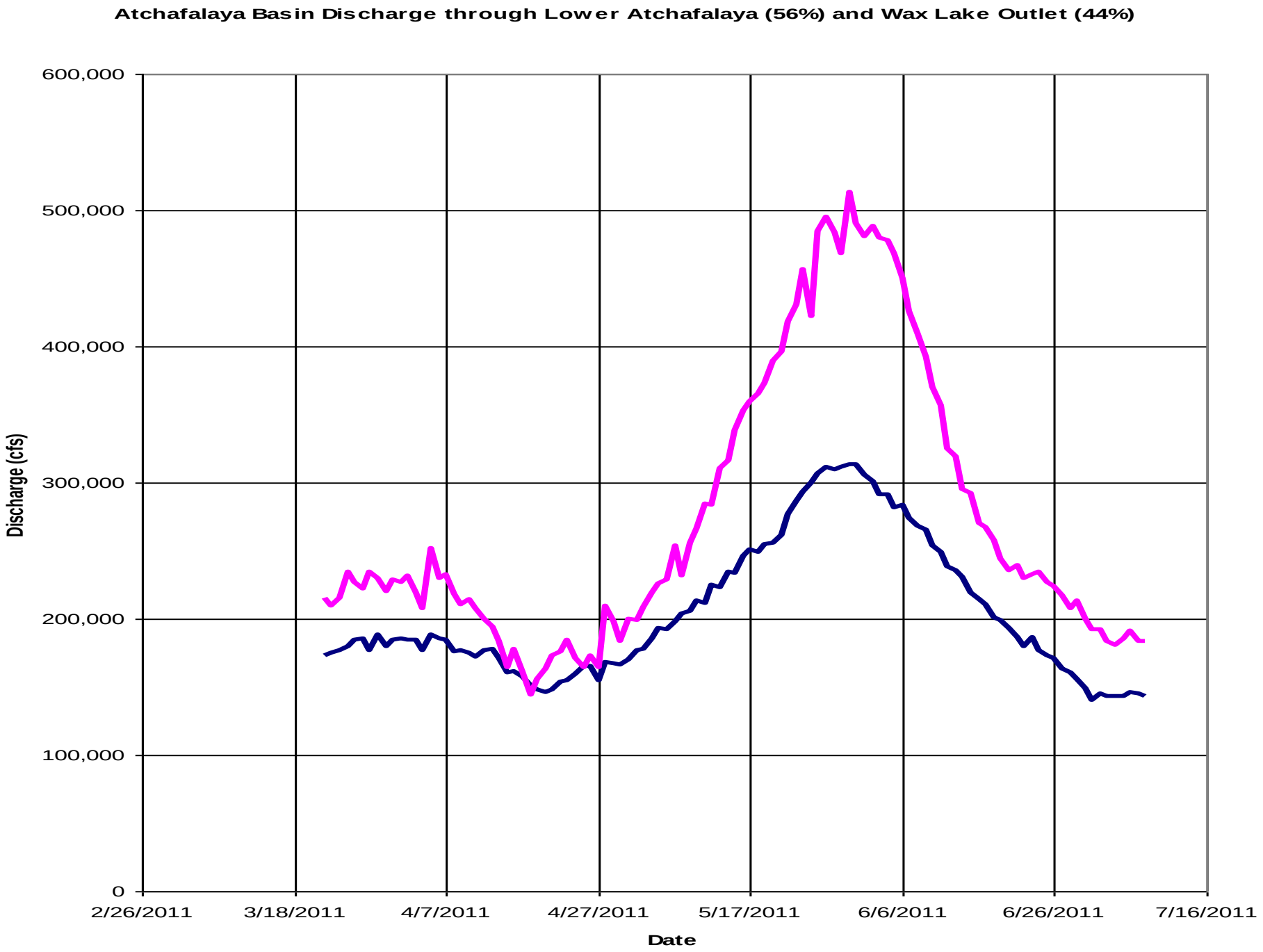
Comparison of 1973 & 2011 at Baton Rouge



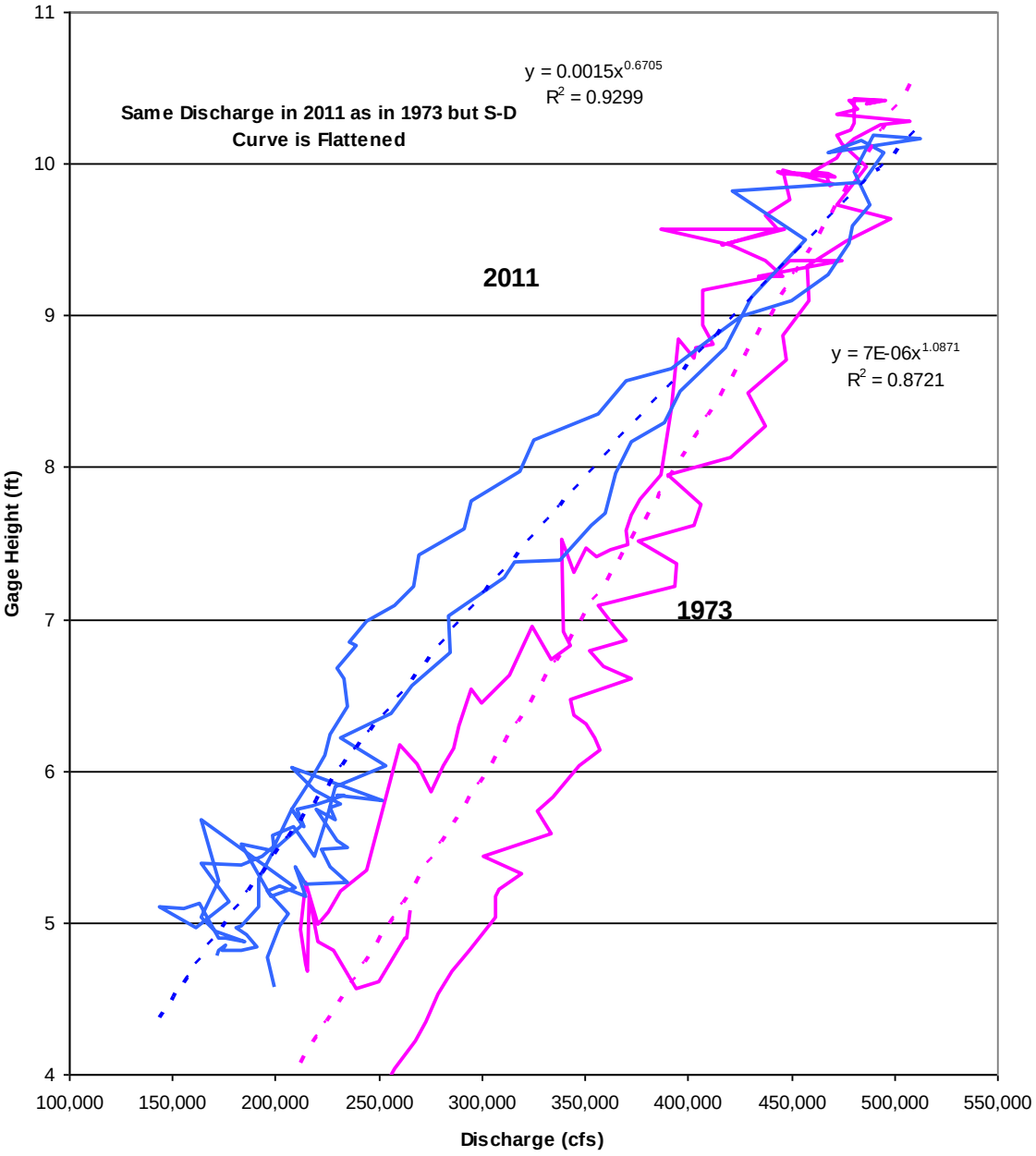
Comparison of 1973 & 2011 at Belle Chasse



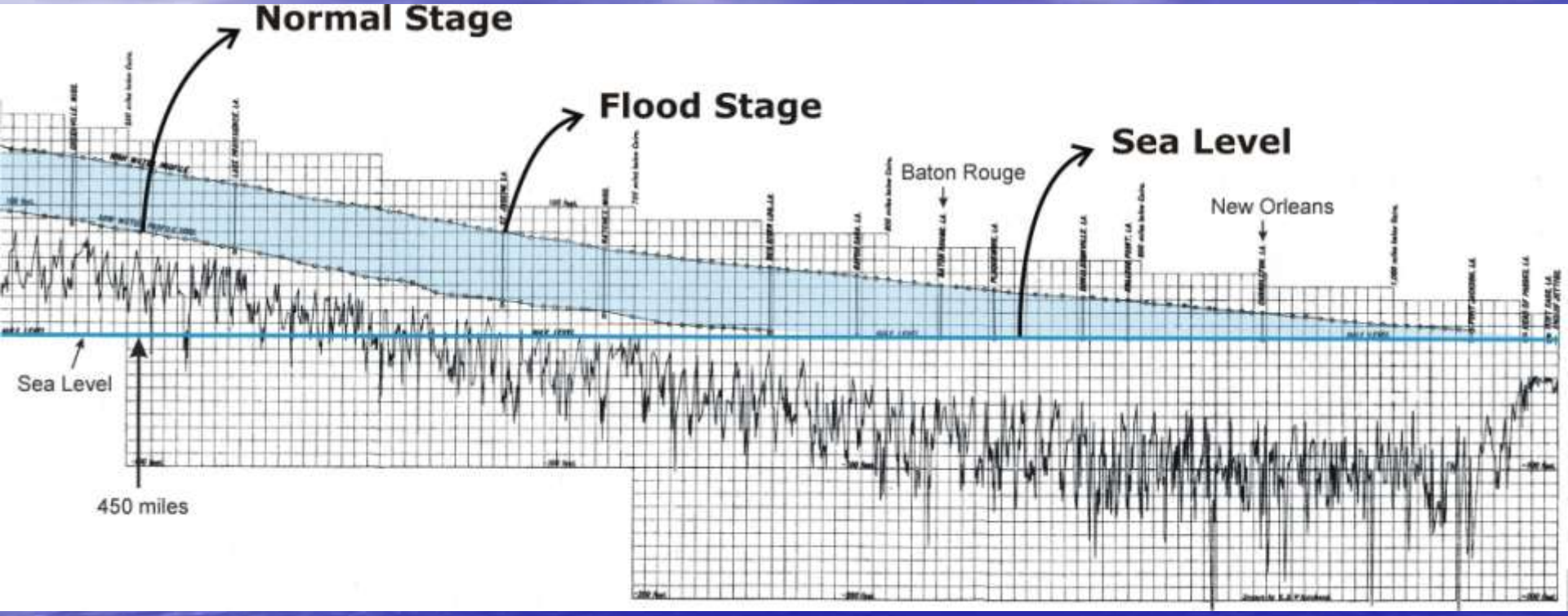

Atchafalaya Input and Output Hydrographs Showing Lag (10 days) and Diminishment of Peak Q (50,000 cfs)
950,000
900,000
850,000
800,000
750,000
700,000
650,000
600,000
550,000
500,000
450,000
400,000
350,000
300,000
Discharge (cfs)
2/26/2011
3/18/2011
4/7/2011
4/27/2011
5/17/2011
6/6/2011
6/26/2011
7/16/2011
Date


Atchafalaya Basin Discharge through Lower Atchafalaya (56%) and Wax Lake Outlet (44%)
600,000
500,000
400,000
300,000
200,000
100,000
0
Discharge (cfs)
2/26/2011
3/18/2011
4/7/2011
4/27/2011
5/17/2011
6/6/2011
6/26/2011
7/16/2011
Date

Comparison of Stage Discharge Curves on Lower Atchafalaya River at Morgan City: 1973 and 2011

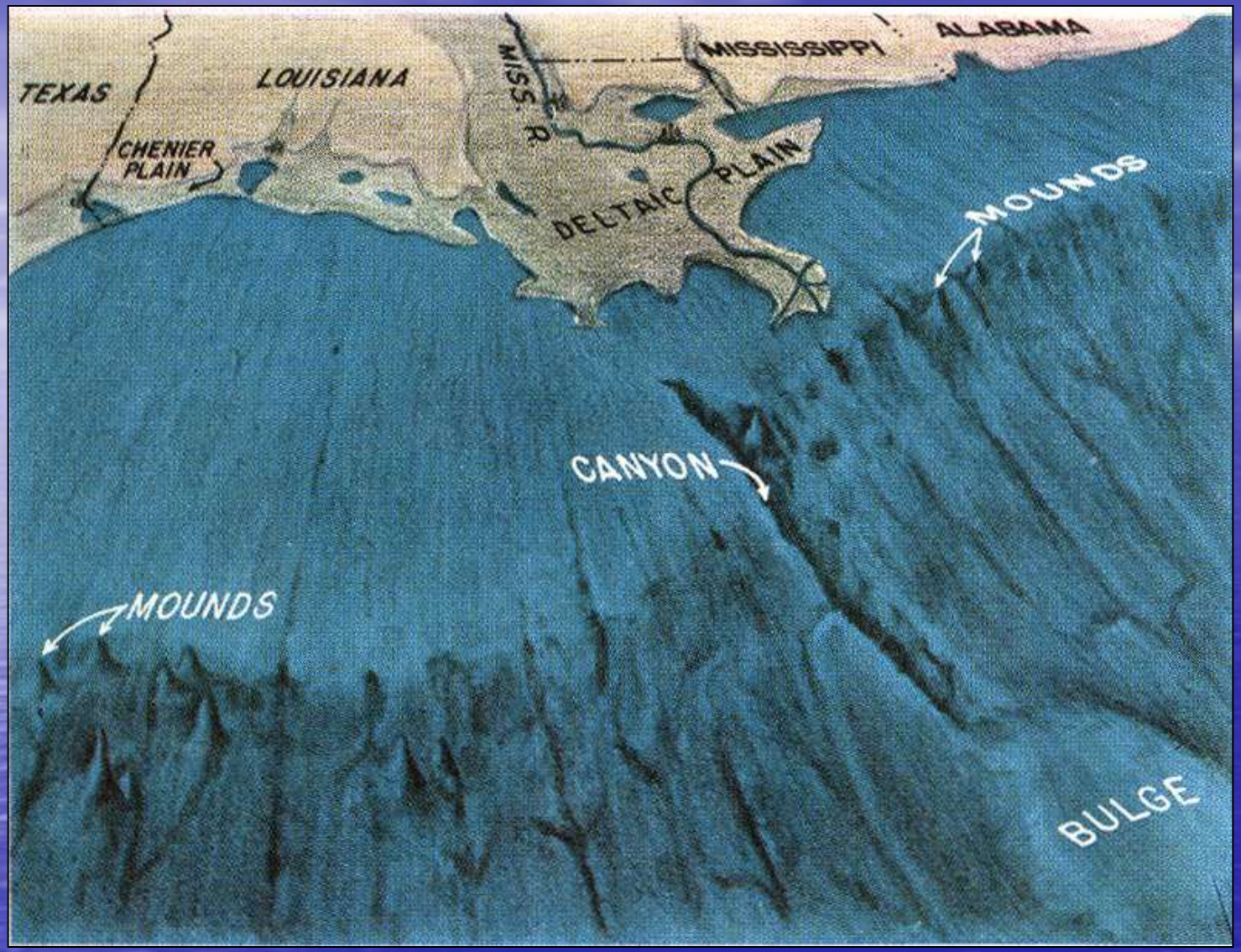


Rising Profile of the Lower Mississippi



The bed of the Mississippi River is below sea level during the last 450 miles of its course, up to Greenville, Mississippi.

The employment of dual levees, lengthening of the jetties, and the silt load of the river have combined to heighten the channel bed and lower the hydraulic grade, lifting the river's flow surface.



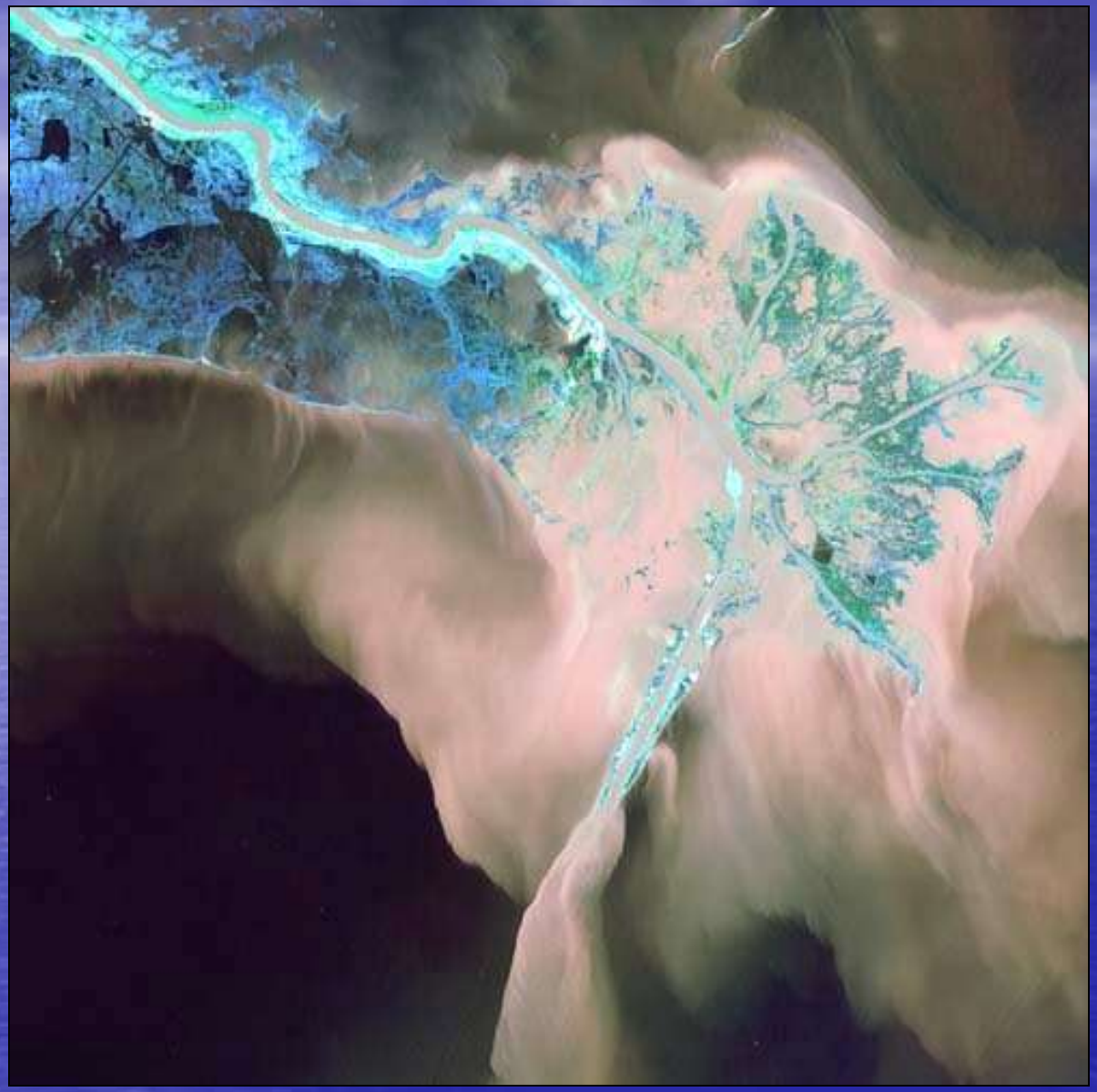
- **The high-stand mud ediface digitate (birdfoot-shaped) delta deposited by the Mississippi River is the *only delta in the world* that extends out to the edge of the Continental Shelf (image from Fisk, 1956).**

Change is coming, get ready for it…

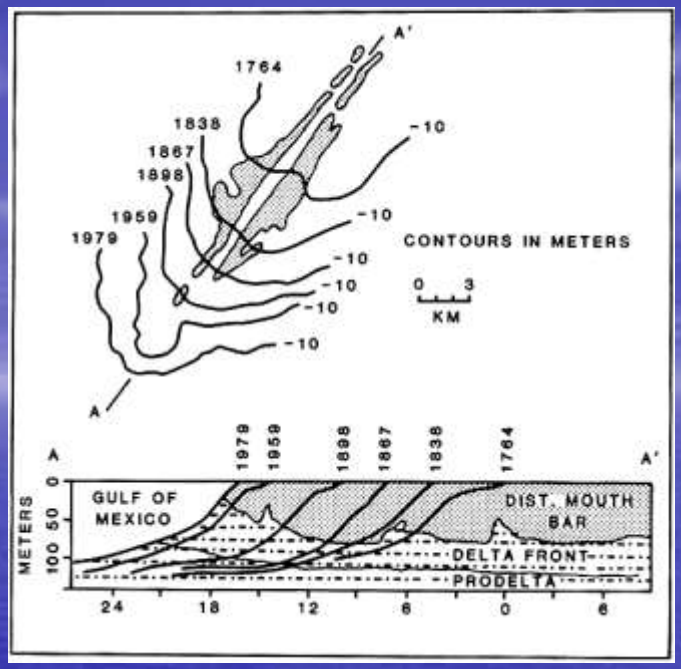
Historic land loss in the Birdsfoot Delta through 2005, shown in orange. There is very little land mass physically constraining the main stem channel, and its flow is becoming diffuse, especially during this year's flows. Less than a third of the river's flow now makes it to the main navigation outlets (from LSU Marine Sciences).

- Land loss shown in orange
- During the next large runoff event, the river will likely jump its banks somewhere above Head-of-Passes
- We'll be stuck with wherever it decides to go


Venice
Baptiste Collette
Cubit's Gap
Grand Pass
Tiger Pass
West Bay
Head of Passes
Pass A Loutre
South Pass
Southwest Pass
The east channel off Head of Passes used to convey 25% of the river's flow. That's now fallen just to 7 or 8%. Dredge spoils have been placed in Pass-a-Loutre and it has become blocked.
Two new channels are siphoning water off to the west, at Tiger Pass and Grand Pass.
The 11-mile long Bohemia Spillway and Bayou Baptiste Collette lie along the lower river's eastern bank. These four outlets are now siphoning off about 67% of the river's flow, above Southwest Pass.
NASA image (2001)



- **Flow dispersion of the lower Mississippi River. The outflow deceleration is responsible for about 20 to 30% of the siltation occurring in the lower Mississippi River channel, while the other 70 to 80% of the accumulated sediment is not explained (Barras et al., 2009).**



Since 1877 the jetties have extended the river's length by 11.3 km, lowering the hydraulic gradient, while sea level has risen 13 inches.

- **The 'depositional center' of the lower Mississippi River is moving upstream each year, increasing dredging costs. In 2010 the dredging cost $100 million, but, the Corps was unable to maintain the 45 ft deep navigation channel (for the first time).**
- **New Orleans generates about $107 billion each year in revenue, or about $294 million per day. It remains to be seen if Congress will appropriate more than $100 million annually to maintain the navigation channel, or will seek some sort of match from those navigation interests who have so much at stake.**

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Mississippi Delta Region