# Geophysical Examination of Ohio River Levees for Enhanced Flood Performance Evaluation

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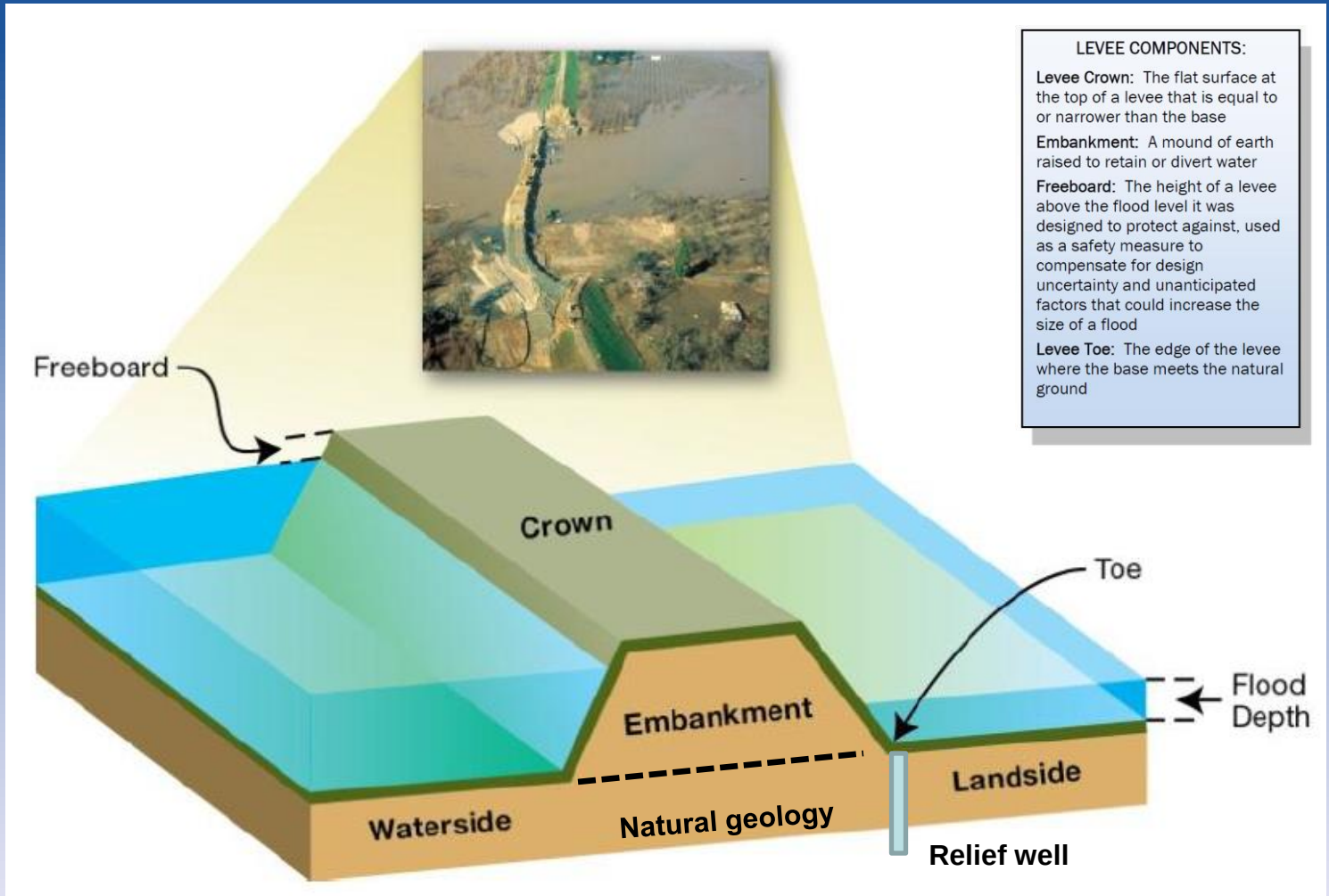
# Talk Outline

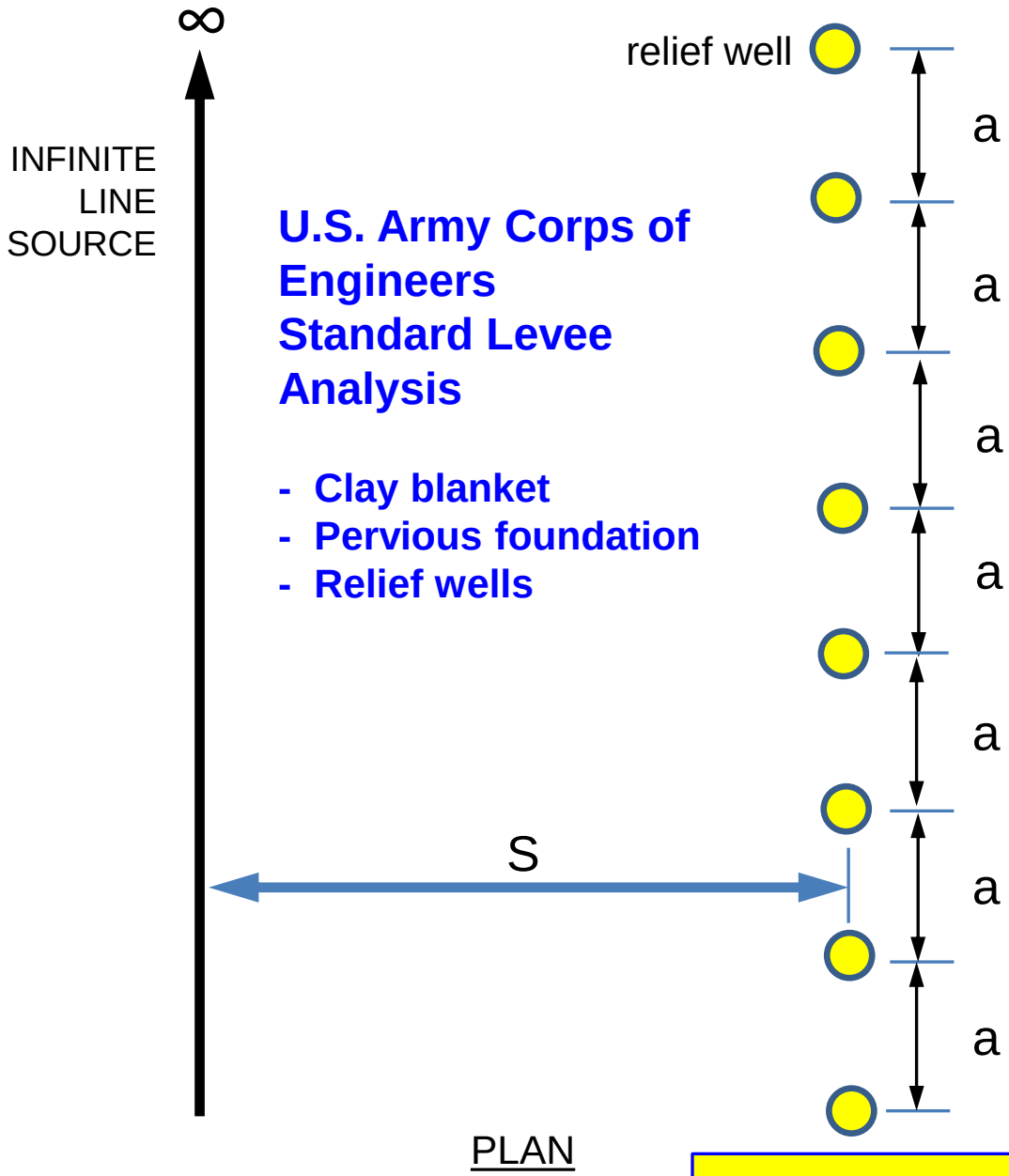
- Evaluation of levee systems in the United States
- Levee performance and failures
- Case study of the geophysical evaluation of a large levee system along Ohio River

# What is a Levee?



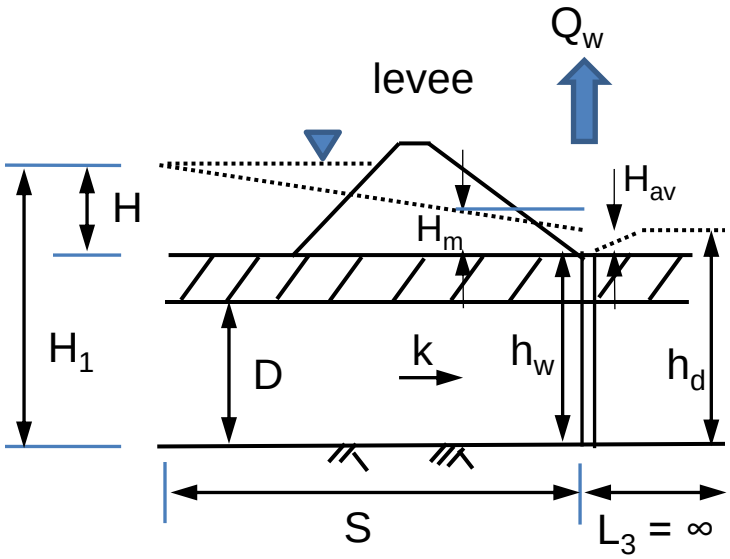

***"a man-made structure, usually an earthen embankment, designed and constructed in accordance with sound engineering practices to contain, control, or divert the flow of water in order to reduce the risk from temporary flooding."***

- Federal Emergency Management Agency (FEMA)




**U.S. Army Corps of Engineers Standard Levee Analysis**

- **Clay blanket**
- **Pervious foundation**
- **Relief wells**



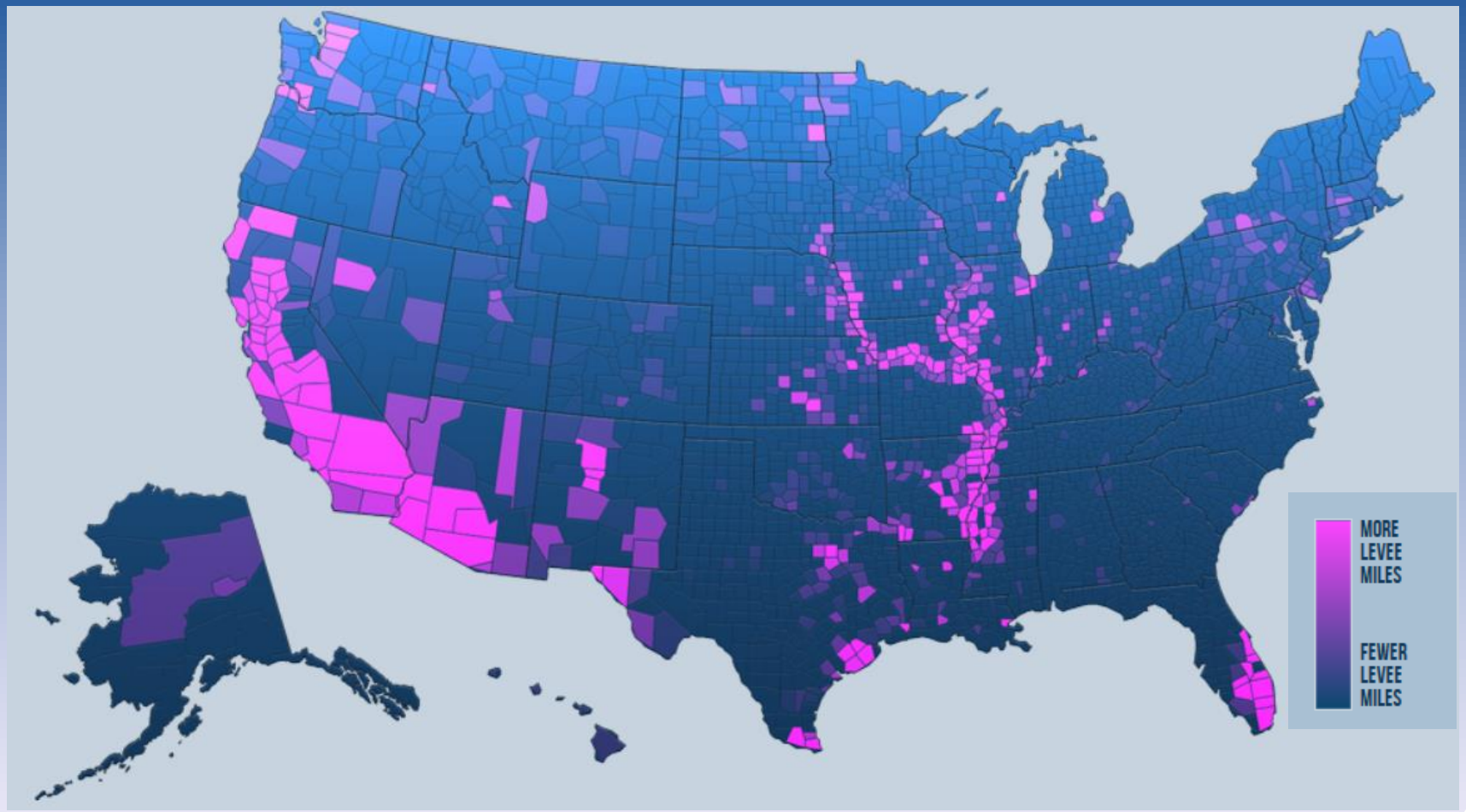

SECTION

Find $H_m$, $H_{av}$, Qw

Condition: One k

**Question: How safe is the Levee?**

# Levee Systems in the United States




Federal Emergency Management Agency's Midterm Levee Inventory as of July 2012.

# Levee Systems in the United States


**Factoids:**

- **100,000+ miles of levees in all 50 States**
- **Nearly 85 % are locally-owned, operated and maintained. Average age – greater than 55 years.**
- **ASCE Grade D- infrastructure report**
- **Public safety at risk with tens of millions living and working in protected areas**
- **Repair and rehabilitation estimated at $100 billion**
- **Flood damage saved in 2011 = $141 billion**

Federal Emergency Management Agency's Midterm Levee Inventory as of July 2012.

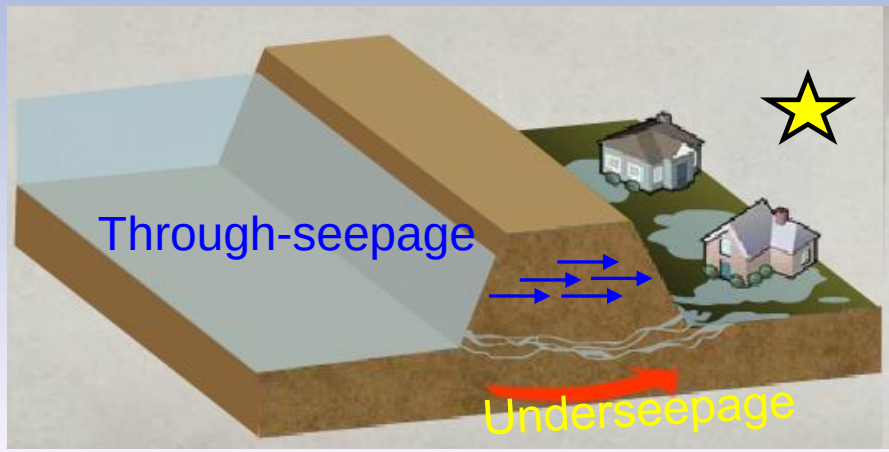
# Why does a levee fail?

- **Geologic Variability:** Unaccounted for soil/bedrock conditions from ***standard investigations*** – e.g., **thin surficial blankets**, **higher permeability zones**, interconnected uniform granular zones.

- **Flood load exceeds design:** Increase in seepage pressures beyond expectation, under-designed system to carry flows away from levee.

- **Maintenance activities ignored:** Embankment erosion remains unchecked; excess vegetation; relief wells plugged; animal burrow holes left, collapsed culvert penetrations; etc.

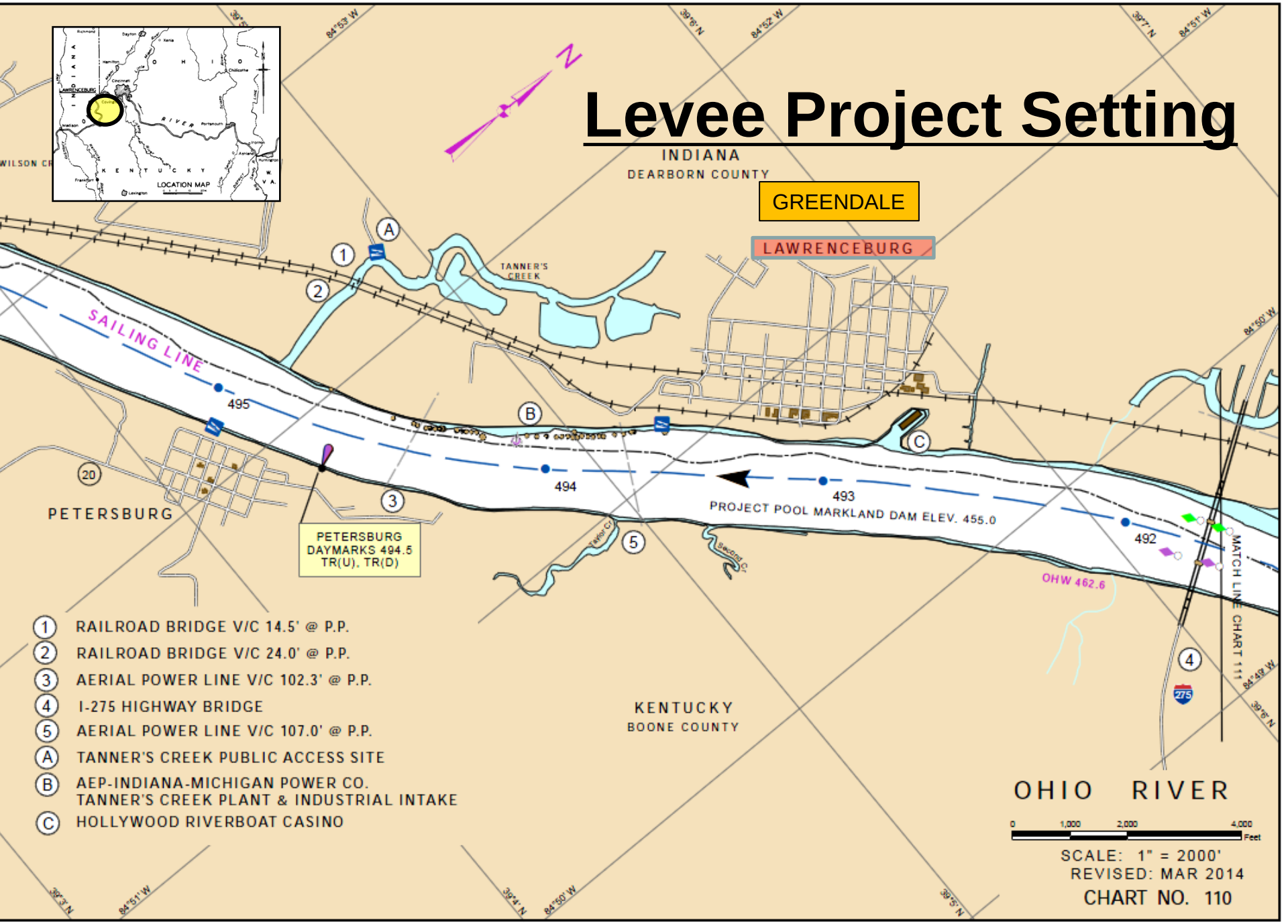
# Levee Failures




## SEEPAGE

Seepage occurs when, over time, water begins to seep under or through a levee, creating weak spots in its structure. The first signs are puddles of standing water on the inboard side of the levee. Sand boils, bubbling springs at the base of the levee, also begin to form, causing the soil to become unstable, and the levee structure to be compromised. This can result in a total collapse of the levee.

# Levee Project Setting

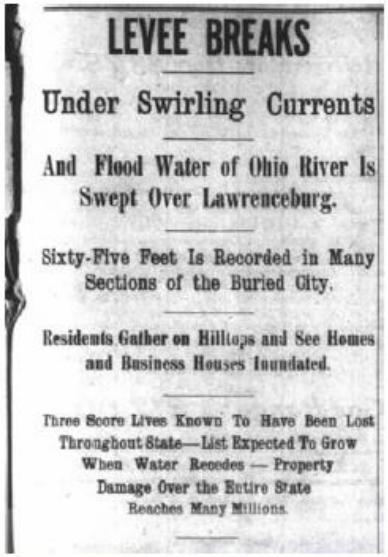


# History of the Lawrenceburg Levee

Lawrenceburg Flood Protection Works

## March 14, 1884

"The rise in the river poured through the broken levee and spread the water over all the lower portions of town." –*The Cincinnati Enquirer*



LEVEE BREAKS

Under Swirling Currents

And Flood Water of Ohio River Is Swept Over Lawrenceburg.

Sixty-Five Feet Is Recorded in Many Sections of the Buried City.

Residents Gather on Hilltops and See Homes and Business Houses Inundated.

Three Score Lives Known To Have Been Lost Throughout State—List Expected To Grow When Water Recedes — Property Damage Over the Entire State Reaches Many Millions.

## Town Hall Bell Warns Residents; Lawrenceburg Loses Flood Fight

## March 29, 1913

"More than 50 feet of the levee broke at 2:50 o'clock in the afternoon, and at 8 o'clock tonight the entire city and surrounding country was under from 25 to 65 feet of water. Every resident of the city had fled to the hills when the warning came several days ago…Thousands of persons, standing on the hilltops saw the large cement levees give way…Every home and business in the city is covered with water, with the exception of those on High Street." –*The Cincinnati Enquirer*

LAWRENCEBURG, INDIANA. GREAT FLOOD OF JANUARY 1937.

PHOTO. BY DAN HOBY

## January 22, 1937

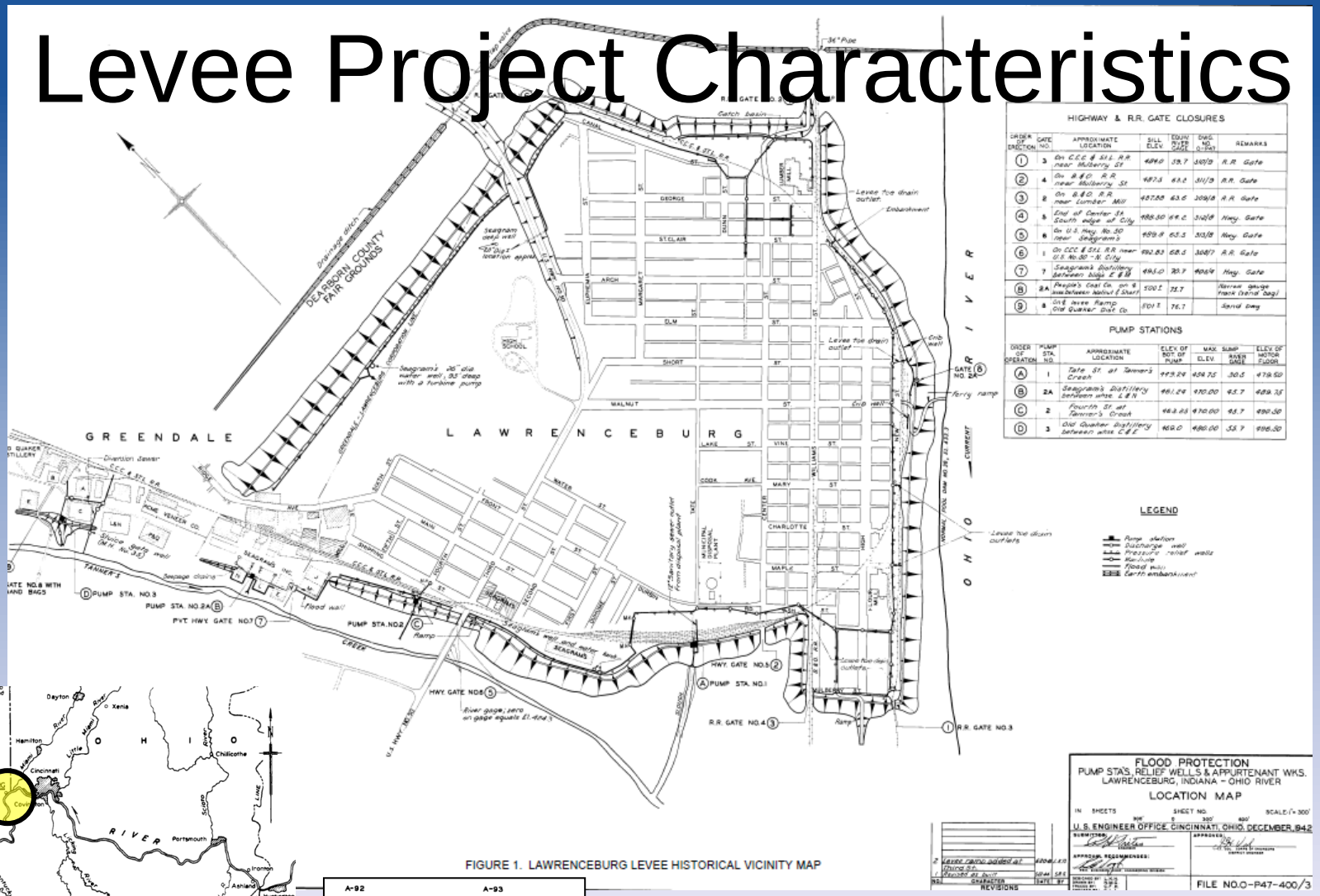
"Half of 7,000 residents of city flee to higher ground as river pours through recently completed flood embankment." –*The Cincinnati Enquirer*

**January 24, 1937**: "The water tonight stood at 74 feet, one foot higher than the levee."

## A New Levee

The Lawrenceburg Flood Protection Project was originally designed and constructed from 1940 to 1944 under the direction of the U.S. Army Corps of Engineers, Cincinnati District. It consists primarily of earthen levees reaching a maximum height of 44 feet along a combined length of about 18,300 feet. With the crest of the levee elevation ranging between about 500.0 ft to 504.0 ft above sea level, it includes access openings (four traffic gate openings, two railroad date openings), five pumping plants and a system of 173 uplift pressure relief wells along the landside toe of the earth embankment levee segments.

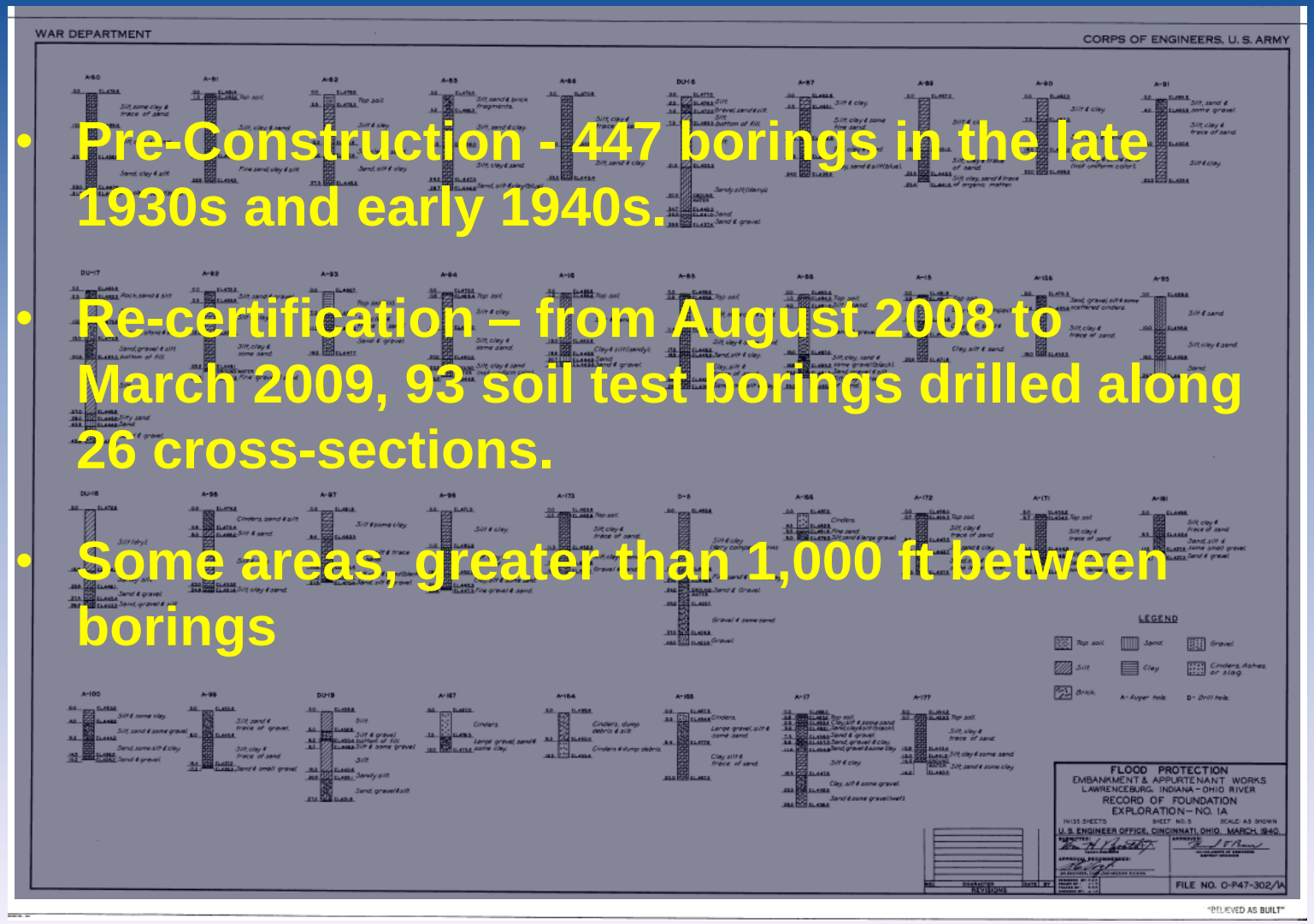
# Levee Project Characteristics



# Levee Project Characteristics

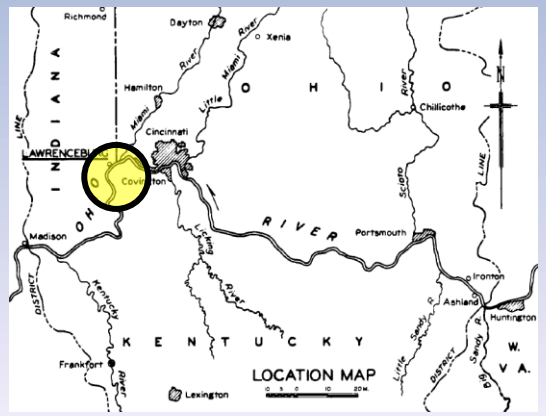
- **Existing System** - designed and constructed from 1940 to 1944 under the direction of the U.S. Army Corps of Engineers, Cincinnati District
- **Substantial System** – about **18,300 ft in length**, with max. height of 44 ft; wraps around the city.
- **Flood Control** – access openings (four trafffic gates, two railroad gates, 5 pumping stations, 173 pressure relief wells along landside toe.
- **Relief Well Spacing** - 50 to 150 ft, penetration ranges from 6 to 17 percent into the aquifer.

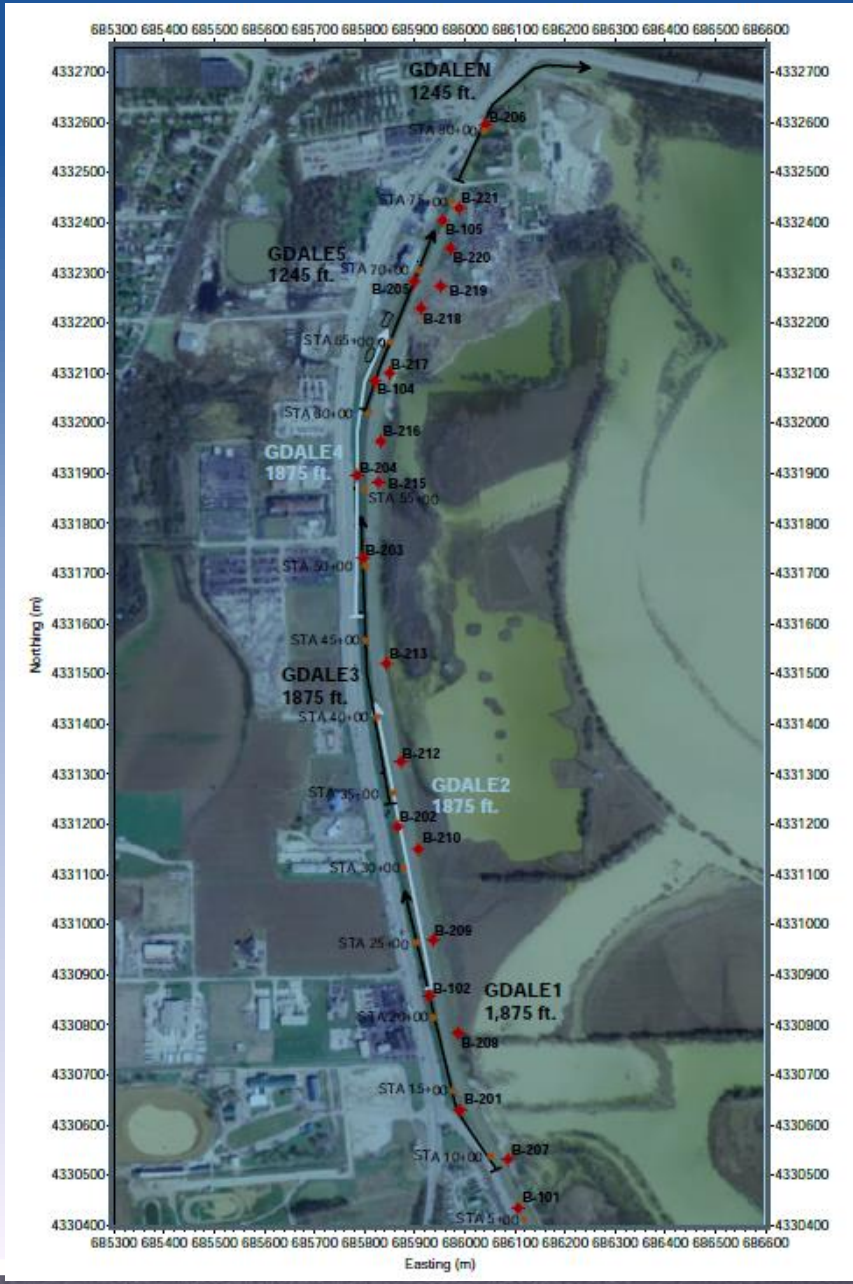
# Subsurface Investigations




- Pre-Construction - 447 borings in the late 1930s and early 1940s.
- Re-certification – from August 2008 to March 2009, 93 soil test borings drilled along 26 cross-sections.
- Some areas, greater than 1,000 ft between borings

# Greendale Levee



# Geophysical Survey

- **Confirm levee/geologic conceptual site model:** Concerned with levee and geology variability over more than 7 miles distance.
- **Locate potential areas of concern for redesign or modification:** Levee material and pervious foundation zones of higher flow/permeability; locate existing zones of potential preferential flow pathways (e.g., developing sand boils).
- **Recommend levee operation and maintenance program based on results:** Inspection, relief well improvement/replacement; river level/water level monitoring, priority ranking.

# Geophysical Survey
# 2D Electrical Resistivity

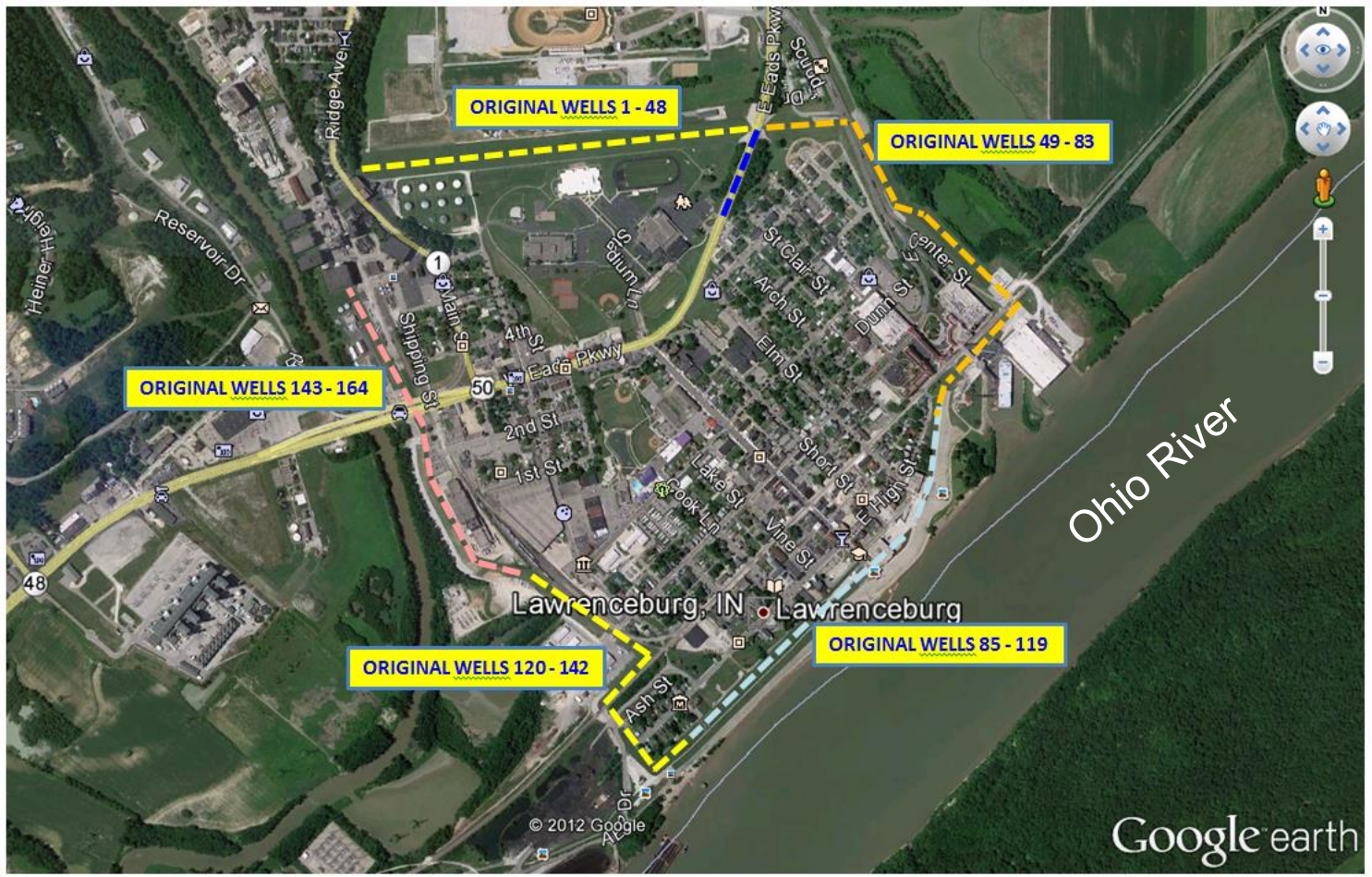
## Data Collection

- **AGI Supersting R8 Earth Resistivity Meter**
- **dipole-dipole array of 56 to 84 electrodes**
- **3 to 4 m electrode spacing**

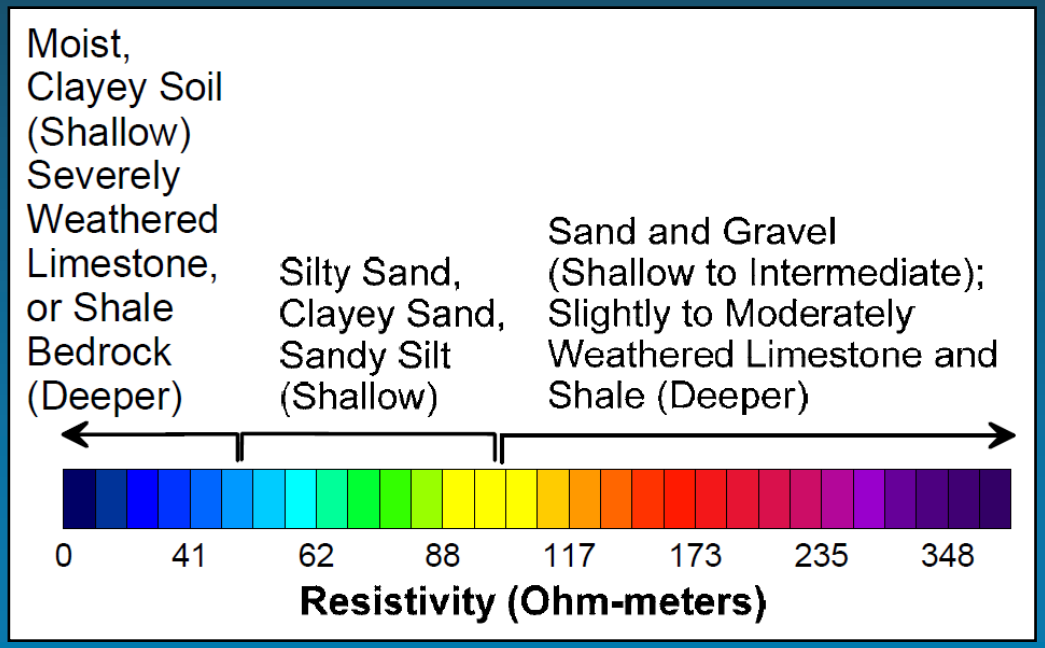
## Data Analysis

- Data inversed-modeled using the software EarthImager v. 2.4 to obtain “actual” true resistivity cross-sections of the subsurface.

# Lawrenceburg Levee System



# Resistivity Color Scale




## Material Types

**BLUE**

Clayey soils (shallow)
Shale/weath. LS (deep)

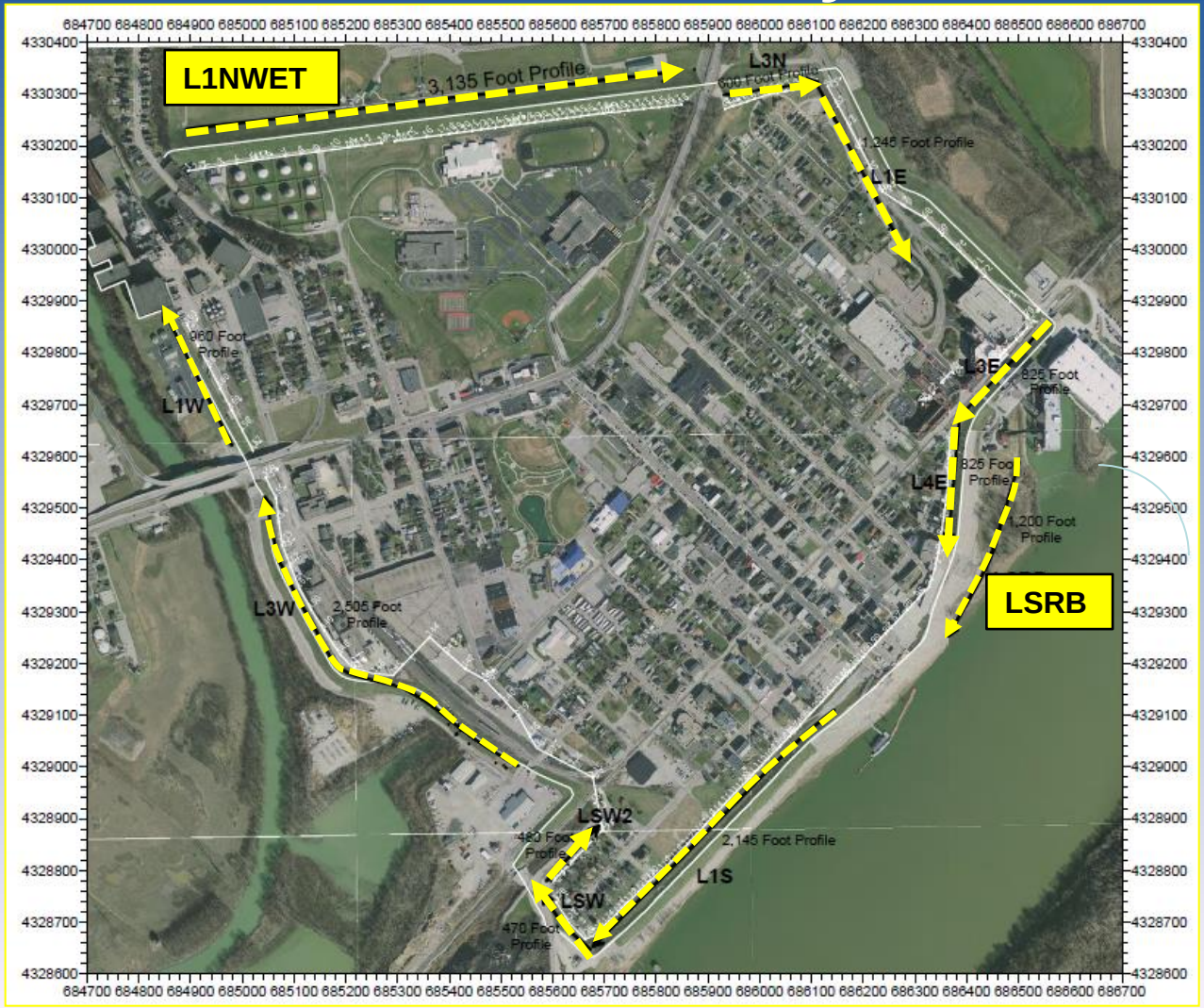
**GREEN and YELLOW**

Silty sands/Clayey Sands

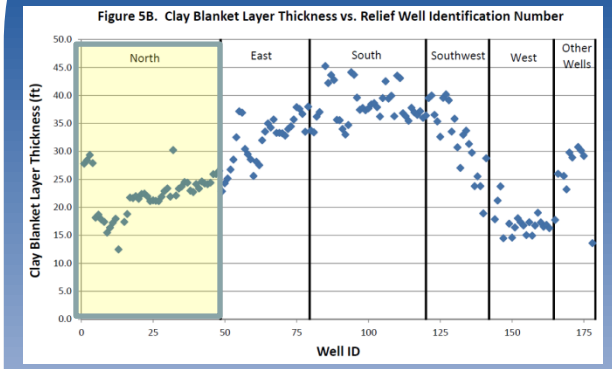
**YELLOW and RED**

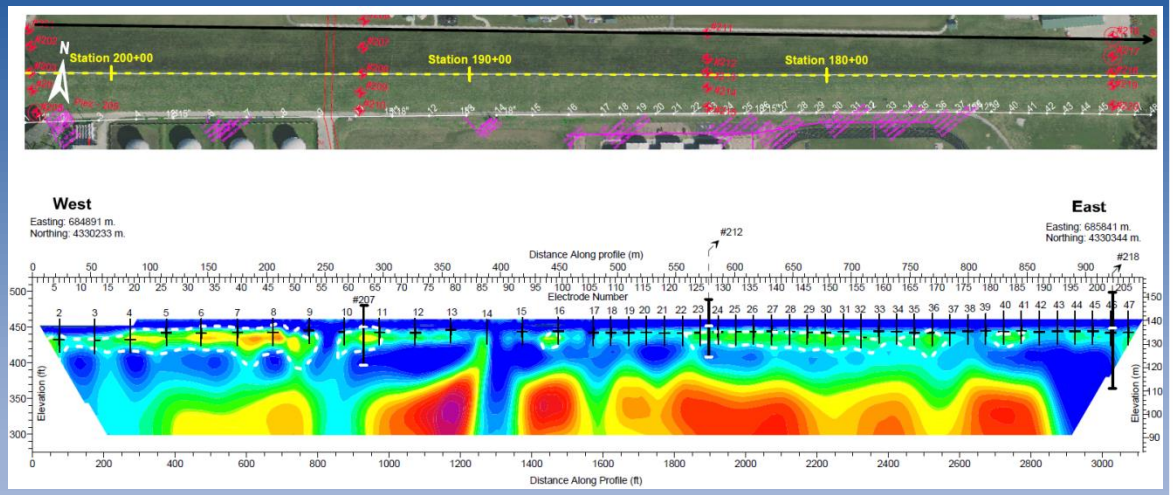
- Sand and gravel

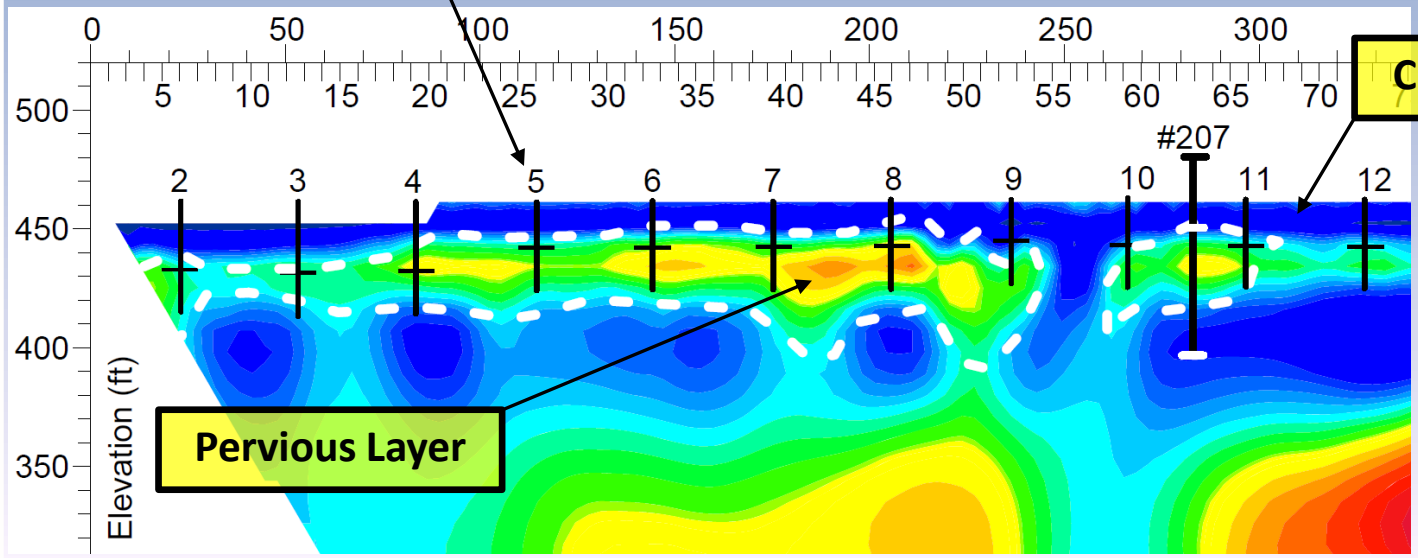
# Lawrenceburg Levee
# 2D- Electrical Resistivity Profile Lines



# Geophysical Survey – North Levee



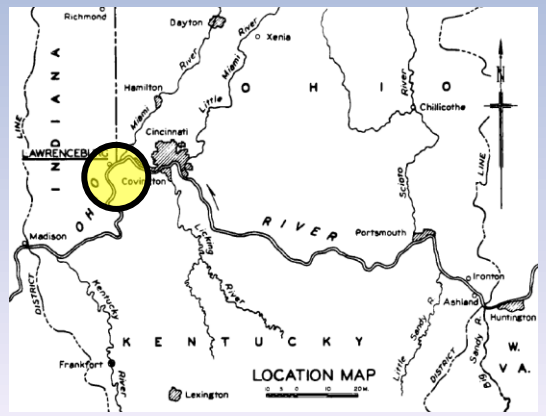



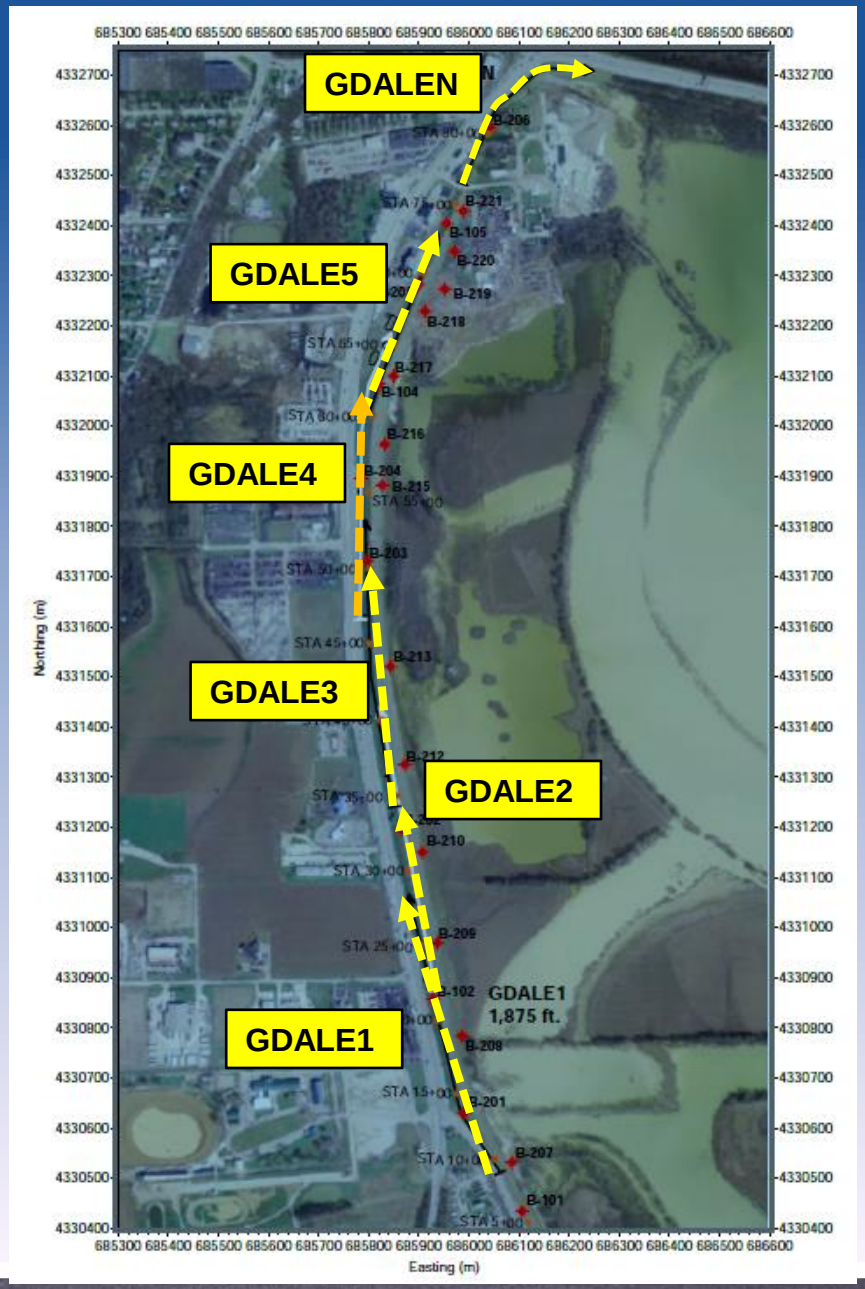




- Clay Blanket
- Pervious Layer
- High permeability zones

# Greendale Levee

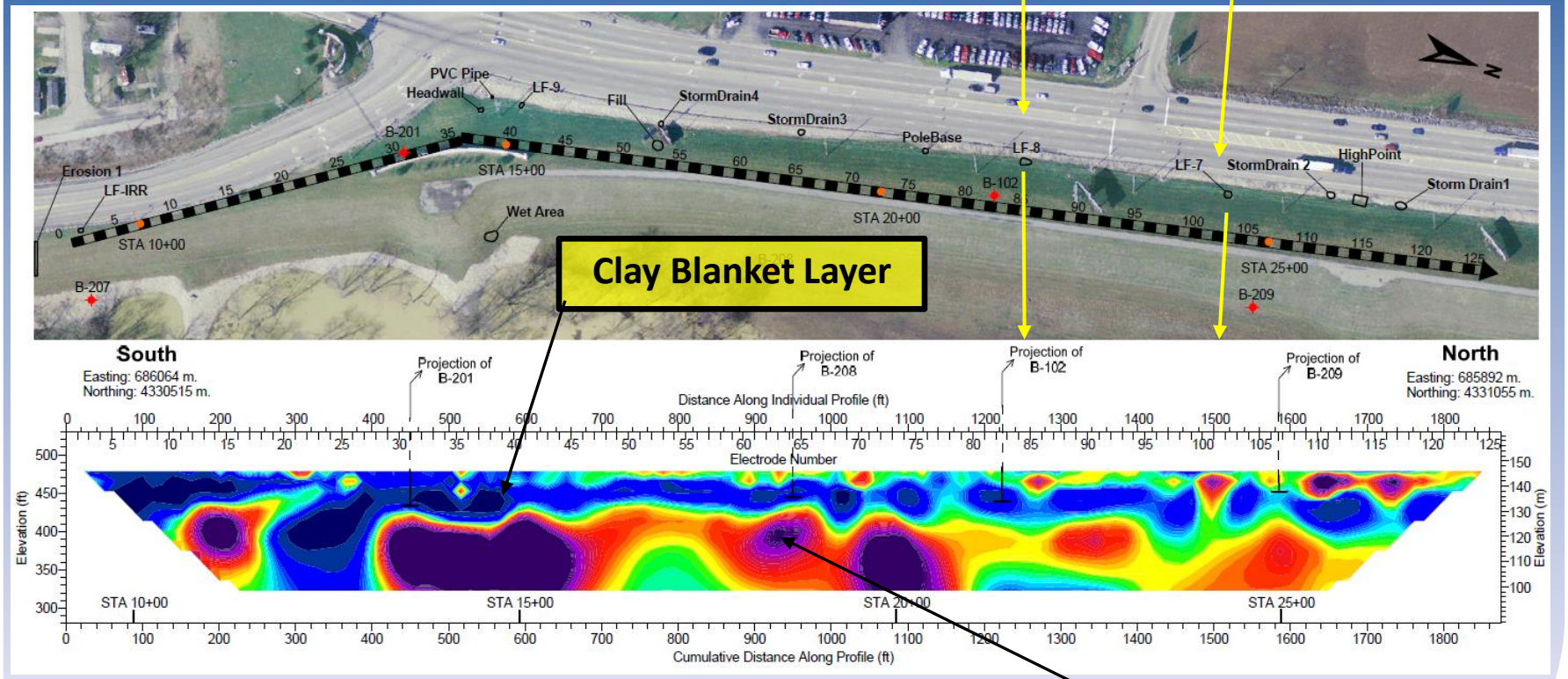
## 2D-ERI
## Terrain Conductivity



# Resistivity Profile Line GDALE1

**Developing Sand Boils**

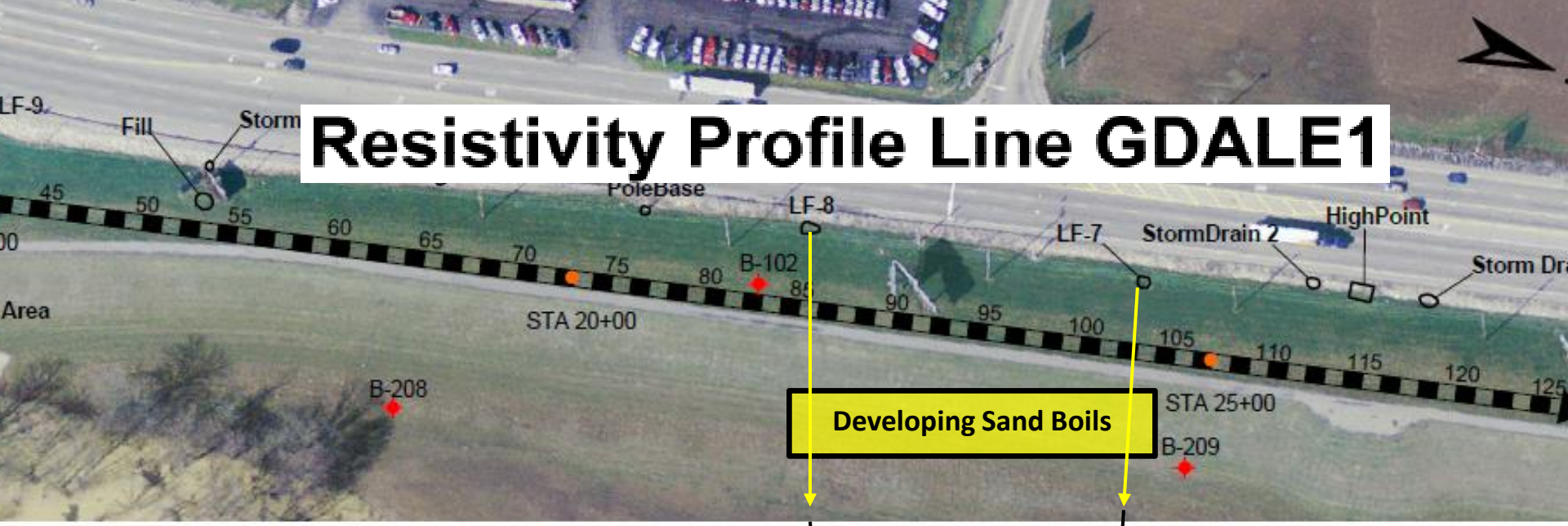


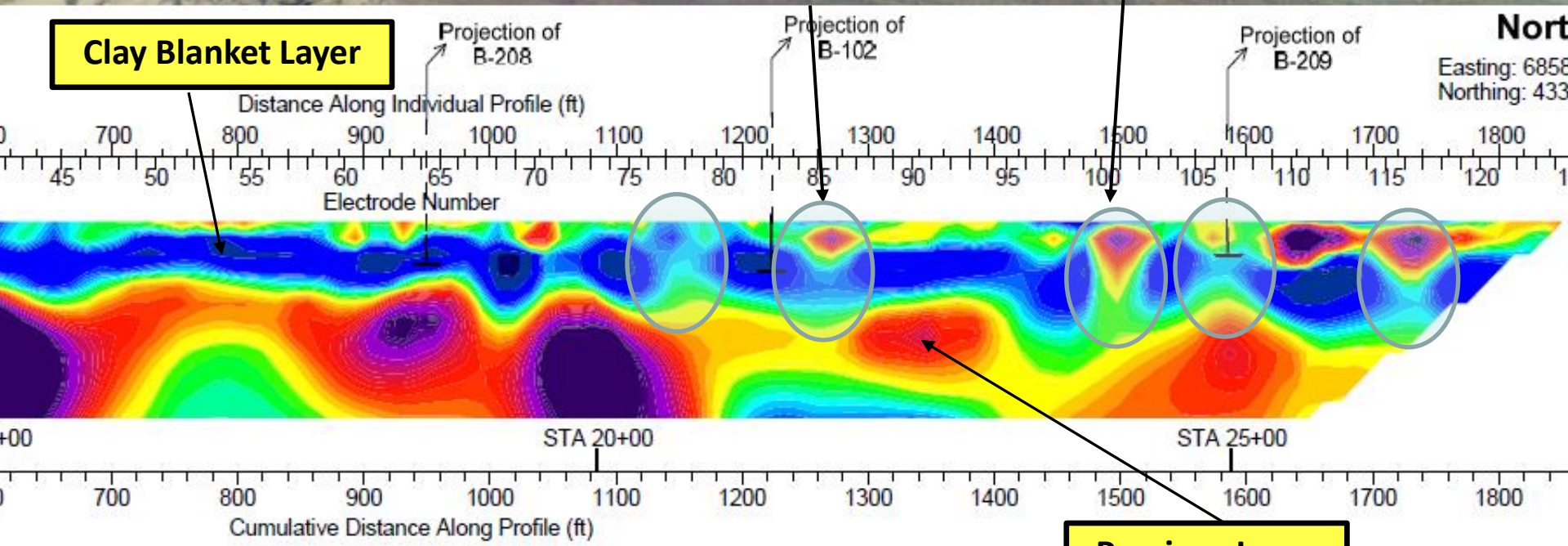

**Clay Blanket Layer**

**Pervious Layer**

**Observations: Increased shallow granular zones toward the North; some evidence of lack of continuity of the clay blanket layer toward the north; observations of potential developing sand boils near northern end of profile.**

# Resistivity Profile Line GDALE1

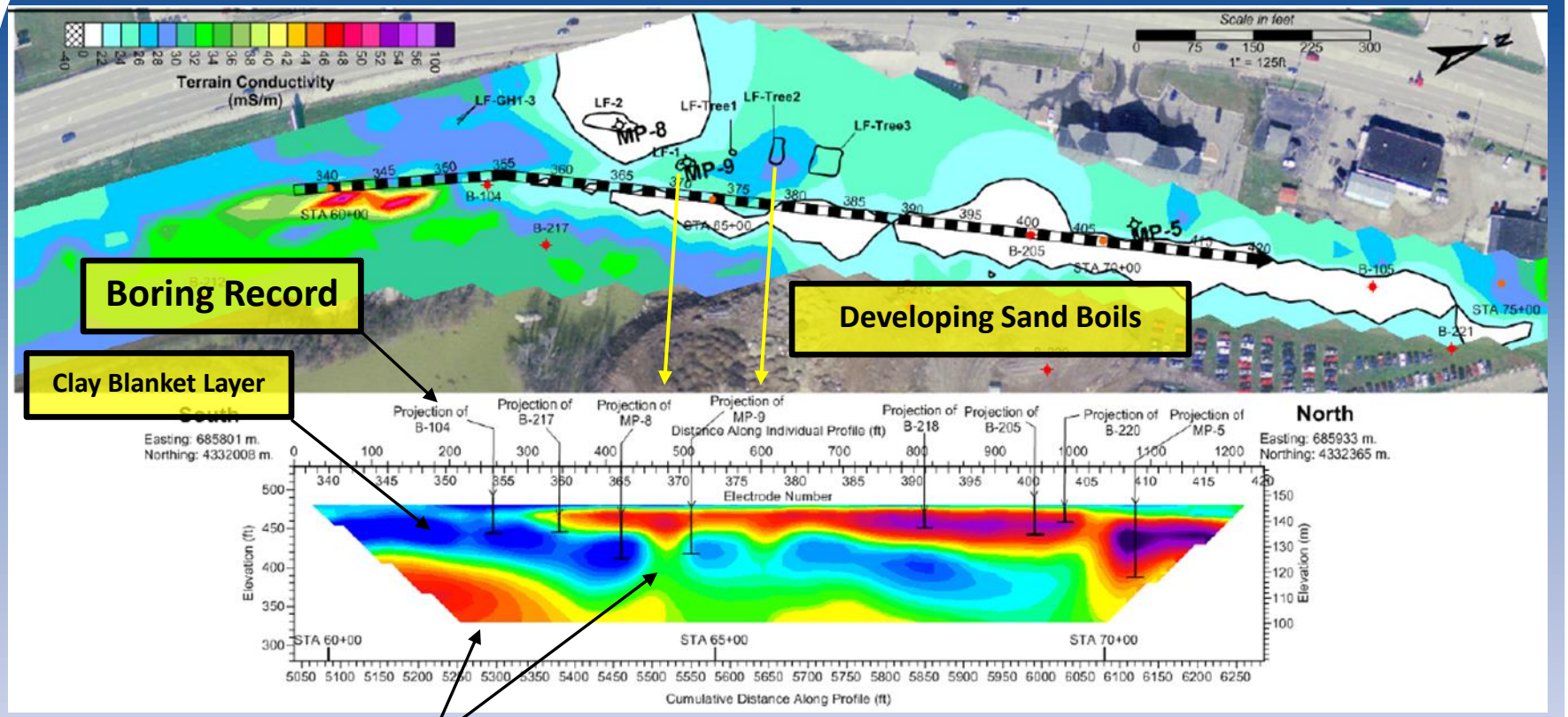


# Resistivity Profile Line GDALE1

**Levee Feature 7 (LF-7):** Surface depression (right of stake) along the dry side of the levee. According to the LCD, this depression is in line with the fiber optic cable.

# Resistivity Profile Line GDALE5




**Boring Record**

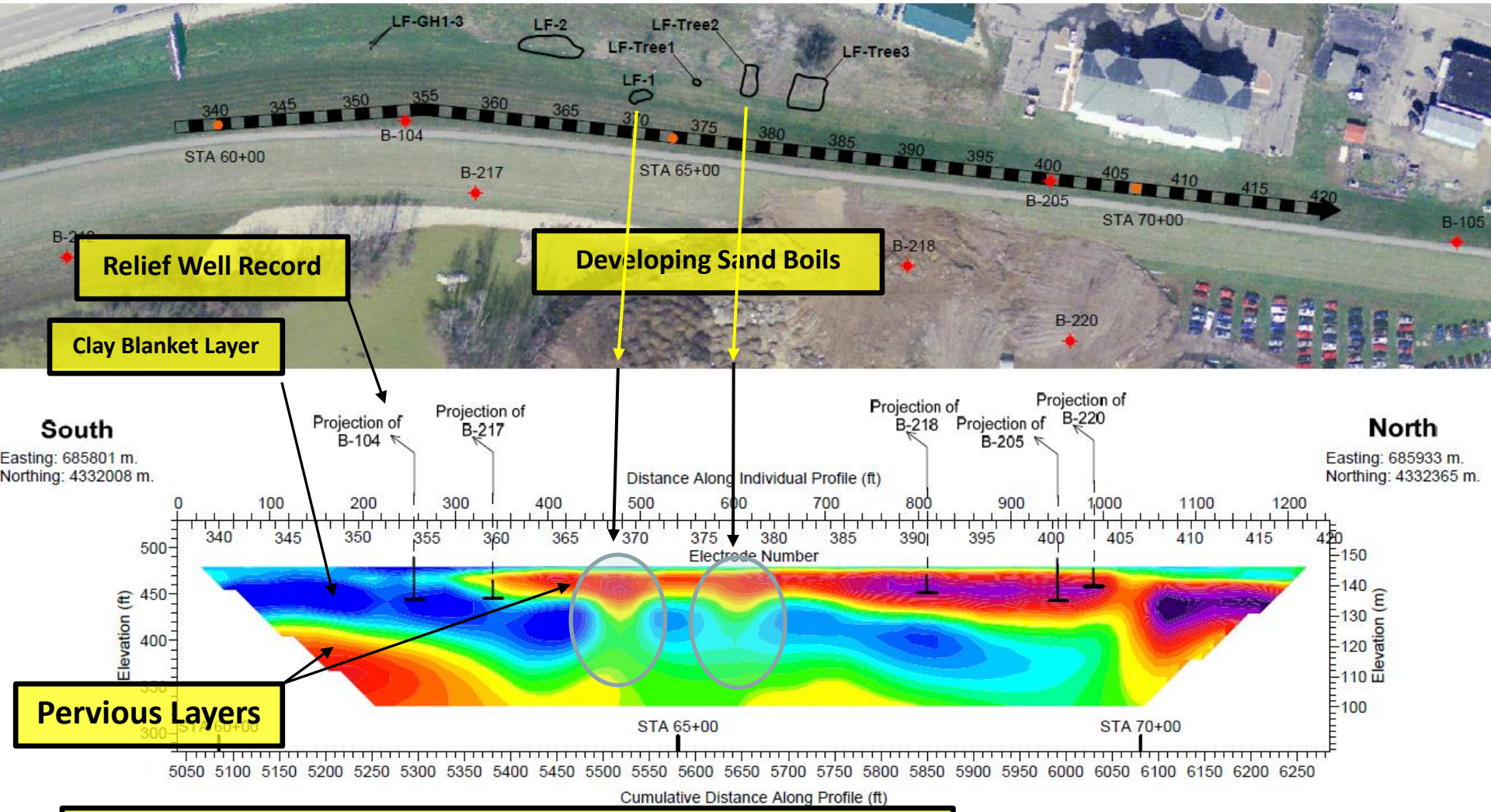
**Clay Blanket Layer**

**Developing Sand Boils**

**Pervious Layers**

**2D Resistivity Profile with Borings Provides Continuous Upper Blanket Thickness and high resistivity lower pervious zone**

# Resistivity Profile Line GDALE5




**2D Resistivity Profile with Borings Provides Continuous Upper Blanket Thickness and high resistivity lower pervious zone**

# Resistivity Profile Line GDALE5


**Levee Feature 1 (LF-1):** Depression along dry side of levee

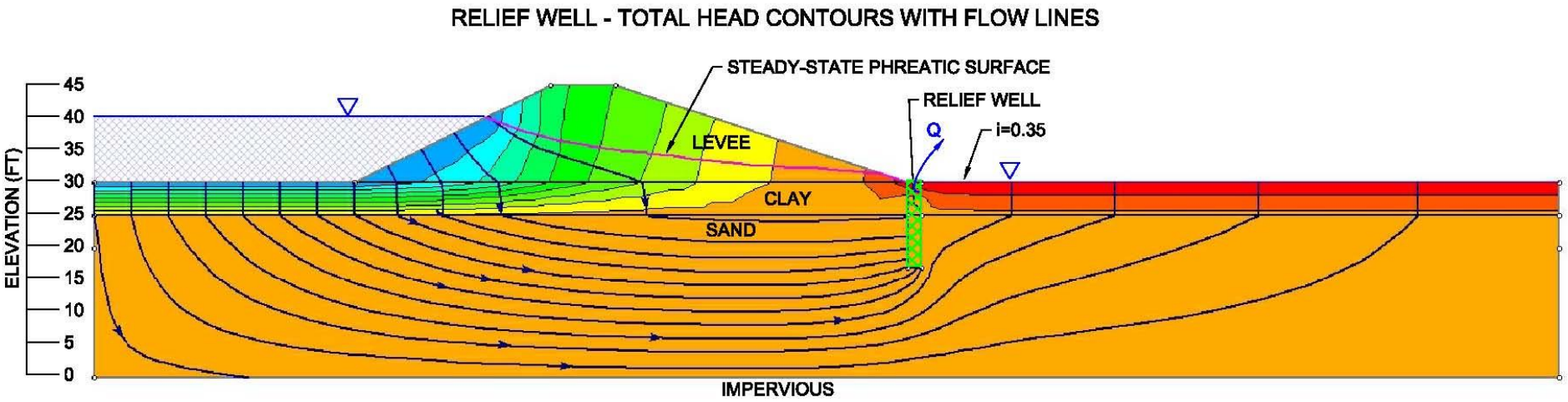
# Resistivity Profile Line GDALE5

**Levee Feature Tree 1 (LF-Tree1):** Surface depression along the dry side of the levee. The depression can be seen where the white pole is protruding from the ground. According to the LCD, the property line is at the turf/cornfield interface.

# Conclusions

- Geophysics was critical for confirming the accuracy of the results of past historical investigations.
- Geophysical results indicated the likely location of levee construction defects.
- The results identified the locations of developing sand boils and areas of maximum discharge.
- Provided optimal locations for ongoing levee water level monitoring during flood events.
- Provided critical understanding of areas during upgrading and repair.

# THANKS!

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