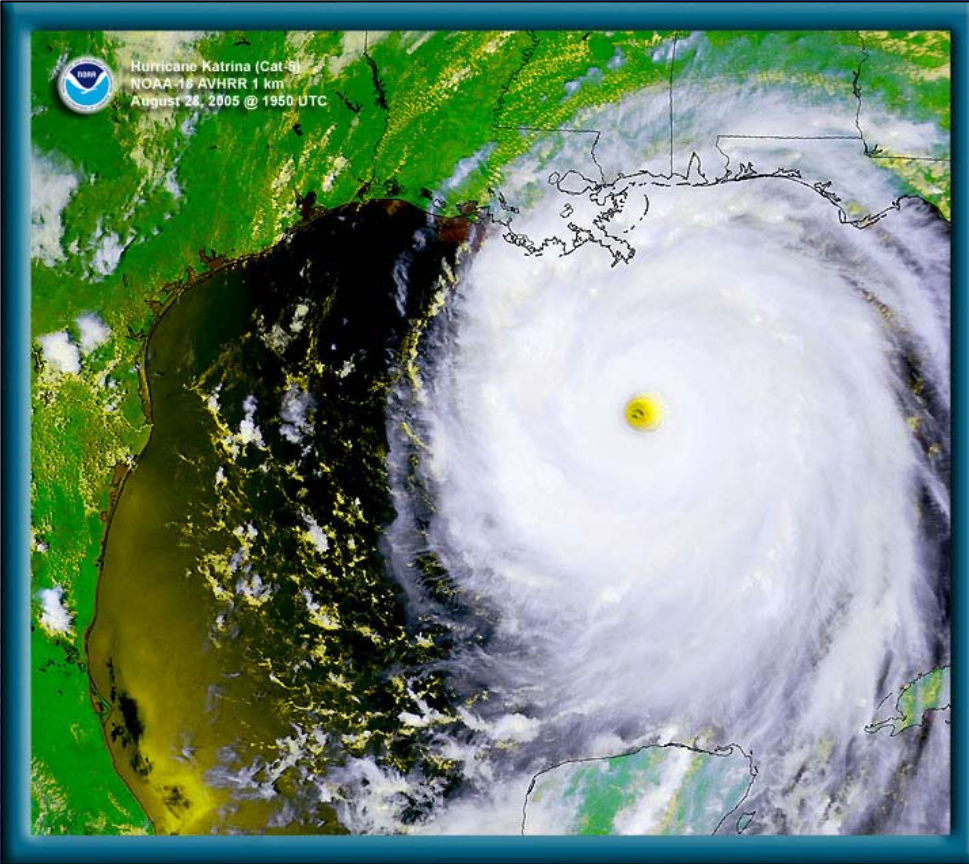


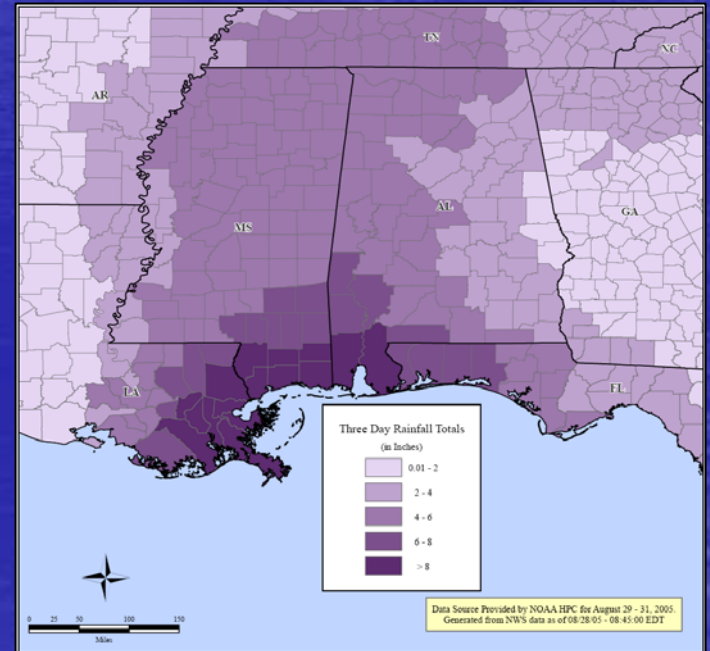
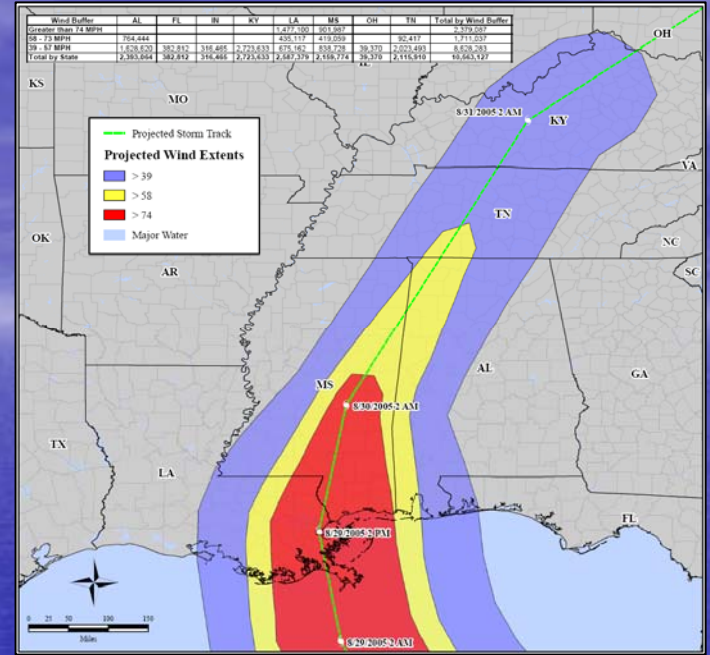
PART 4

**HURRICANE
KATRINA STRIKES
NEW ORLEANS
AUGUST 2005**

Hurricane Katrina



Hurricane Katrina swept across southern Florida and lost momentum, then gained speed and water, showing the second lowest barometric pressure ever recorded. The predicted storm surge was 18 to 28 feet; a record for New Orleans.



Katrina Landfall

- Historically, there haven't been but a handful of Category 4 or 5 hurricanes that have ever been photographed making landfall.





New Orleans is a High Maintenance Place

- New Orleans has always been a high maintenance city
- The city did not stray much beyond the old Mississippi River levee mound until after the MR&T flood control project constructed Federal levees.



NEW ORLEANS AND VICINITY

THIS MAP PUBLISHED ANNUALLY BY AAA
HEATHROW, FL. 32748. 2000 EDITION

Scale in Miles
Scale in Kilometers

ONE INCH EQUALS APPROXIMATELY 1/32 OF A MILE OR 1/3 KILOMETERS

LEGEND

<ul style="list-style-type: none"> Interstate Major Highway State Road Local Road Unimproved Road Point of Interest 	<ul style="list-style-type: none"> Controlled Access Toll Road Interchange Major Airport Unimproved Road Point of Interest
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The area of this map is in the Central Time Zone

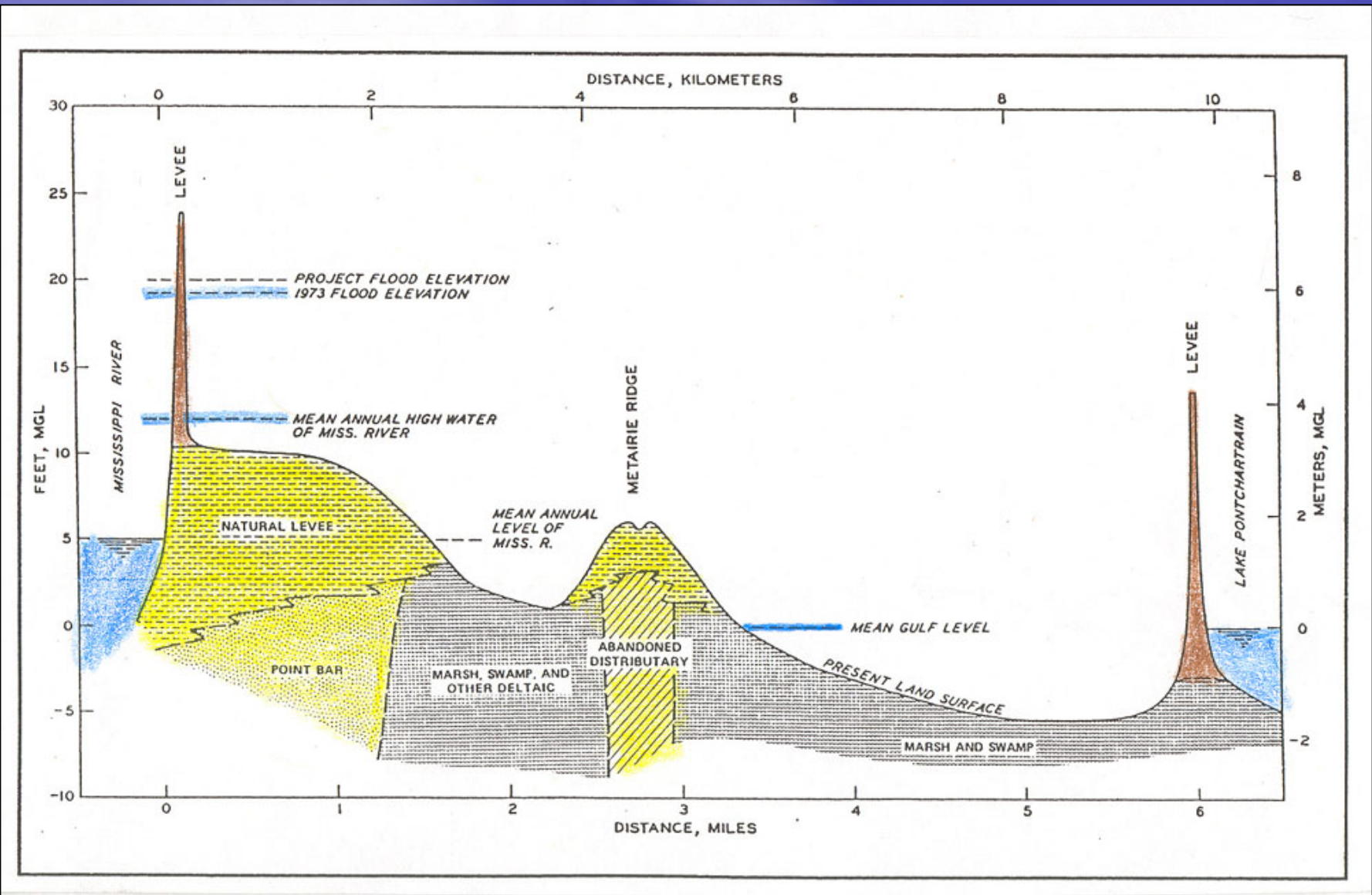
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MISSISSIPPI RIVER
LAKE PONTCHARTRAIN
LAKE VISTA

Industrial Canal

17th St Canal

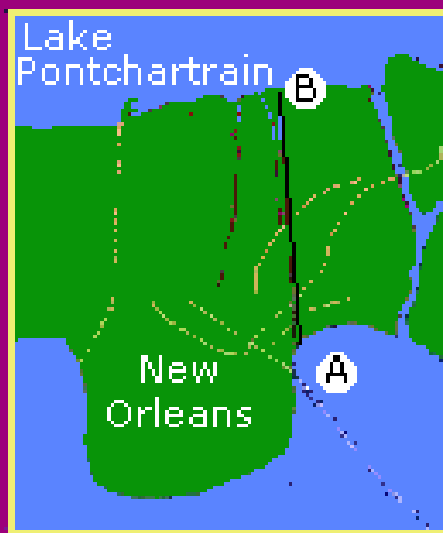




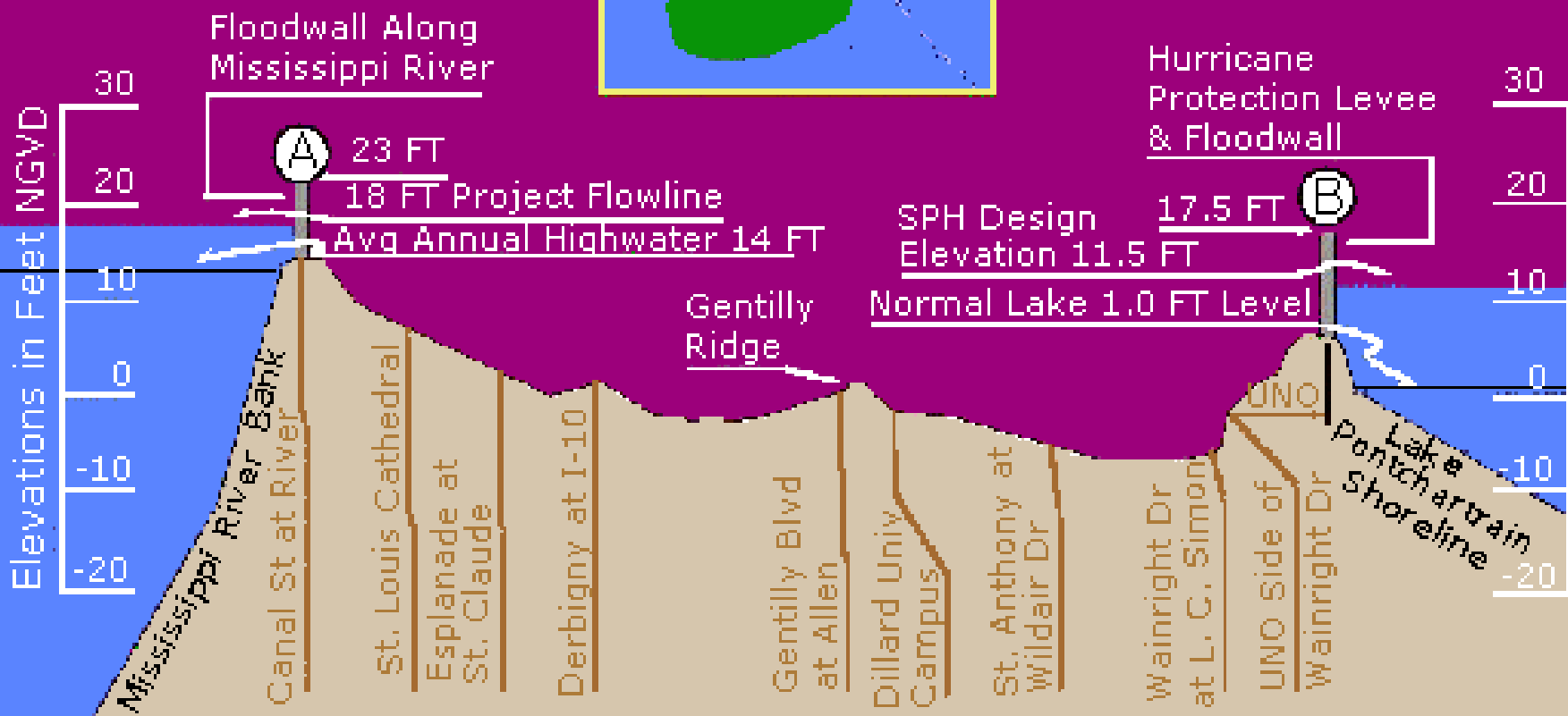
Much of New Orleans lies below sea level, Lake Ponchartrain, and the Mississippi River, making it particularly vulnerable to flooding. Mississippi levee 24.5 feet; Pontchartrain levee 13.5 feet.

City of New Orleans Ground Elevations

Area Map



From Canal St. at
Mississippi River
to the
Lakefront at U.N.O.



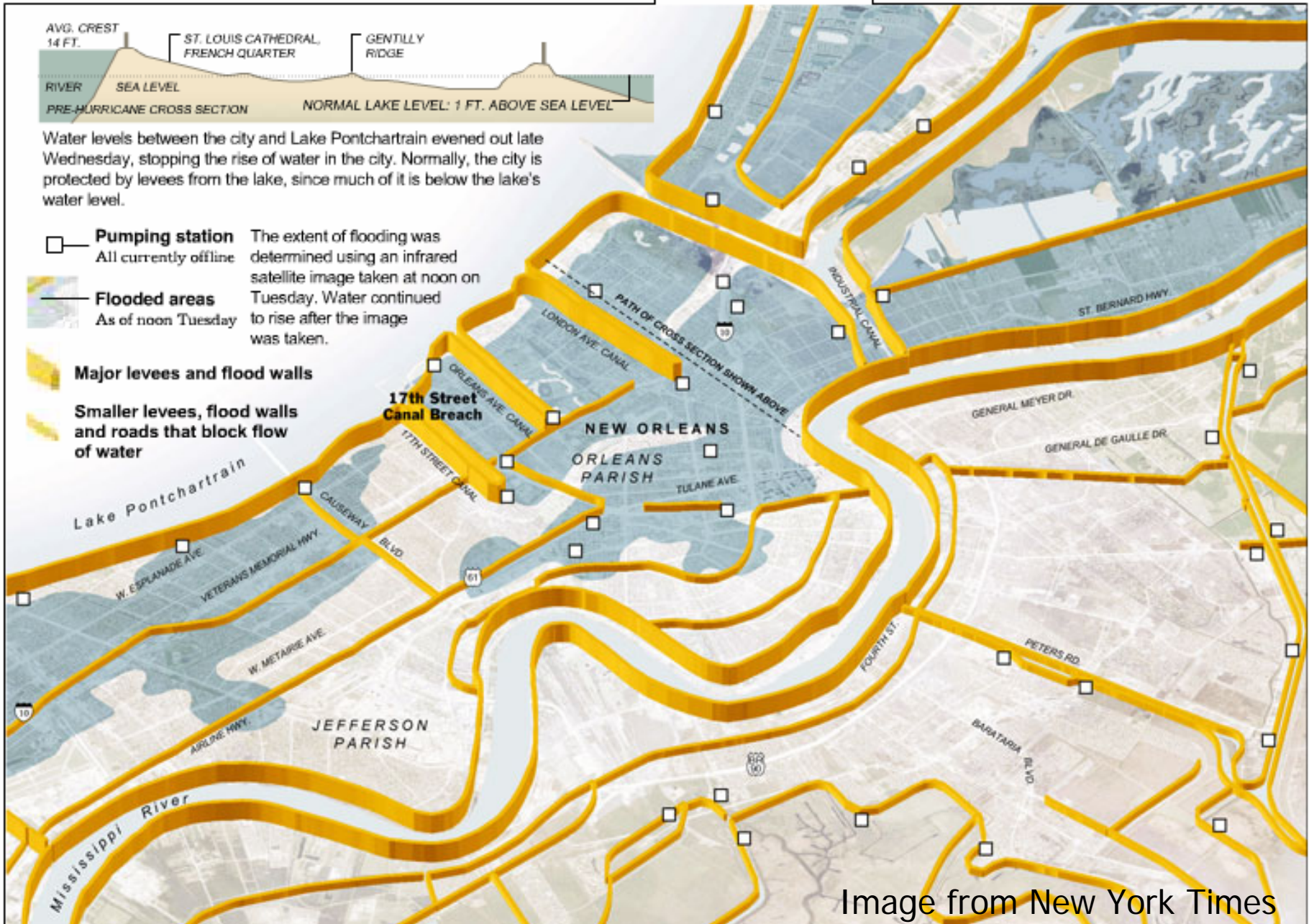


Image from New York Times

A complex network of levees protected the city from flooding, but it was two drainage canals that were overtopped on August 29, 2005.

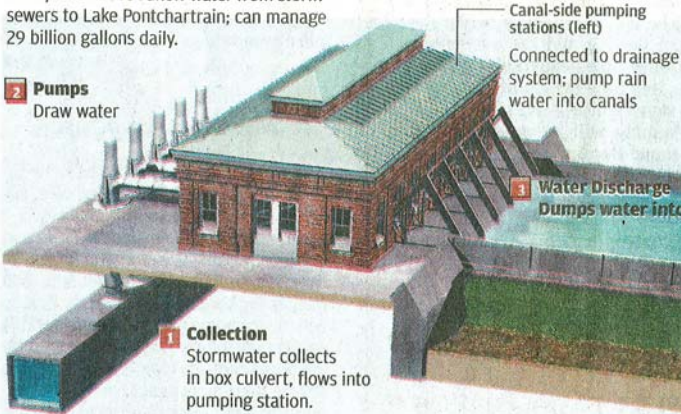
Pumping the floodwater out ...

Once New Orleans' breached levees are repaired, the city's complex system of levees, floodwalls, canals, pumps and locks can be used again to make the below-sea-level city dry.

THE SYSTEM

Pumps at drainage pumping stations throughout the system move runoff water from storm sewers to Lake Pontchartrain; can manage 29 billion gallons daily.

2 Pumps
Draw water

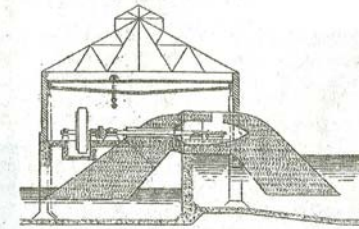


1 Collection
Stormwater collects in box culvert, flows into pumping station.

FIRST PUMPS

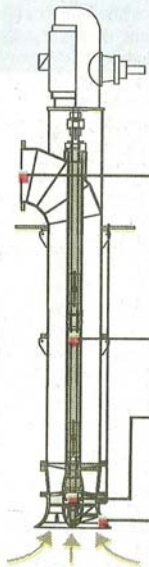
Original pumps, known as Wood screw pumps, were designed in 1913 by Albert Baldwin Wood; about 50 still in use.

Canal-spanning pumping stations (right)
Similar to locks; raise level of water in canal so it can flow easily into lake.



4 Locks

Allow water from canal to flow into lake; may be opened if water level in lake is lower than that in canal or to let small vessels into canal; keep lake water from backing up.



TYPICAL MODERN PUMP

Vertical pumps have replaced some original pumps; lower part is submerged in water in canal or storm sewer system.

Water discharge

Capacity: Most used in New Orleans can pump up to 250,000 gallons per minute.

Height: 30-40 feet

Drive shaft: Connected to diesel or electric engine; powers impeller.

Impeller: Propeller-like device moves water up pump.

Suction bell: Water enters pump here.

CRACKS IN THE WALL

First built in 1897, the aging system was breached in at least three places.

17th St. Canal

About 300-foot breach created when storm surge from lake topped floodwall and moved levee wall horizontally about 20 feet.

London St. Canal

About 300-foot breach in floodwall.

Industrial Canal

Possibly two breaches, 100 feet and 500 feet.



Closed roads hamper evacuations

- 1 Interstate 55** is partially submerged
- 2 Lake Pontchartrain Causeway** is impassable
- 3 Sections of Interstate 10 bridge** are torn off

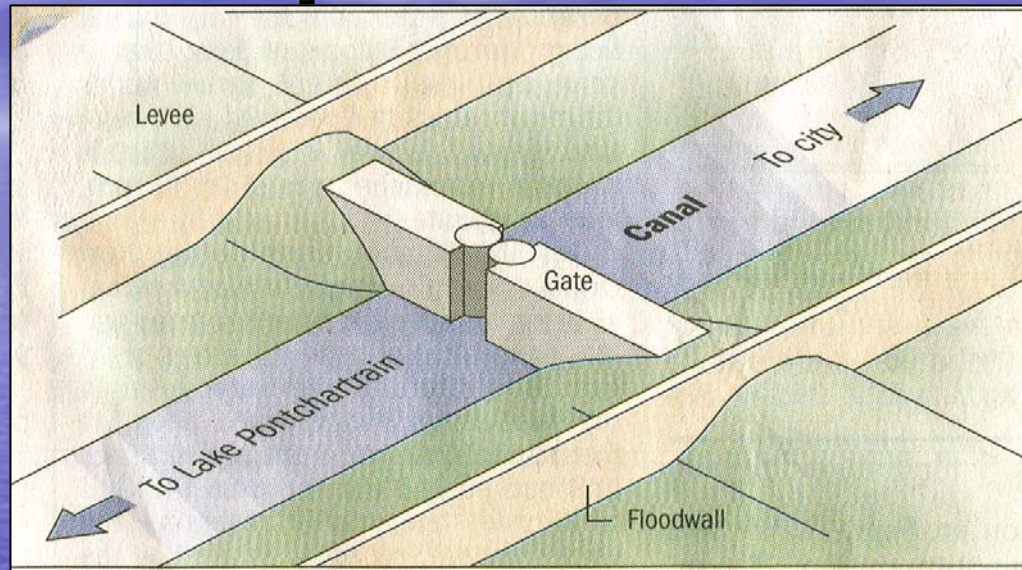
Note: Floodwalls, levees not to scale

SOURCES: Knight-Ridder Tribune; Associated Press; NOAA; AccuWeather; National Hurricane Center; National Weather Service; Insurance Information Institute; Army Corps of Engineers; U.S. Geological Survey; Patterson Pump Co.; Linda Hall Library of Science, Engineering and Technology; Engineering News

Post-Dispatch

All water entering the city must be pumped out, otherwise it would pond in the low-lying areas. Image from St. Louis Post-Dispatch

Tidal Gates on Drainage Canals could have prevented flooding



- In 1955 Congress directed the Army Corps of Engineers to survey coastlines to study how to build hurricane protection systems as a part of the Lake Pontchartrain and Vicinity Hurricane Protection Plan.
- In 1961 the Corps proposed a hurricane flood plan for New Orleans area whose main feature is barriers at the passes into Lake Pontchartrain that will prevent storm surge water from entering the lake. These were opposed by local agencies, so never built.

Image taken from Wall Street Journal.

10 M SPOT Satellite Image: 2 Sept 2005

Areas flooded when the two drainage canal flood walls were overtopped, leading to full-scale breaches of the supporting embankments. The breaks were along the 17th Street and London Avenue drainage canals, which convey pumped water to Lake Pontchartrain.



The break on the 17th Street Canal is circled. Note debris piled up against Hammond Highway Bridge in foreground.



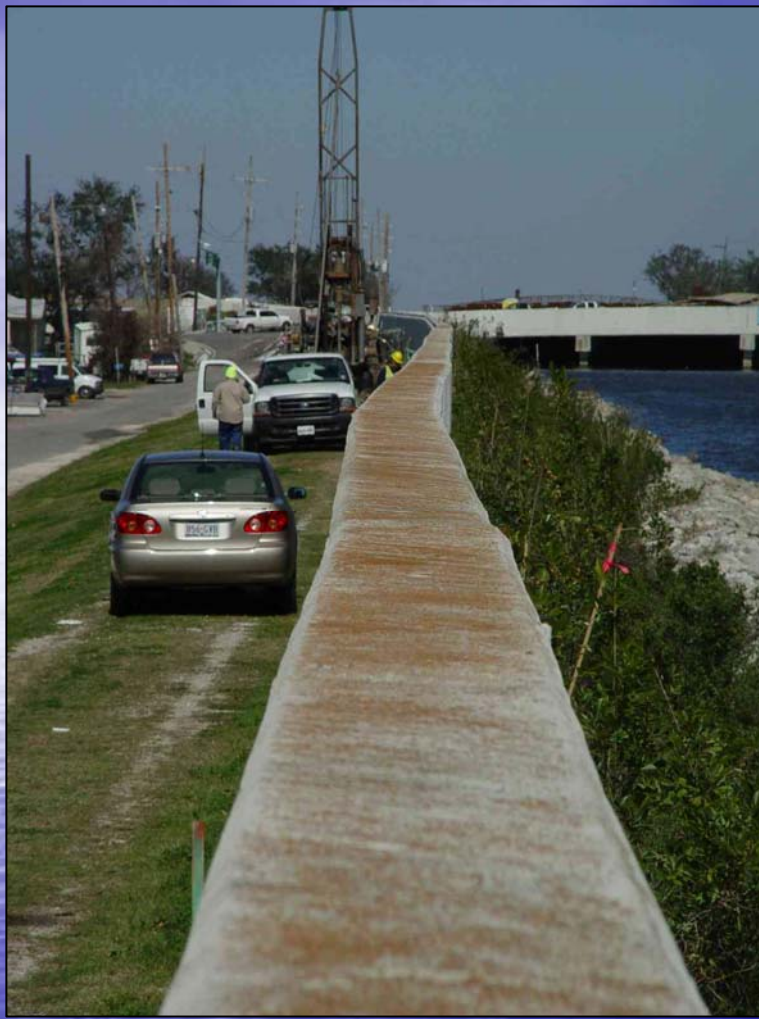
- Aerial oblique view of the 17th Street Canal break, looking east. Note lateral translation of concrete flood wall, between 35 and 50 ft. Photo by Ivor van Heerden.



Lateral translation of I-wall

Ground view of displaced concrete flood wall at 17th Street Canal failure. Note slight back rotation of wall. Photo Iver van Heerden.

08/30/05



- Apparent displacement of the 17th Street Canal flood wall on the west (Jefferson Parish) side, opposite the 17th Street failure.

London Avenue Canal – North Breach



From NSF report November 2005

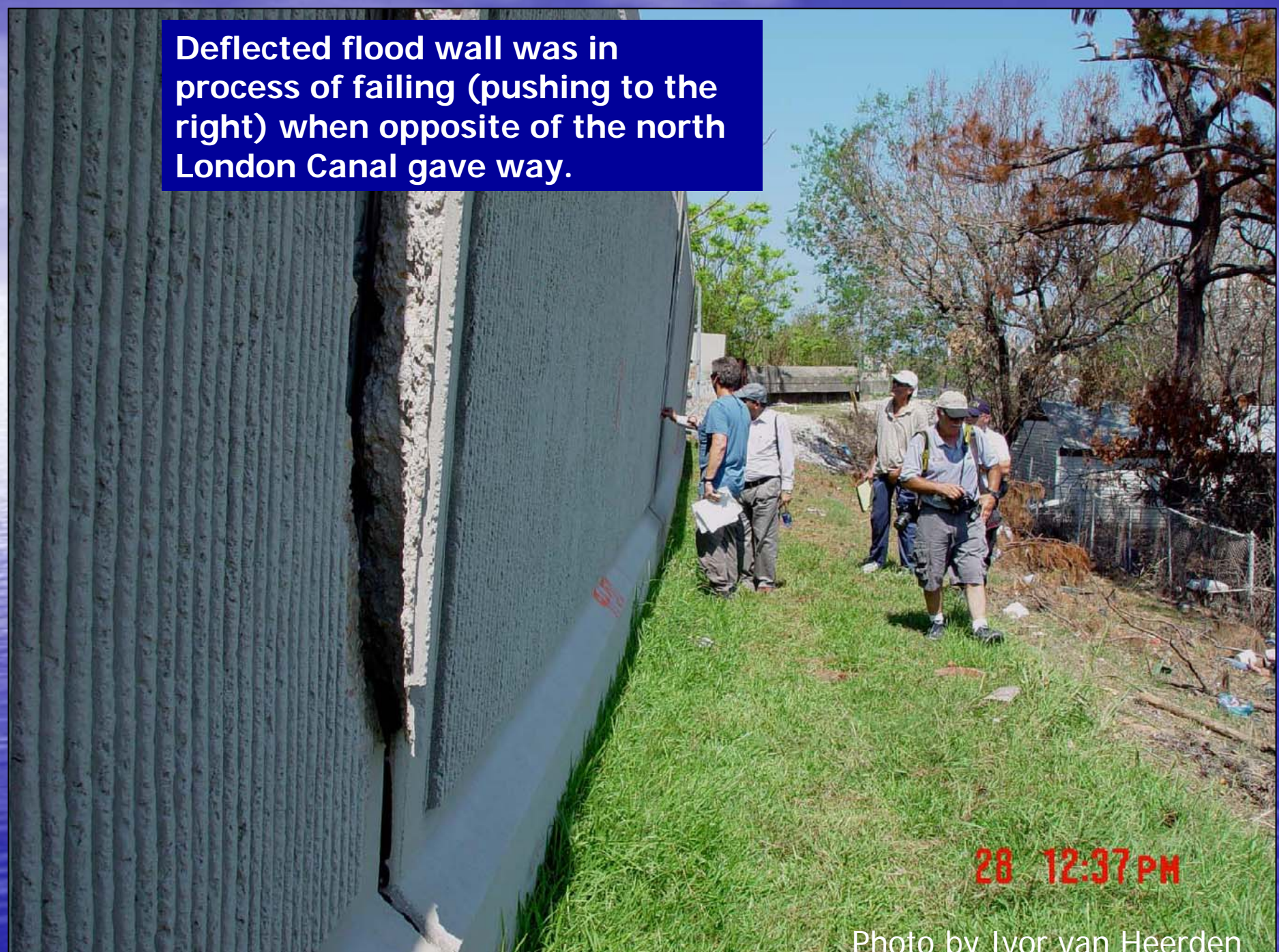
London Ave Canal – Filmore Breach



SEP 7 2005

Photo by Ivor van Heerden

Deflected flood wall was in process of failing (pushing to the right) when opposite of the north London Canal gave way.



28 12:37 PM

Photo by Ivor van Heerden

South London Avenue Canal breach, just north of Mirabeau Drive



SEP 15 2005

Photo by Ivor van Heerden

Scour Trench

Curved wall – why?

Embankment failure



18 11:31 AM

Deflection of concrete I-walls along eastern side of Inner Harbor Navigation Channel. Photo Ivor van Heerden.



10.04.2005 12:08

Did an empty barge break the Industrial Canal flood wall?



damaged wall

An **empty barge** moored at the Lafarge North America construction materials facility on Lake Pontchartrain tore loose of its moorings and crashed through the levee along the Industrial Canal, coming to rest next to a house, shown here. The barge appears to have bumped the flood wall, but only after it had overtopped and failed.



This aerial view shows an example of reverse flow, back into the Inner Harbor navigation Channel.

Note the absence of the concrete flood wall capping the earthen levee, removed by toe scour of the supporting levee embankment when it was initially overtopped

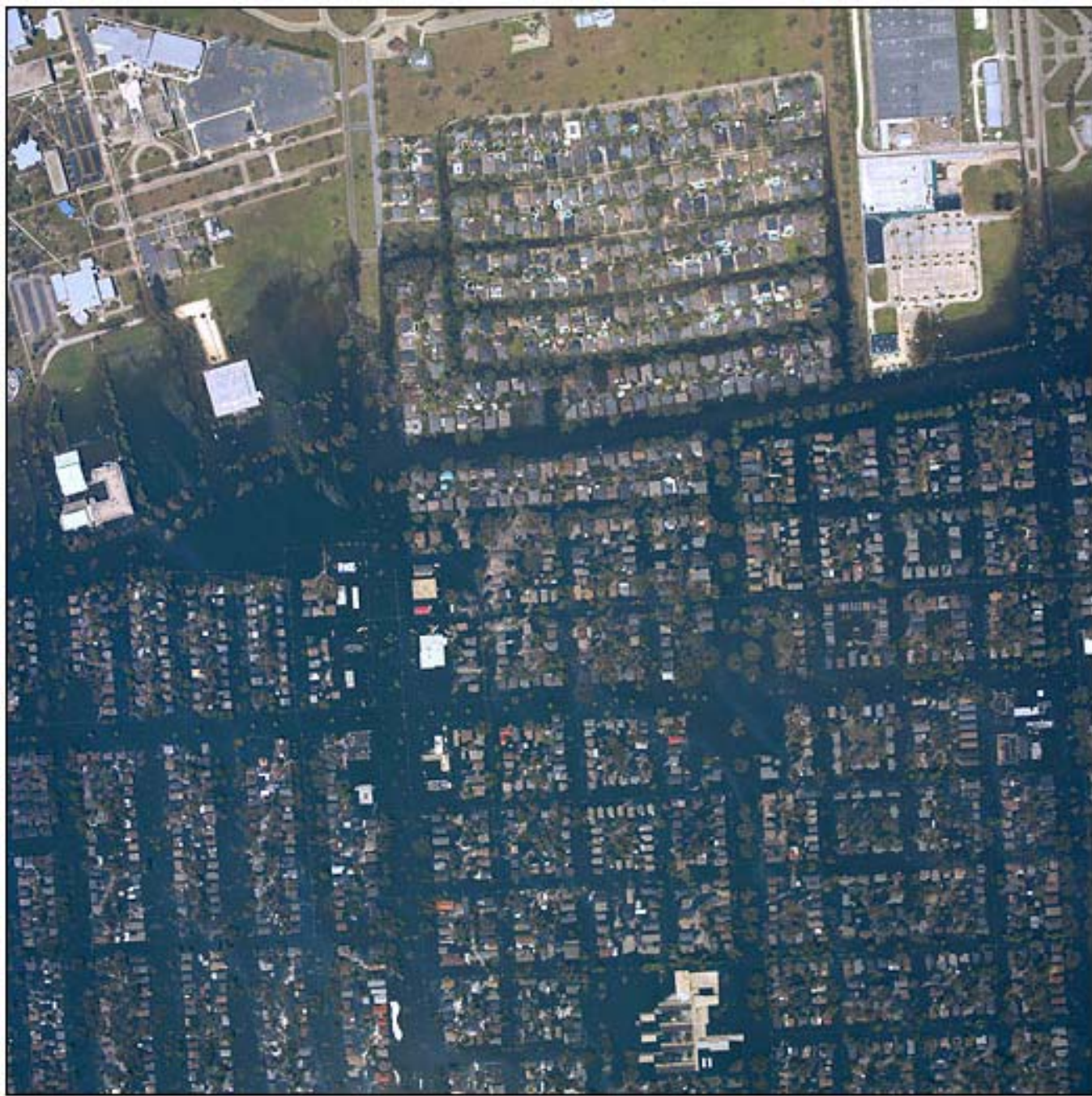
Levees are erodible

Earthen embankment levees usually fail by underseepage along preferential flow paths, engendered by permeability contrasts.

Levees are also 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.

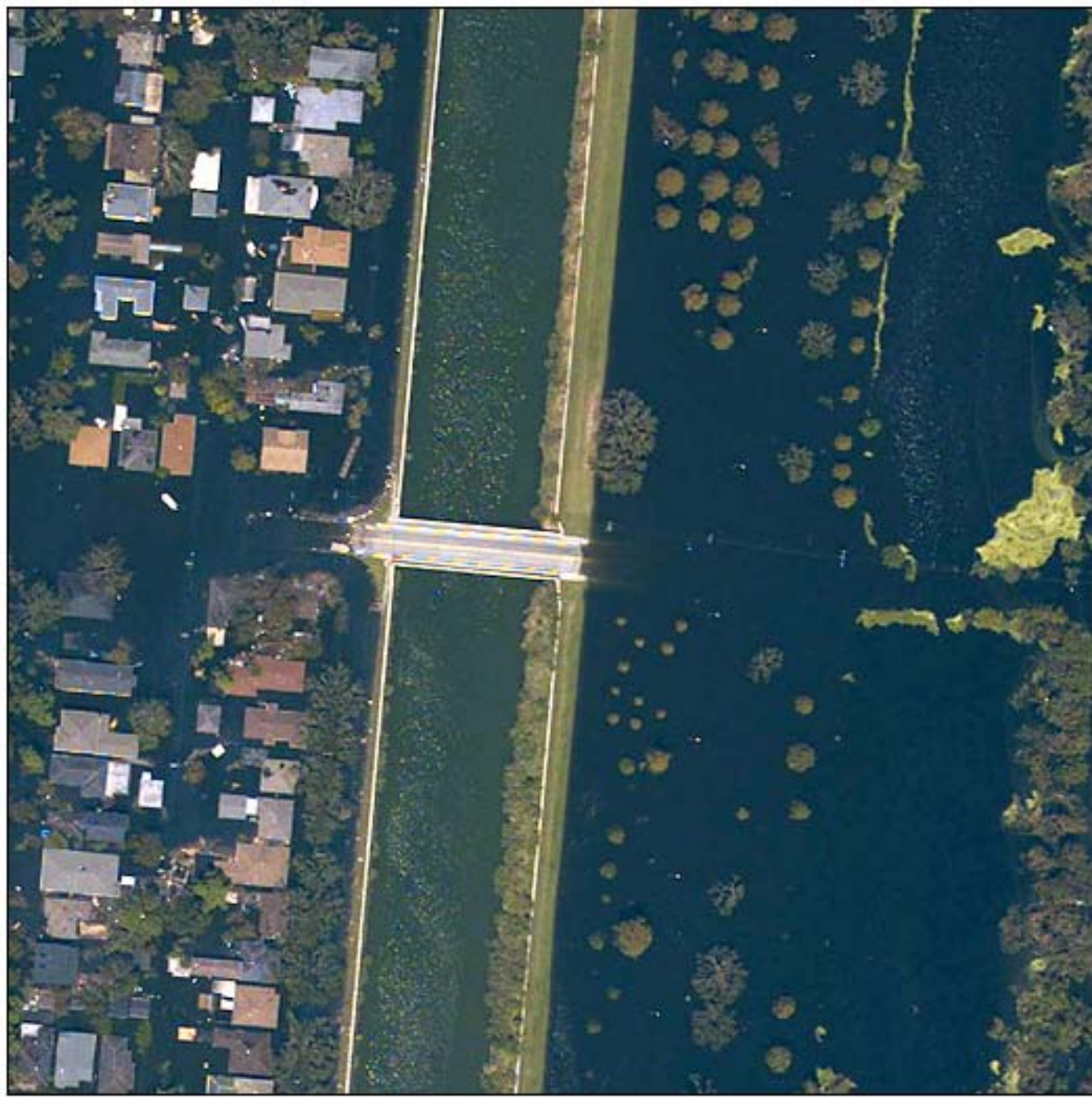




Aerial view of flood inundated urban neighborhood in New Orleans.

The pool level extends to the upper fifth of the image, which is higher ground, lying above the inundated zone.

Old river channels form the high ground across old New Orleans because these channels deposited silty sand levees, which now form low ridges.



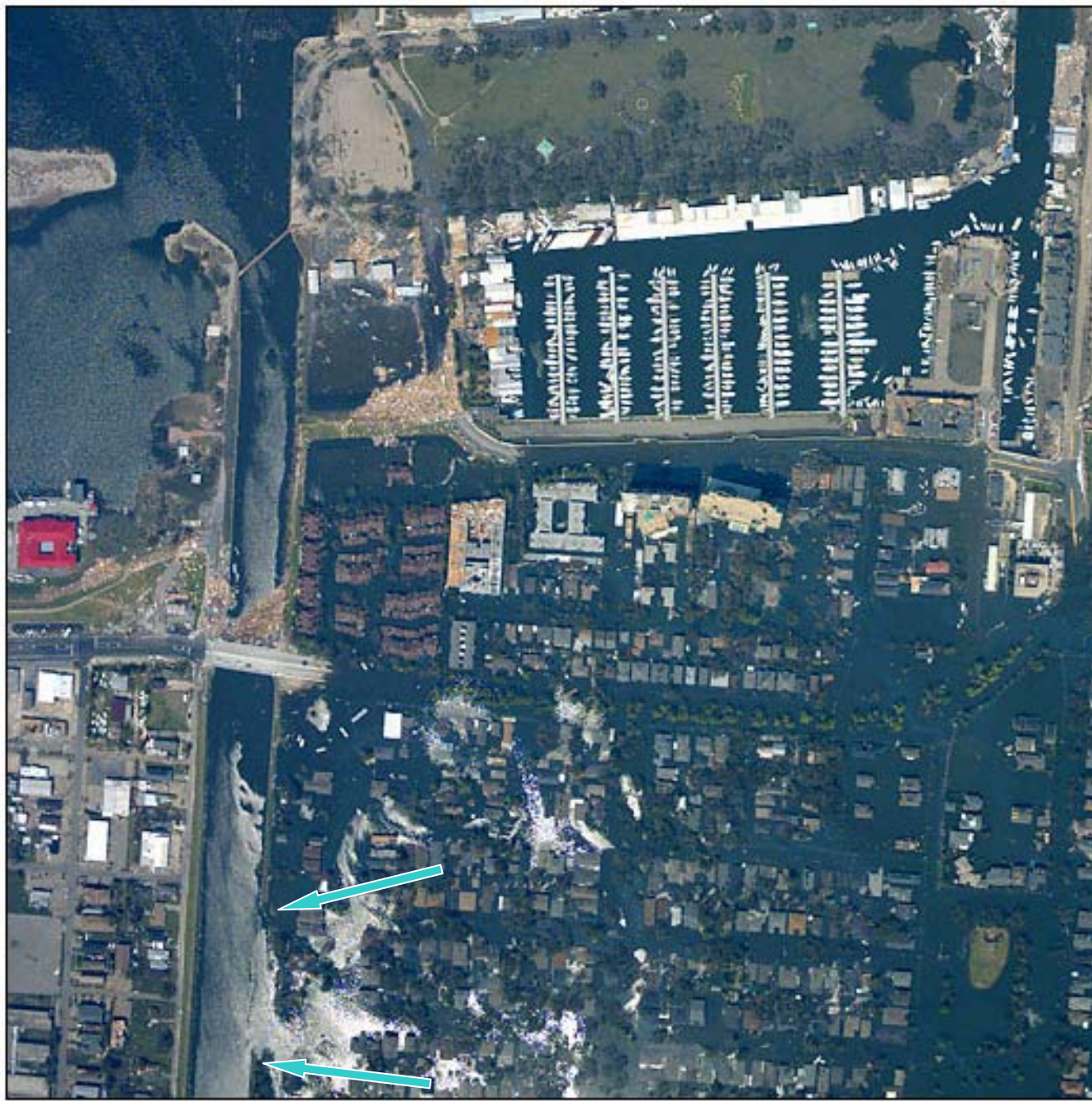
Post flood aerial image showing inundated zones on either side of a drainage canal.

Note how the street crossing the canal is higher than on either side of the canal

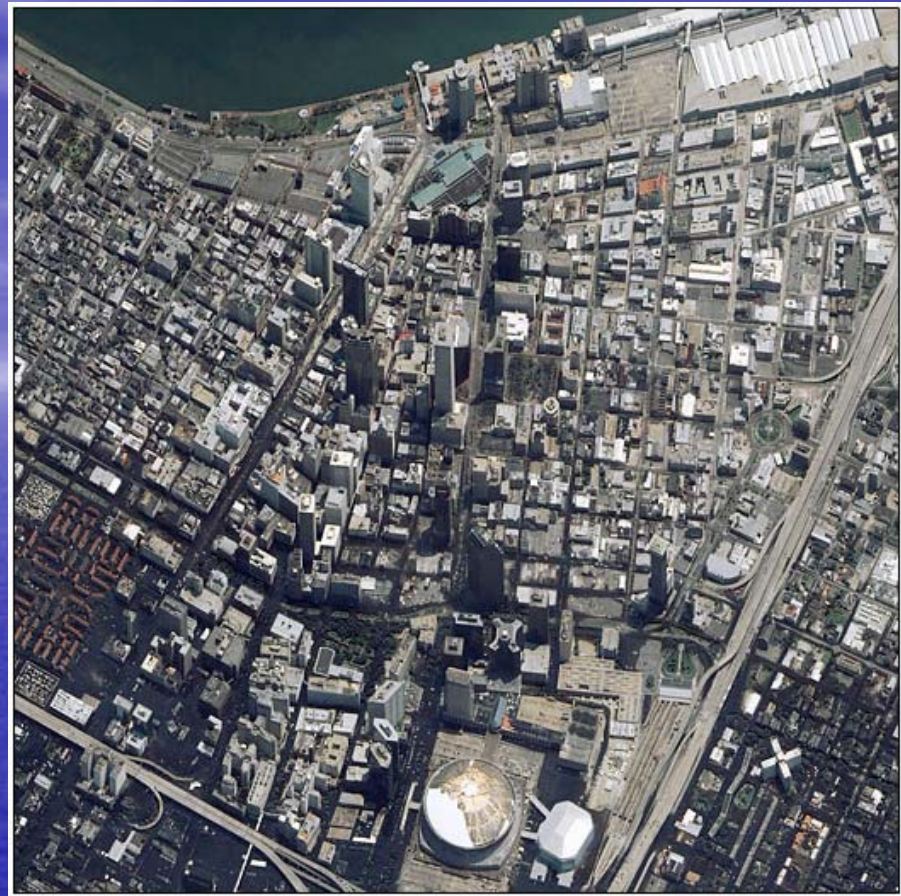
Variances in reflectance of the ponded water is ascribable to dissolved and entrained solids, depth, temperature, oxygen content, temperature, turbidity, and current.

Lower 17th Street Canal

The eastern side of 17th Street Canal I-wall and embankment shifted 50 feet laterally, between arrows, spilling water into the Lakeside neighborhood at right. The Eastern Jefferson Parish (left of the canal) was spared inundation.



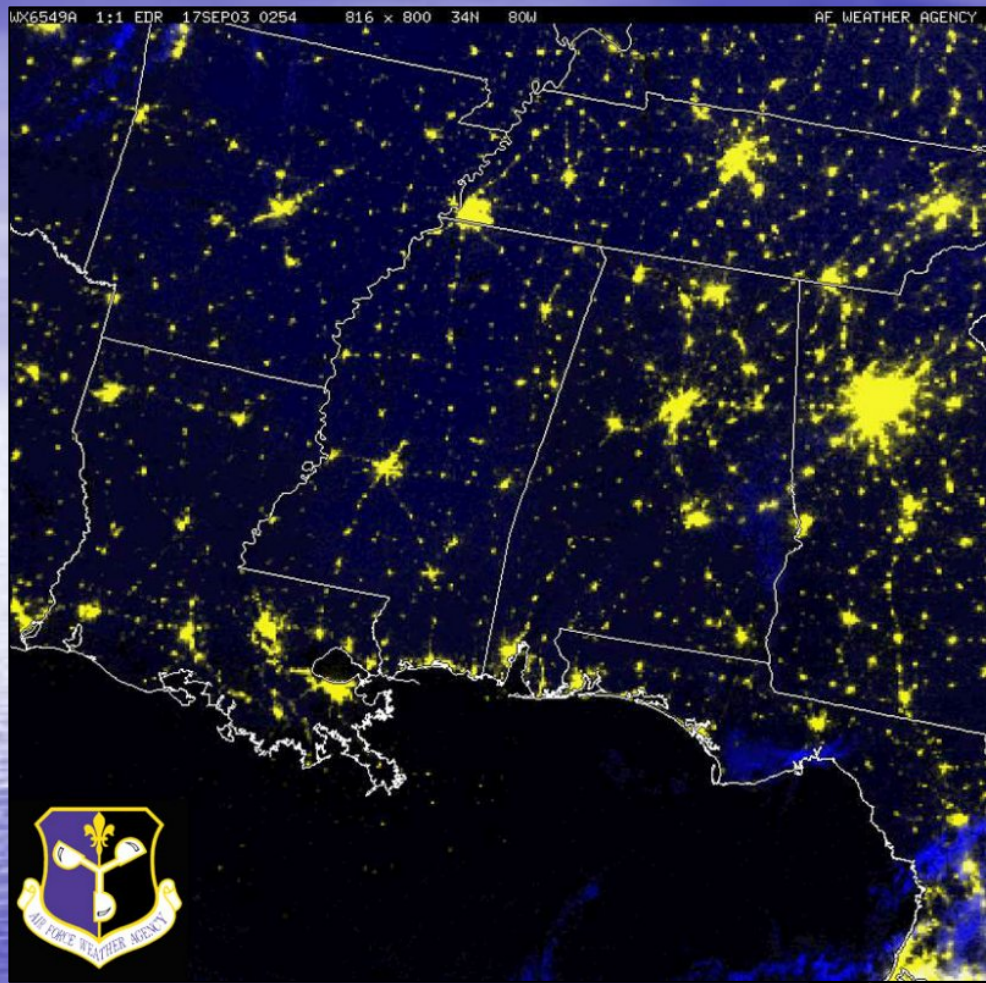
Louisiana Superdome



When the Cold War ended in 1991, everyone searched for “peace dividends.” Civil Defense operations were curtailed or discarded and a new paradigm in emergency services preparedness emerged. A popular concept was replacing Civil Defense shelters with sports stadiums and arenas, using whatever stores they had onsite. This alternative failed to encompass the need for water and power at such facilities, and assumed that they would come through any natural disaster relatively “unscathed”; being designed for extreme events.



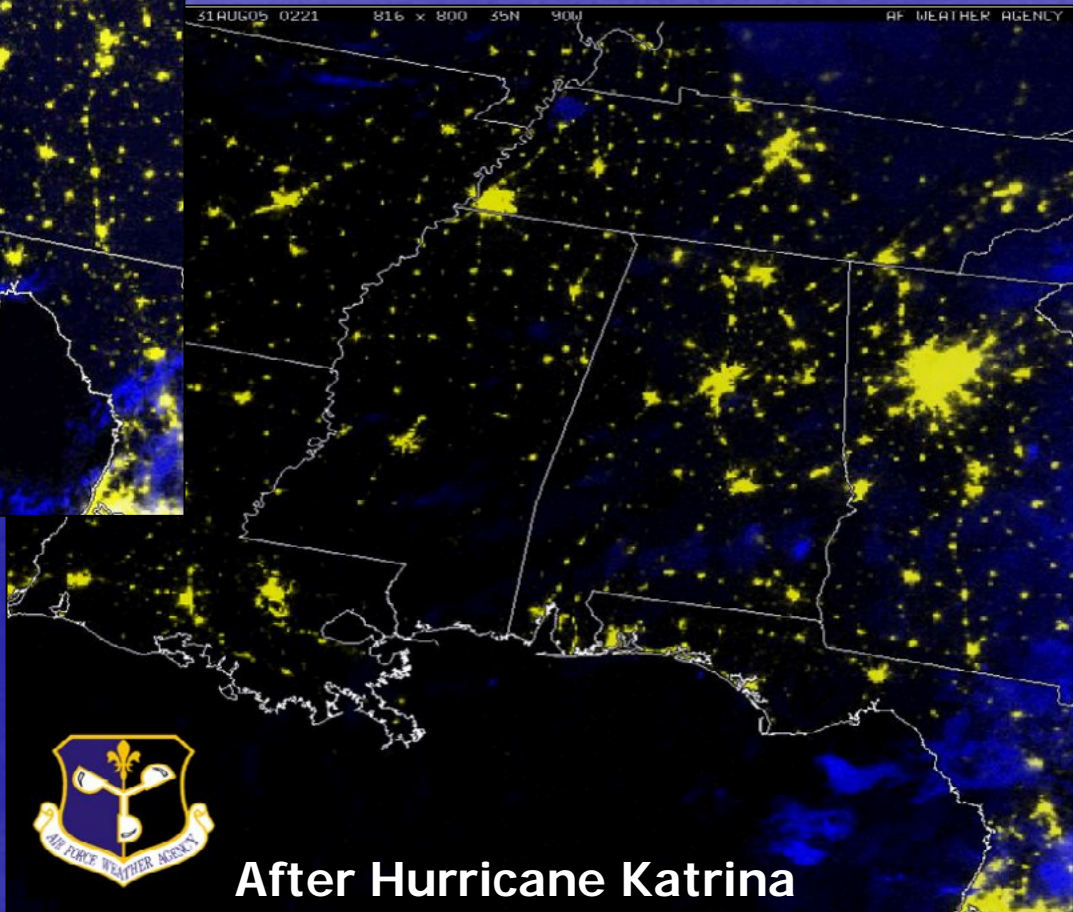
Highways in low-lying swampland are difficult structures to construct because they are usually founded on poorly-drained compressible soils. These foundation conditions are problematic for either elevated embankments (which cause additional settlement) or for pile supported viaducts (subject to downdrag forces). If the highway lies below flood levels, it can't be used to effect vehicular access.



Before Hurricane Katrina

Impacts on Electrical Power

These ELINT images show how much electrical power was knocked out throughout much of the region.



After Hurricane Katrina



Hurricane Katrina - Impact to Petroleum Industry Infrastructure

Louisiana

UNCLASSIFIED

09 Sep 05
2200Z/1700L

MISSISSIPPI

TEXAS

LOUISIANA

Capline Pipeline
over 80% normal capacity

Plantation Pipeline
now at 100% normal capacity

Colonial Pipeline
now flowing at 100% capacity

(Total) Atofina
Petrochemicals, Inc.

Placid Refining Co.

ExxonMobil
Refining and Supply Co.

Valero Energy Corporation

Motiva (Shell) Enterprises LLC

Valero Energy Corporation

Beaumont

Lake Charles

Motiva (Shell) Enterprises LLC

New Orleans

Slidell

Biloxi-Gulfport

Murphy Oil USA, Inc.

Impacted Refineries

- Operational; receiving SPR
- Reduce runs; receiving SPR
- Shutdown
- Reduced runs
- Restarting
- Plantation Pipeline
- Colonial Pipeline
- Capline Pipeline
- LOOP Facilities

Marathon Ashland
Petroleum LLC

Shell Chemical LP

(ExxonMobil)
Chalmette Refining LLC

ConocoPhillips Company

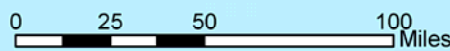
Clovelly Terminal
has no power

Fourchon Terminal is shutdown

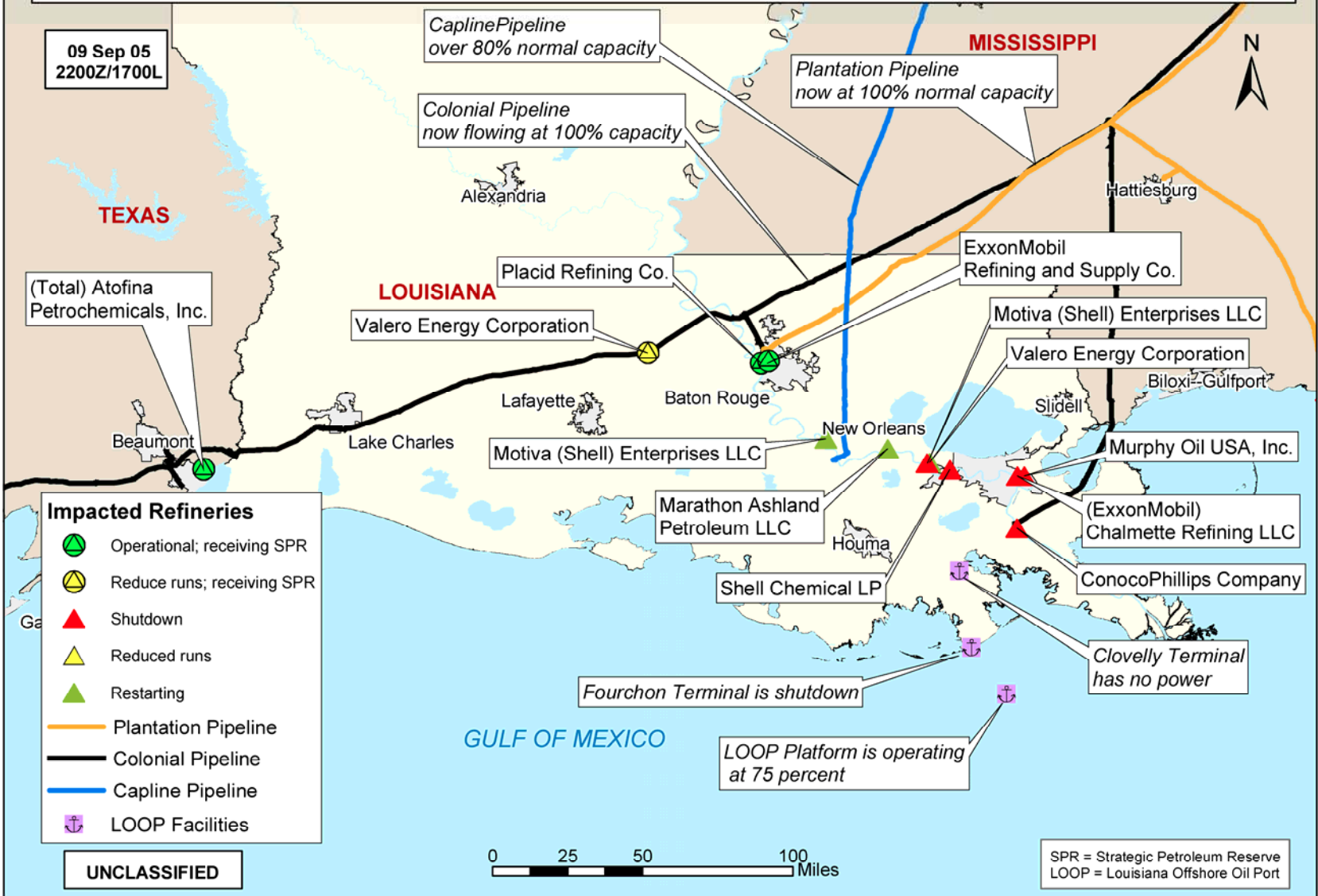
LOOP Platform is operating
at 75 percent

GULF OF MEXICO

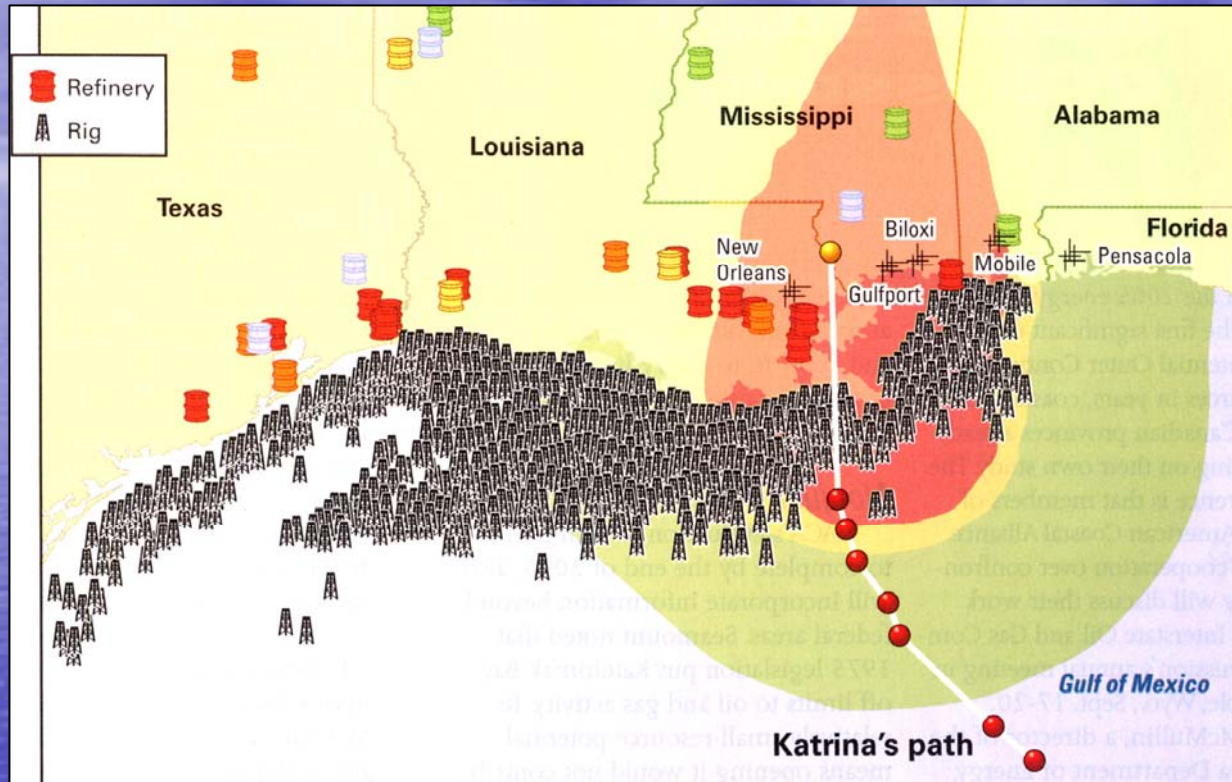
UNCLASSIFIED



SPR = Strategic Petroleum Reserve
LOOP = Louisiana Offshore Oil Port



Impacts on Petroleum Industry



- 79 drilling rigs and 482 production platforms were evacuated during Katrina; stopping 1.4 million b/d of oil and 8.3 bcfd of natural gas production