Ohio River Levee Performance Evaluation under Flood Conditions

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Consulting Professionals
for the Earth and the Environment

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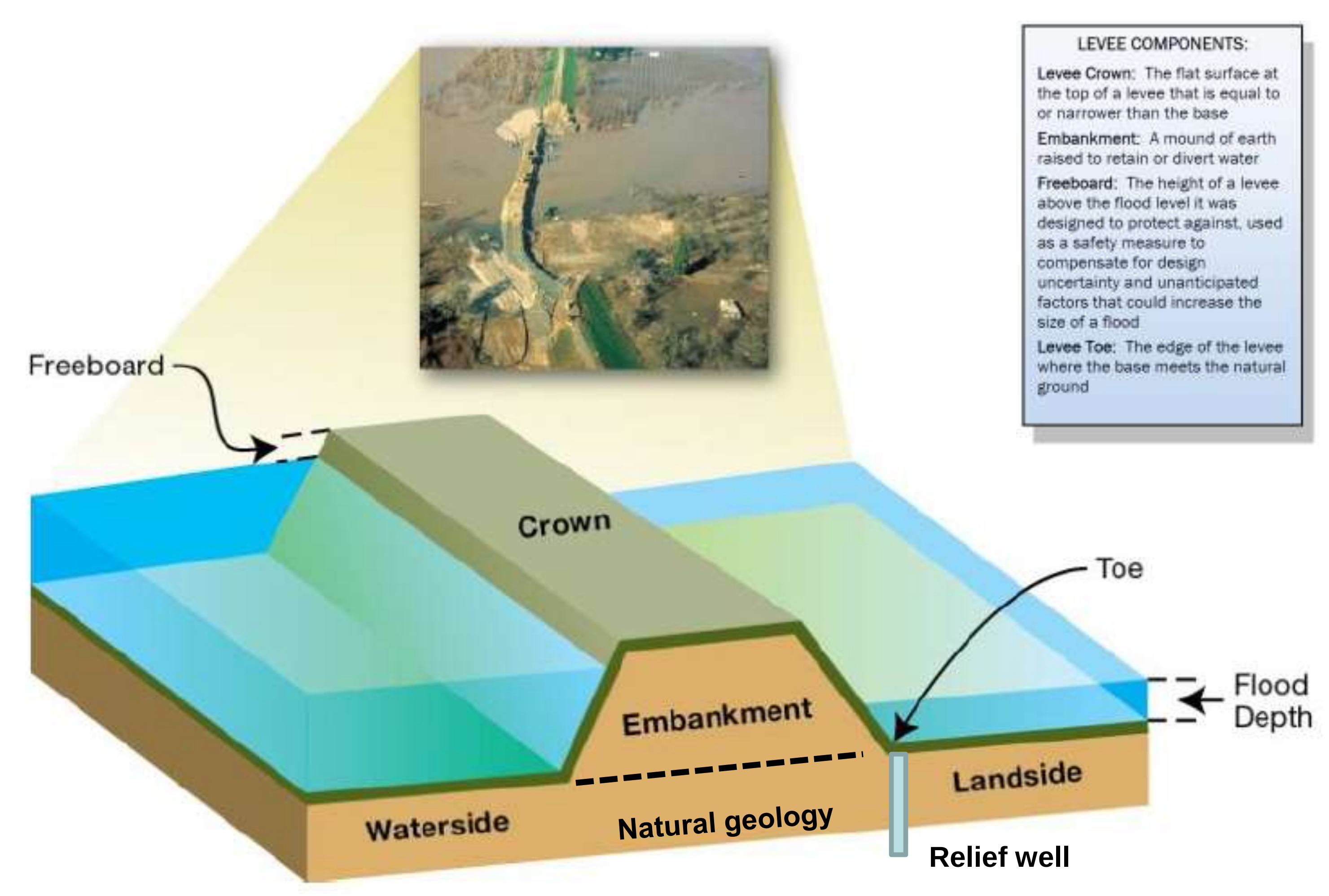
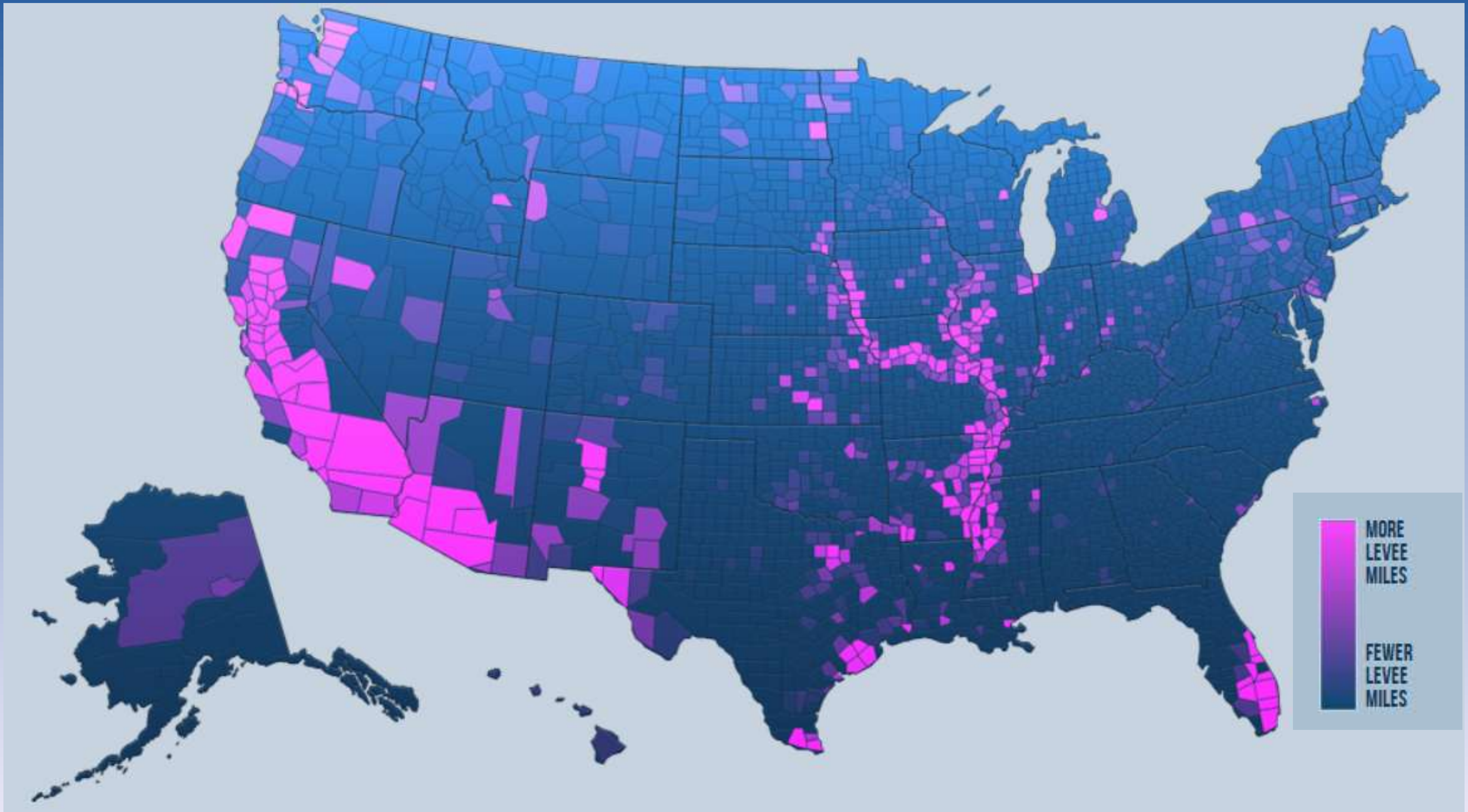
What is a Levee?



"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)

Levee Systems in the United States



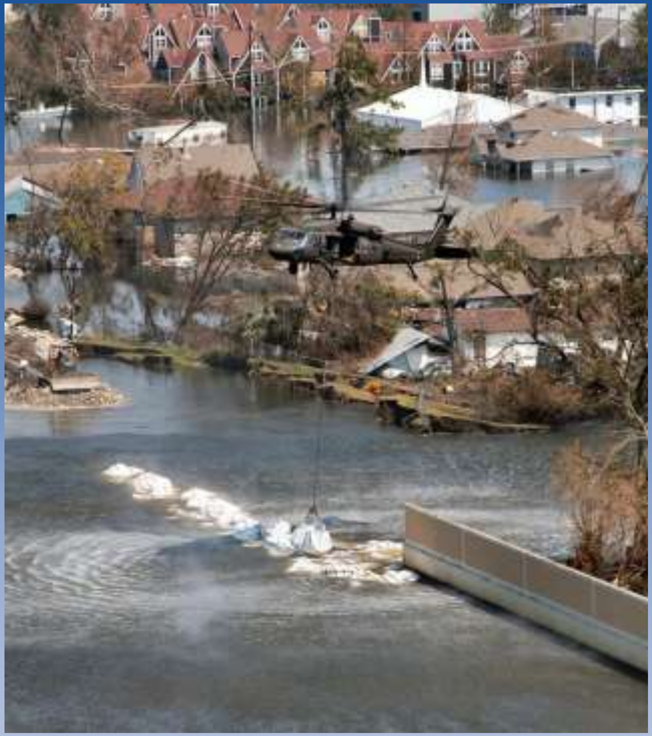
Federal Emergency Management Agency's Midterm Levee Inventory as of July 2012.

Levee Systems in the United States

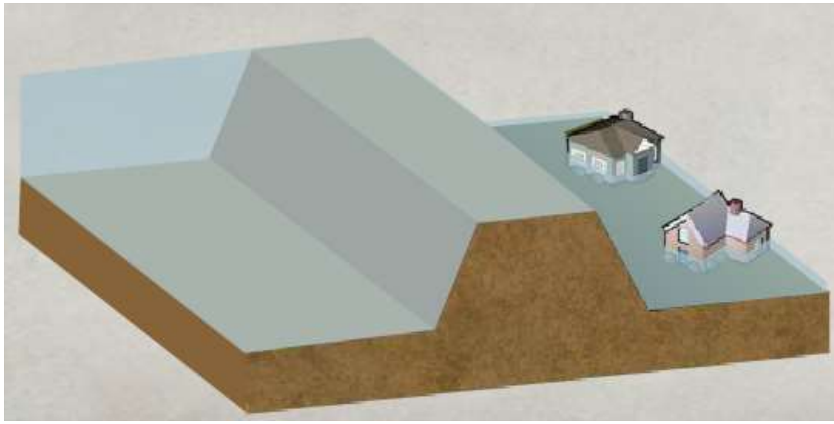
Factoids:
- **100,000+ miles of levees in all 50 States**
- **Nearly 85 % are locally-owned, operated and maintained.**
- **ASCE Grade D- infrastructure report**
- **Public safety at risk with tens of millions living and working in protected areas**
- **Repair and rehabilitation estimated at $100 billion**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

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

Levee Failures



Failure Modes

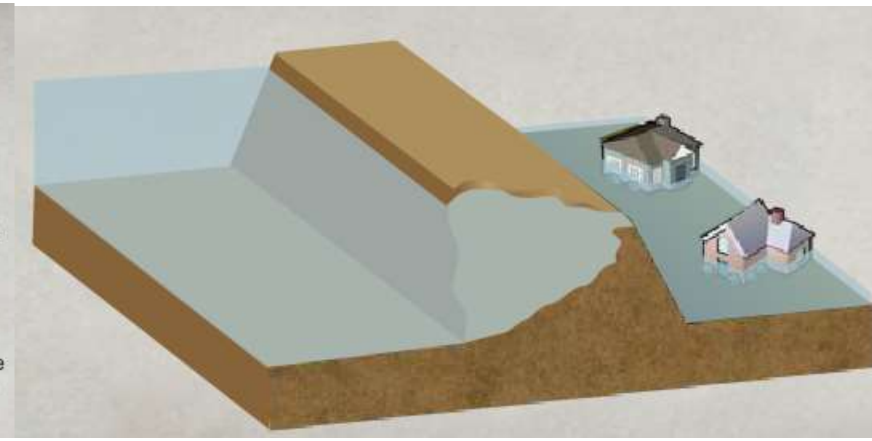


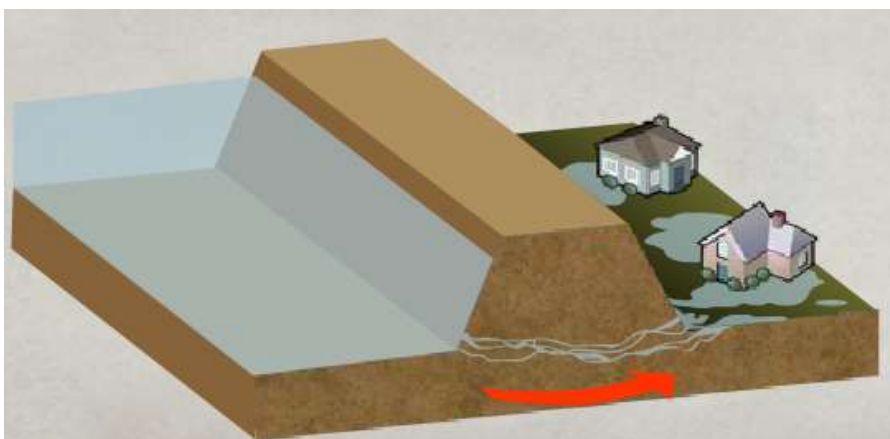
OVERTOPPING

After a heavy rain, floodwaters often rise. At times, river levels can rise to a point where they're higher than a levee's crown. As water begins to flow over its crown, the area intended to be protected will flood.

BREACHING

Breaching occurs when part of a levee gives way, creating a hole for floodwaters to pass through. A hole in a levee can be the result of burrowing animals, erosion, or slumps and cracks in the levee. Once water levels rise, the levee's weakened banks begin to erode. The levee's holes eventually turn into gaps, and as the pressure mounts, entire sections of the levee can give way.





SEEPAGE

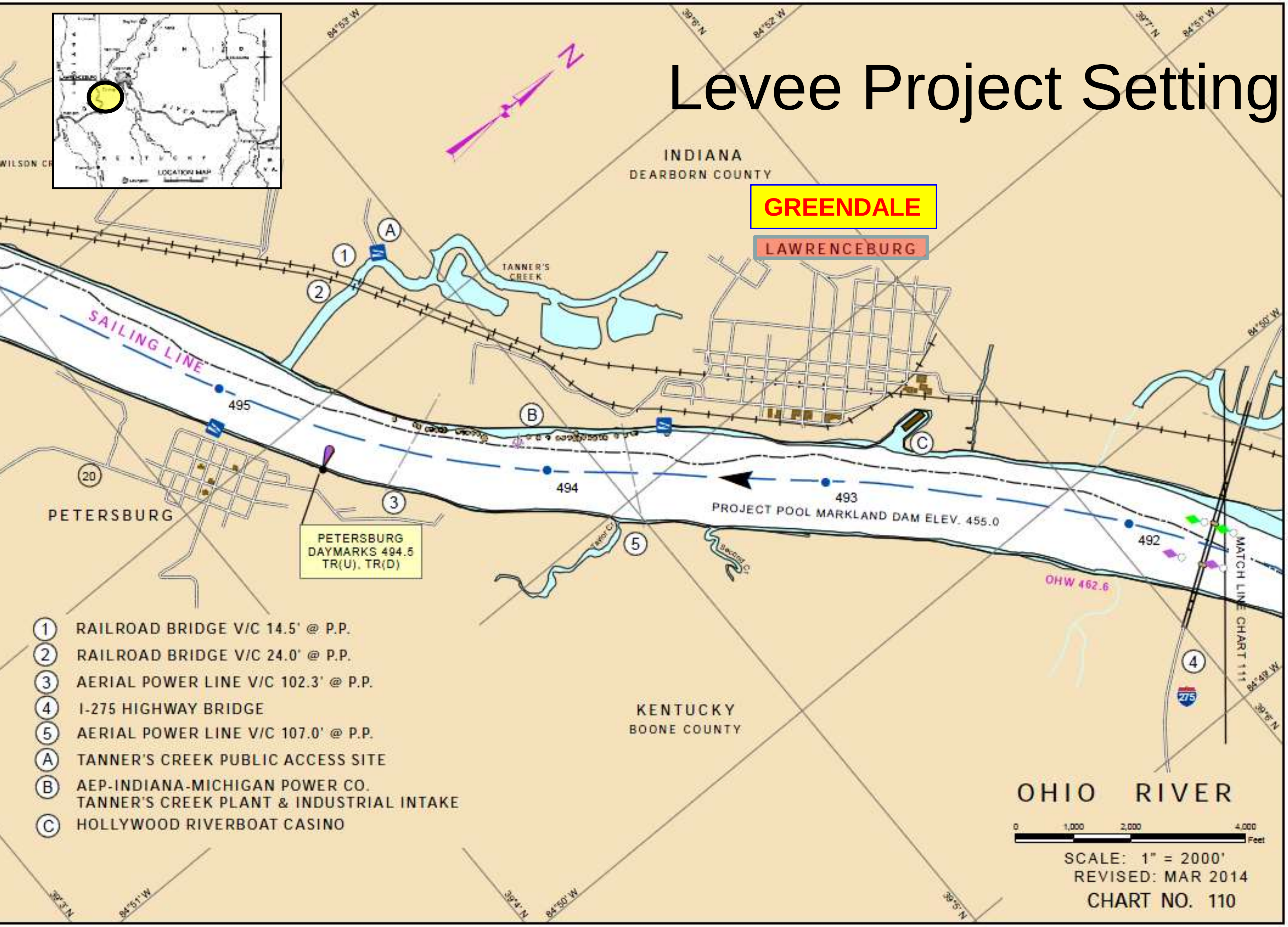
Seepage occurs when, over time, water begins to seep under or through a levee, creating weak spots in its structure. The first signs are puddles of standing water on the inboard side of the levee. Sand boils, bubbling springs at the base of the levee, also begin to form, causing the soil to become unstable,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

Seepage

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; encroachments, etc.

Levee Project Setting



History of the Lawrenceburg Levee

Lawrenceburg Flood Protection Works

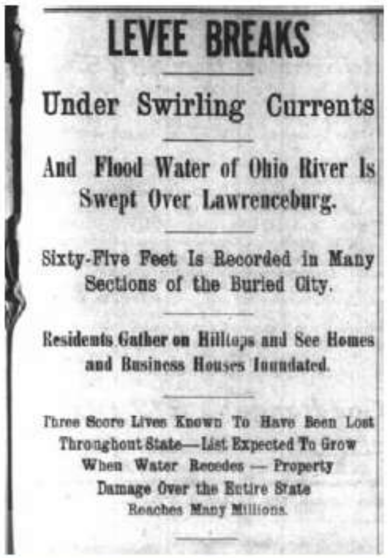
Town Hall Bell Warns Residents;
Lawrenceburg Loses Flood Fight

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*

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.

January 22, 1937

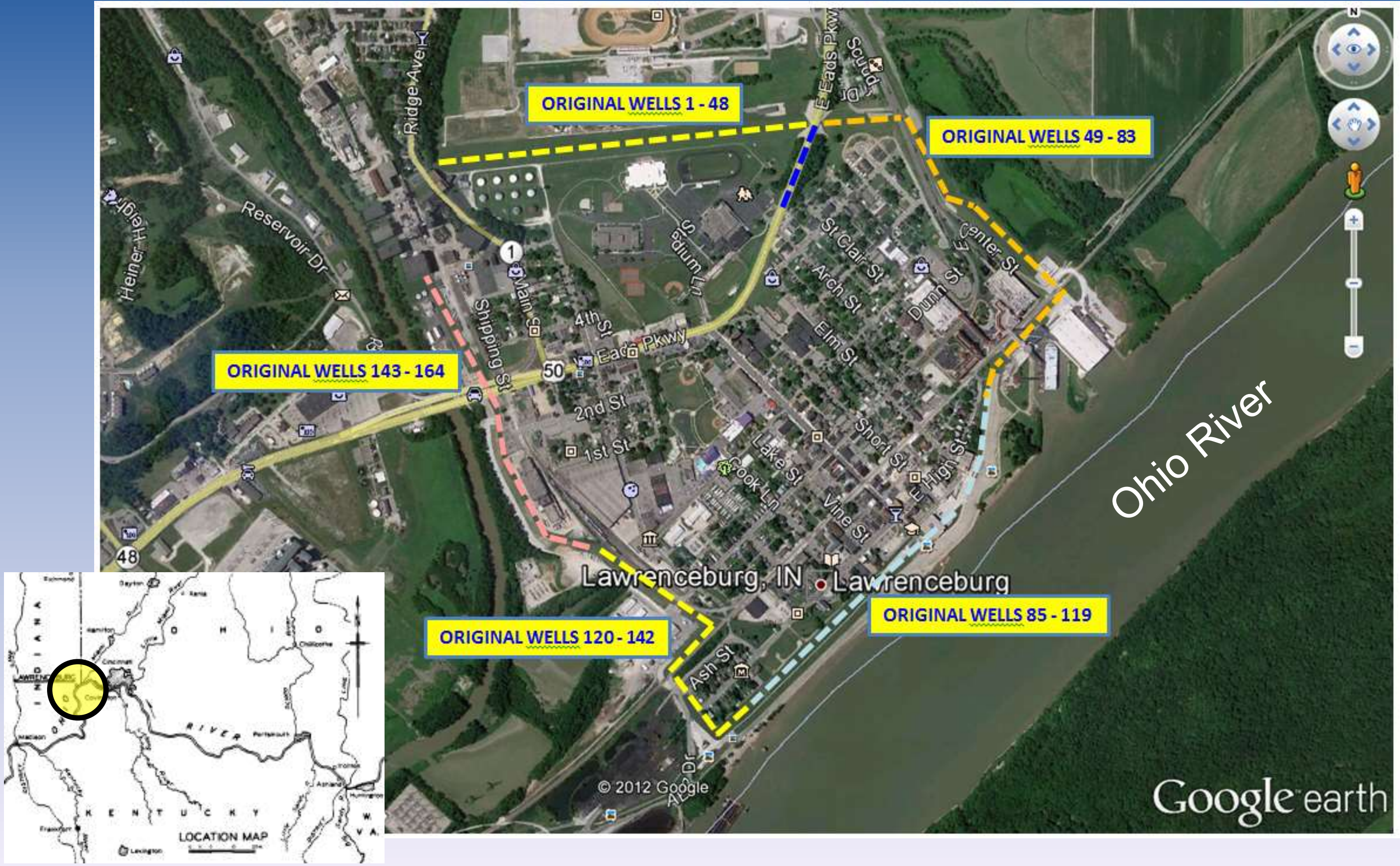
"Half of 7,000 residents of city flee to higher ground as river pours through recently completed flood embankment." –*The Cincinnati Enquirer*

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.

Lawrenceburg Levee System



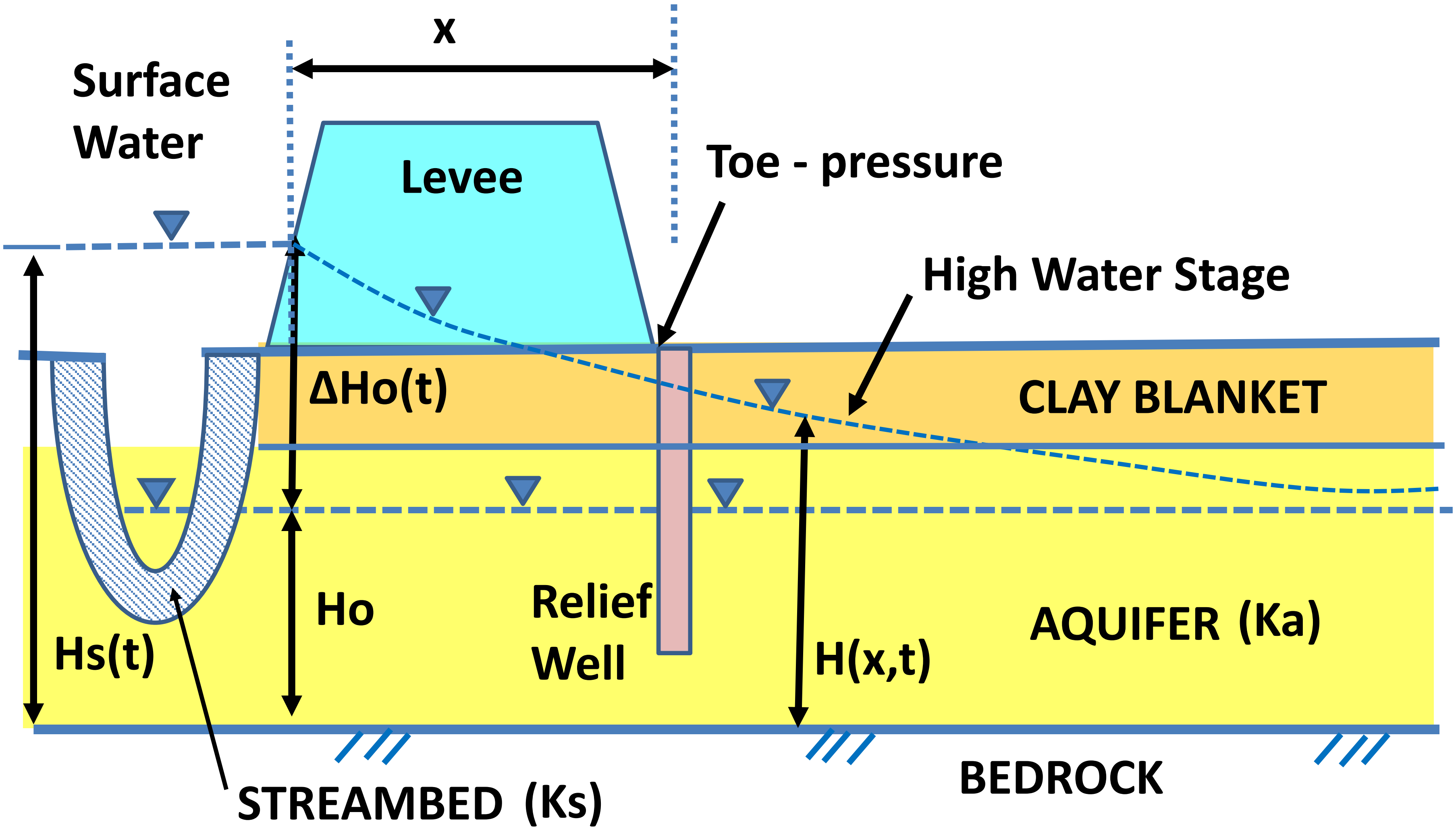
Levee Project Characteristics

- 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.

- Well spacing from 50 to 150 ft, penetration ranges from 6 to 17 percent into the aquifer.

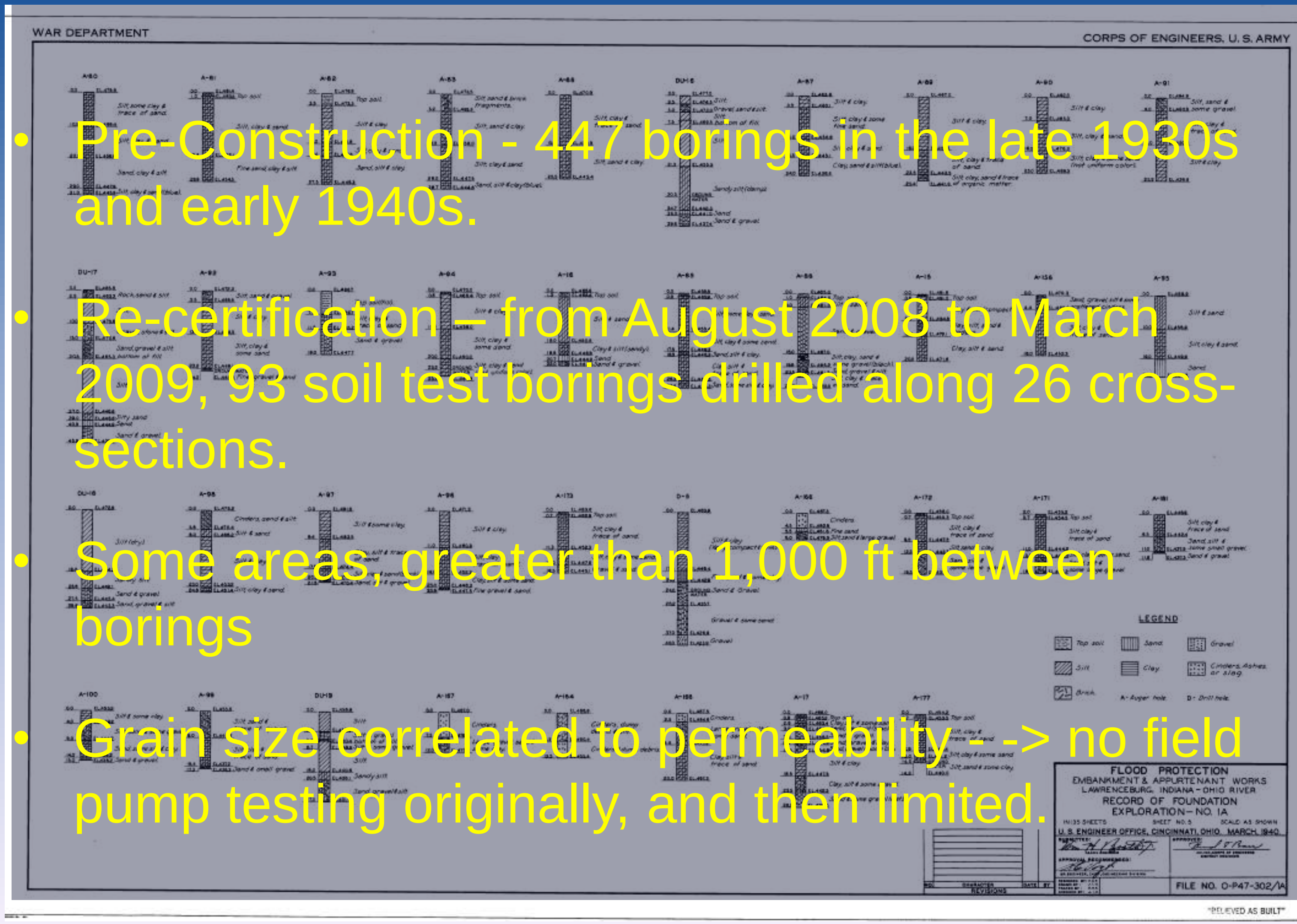


CONCEPTUAL SITE MODEL

Challenges Encountered During Evaluation

- **Geologic Setting and Scale:** Variability of alluvial/glacial deposits; 5 mile length of levee.
- **Lack of Performance Observations:** No documentation of levee inspections, behavior during flood conditions, or water/groundwater levels or flow measurements made historically.
- **Construction/maintenance activities:** No repair or rehabilitation of existing relief well system had occurred.

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
- Grain size correlated to permeability - -> no field pump testing originally, and then limited.

Geophysical Survey
2D Electrical Resistivity

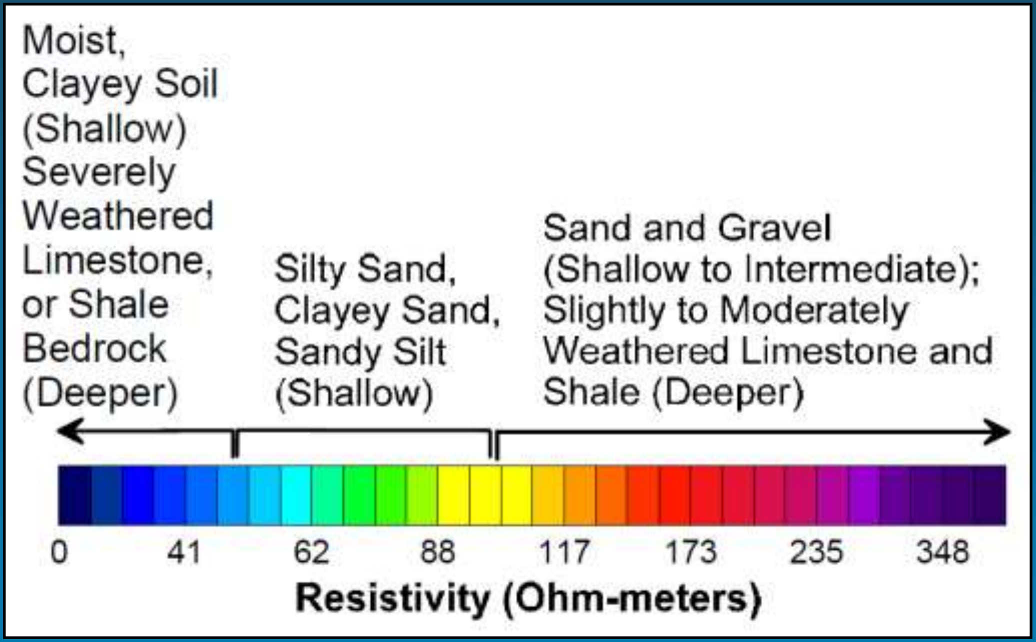
<u>Data Collection</u>

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

<u>Data Analysis</u>

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

Resistivity Color Scale



Material Types

BLUE

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

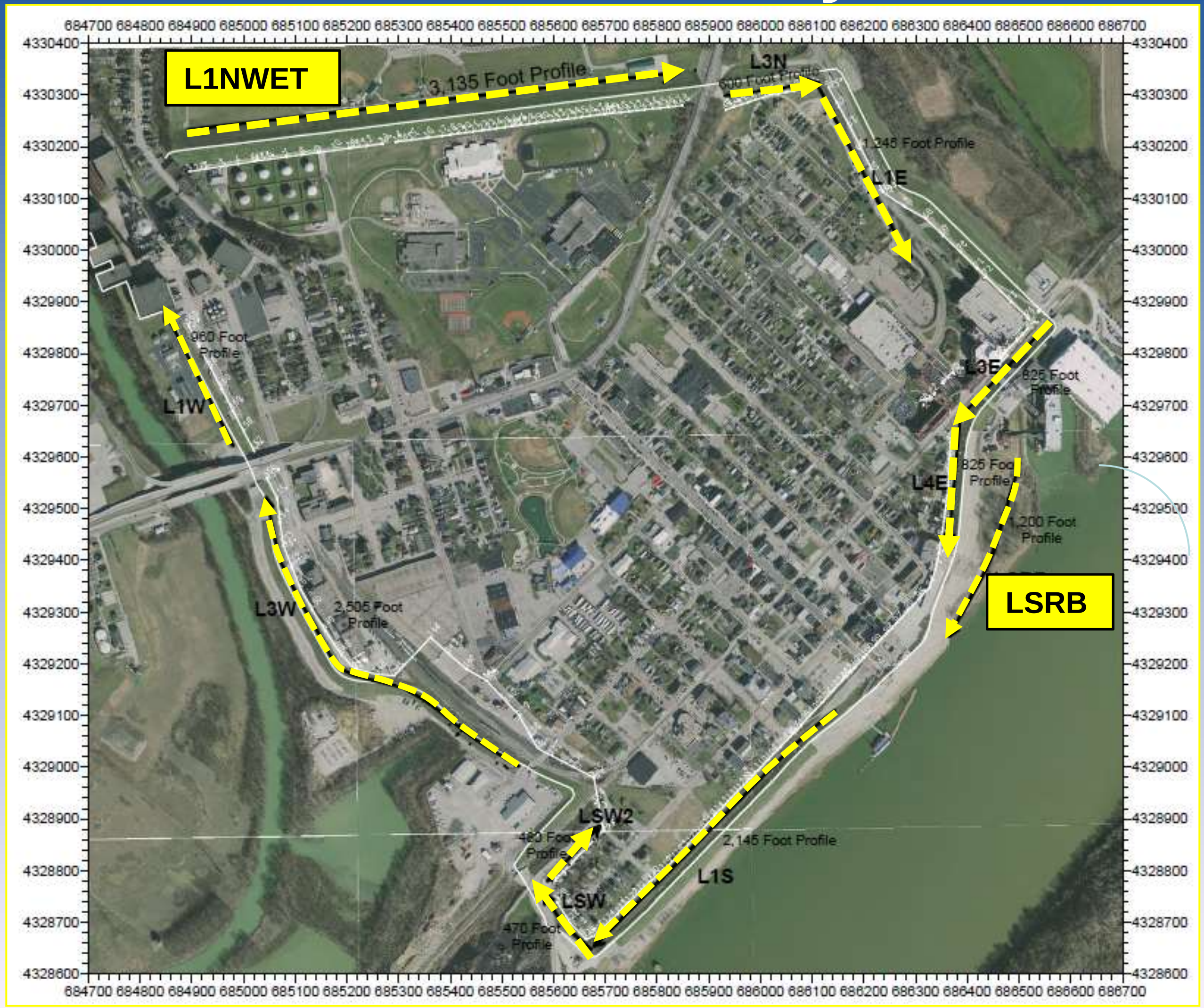
GREEN and YELLOW

Silty sands/Clayey Sands

YELLOW and RED

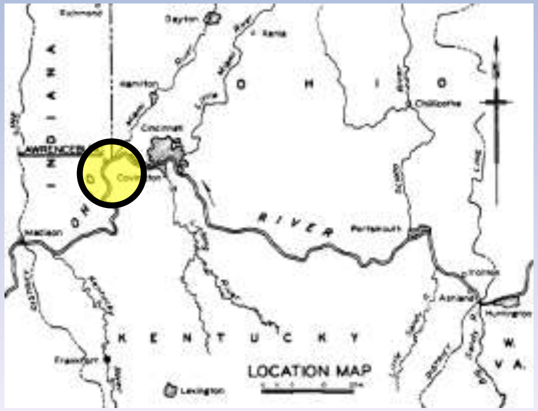
- Sand and gravel

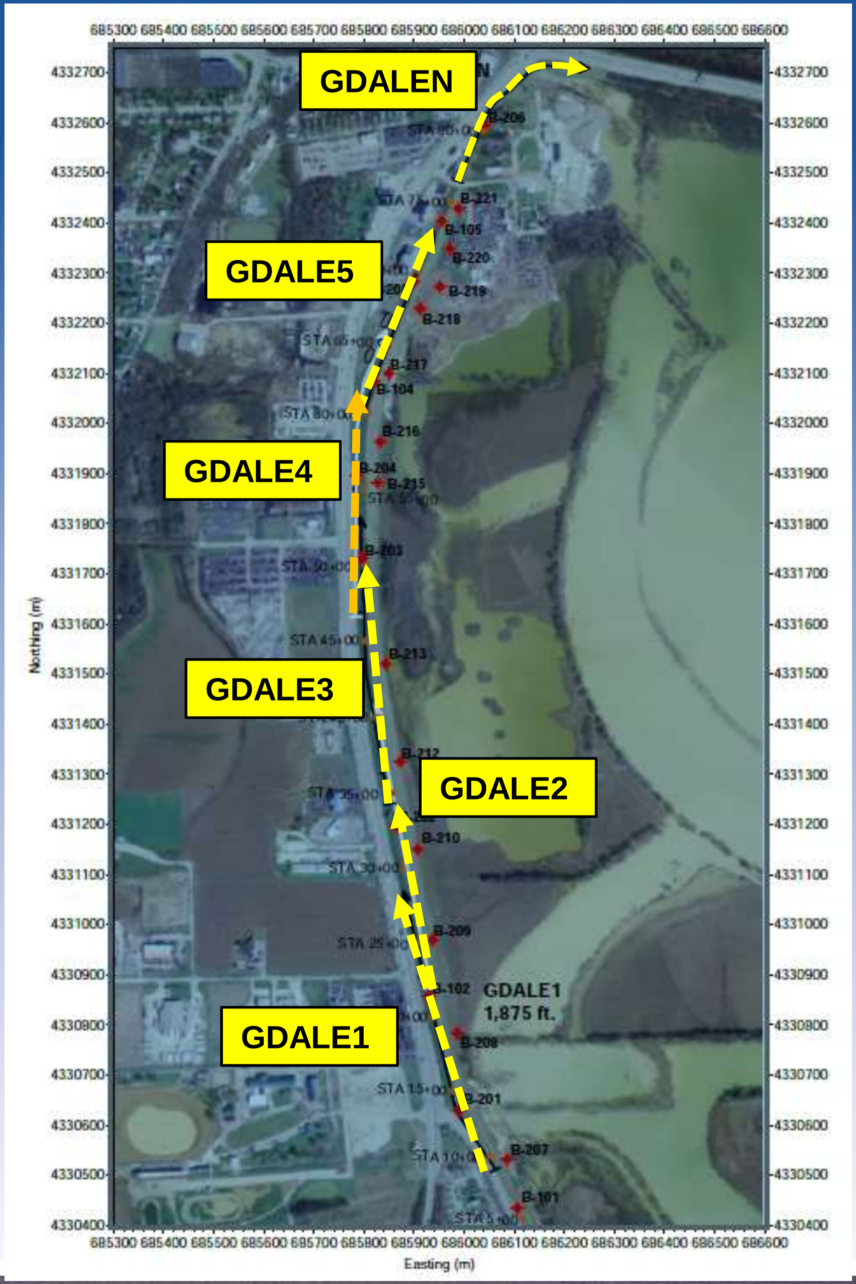
Lawrenceburg Levee
2D- Electrical Resistivity Profile Lines



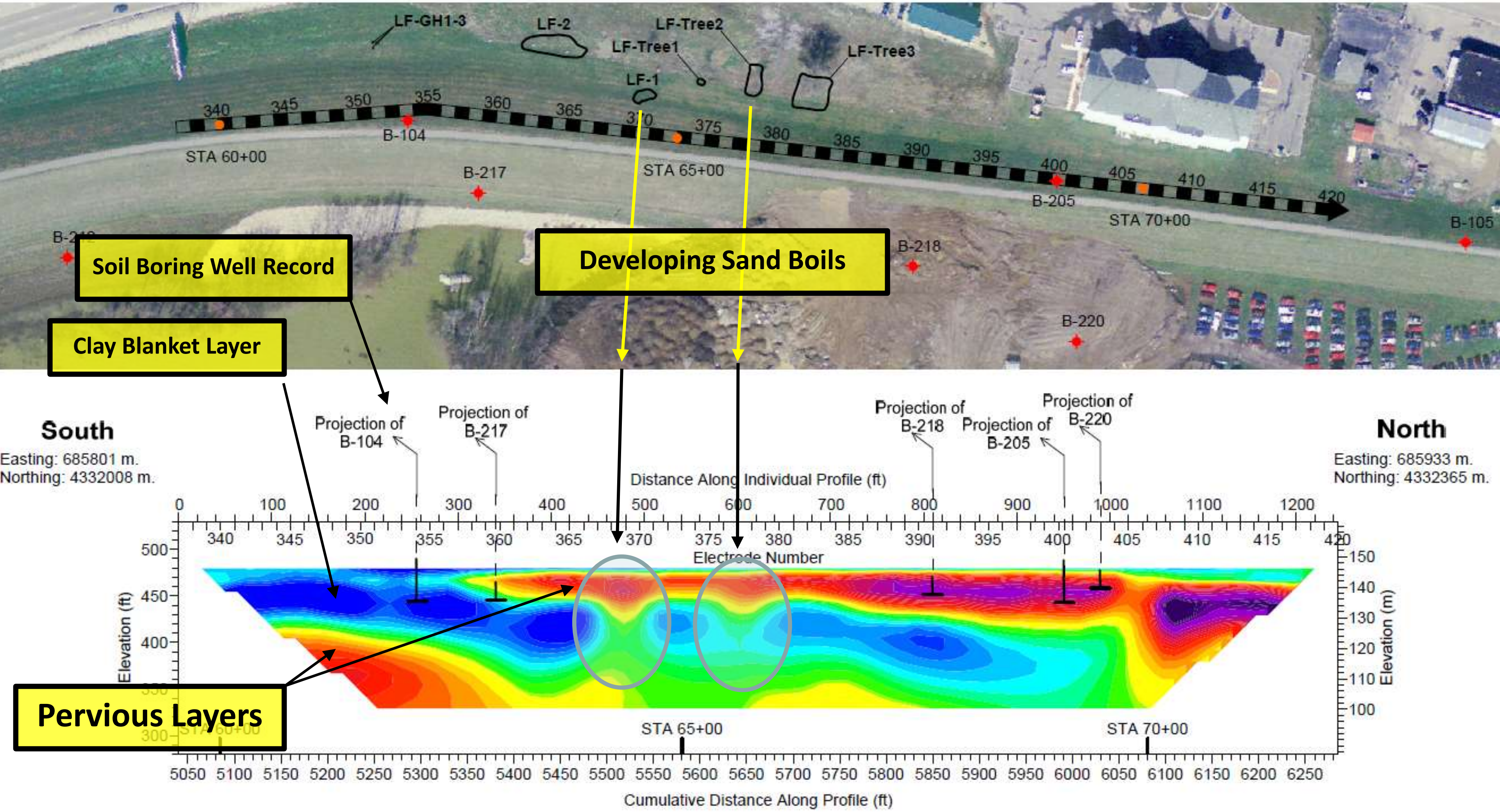
Greendale Levee

2D-ERI
Terrain Conductivity



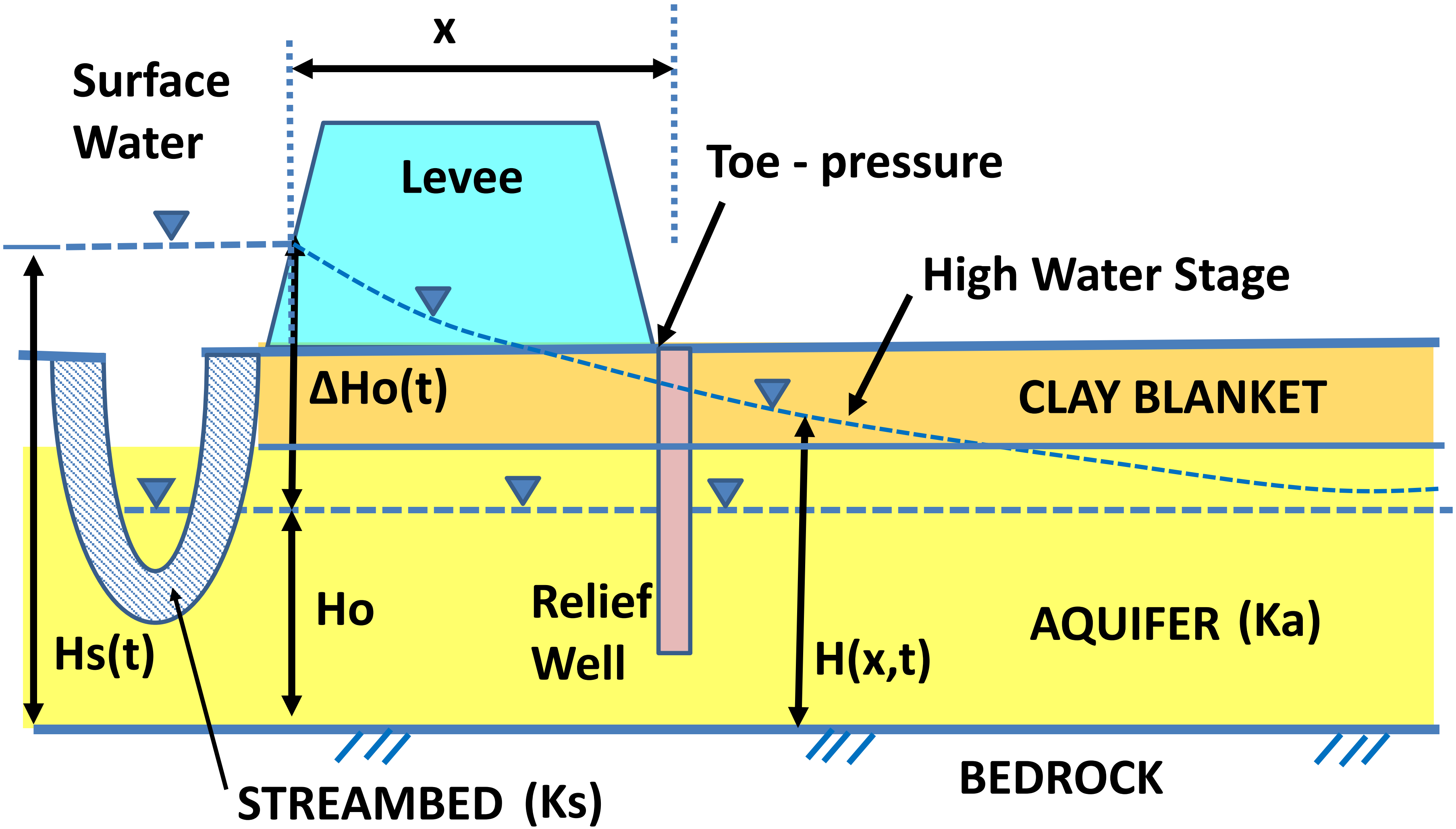


Resistivity Profile Line GDALE5



Resistivity Profile Line GDALE5

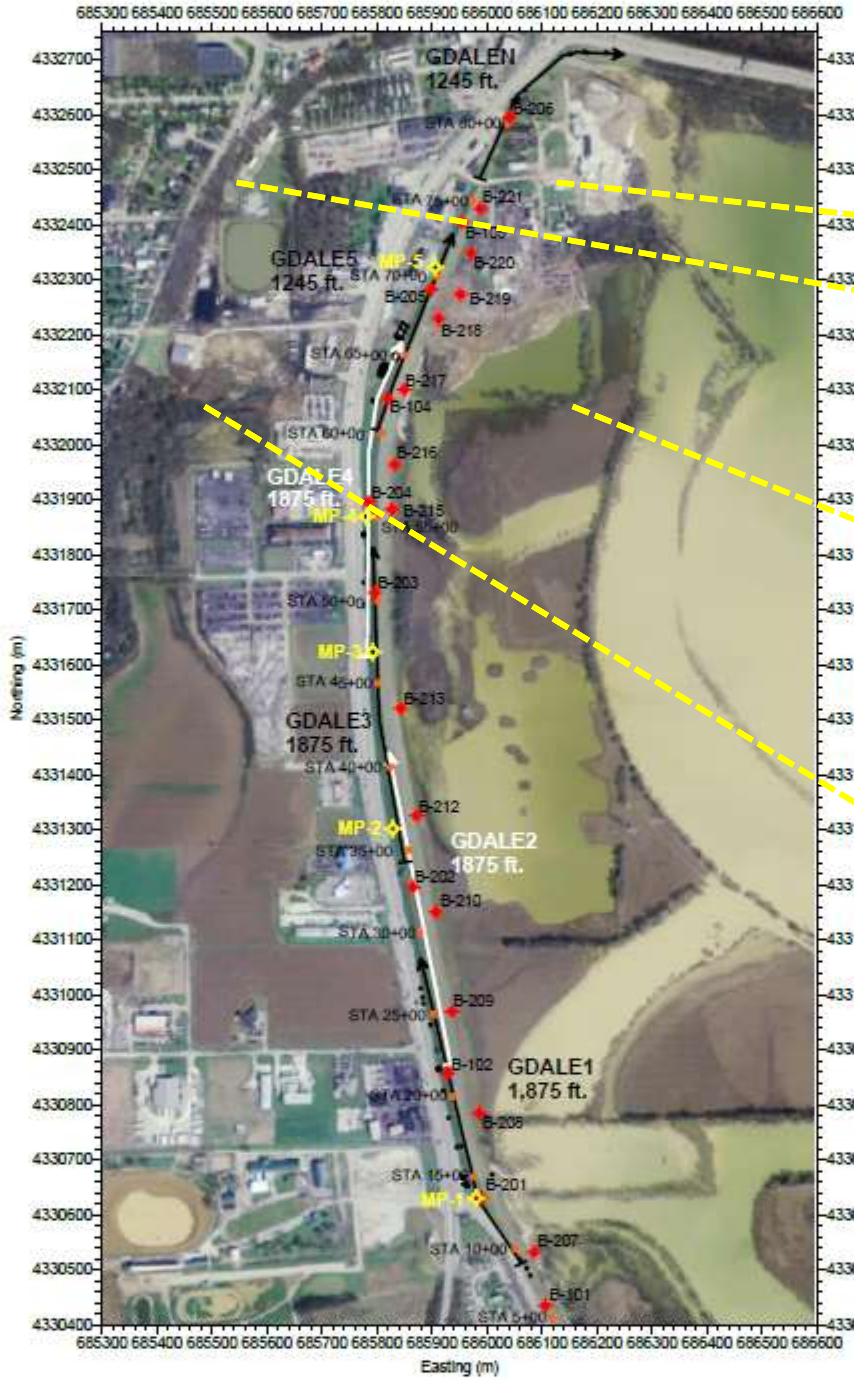
Levee Feature 1 (LF-1): Depression along dry side of levee



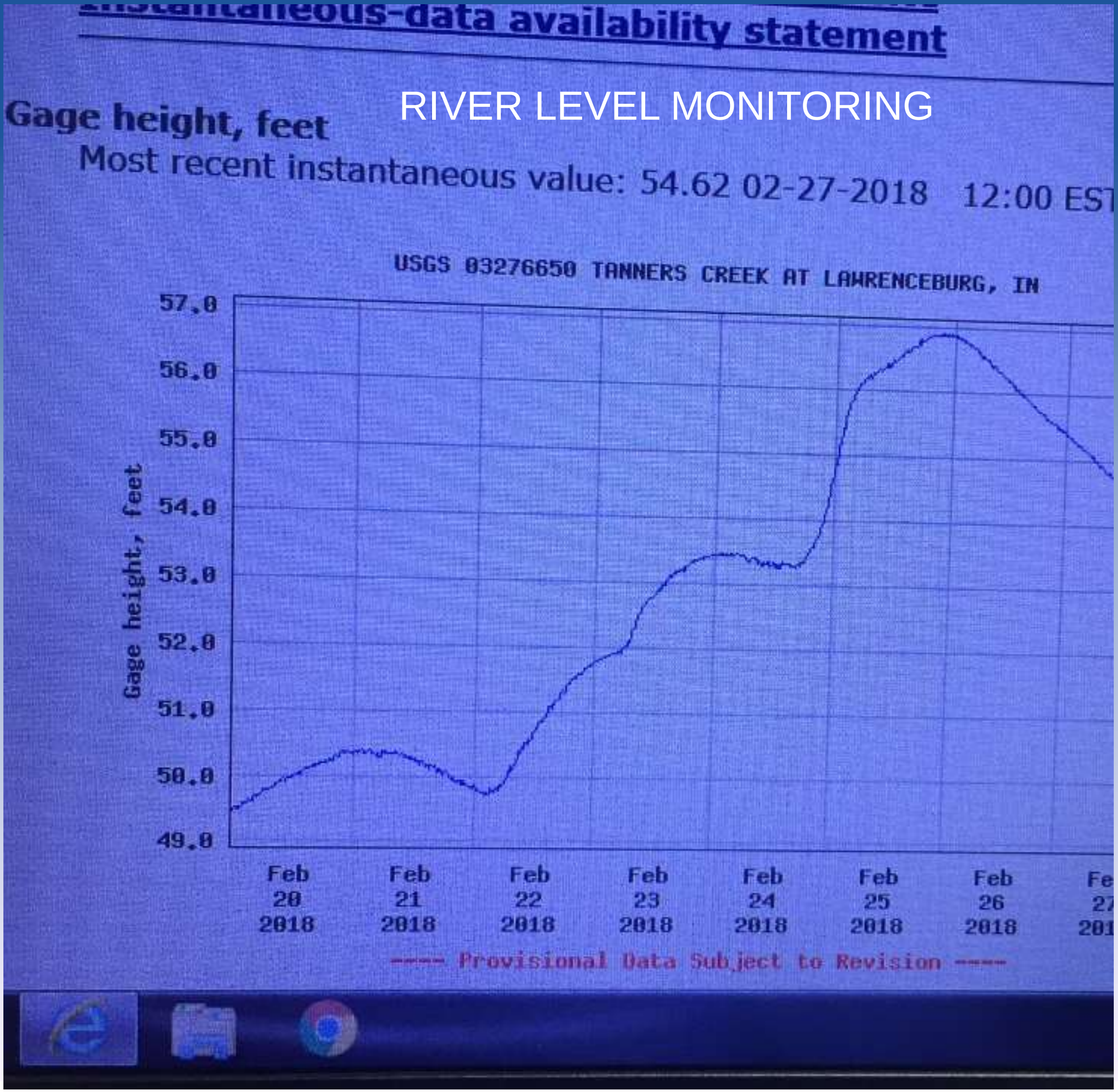
CONCEPTUAL SITE MODEL

Mundell

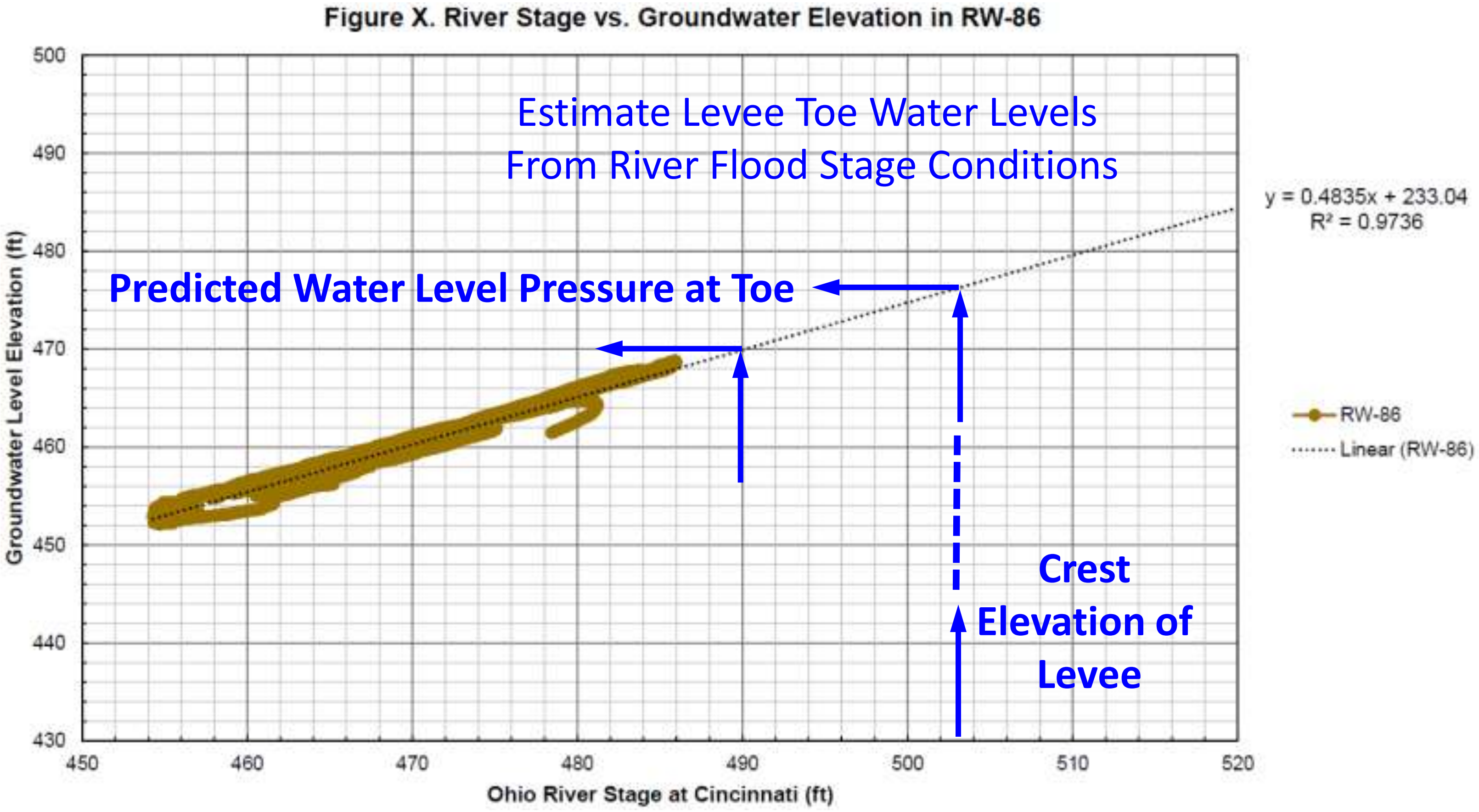
WATER LEVEL MONITORING



RIVER LEVEL MONITORING

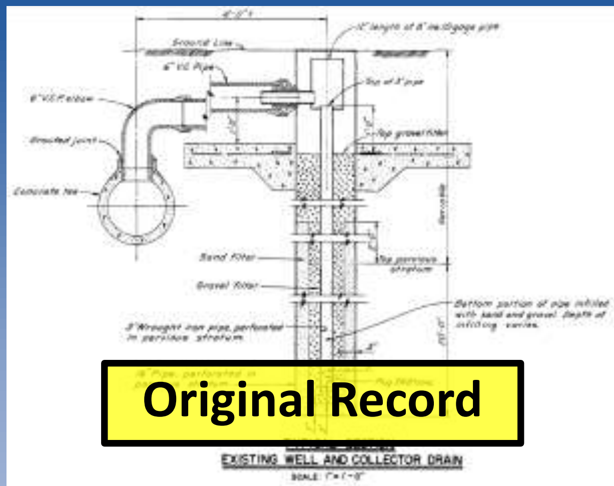


Correlate Water Level to River Levels

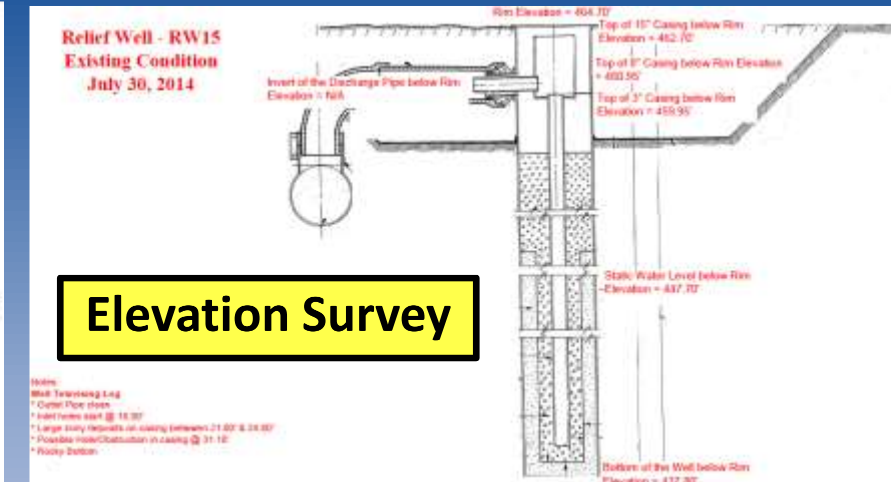



Relief Well Rehabilitation and Assessment

Relief Well Rehabilitation/Documentation



Original Record



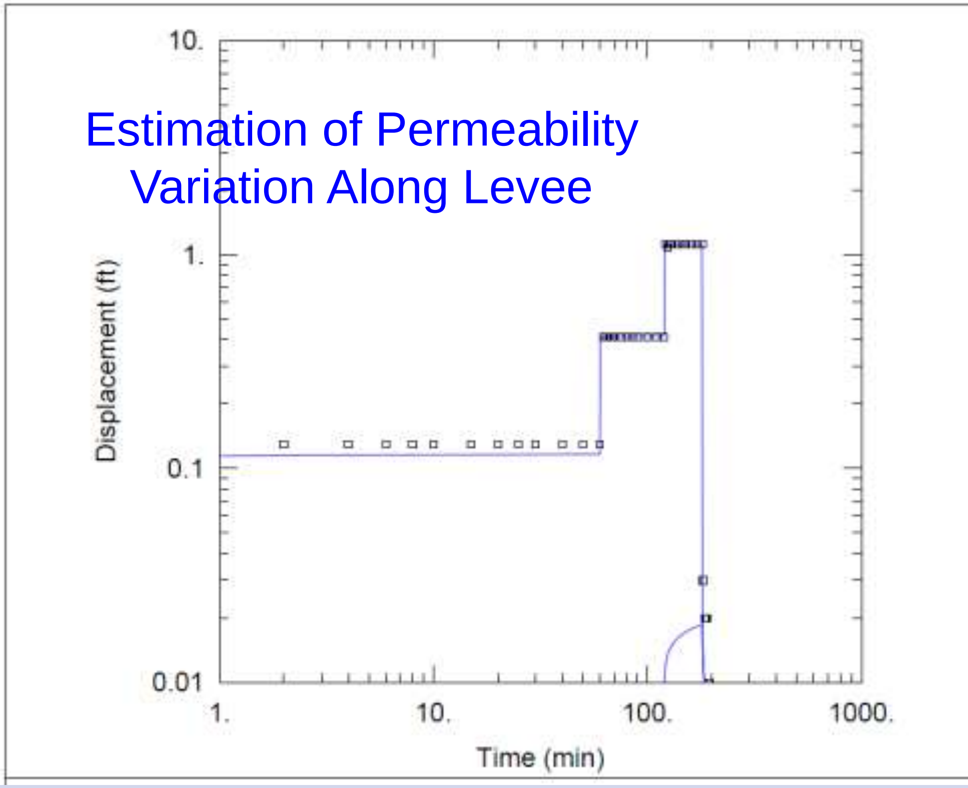
Elevation Survey

Location

Rehabilitation Video

Pump Testing of Relief Wells

Estimation of Permeability Variation Along Levee



WELL TEST ANALYSIS

Data Set: T:\...\RW-11 POST_Theis (1935) Confined Solutio
Date: 05/14/15 Time: 08:42:15

PROJECT INFORMATION

Company: Mundell & Associates Inc.
Client: LCD
Project: M14051
Test Well: RW-11
Test Date: 9/16/14

SOLUTION

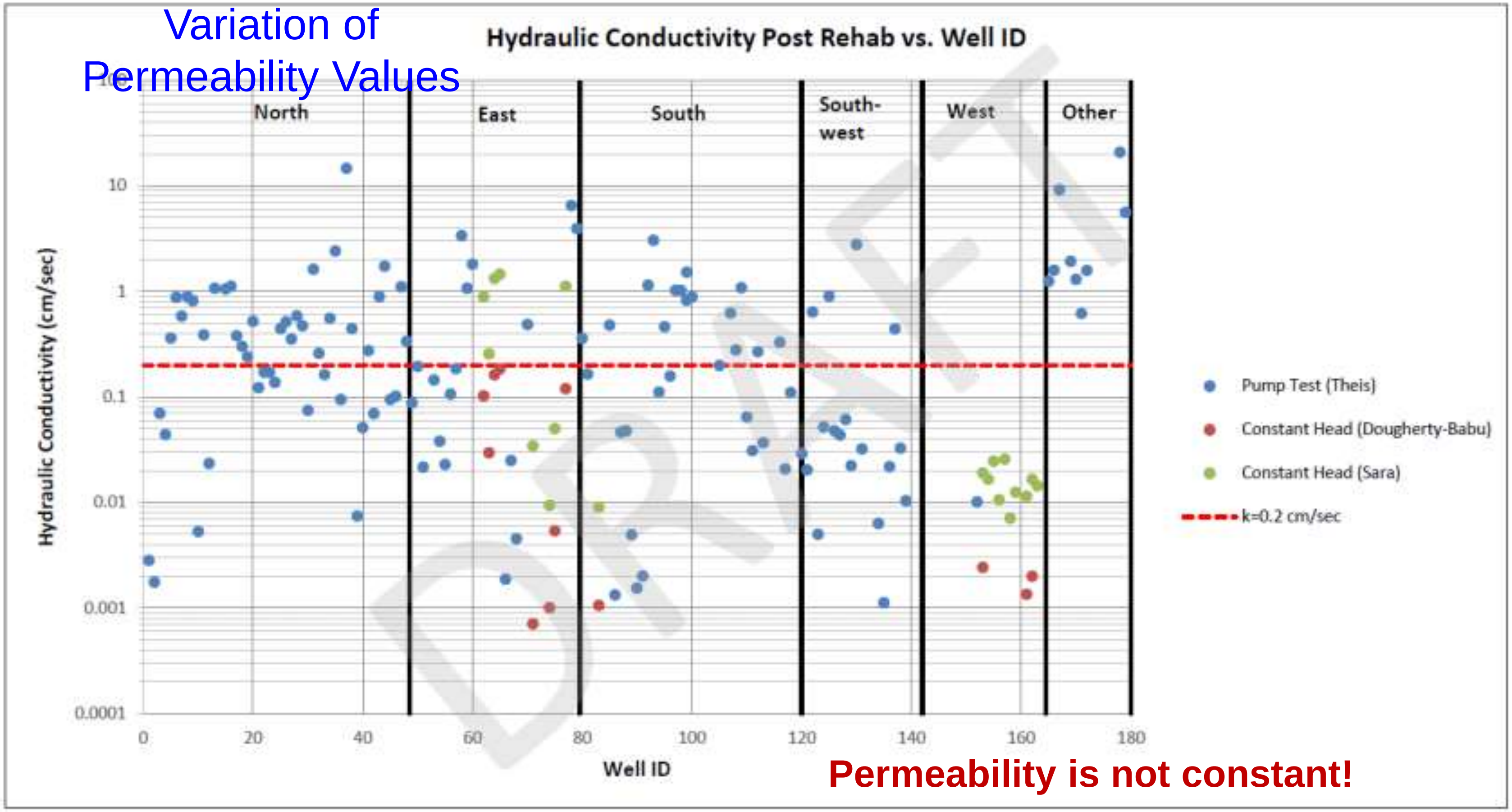
Aquifer Model: Confined
Solution Method: Theis (Step Test)

T = 1480.4 cm^2/sec
S = 0.01646
Sw = 20.
C = 0.01522 min^2/ft^5
P = 2.44

Step Test Model: Jacob-Rorabaugh
Time (t) = 1. min Rate (Q) in cu. ft/min
$s(t) = 0.1626Q + 0.01522Q^{2.44}$
W.E. = 47.02% (Q from last step)

Pump Testing of Relief Wells

Variation of Permeability Values



Permeability is not constant!

Lessons Learned

- Enhanced subsurface characterization with geophysical techniques provides signficant additional data to evaluate potential seepage locations, and informs monitoring efforts of the levee.
- Collection of field measurements and observations during high water events will improve predictions made by simplified engineering analytical methodologies.
- Inspection and maintainance of levee systems is critical for retaining expected performance standards.

THANKS!

RELIEF WELL - TOTAL HEAD CONTOURS WITH FLOW LINES