# Calibrating Artificial Intelligence and Hydrologic Modeling with Smart Monitoring Inputs for Enhanced Levee Safety Predictions under Changing Climate Conditions

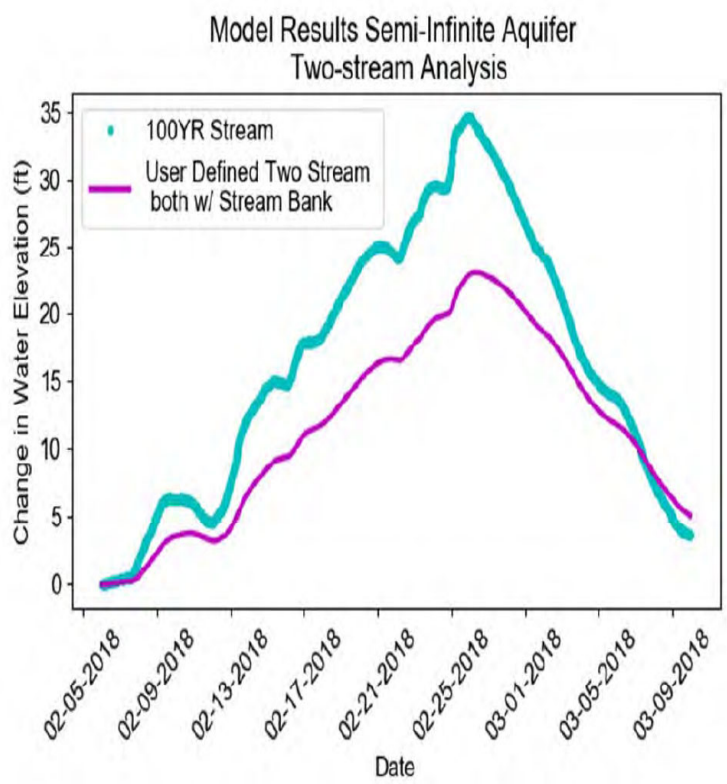

AEG2020 Virtual Conference
September 18, 2020

John A. Mundell, P.E., L.P.G., P.G.
Tyler Balson, Luke Johnstone, Forrest Kunkel

Mundell & Associates, Inc.
*Consulting Professionals for the Earth and the Environment*

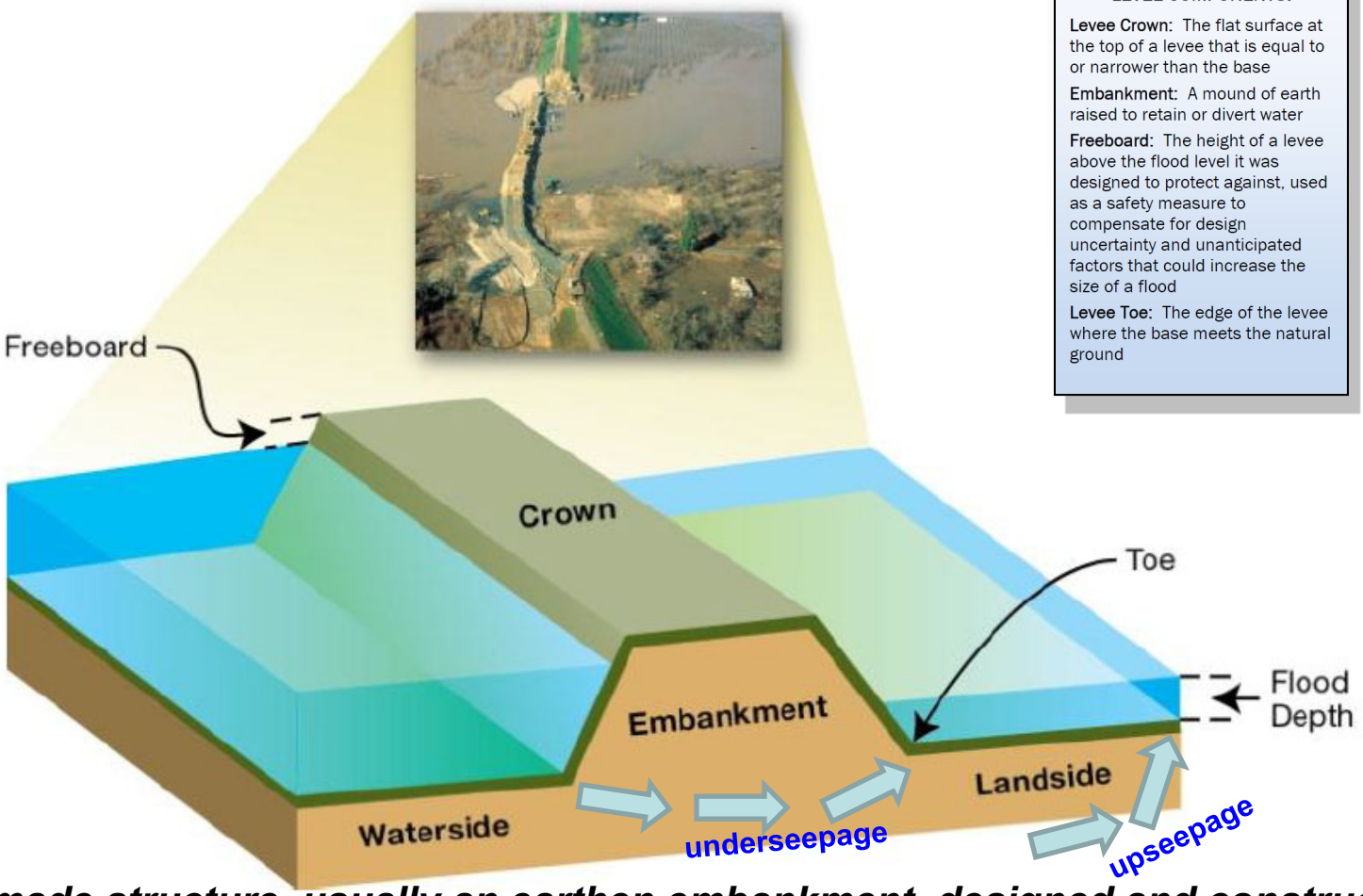
# Presentation Outline

**Figure 16B. Predicted Water Levels at MP-1**
**100-year Flood Event (Hydrologic Model)**




- Performance Evaluation of Levees
- Smart Monitoring Data Collection
- Linear and Hydrologic Modeling
- Artificial Intelligence (AI) and Machine Learning Predictions
- Future Applications

# How does a levee perform?



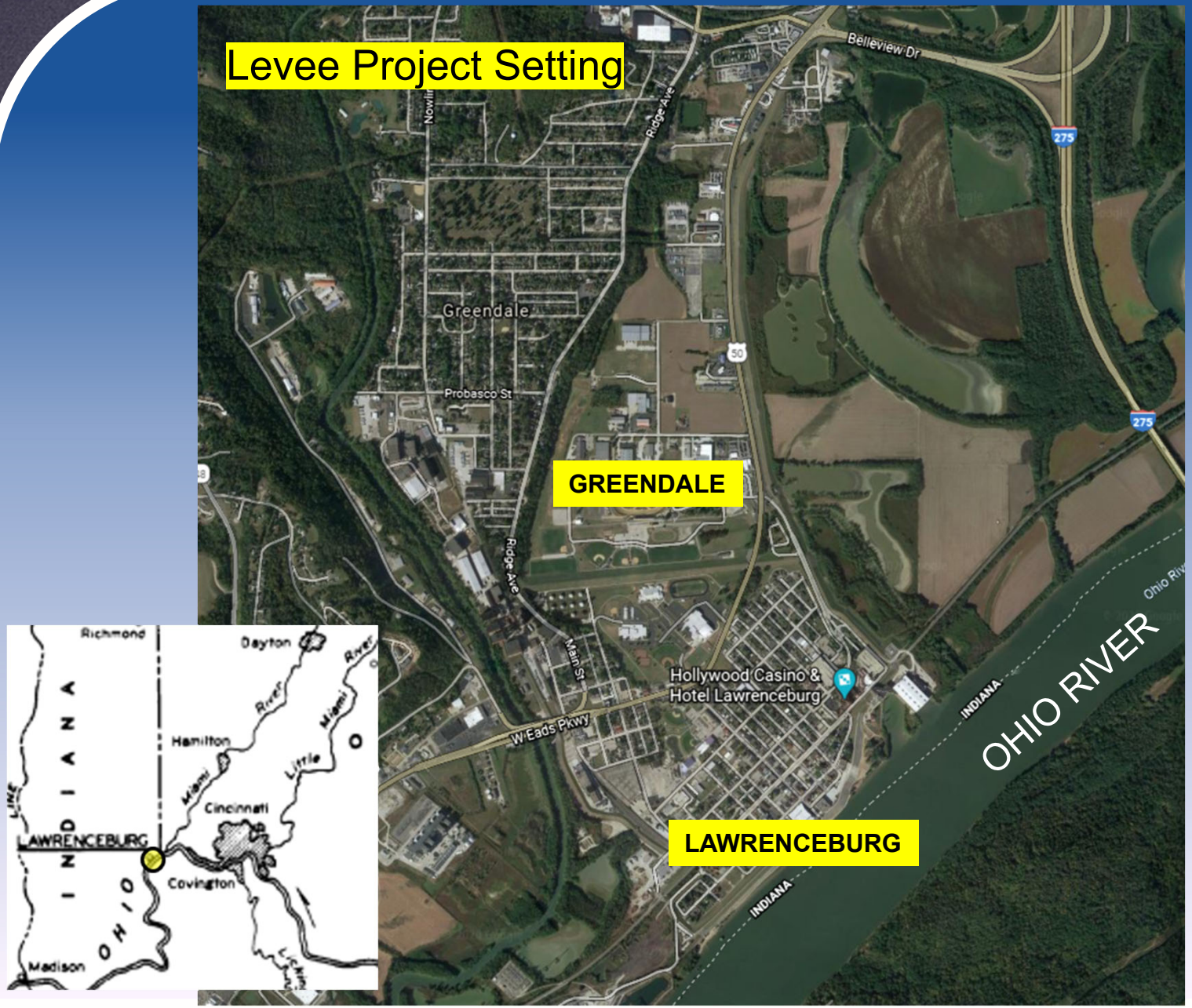

***"a man-made structure, usually an earthen embankment, designed and constructed in accordance with sound engineering practices to contain, control, or divert the flow of water in order to reduce the risk from temporary flooding."***

- Federal Emergency Management Agency (FEMA)

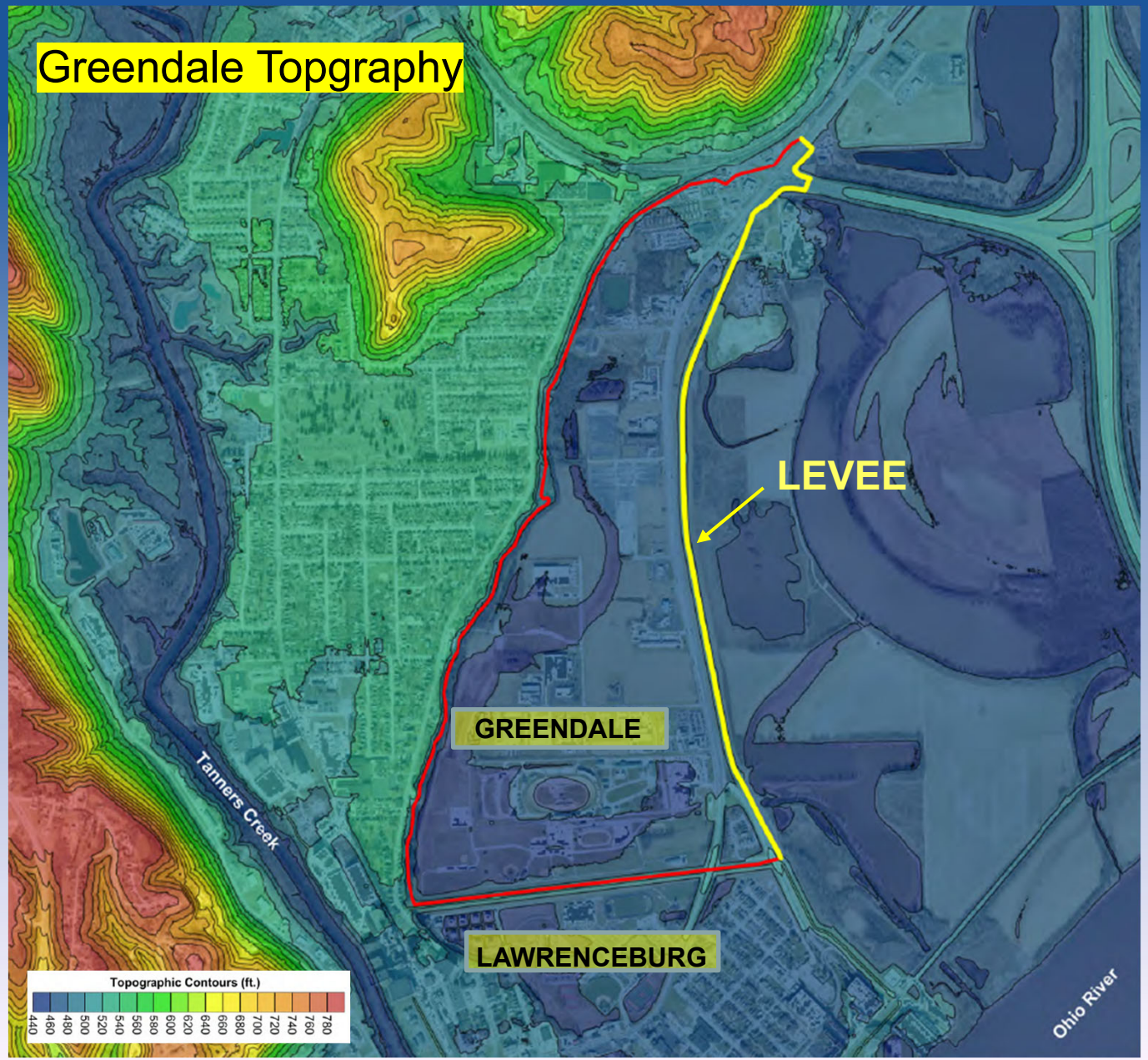
# Why does a levee fail?

- **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 Project Setting

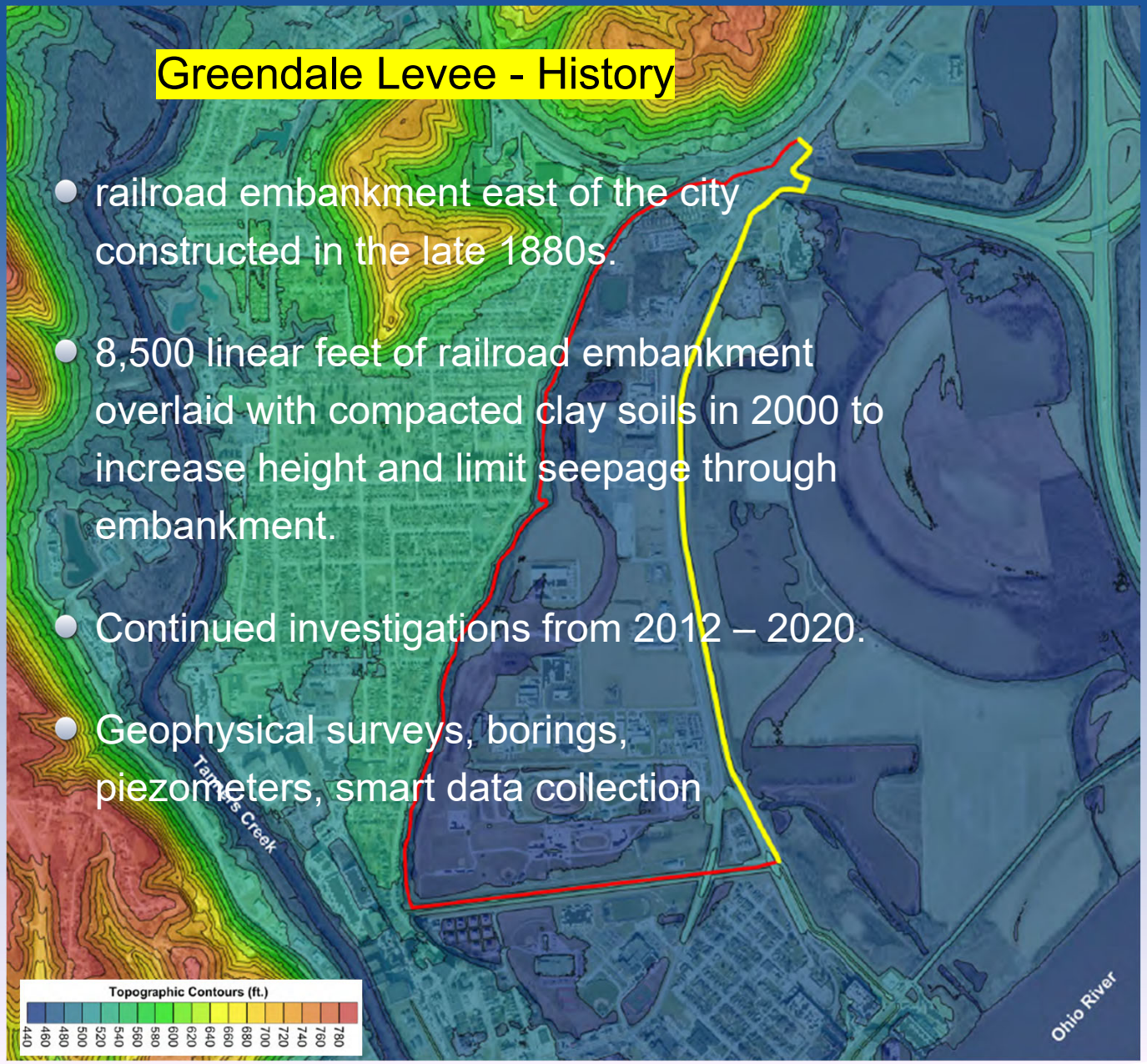


# Greendale Topgraphy



# Greendale Levee - History

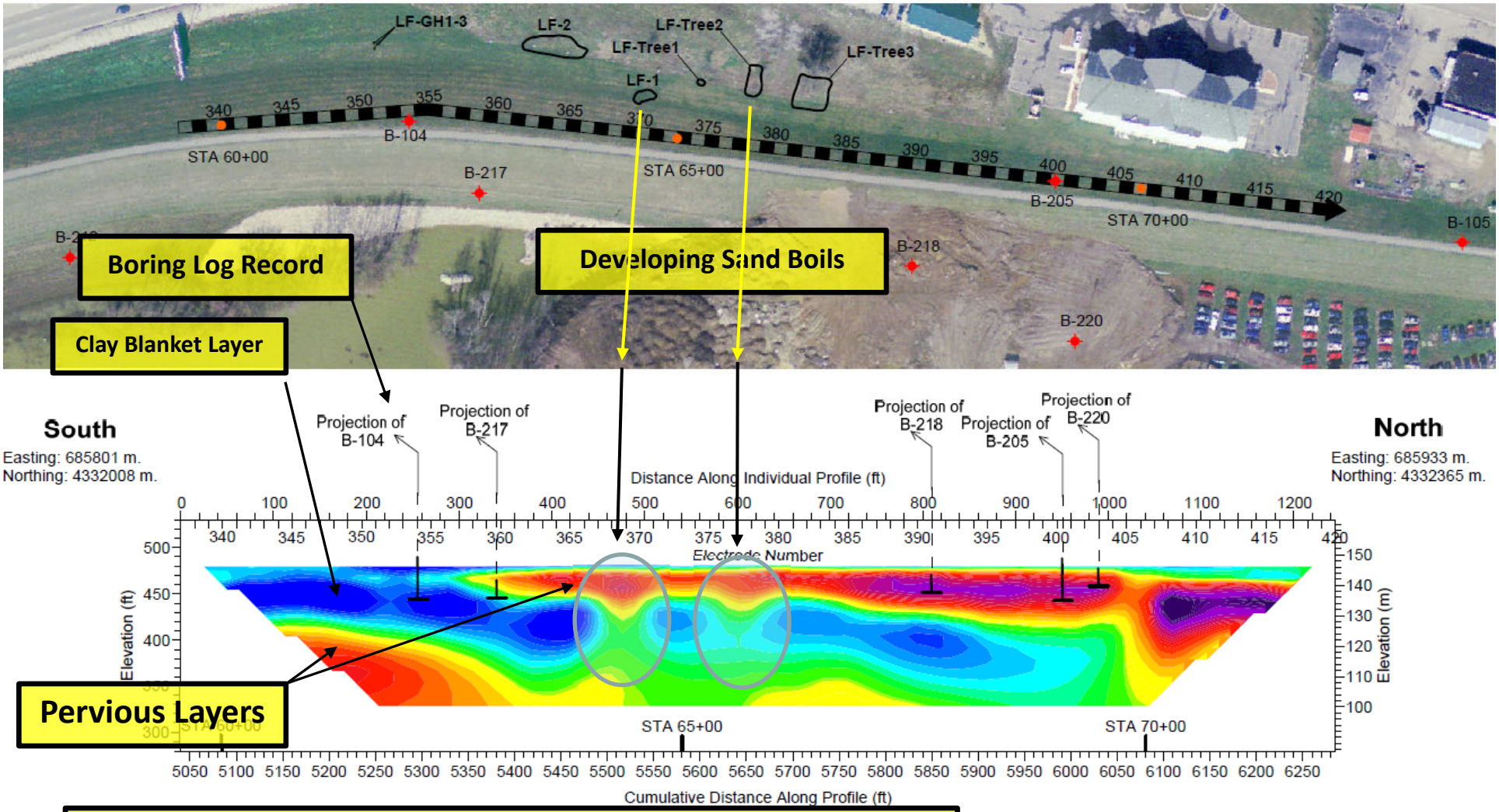
- railroad embankment east of the city constructed in the late 1880s.
- 8,500 linear feet of railroad embankment overlaid with compacted clay soils in 2000 to increase height and limit seepage through embankment.
- Continued investigations from 2012 – 2020.
- Geophysical surveys, borings, piezometers, smart data collection



# Smart Data Inputs

- **Area-specific river gauging** – Tanner's Creek vs. Cincinnati/Markland Dam gauging
- **Area Groundwater Levels** – Piezometer network located at critical levee and city-area locations.
- **Precipitation** – Regional and site-specific rainfall gauging stations.
- **Drone photography** - over multiple time frames during Ohio River high water events to document city inundation extent.
- **Frequency** – automated and continuous

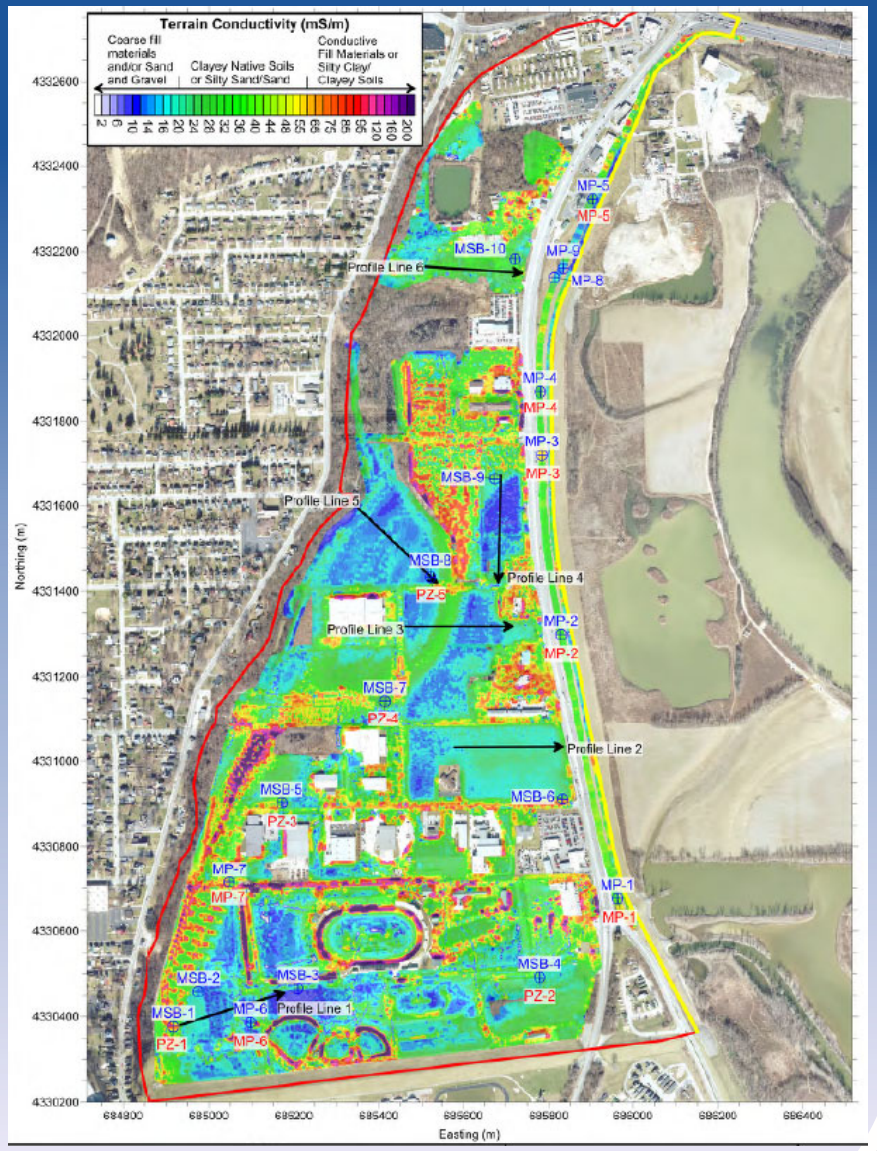
# 2D-Electrical Resistivity Profile



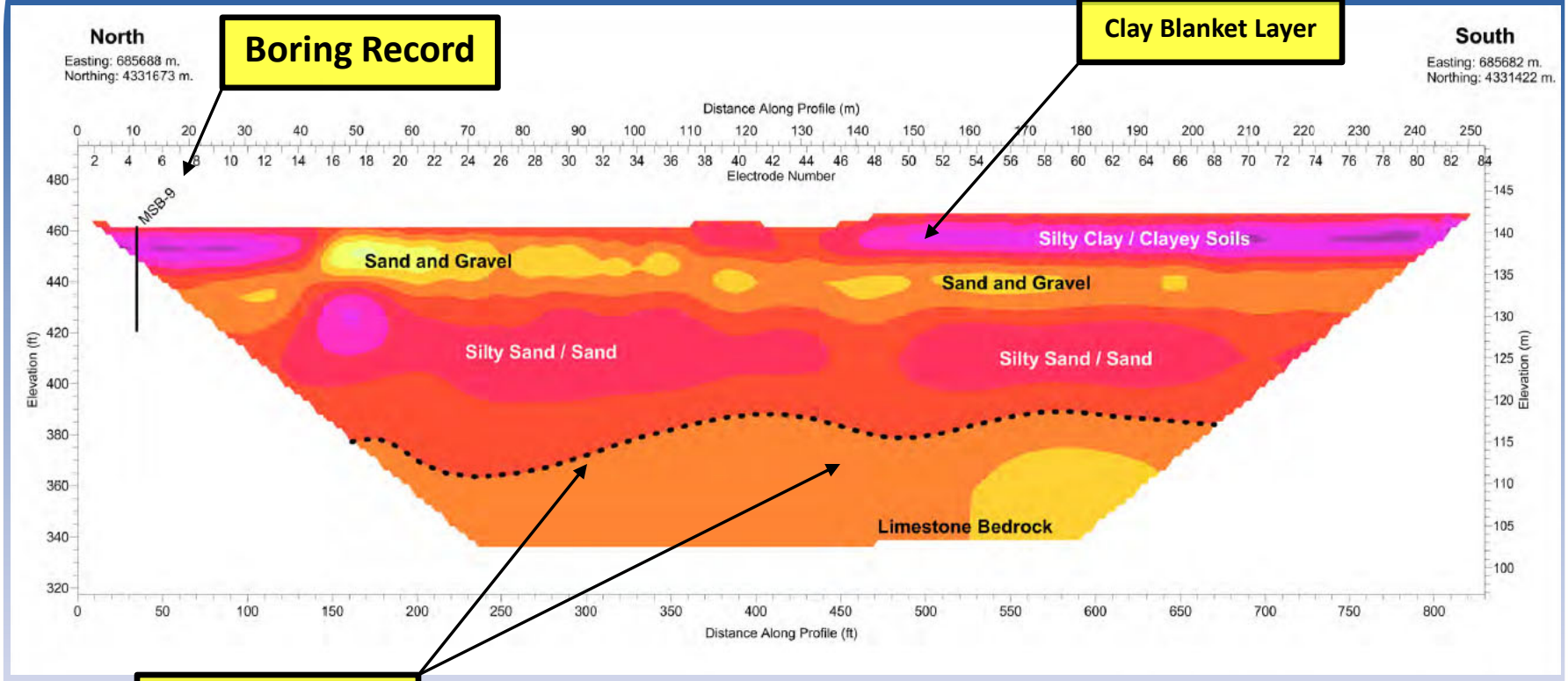

**2D Resistivity Profile with Borings Provides Continuous Upper Blanket Thickness and high resistivity lower pervious zone**

# Terrain Conductivity and 2D Resistivity

- Survey over 350 acres.
- Determine near-surface soil types and clay blanket extent
- Confirm at selected critical locations
- Blue-colored areas indicate less surficial clay and granular cover.



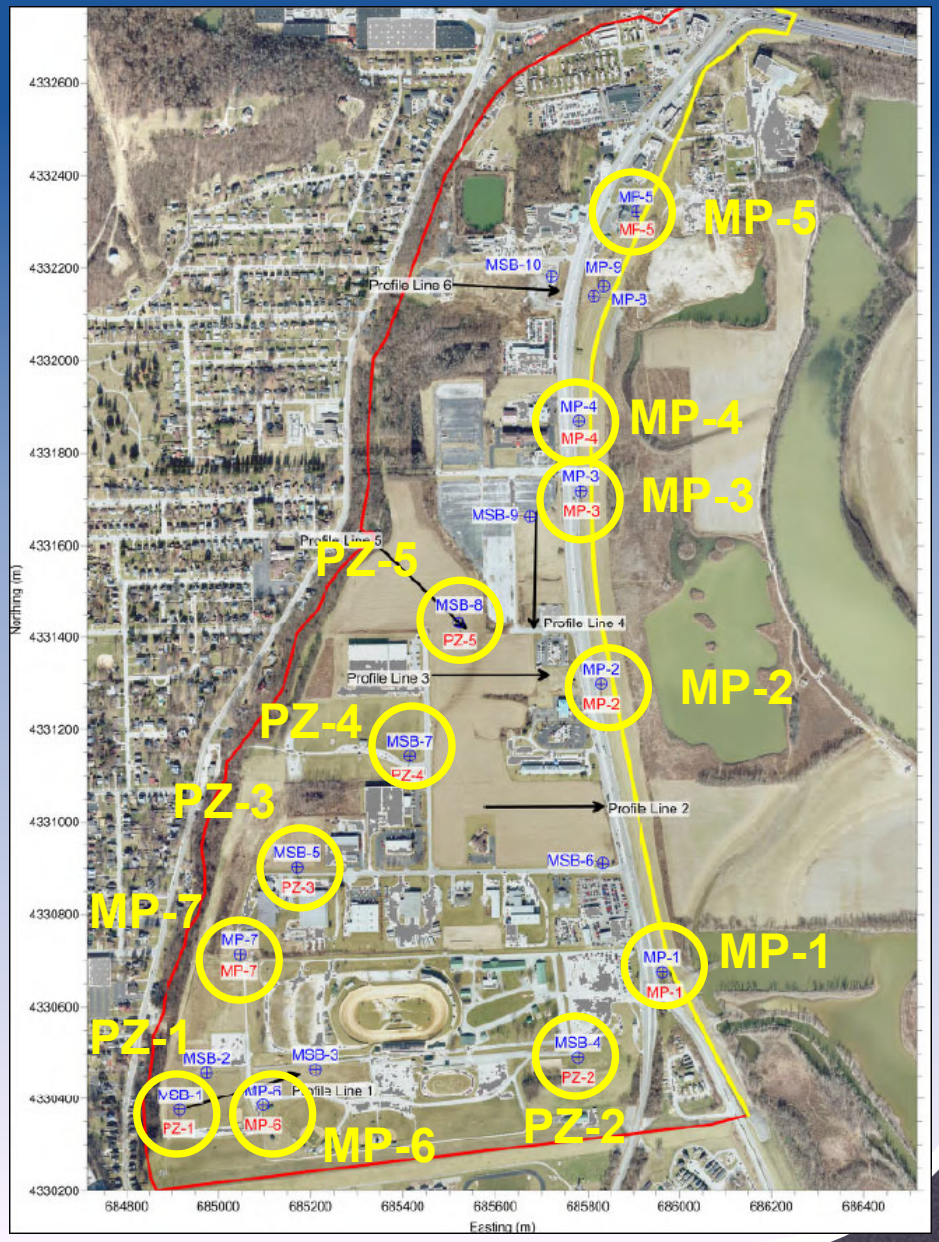
# RESISTIVITY PROFILE LINE 4



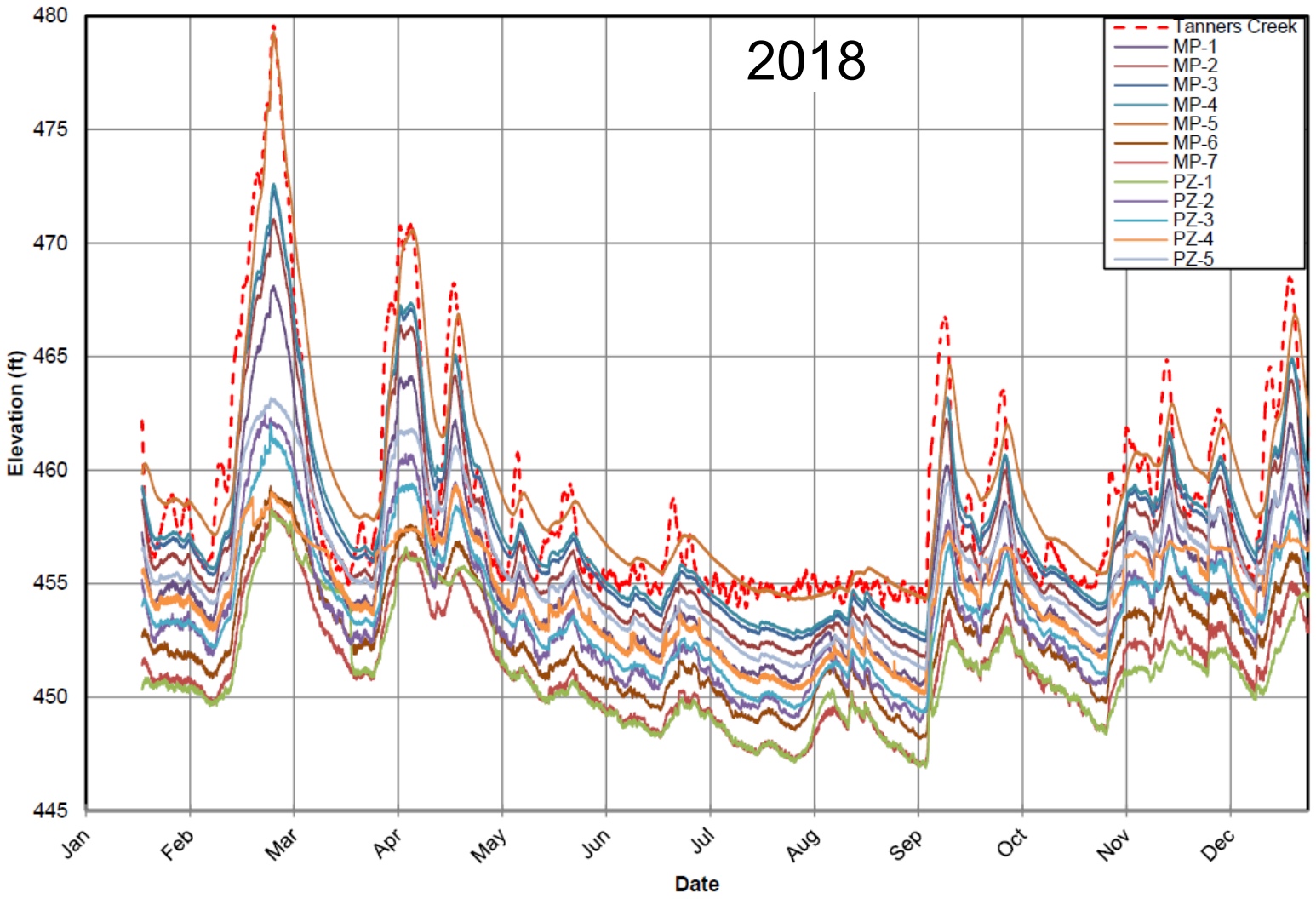

**2D Resistivity Profile Provides Continuous Upper Blanket Thickness and high resistivity lower pervious zones**

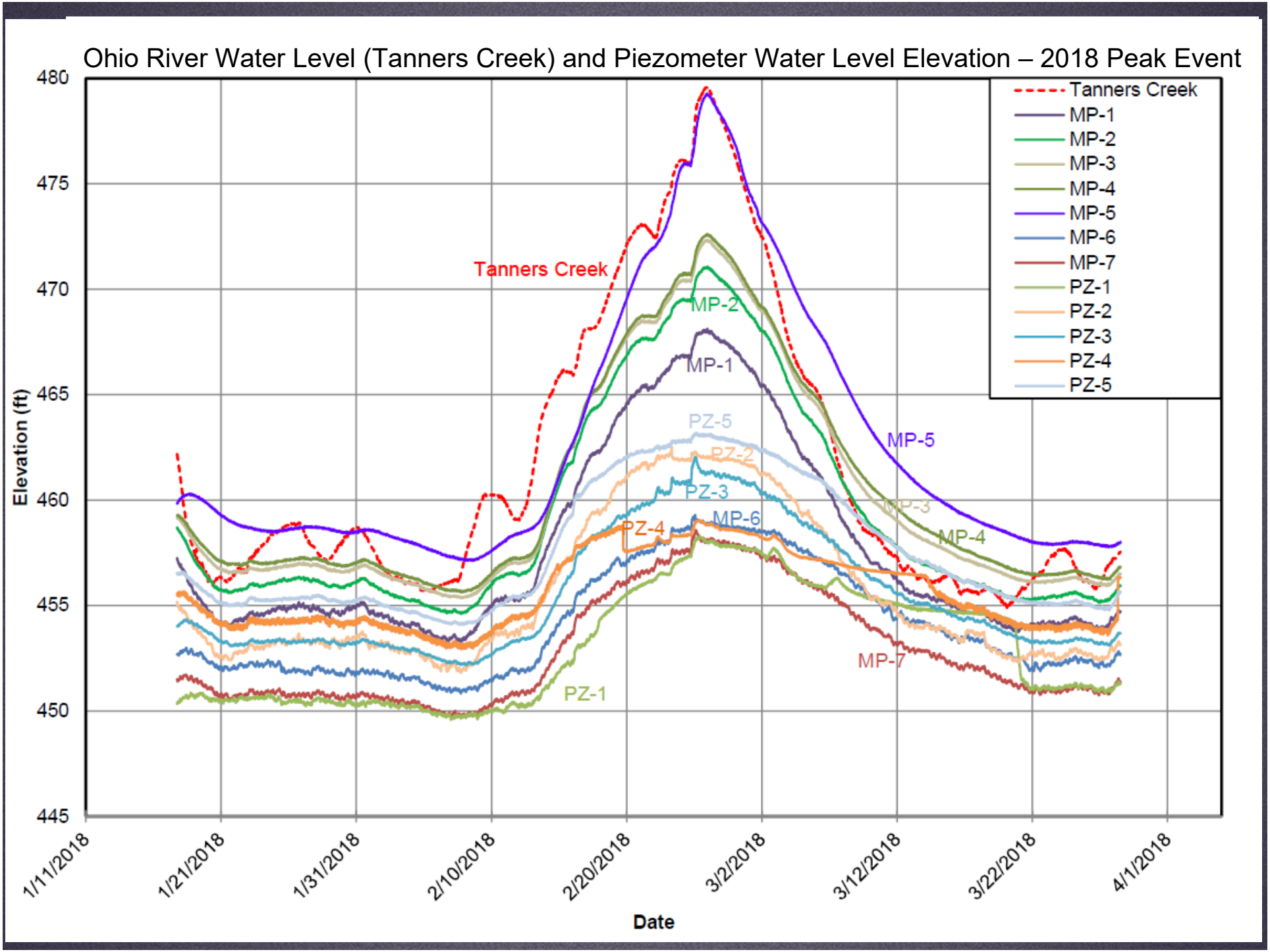
# Greendale

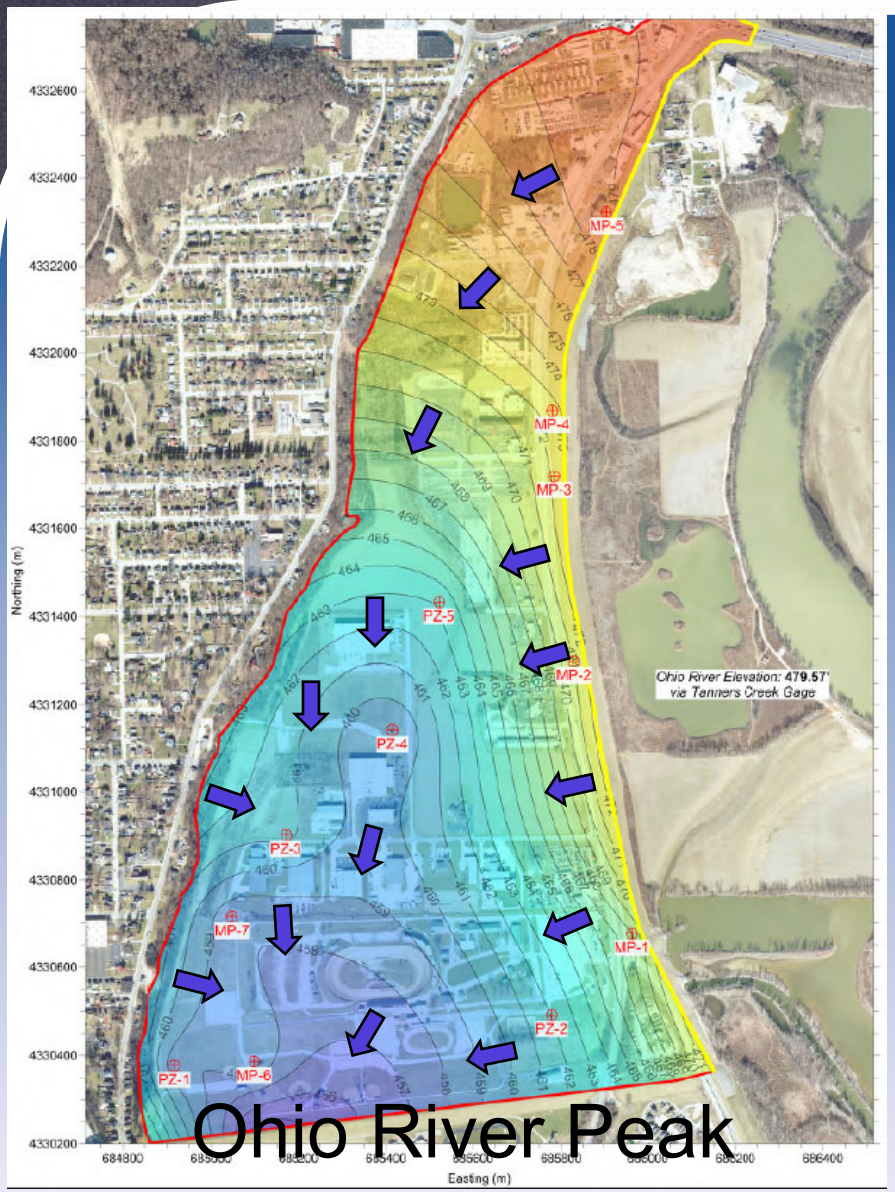
*Smart Data Monitoring Network*
borings/piezometers at 12 critical locations for levee and upseepage



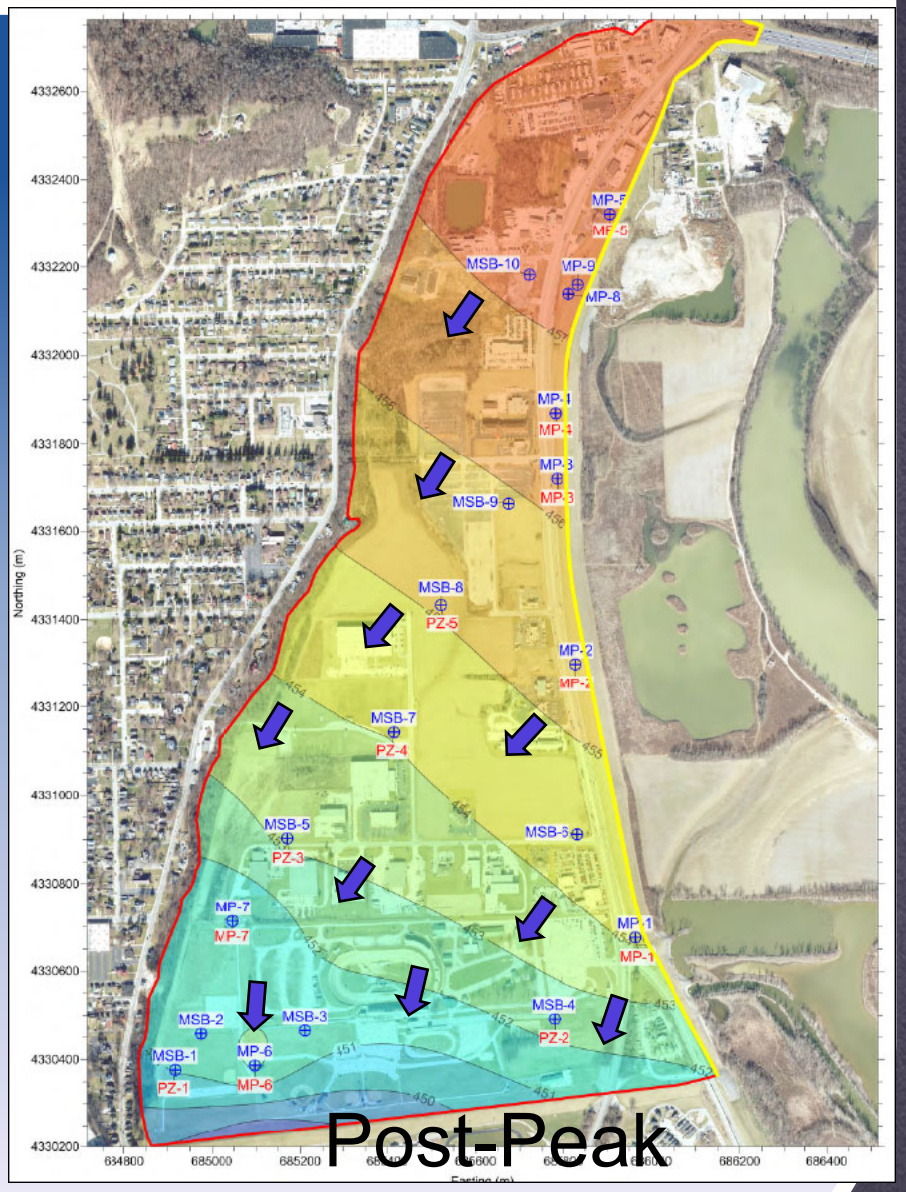
# Ohio River (Tanners Creek) and Piezometer Water Level Elevations




Ohio River Water Level (Tanners Creek) and Piezometer Water Level Elevation – 2018 Peak Event
Elevation (ft)
480
475
470
465
460
455
450
445
1/11/2018
1/21/2018
1/31/2018
2/10/2018
2/20/2018
3/2/2018
3/12/2018
3/22/2018
4/1/2018
Date
Tanners Creek
MP-1
MP-2
MP-3
MP-4
MP-5
MP-6
MP-7
PZ-1
PZ-2
PZ-3
PZ-4
PZ-5

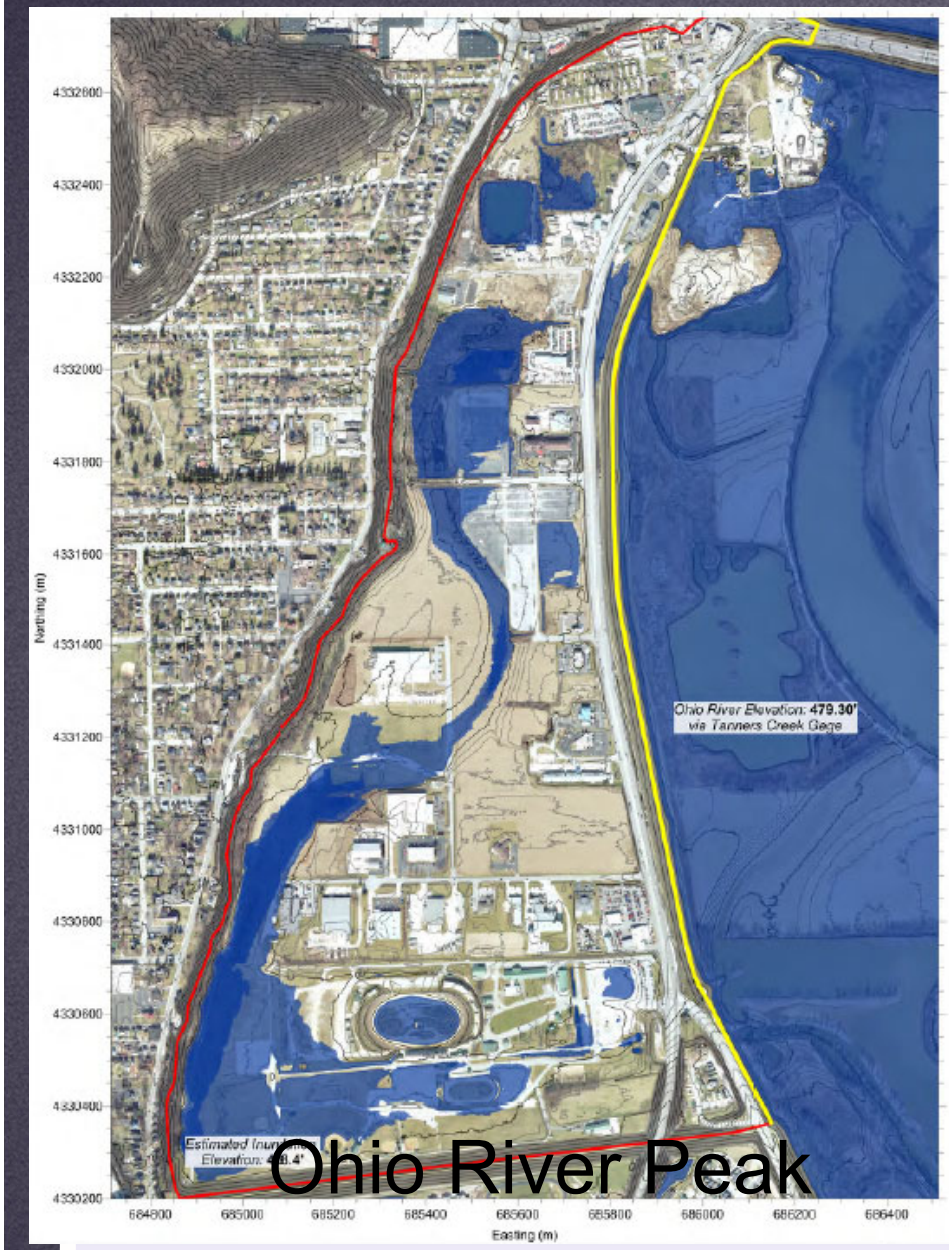


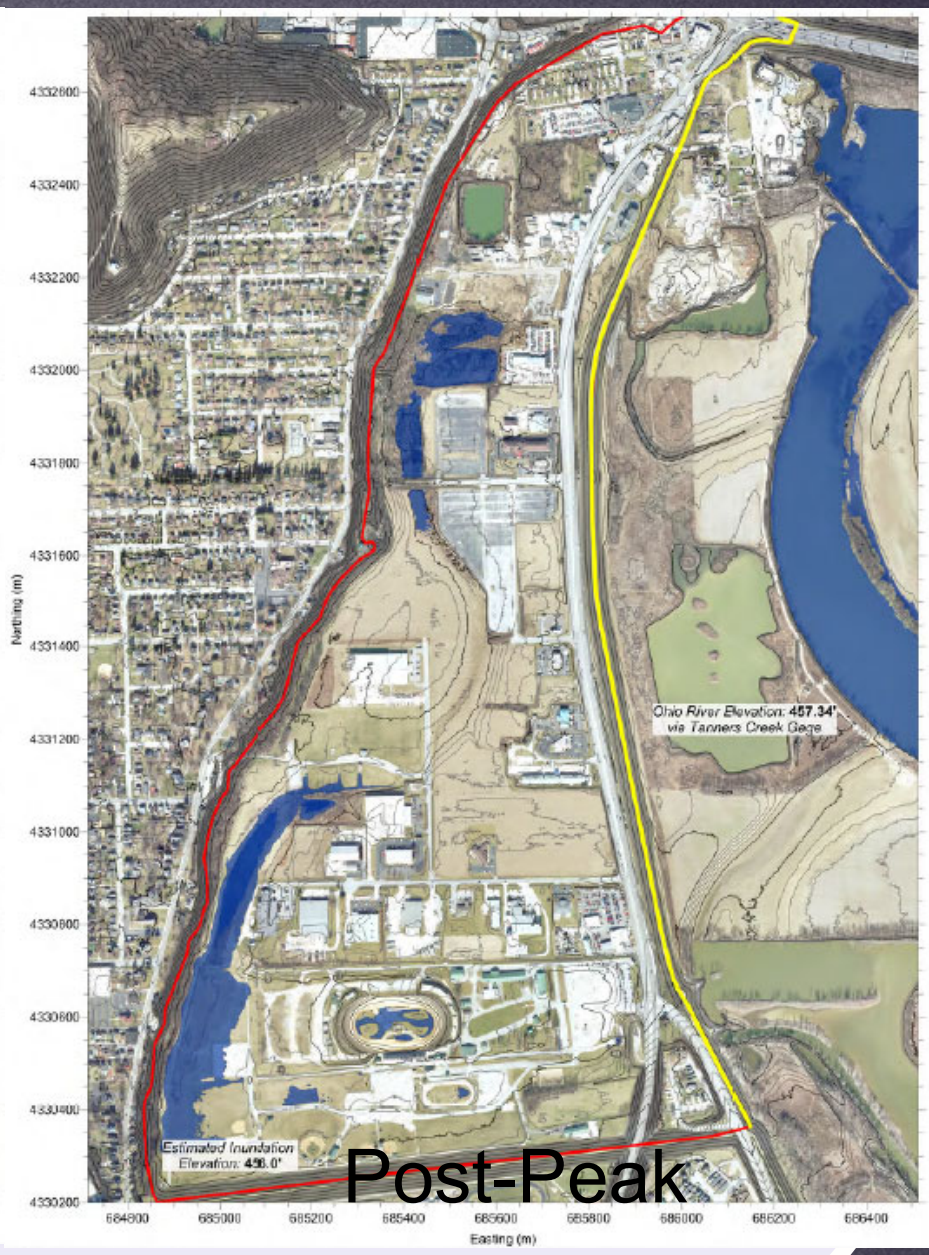

Ohio River Peak




Post-Peak

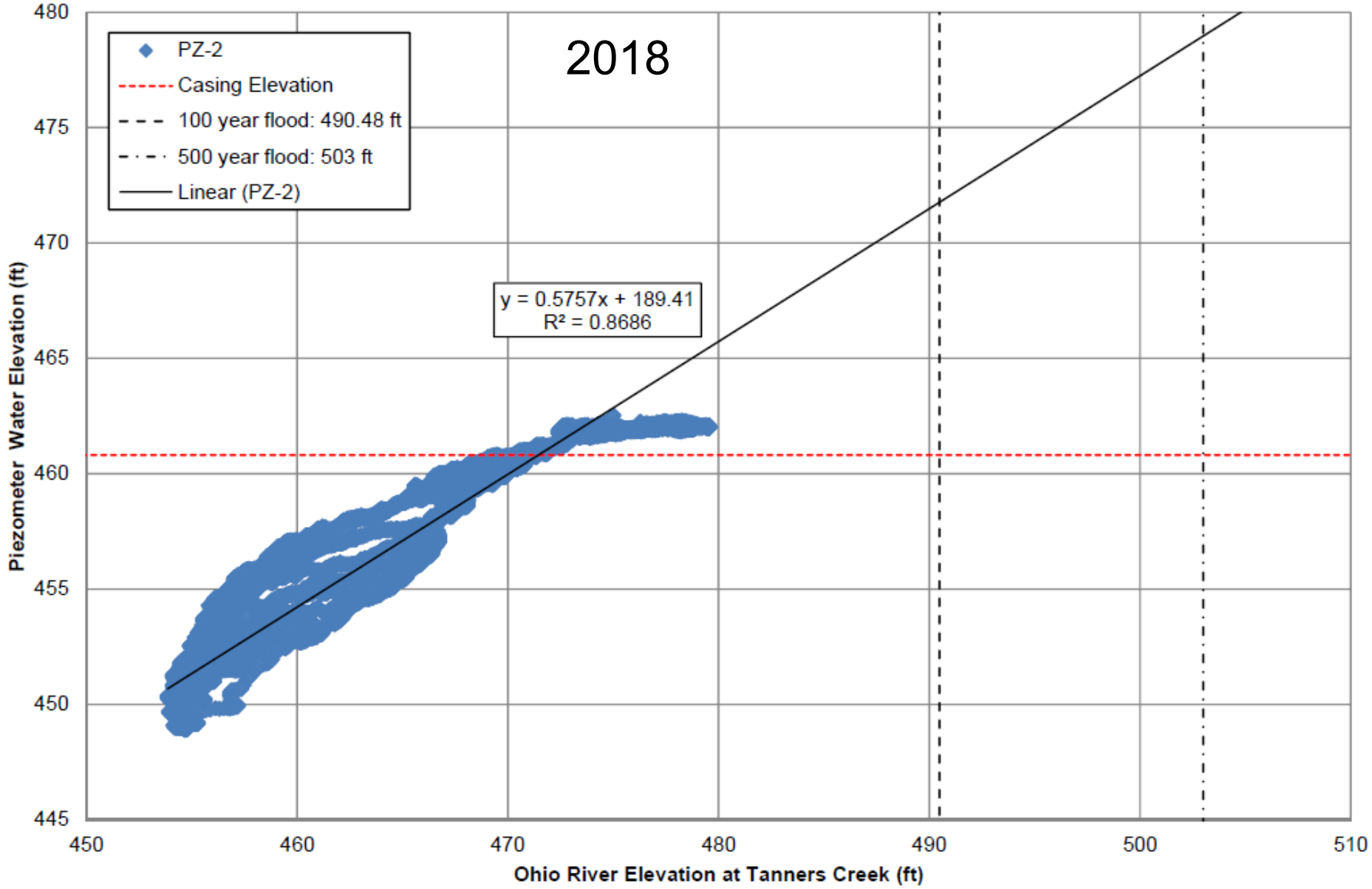
# Potentiometric Surface Maps 2018



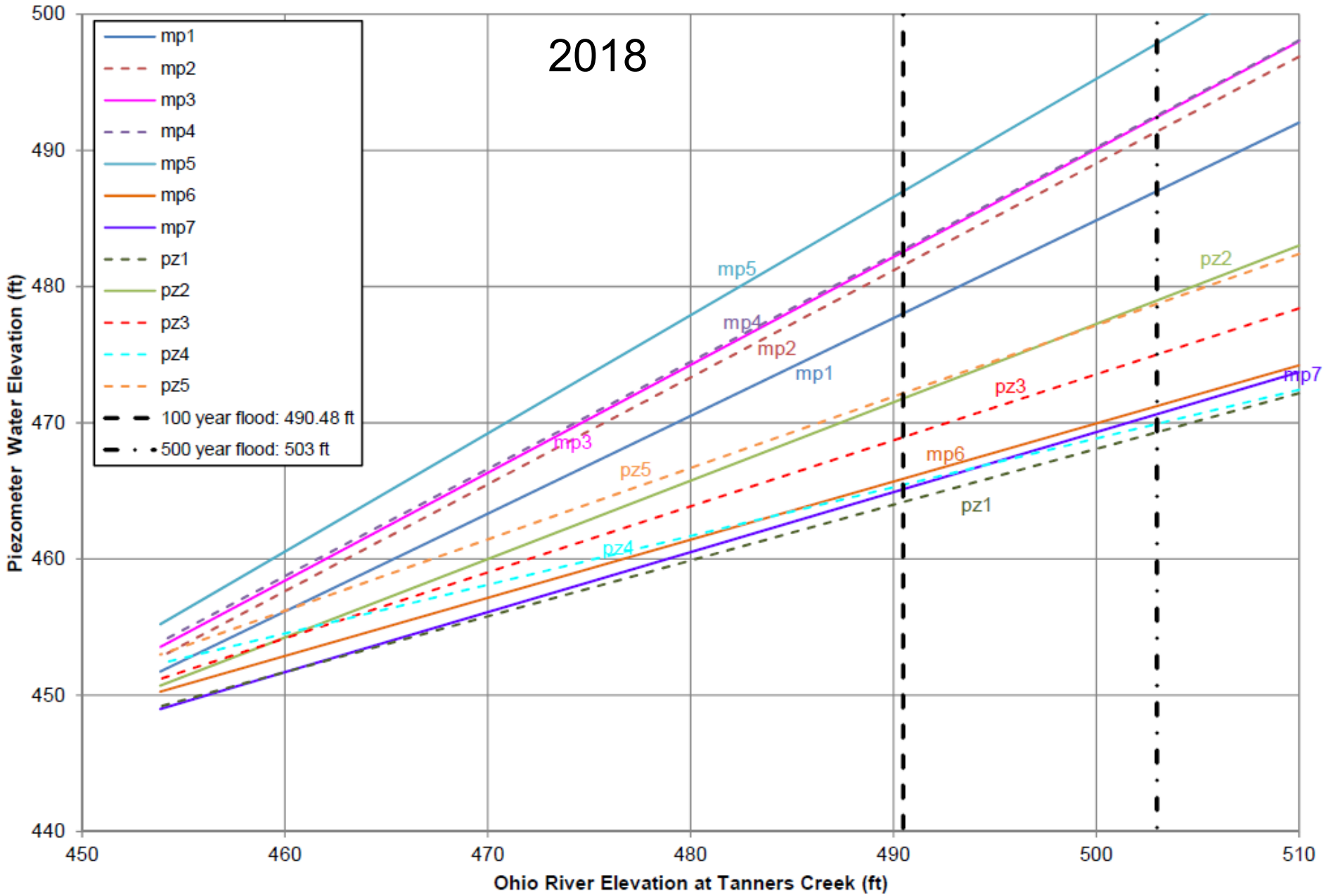




# Inundation Maps 2018 – Drone Photography

# Flood Stage Prediction at Piezometer PZ-2
## Linear Interpolation



# Flood Stage Predictions at Piezometers - Linear Interpolation



# Hydrologic Modeling

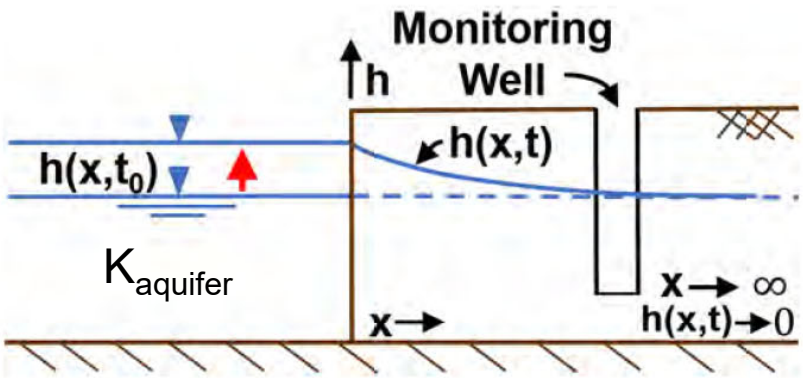



**Figure 15A.** "Semi-infinite aquifer" diagram as described by Hall and Moench (1972)

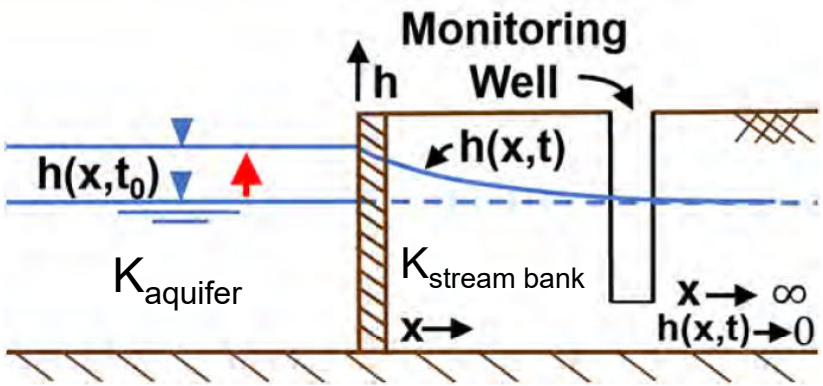


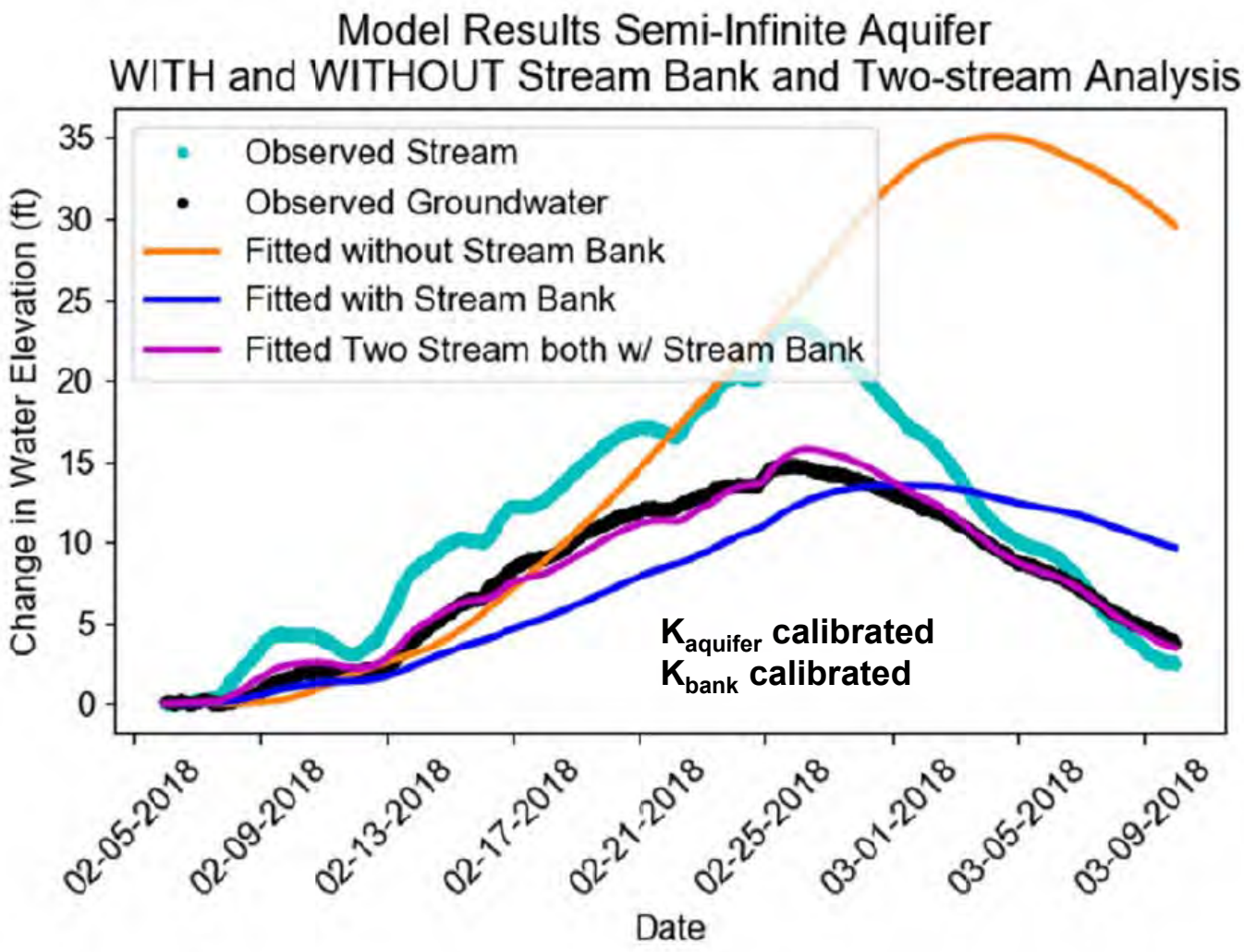

**Figure 15B.** "Semi-infinite aquifer with semipervious stream bank" diagram as described by Hall and Moench (1972)

**Model Inputs:** Aquifer thickness, aquifer hydraulic conductivity, specific yield, distance from well to river, stream bank hydraulic conductivity, stream bank width

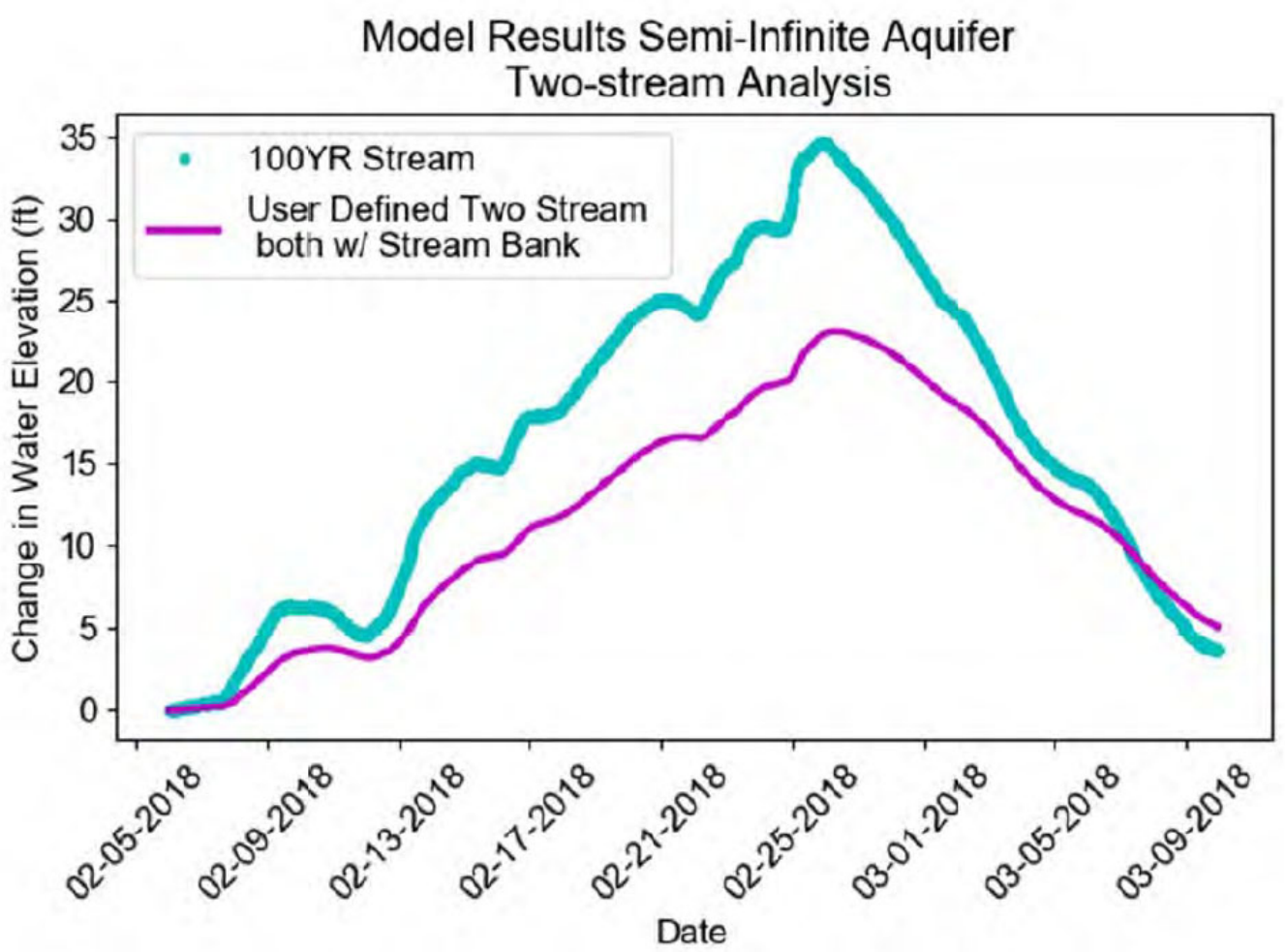
## River Bank Conceptual Site Model

One-dimensional transient analytical solution for a saturated, unconfined aquifer with a horizontal impermeable base and hydrologic boundary (river)

## Figure 16A. Calibrated Hydrologic Model at MP-1
## February-March 2018 High Water Event

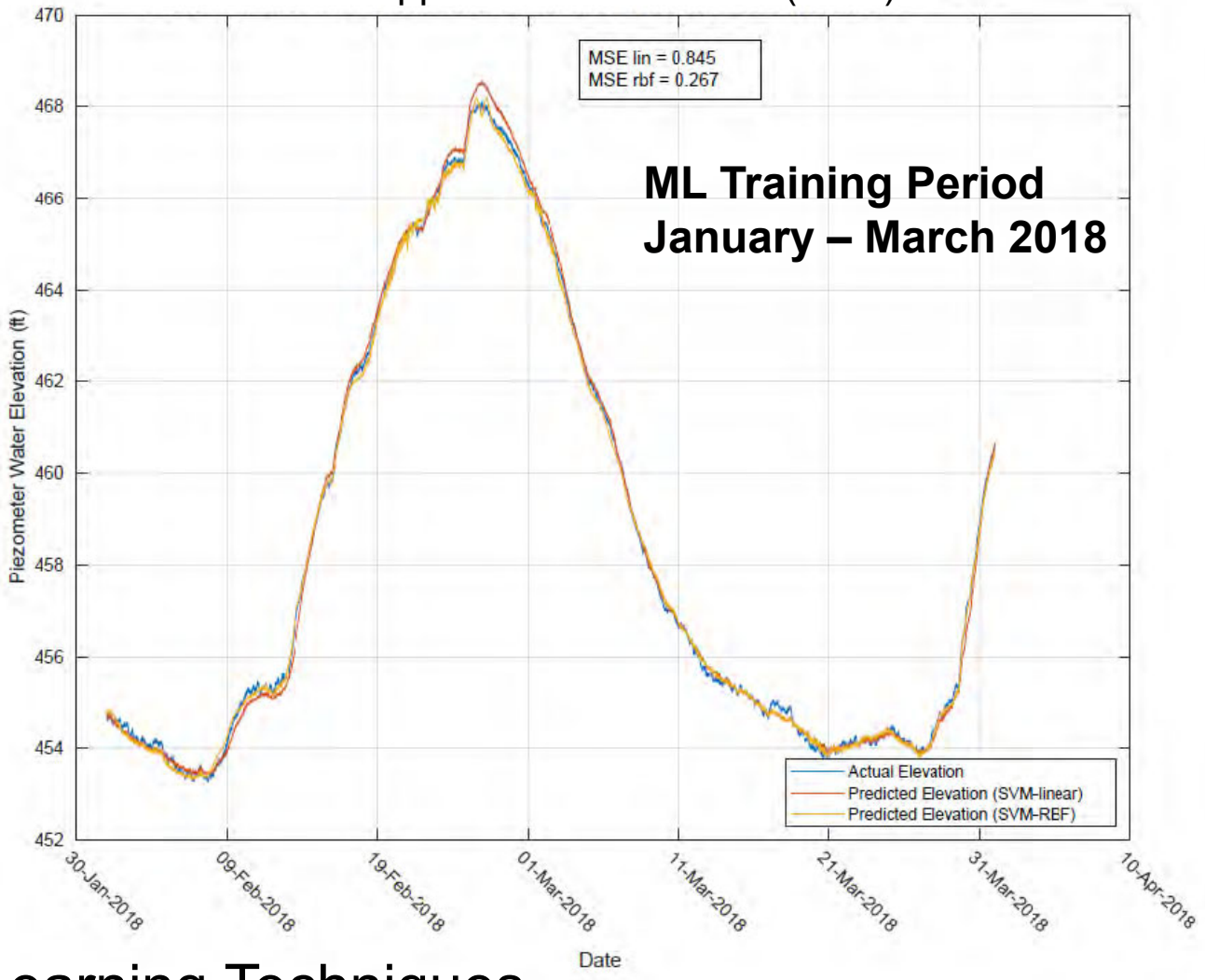


## Figure 16B. Predicted Water Levels at MP-1
## 100-year Flood Event (Hydrologic Model)

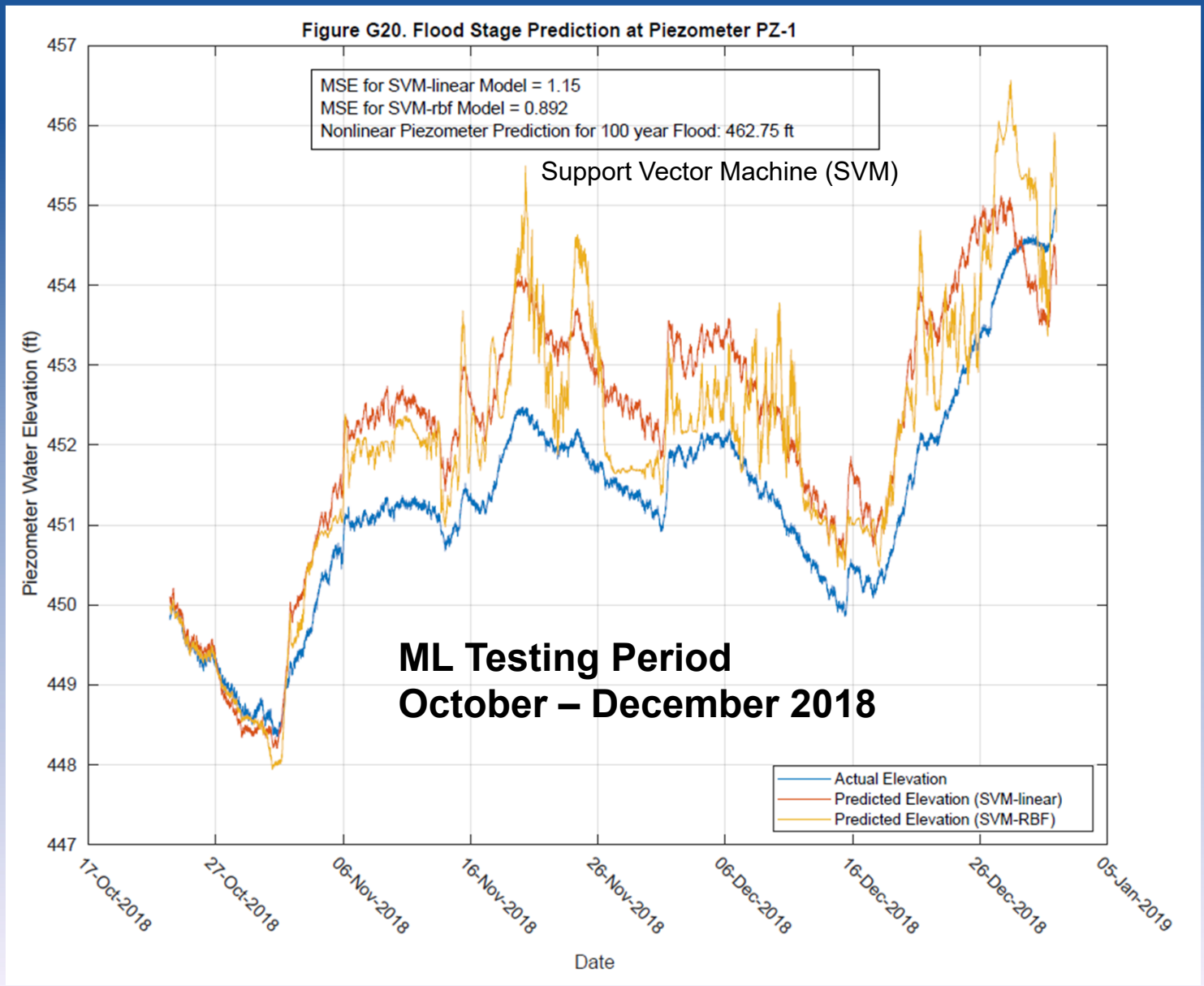


## Figure 12B. Flood Stage Prediction at Piezometer PZ-1
## February-March 2018 High Water Event

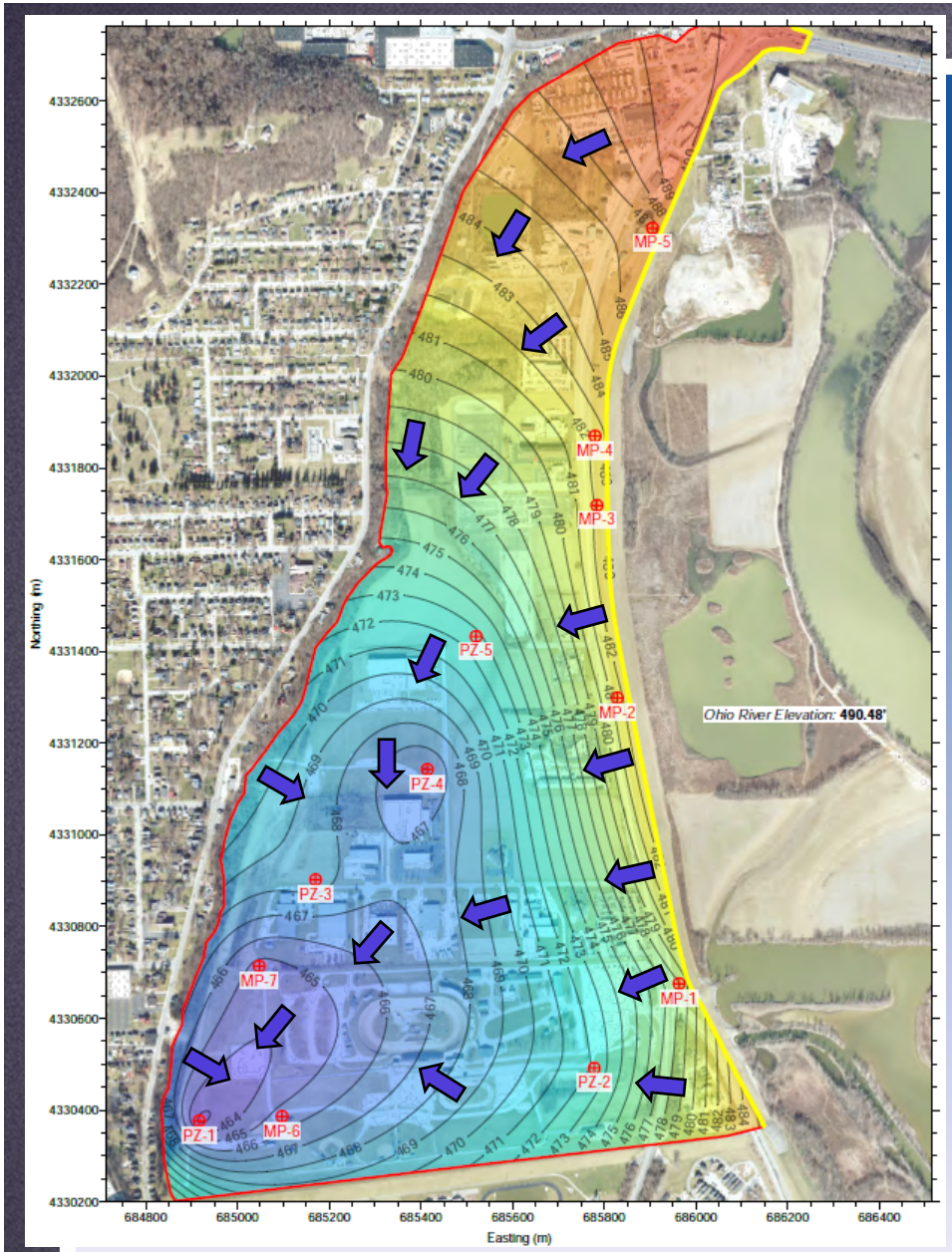
Support Vector Machine (SVM)

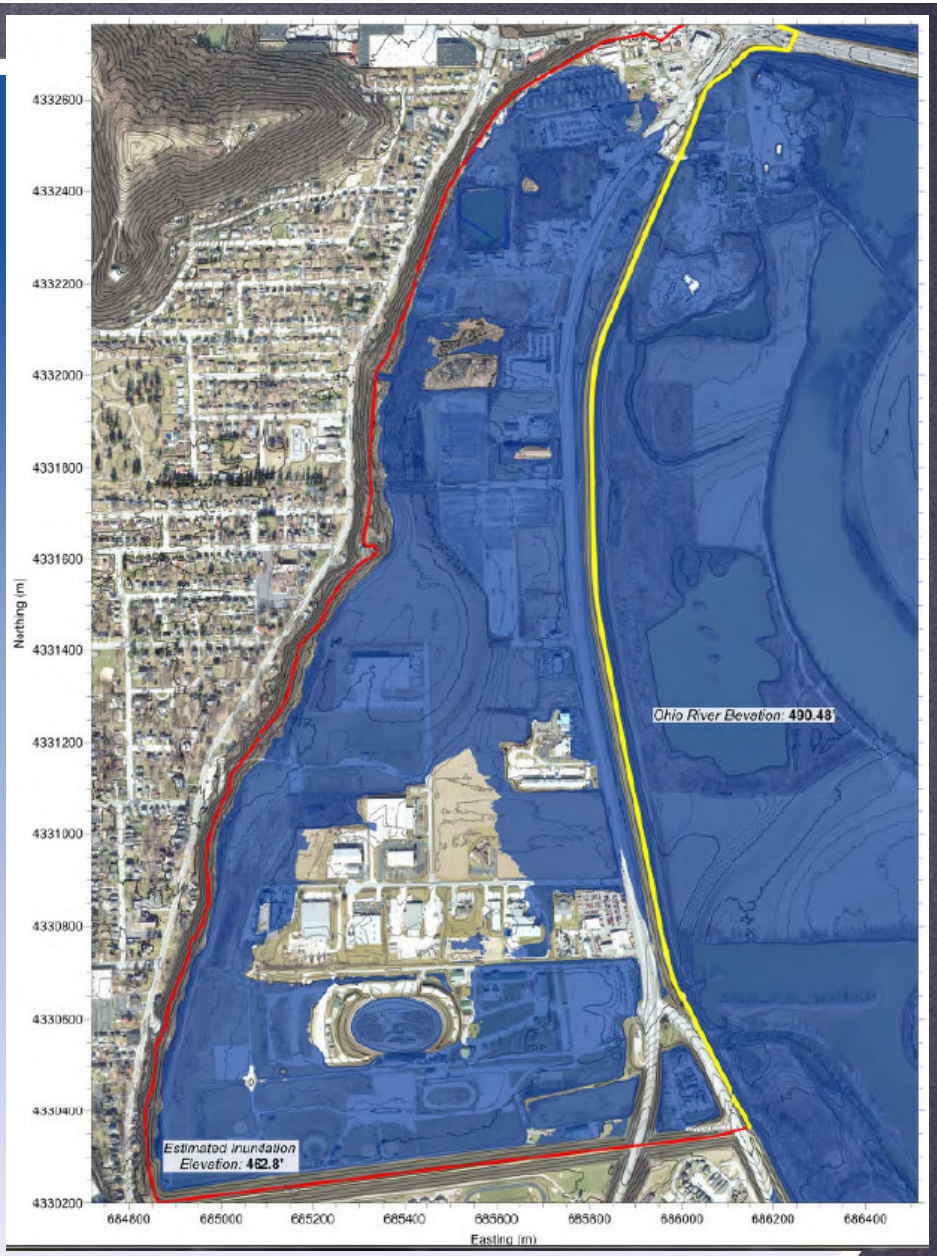



Machine Learning Techniques




# Machine Learning Techniques



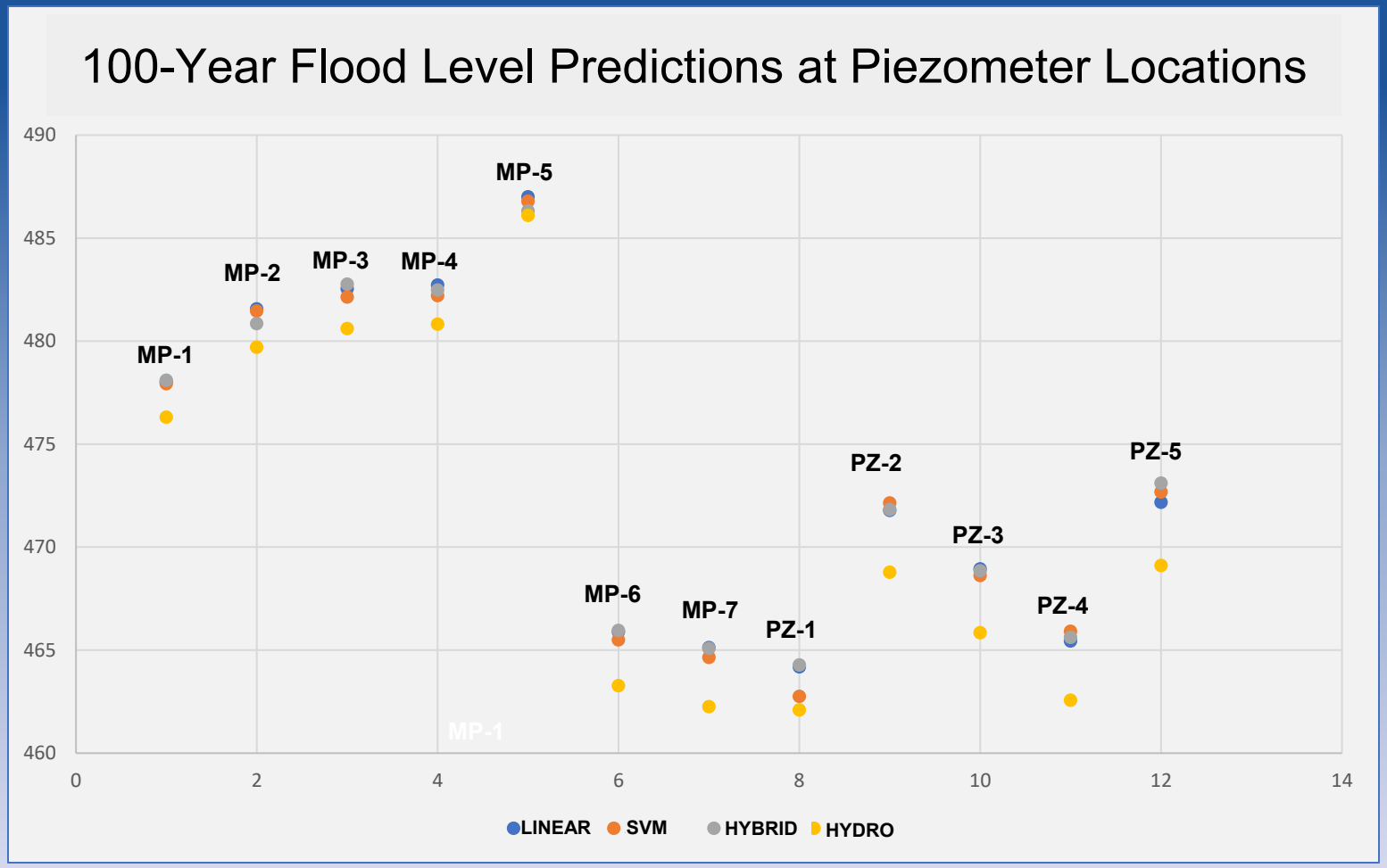




# Potentiometric Map

# Inundation Map

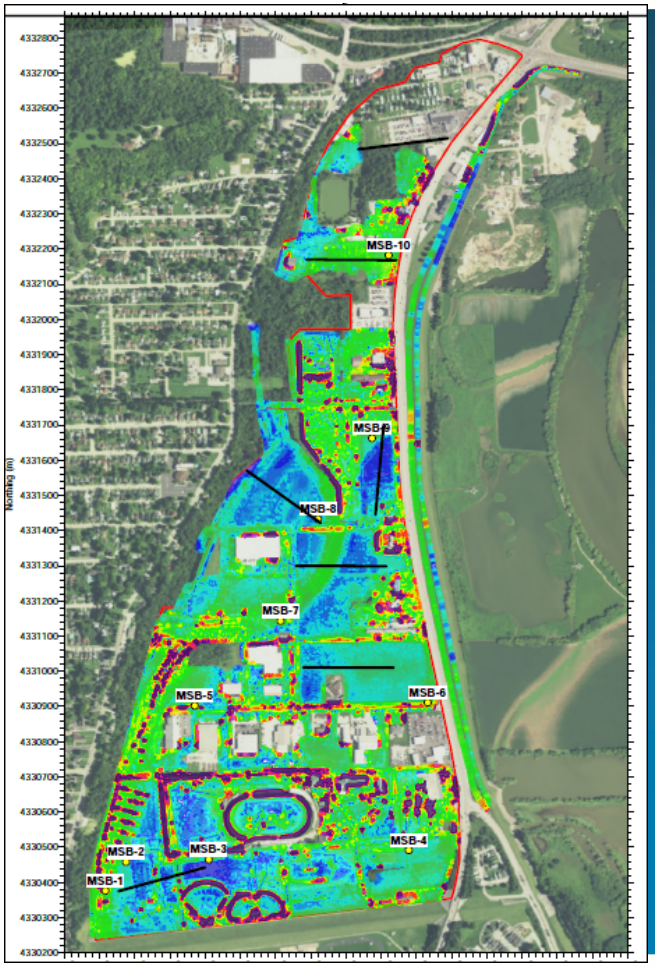
## Hydrid SVM

## Ohio River I00-Year Flood



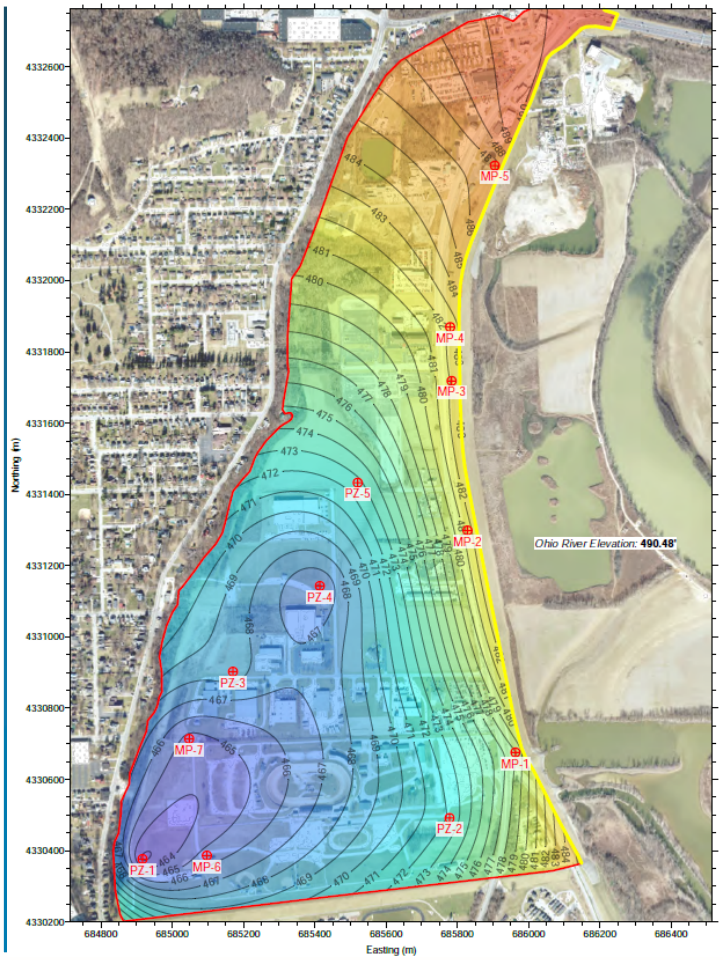

**Linear – Maximum (5 out of 12)**
**SVM – Maximum (2 out of 12)**
**Hybrid SVM – Maximum (5 out of 12)**
**Hydrologic – Minimum all the time**

# Conclusions




- Site characterization studies allowed for the selection of ‘smart data inputs’ at the most critical locations along the Greendale Levee and within the City of Greendale.
- The smart data inputs allowed linear and hydrologic modeling results to be calibrated against real data to improve the confidence in 100-year Ohio River high water event predictions.

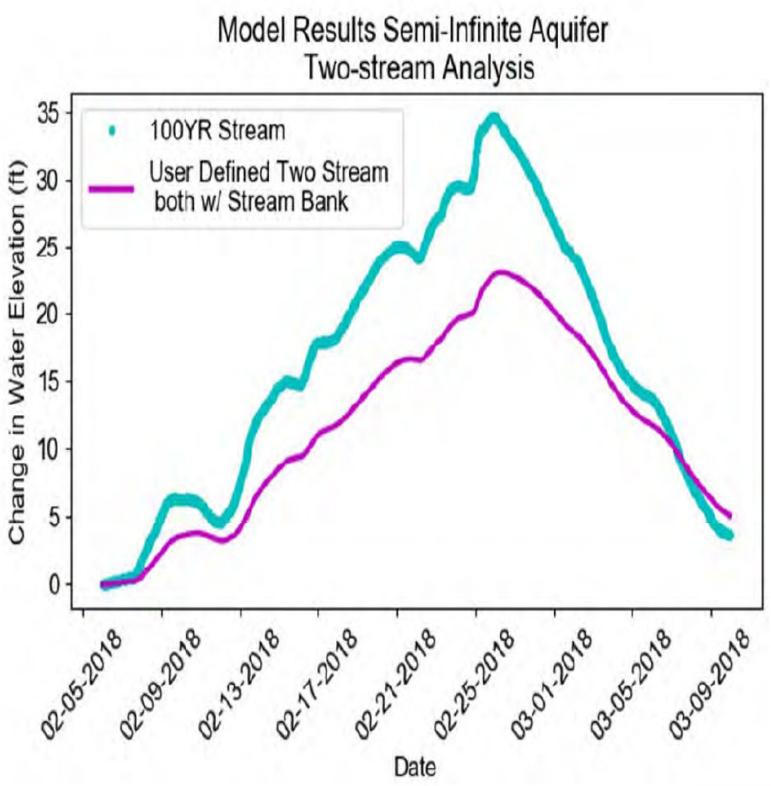
# Conclusions




- Smart data allowed for the development of non-linear Machine Learning (ML) models that accurately simulate river and groundwater levels during the 2018 Ohio River high water event.

# Conclusions

**Figure 16B. Predicted Water Levels at MP-1**
**100-year Flood Event (Hydrologic Model)**




- Linear, Machine Learning and Hydrologic analyses all indicate severe inundation of Greendale for the 100-year Ohio River high water event.
- ML techniques appear to be able to replicate predictions made from calibrated linear and hydrologic models based on real world physical relationships.