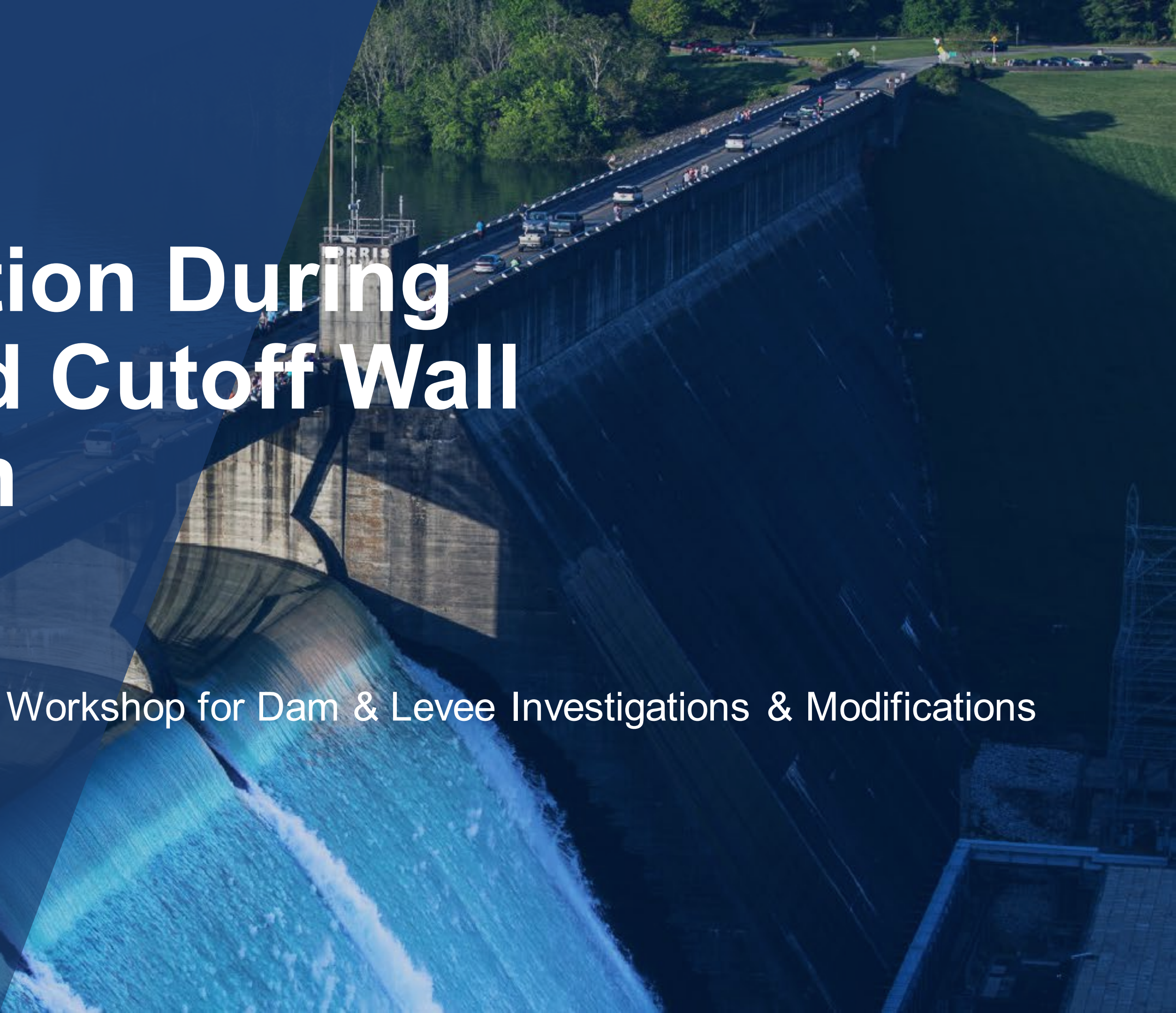
TVA TENNESSEE VALLEY AUTHORITY

Instrumentation During Grouting and Cutoff Wall Construction

Scottie L. Barrentine, PE

AEG – Specialty Geotechnical Workshop for Dam & Levee Investigations & Modifications

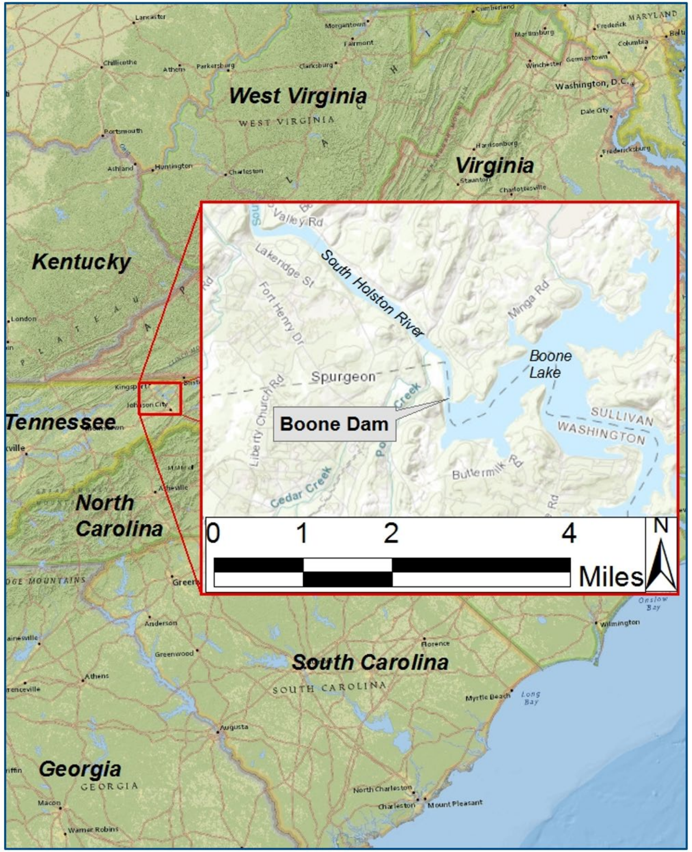
December 7, 2021



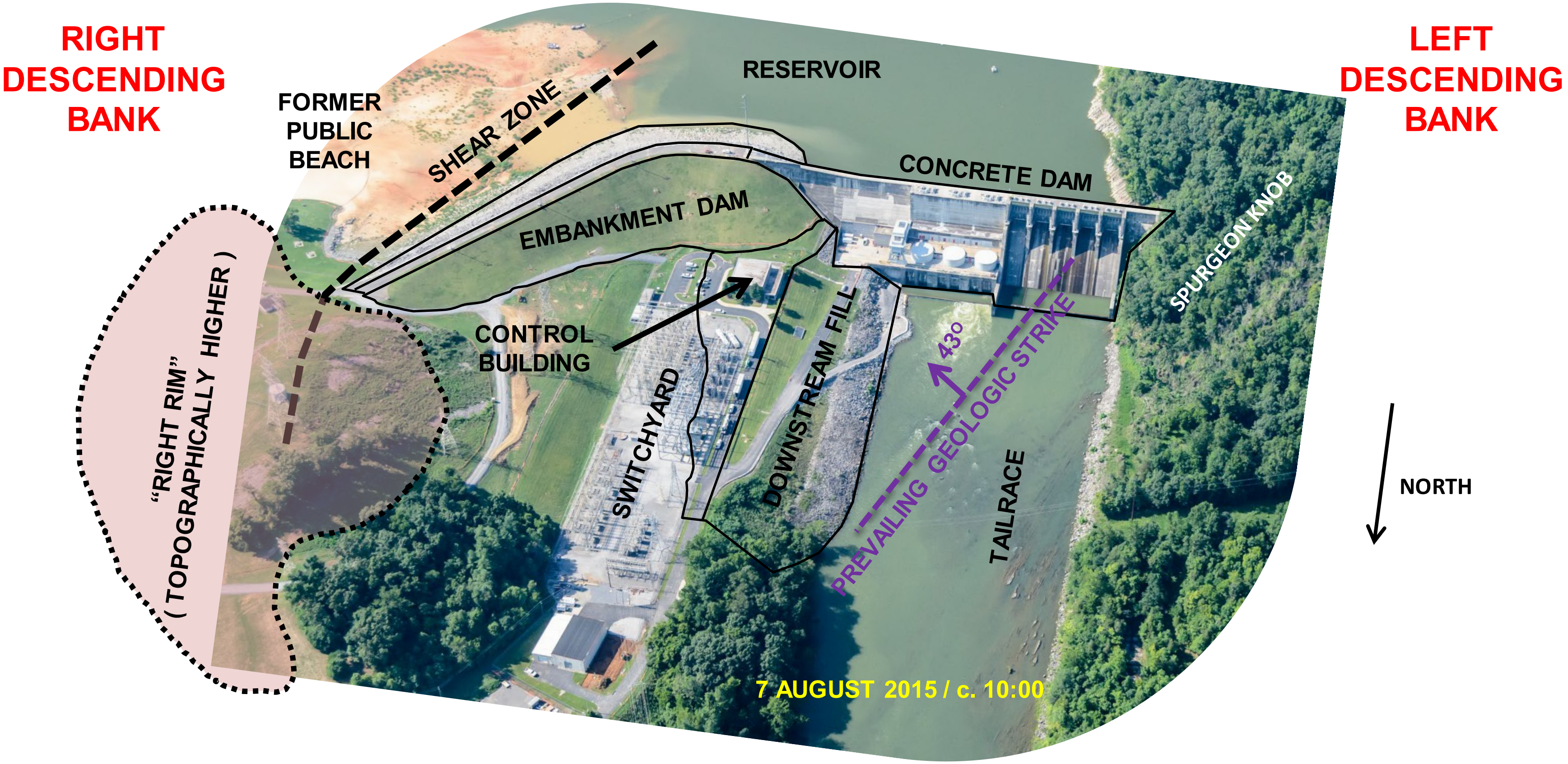
Welcome to Boone Dam

LOCATION OF BOONE DAM

- Owned and operated by the Tennessee Valley Authority.
- Located on the South Holston River in Northeast Tennessee.
- Used for hydroelectric generation, flood control and recreation.
- Constructed between 1950 and 1952.
- Concrete gravity dam across the South Holston River channel with an earth embankment dam.
- Approximately 900’ embankment dam.

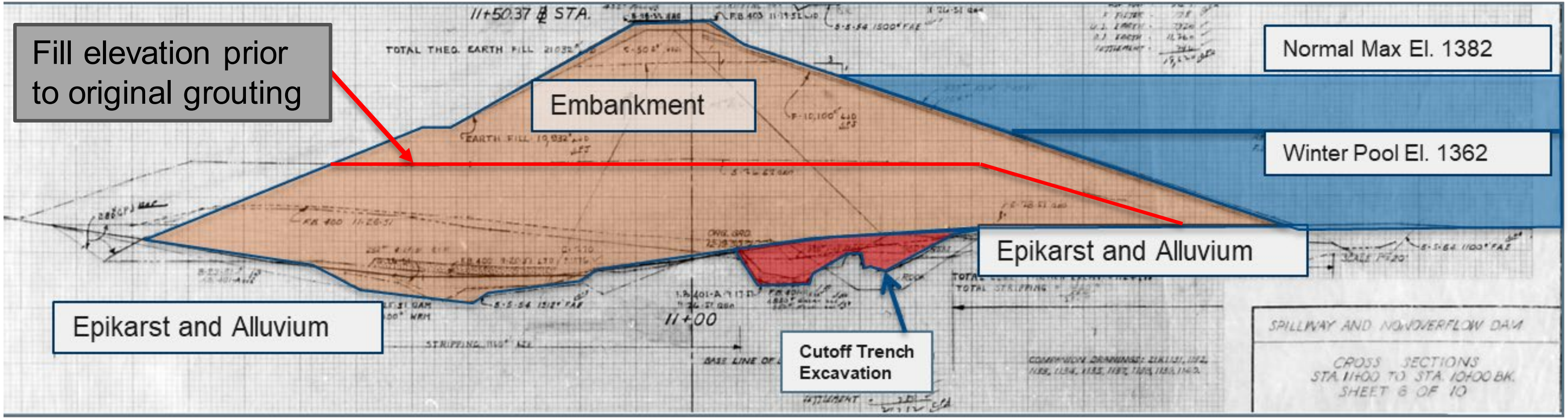


SURFACE FEATURES AT BOONE DAM

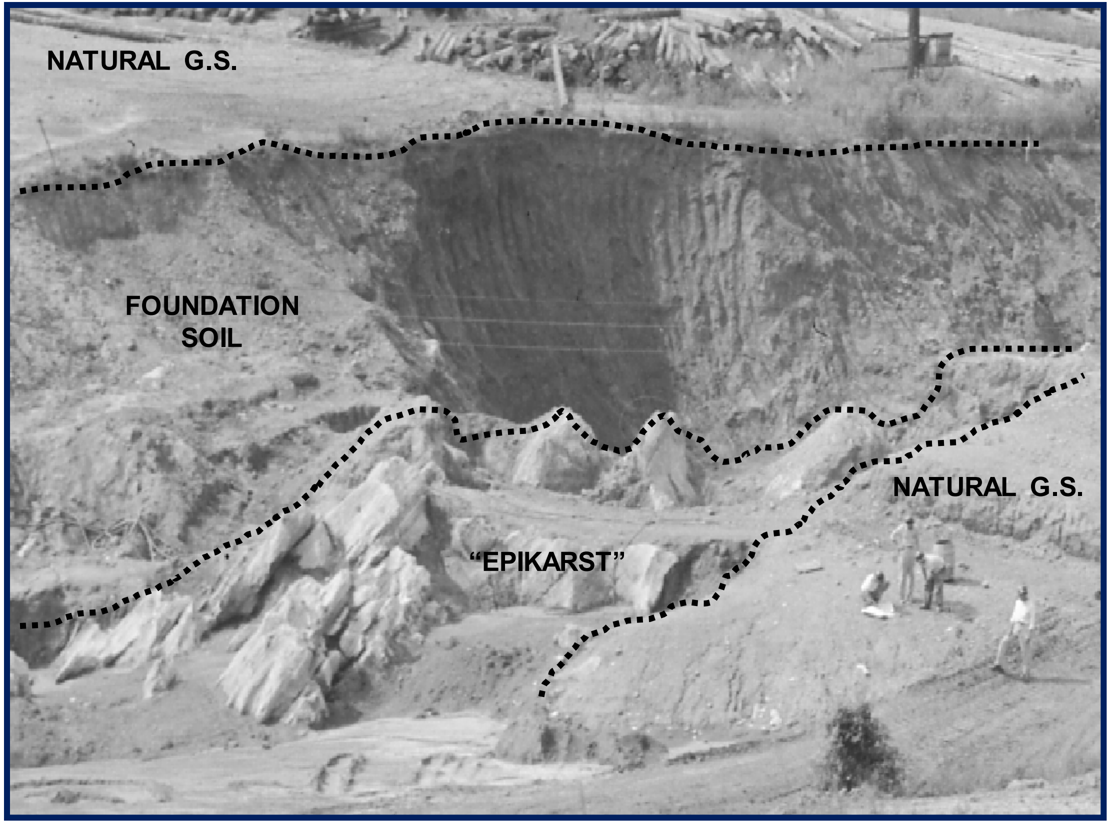


AS-BUILT CONDITIONS OF THE RIGHT EMBANKMENT

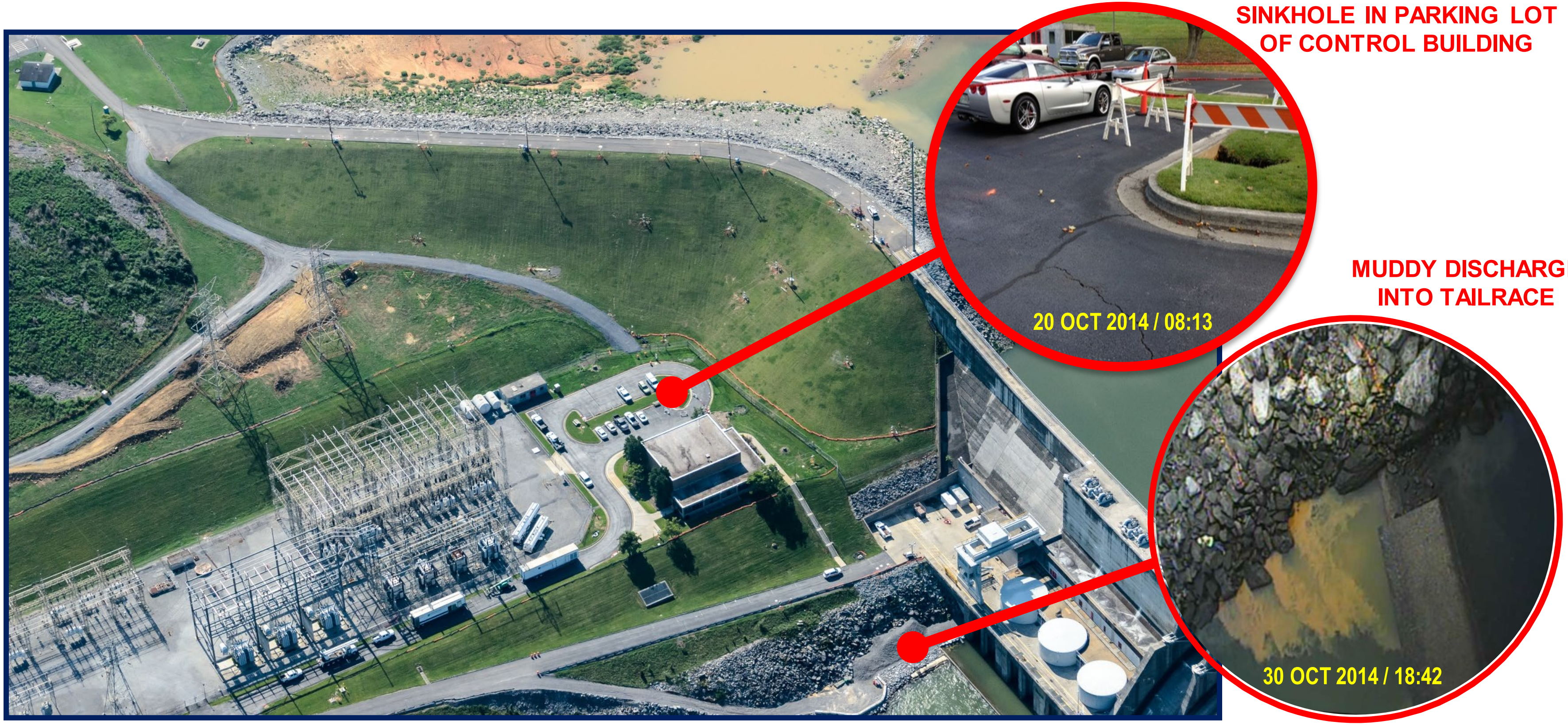
- Cutoff trench excavated into the epikarst was backfilled with compacted clay.



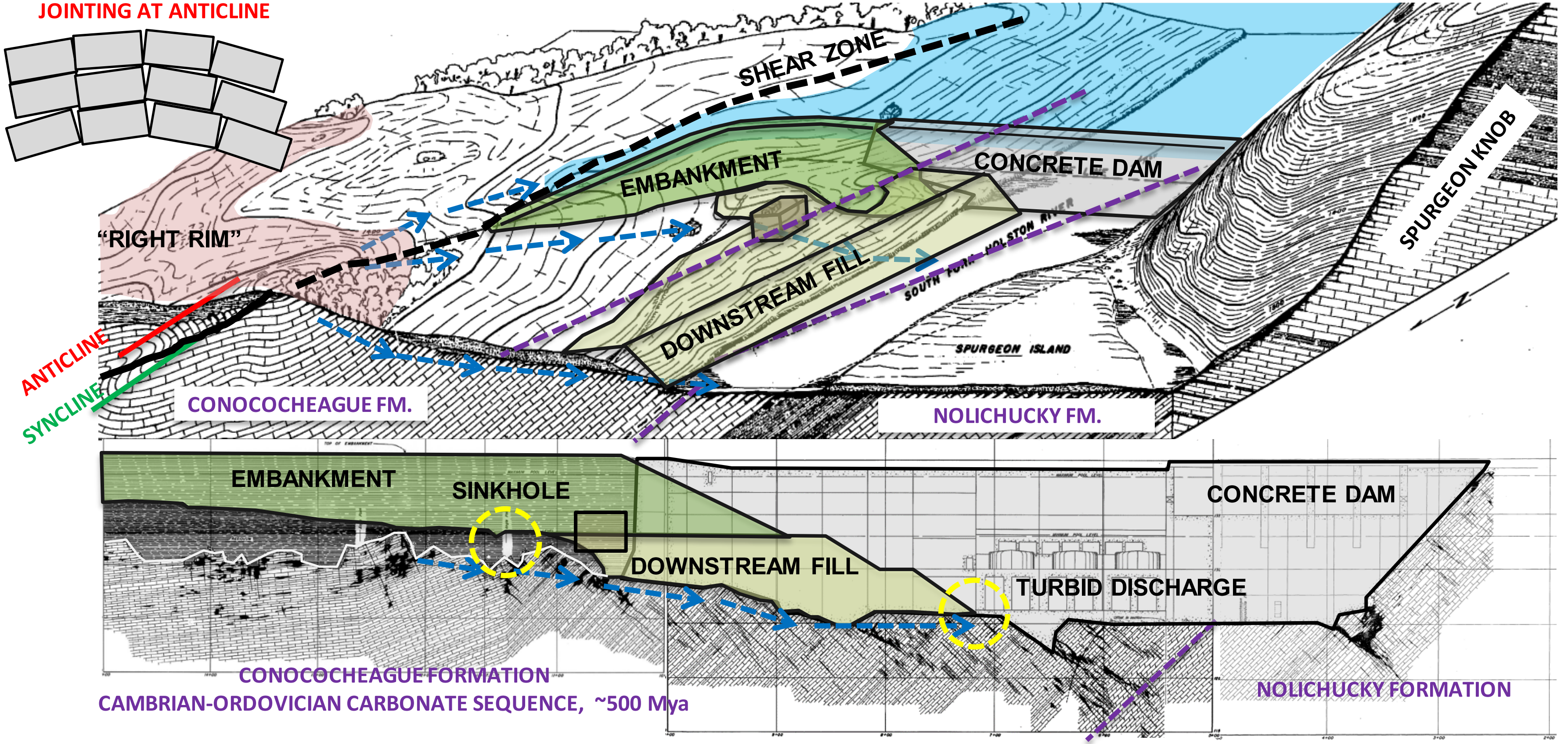
CONSTRUCTION OF CUTOFF TRENCH, ~1951



OBSERVATIONS IN OCTOBER 2014



GEOLOGY AT BOONE DAM (STRATIGRAPHY)



Advanced Instrumentation Systems for Investigation and Construction

TENNESSEE VALLEY AUTHORITY

INSTRUMENTATION FOR EXPLORATION

- Within a karst system significant number of instruments may be required to understand the flow patterns

- Design instrumentation to understand vertical and horizontal flow directions

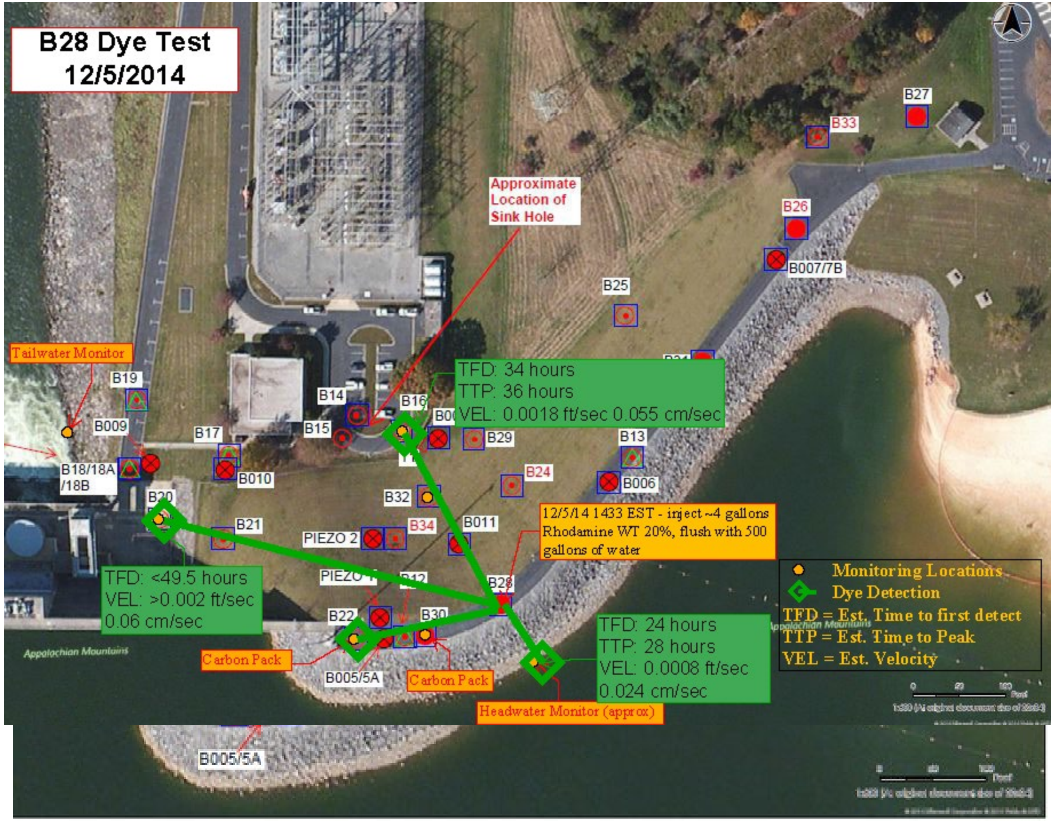
- Design instrumentation for dye tracing

- Guide where to place the next instruments based on analysis of previous instruments

- High frequency reading intervals required to understand relationship to environmental factors

MAPPING KARST - Nov 2014

- Soil and Bedrock Coring
  - (~ 26 borings)
- Televiewer / Borehole Camera surveys
- Instrumentation
  - Mix of Nested PZs and Open Standpipes
- Dye Testing

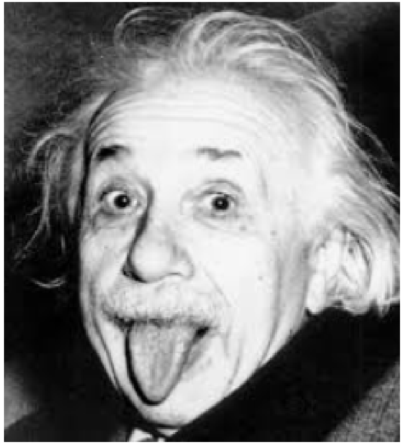


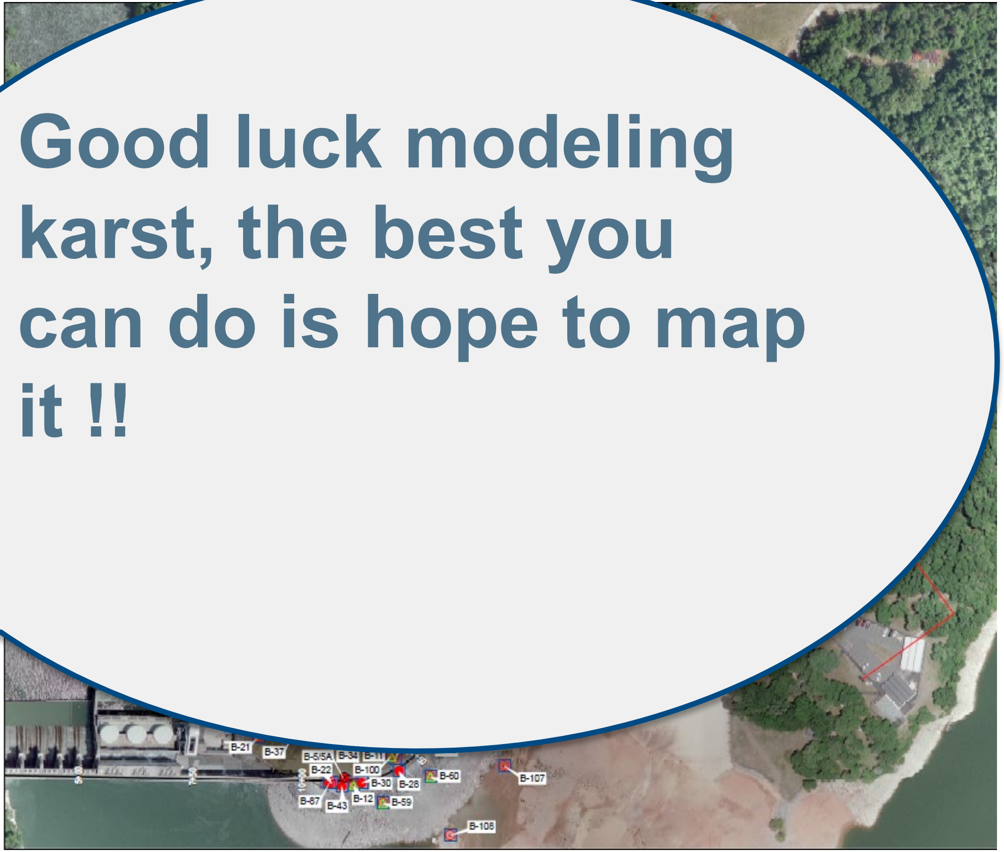
MAPPING KARST - 2015

- Soil and Bedrock Coring
  - (~ 48 borings)
- Televiewer / Borehole Camera surveys
- Instrumentation
  - Mix of Nested PZs and Open Standpipes

MAPPING KARST - 2017

- Soil and Bedrock Coring
    - (>96 borings)
- Televiewer / Borehole Cam
  surveys
- Instrumentation
    - (>200 piezometers)



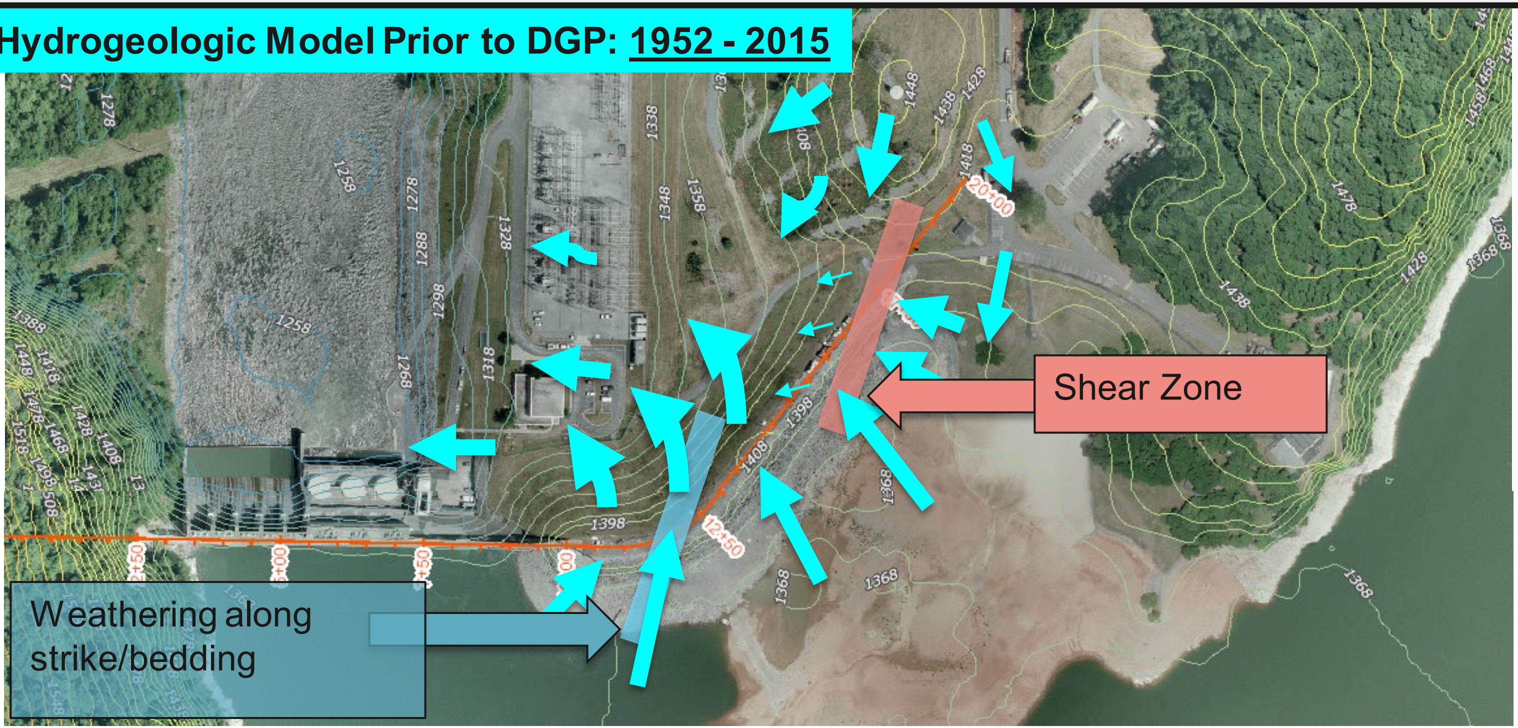


Good luck modeling karst, the best you can do is hope to map it !!

Key Observations:

1. Predominant flows in epikarst with contribution from the higher elevations of the right rim;
2. Concentrated flow occurs through the alluvial trough and within solution features along bedding;
3. The original cutoff was not effective at cutting off flows from the reservoir;
4. The "shear zone" is performing as an aquitard;

Hydrogeologic Model Prior to DGP: 1952 - 2015

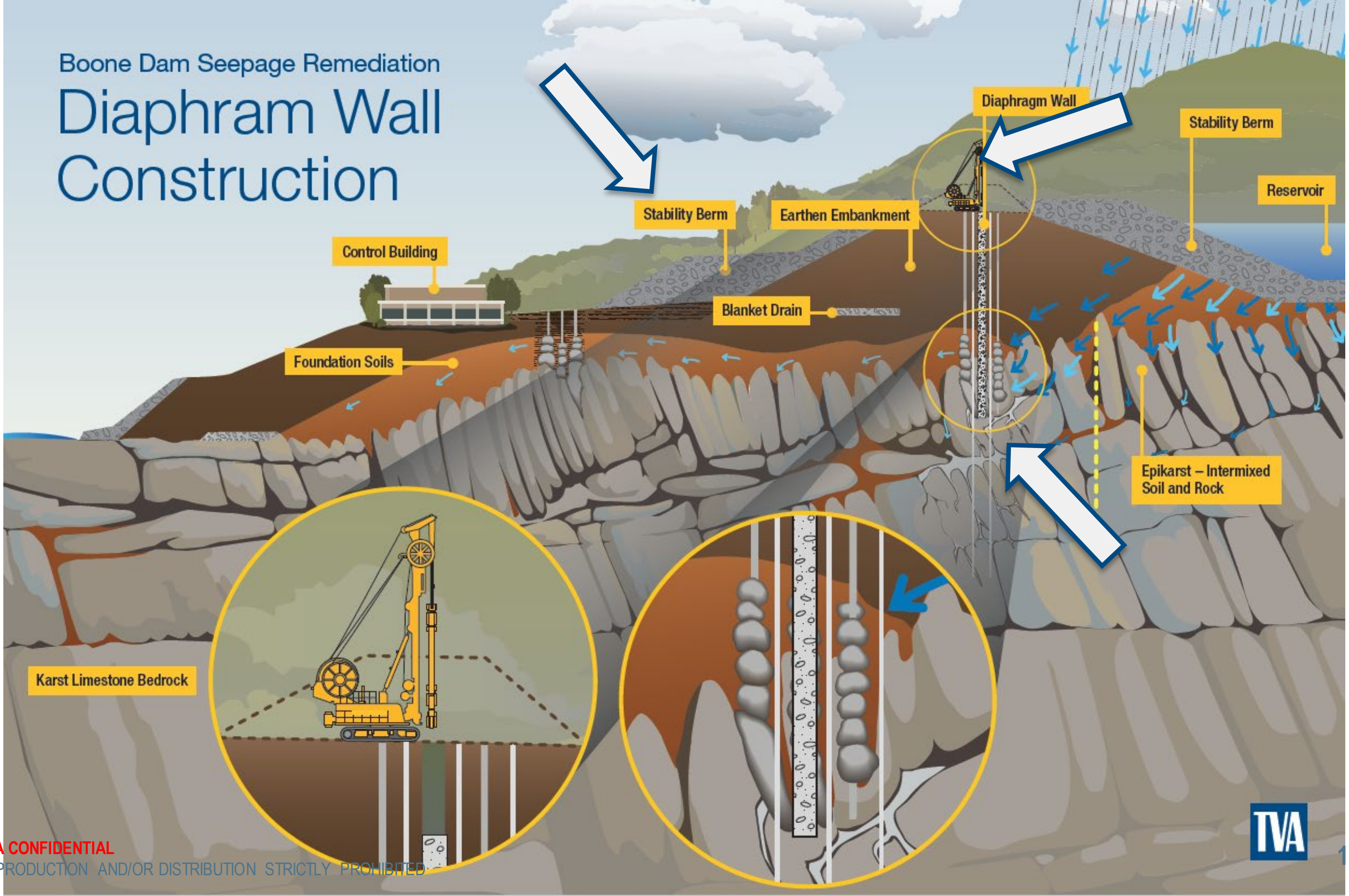


Instrumentation Planning for Construction

TVA TENNESSEE VALLEY AUTHORITY

Boone Dam Seepage Remediation

Diaphram Wall Construction



INSTRUMENTATION PLANNING FOR CONSTRUCTION

Considerations for System Development

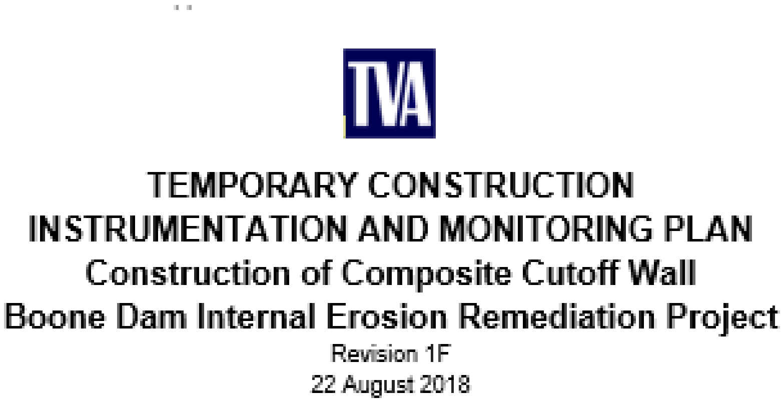
- What is the risk to the dam?
- Who is going to own and operate the system?
- What is the risk to construction process?

INSTRUMENTATION PLANNING FOR CONSTRUCTION

Instrumentation and Monitoring Plan is a MUST!!!

Contents should include:

- Organization of the monitoring Team
- PFM's being monitored
- System Design and Operations
    - Operation
    - Redundancies
    - Actions for Damage
    - Replacement
    - Outages



TEMPORARY CONSTRUCTION
INSTRUMENTATION AND MONITORING PLAN
Construction of Composite Cutoff Wall
Boone Dam Internal Erosion Remediation Project
Revision 1F
22 August 2018

INSTRUMENTATION PLANNING FOR CONSTRUCTION

Instrumentation and Monitoring Plan is a MUST!!!

Contents should include:

- **Network Design Diagrams**
- **Instrumentation Installation Records and Data**
- **Instrumentation Tables with Constants**

INSTRUMENTATION PLANNING FOR CONSTRUCTION

Instrumentation and Monitoring Plan is a MUST!!!

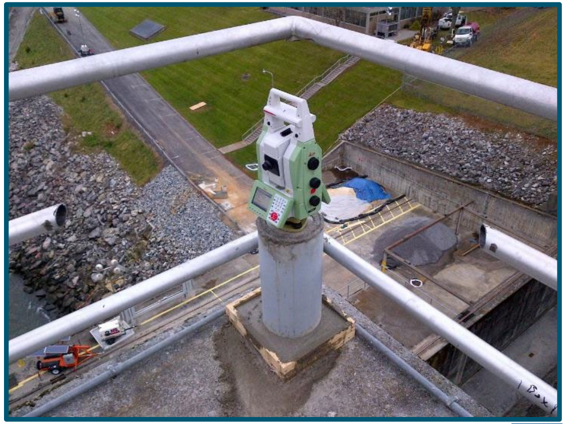
Contents should include:

- **Monitoring, Alerts, and Responses**
  - **Alert Levels**
  - **Actions**
  - **Construction restart**
- **Reporting**
  - **Routine Reporting**
  - **Incident Reporting**

INSTRUMENTATION PLANNING FOR CONSTRUCTION

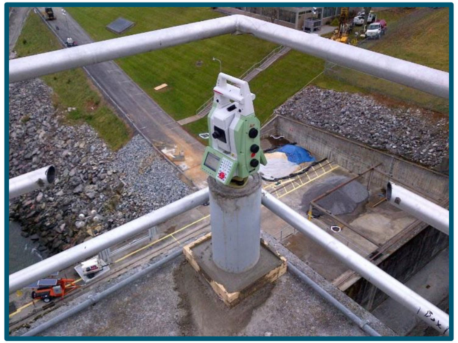
What Needs to Be Monitored?

- Deformation
  - Automated Total Station
  - Inclinometers
  - Shape Array Accelerometers
- Groundwater
  - Open standpipe
- Porewater Pressures
  - Grouted-in-Piezometers
- Toe Drain Flows
  - Automated Flumes



INSTRUMENTATION PLANNING FOR CONSTRUCTION

Deformation Monitoring – Three ATS Systems



INSTRUMENTATION PLANNING FOR CONSTRUCTION

Deformation Monitoring – Inclinometers

INSTRUMENTATION PLANNING FOR CONSTRUCTION

Groundwater and Porewater

- **Split the Piezometer network into to Construction Monitoring and Hydrogeological Monitoring**

SYSTEM DESIGN FOR CONSTRUCTION

How do you gather, control, and make useful information out of so much data?

- **Hardware Design**
- **Network Design**
- **Reporting Design**

HARDWARE DESIGN FOR CONSIDERATIONS

In All Things Remember the 3 R’s (Robust, Redundant, Reliable)

- **Robust and Reliable**
  - **How long will your equipment be exposed?**
  - **Think about the improbable.**

HARDWARE DESIGN FOR CONSIDERATIONS

Hardware Considerations

- Redundant Power Supplies (Solar and AC)
- Quality boxes and ventilation
- Conduit Drainage and vents
- Quality gear
- Spare Parts onsite

NETWORK and PROGRAMMING CONSIDERATIONS

In All Things Remember the 3 R's (Robust, Redundant, Reliable)

- **Can you access engineering units onsite in the event of a blackout?**
- **Are you vulnerable to Cyber events?**
- **How does the data get to the web?**

NETWORK and PROGRAMMING CONSIDERATIONS

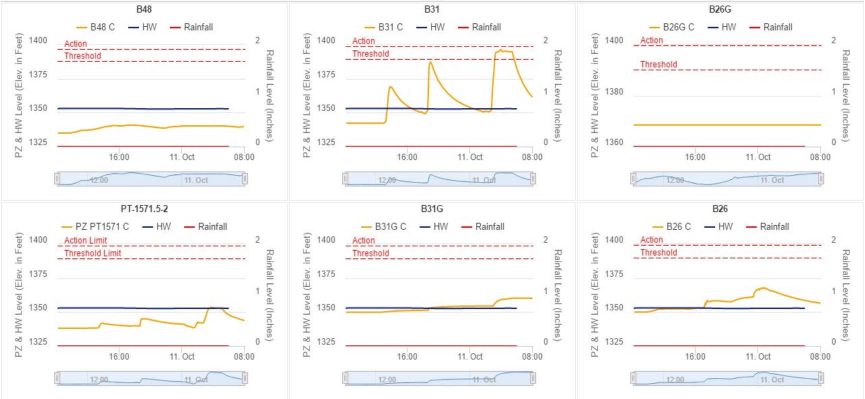
Network Design Considerations

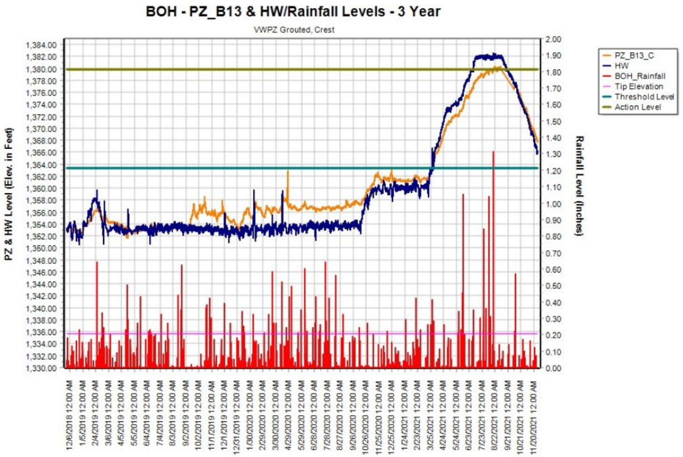
- Redundant Network Communications (Fiber, Cellular, & Laptops)
- Programming Dataloggers to Calculate Engineering Units
- Send Both Raw and Calculated Data to Servers
- Consider Separate Servers for Backup
- Cyber-Security

REPORTING DESIGN CONSIDERATIONS

In All Things Remember the 3 R's (Robust, Redundant, Reliable)

- **Active and Passive Reporting**
- **How fast does your reporting tools work?**
- **Are they redundant?**
- **How are alerts sent?**
- **Is it compatible with Information Management Systems?**





REPORTING DESIGN CONSIDERATIONS

Reporting Design

- Boone utilized two separate software programs for construction monitoring
  - One for onsite fast paced monitoring with highly configurable dashboards. This system received engineering units from the dataloggers.
  - The other system received raw data and calculated as a separate check. This system sent daily emails for weekly, monthly, and long term plots.

REPORTING DESIGN CONSIDERATIONS

Reporting Design

- Onsite personnel was responsible for monitoring the system for alerts with the first system
- The second system would send email alerts and test alerts for threshold and action exceedances.
- These systems would communicate with an IMS/GIS system to bring in a complete picture.

In All Things Remember the 3 R’s (Robust, Redundant, Reliable)

Why ?

Why Have the Advanced System?

- FIRST - Dam Safety

- Engineering during Construction
  - Instrumentation verifies design assumptions
  - Instrumentation informs staged construction
  - Grouting control
  - Dam responses

- AND........

Dam Response to Construction Activities

Utilizing Instrumentation to Control Grouting Construction

Exploratory Drilling and Grouting

- 539 LMG holes Drilled & Grouted
- 276 HMG Holes Drilled & Grouted

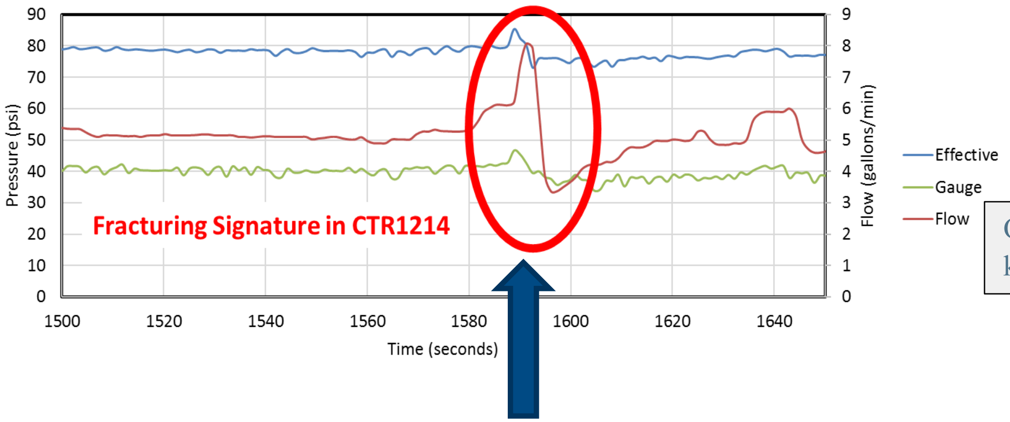
Total Drilling Footage

21.0 Miles

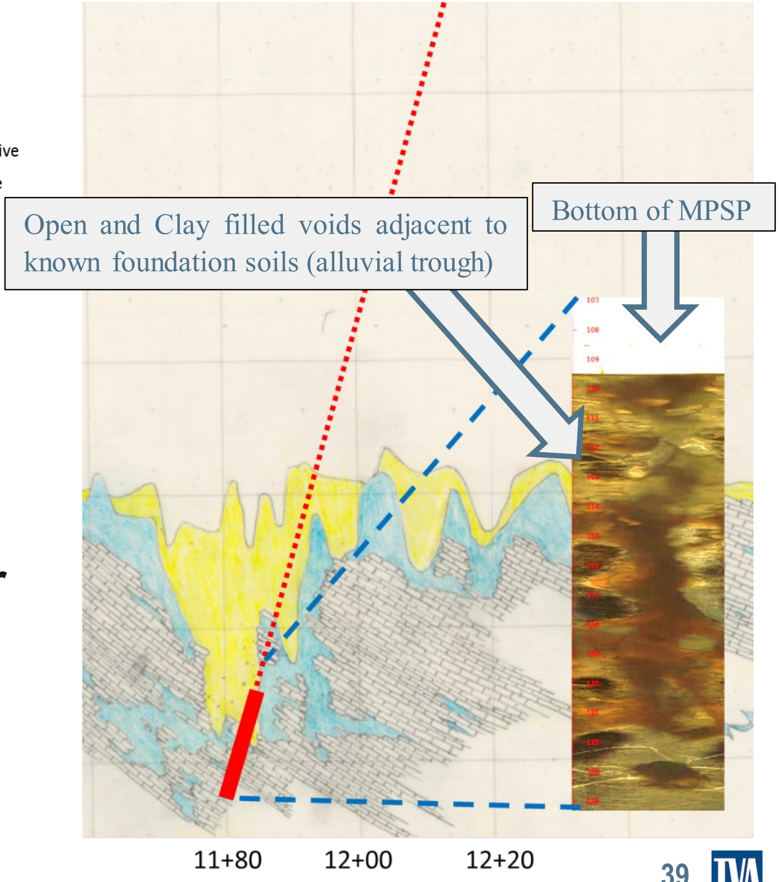
Total Grout Placed

233 Avg. concrete truck loads

Controlling Grouting With Instrumentation

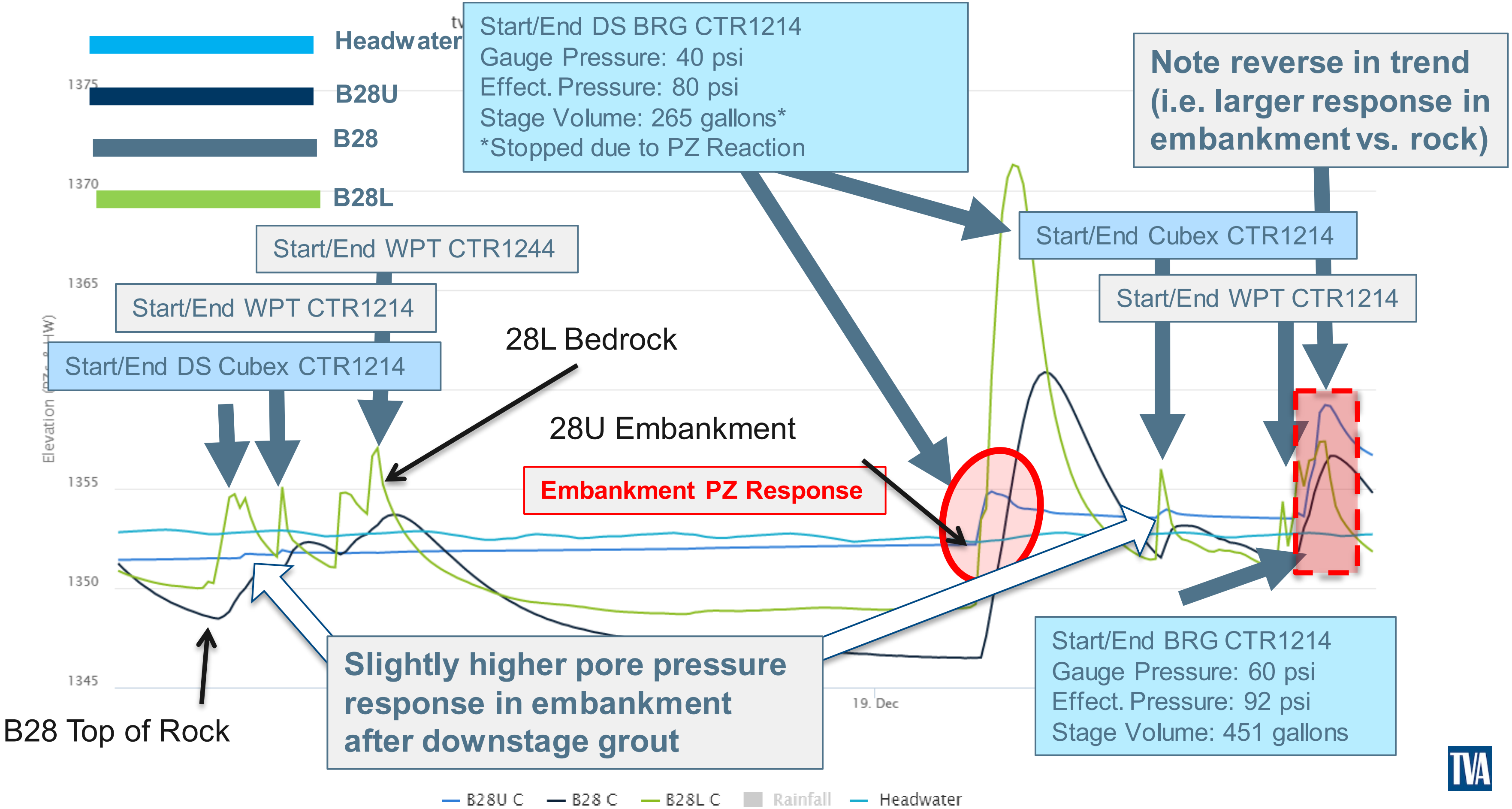


Note: Pressure drop prior to flow spike



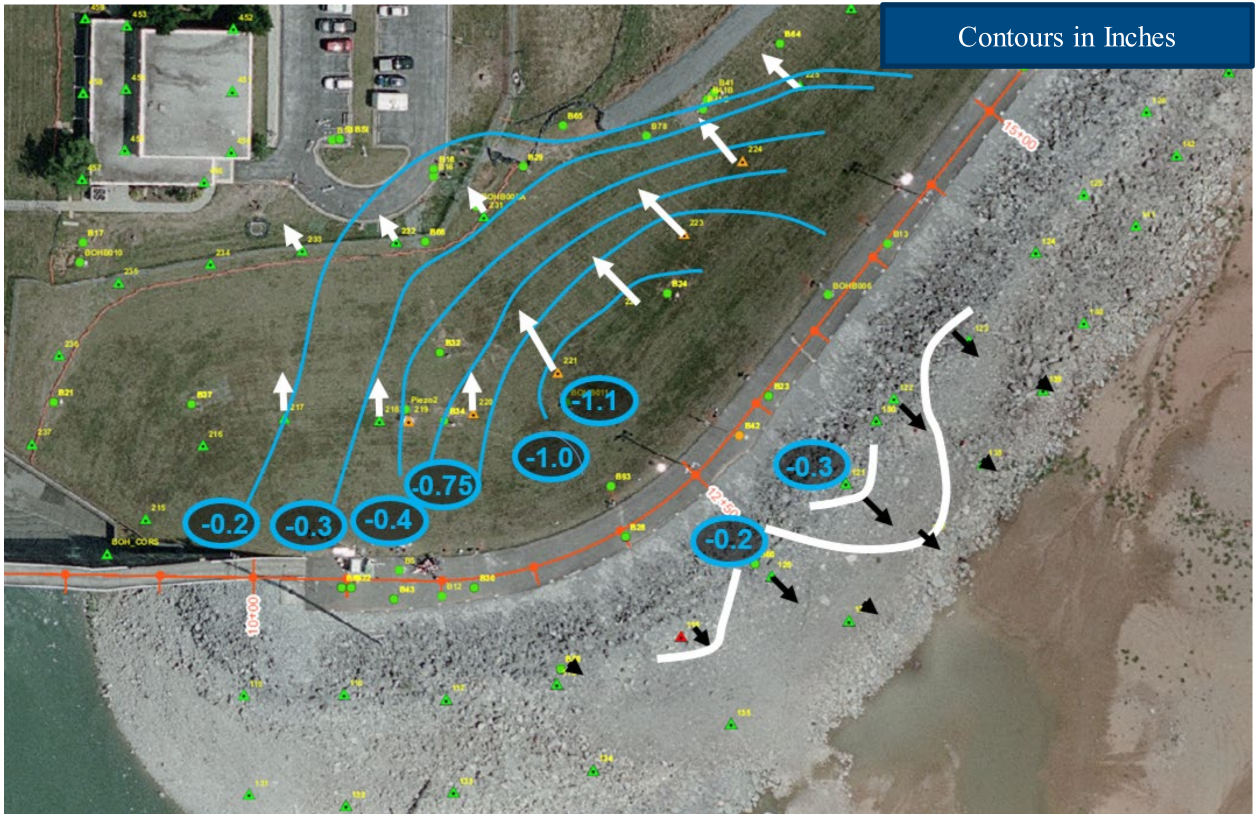
Grouting was stopped due to a piezometer response in the embankment

Piezometric Responses to Drilling and Grouting

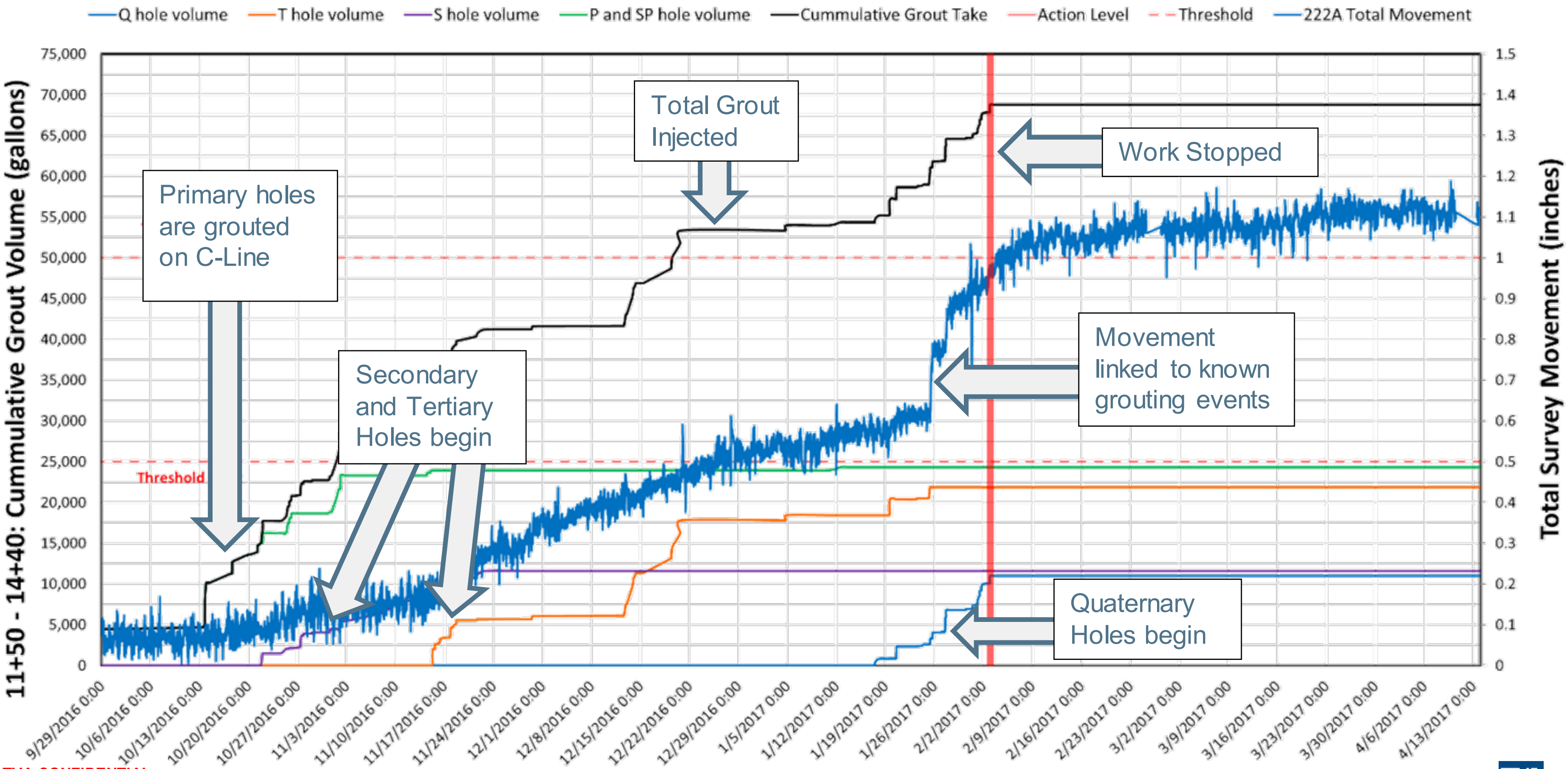


Controlling Grouting by Instrumentation

Deformations measured by the ATS system

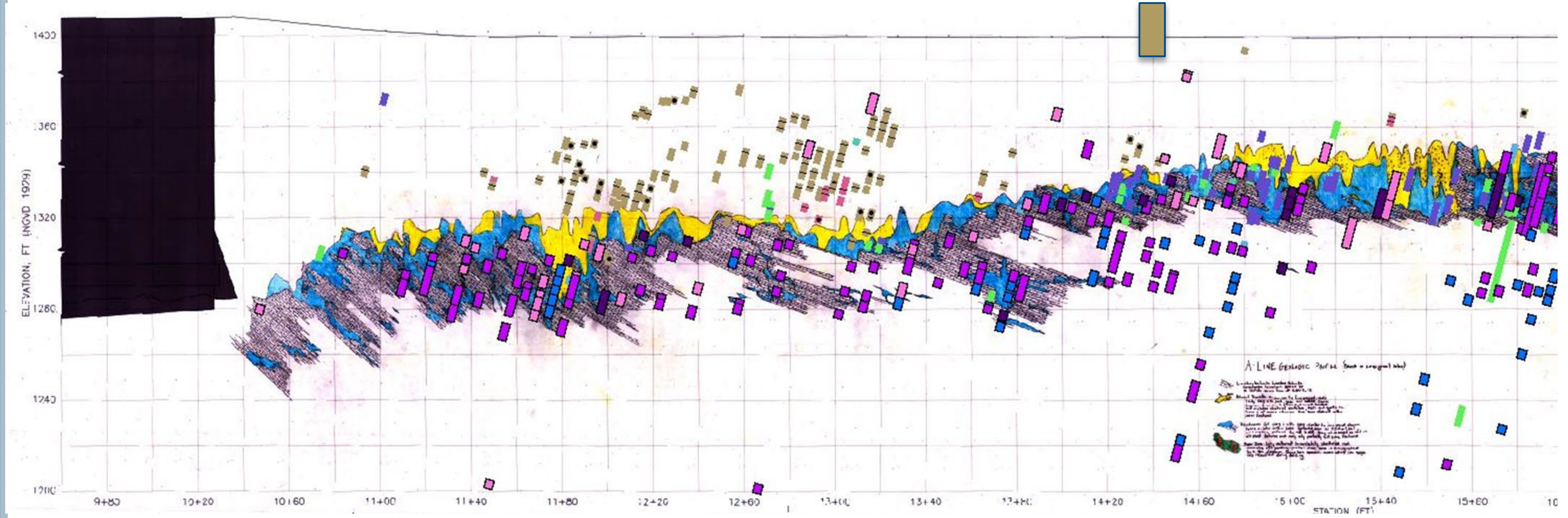


Evaluation of Deformation



Grout Observations from Sonic Drilling

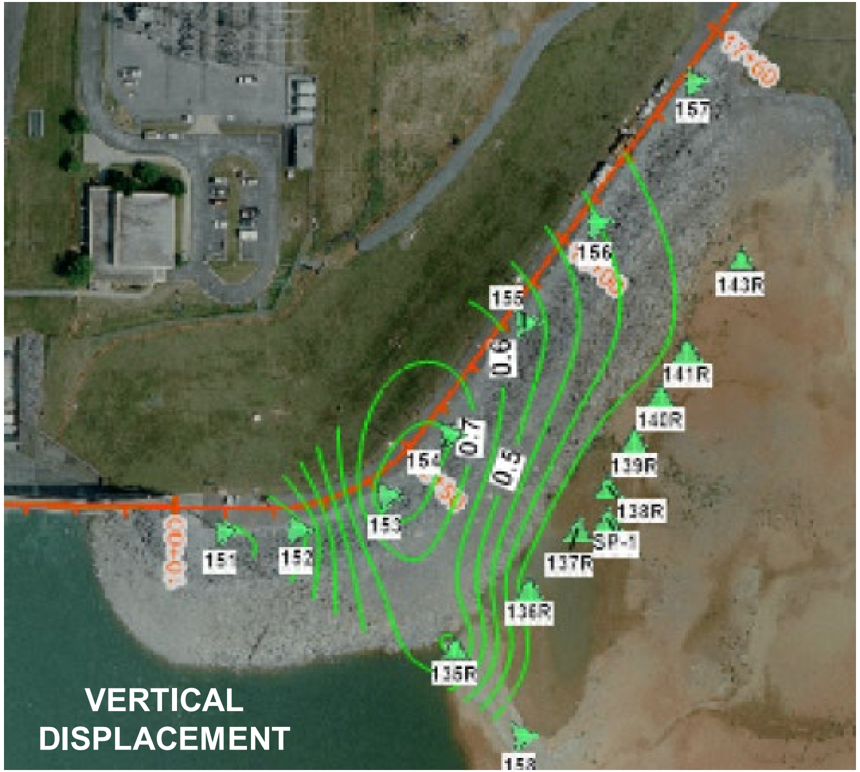
HMG Observation

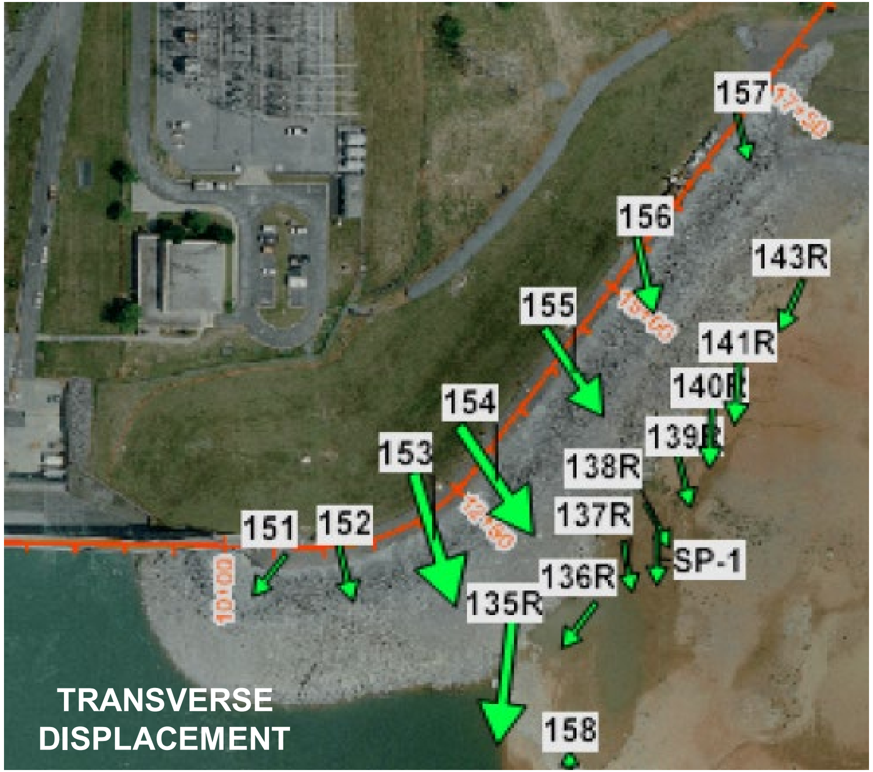


Response to Berm Construction

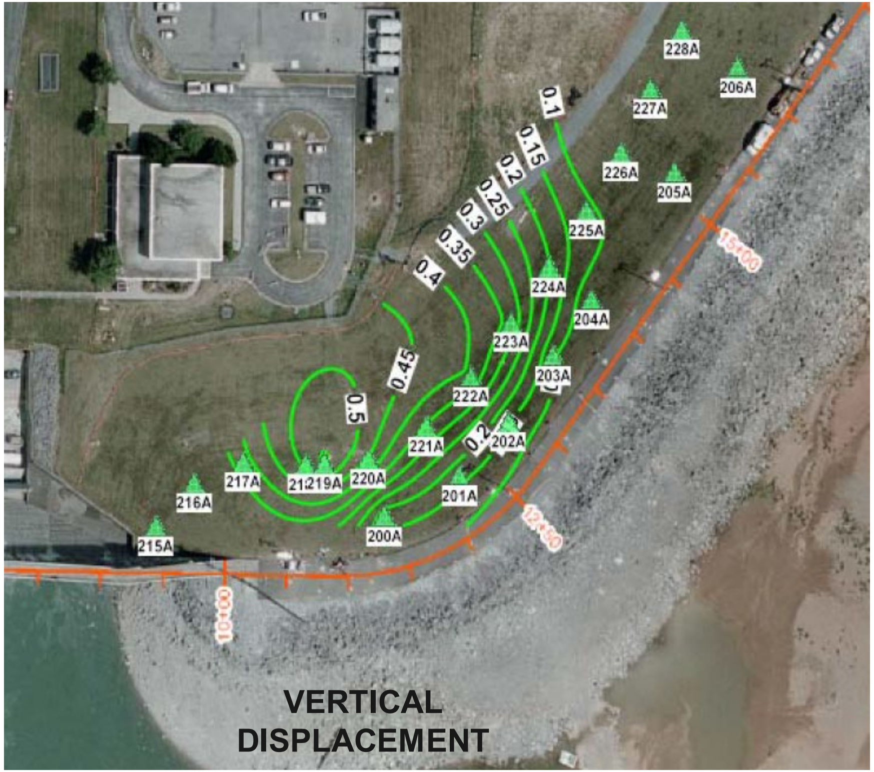
Berm Construction

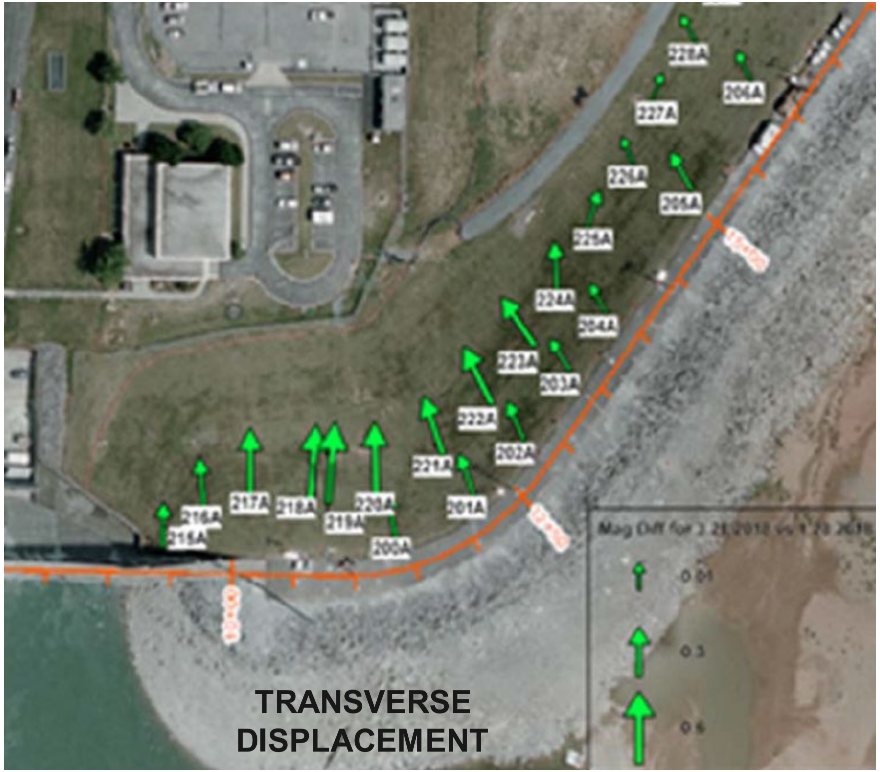
PATTERNS OF U/S SURVEY PRISM DISPLACEMENTS



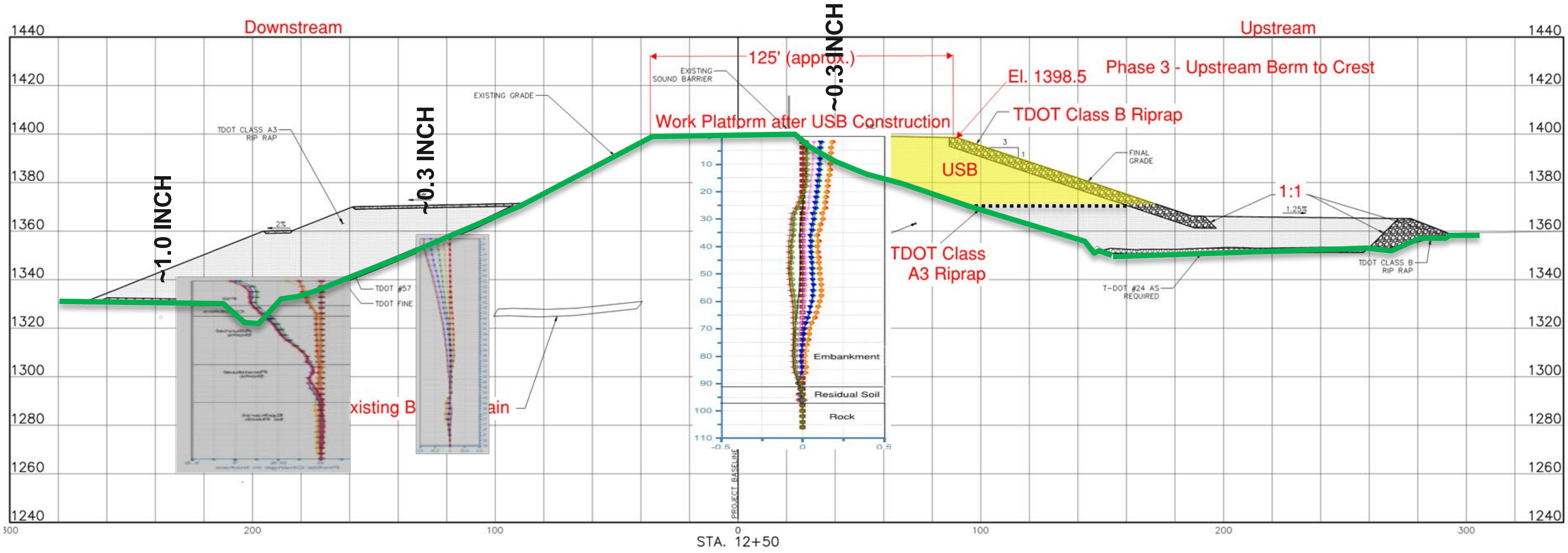


PATTERNS OF D/S SURVEY PRISM DISPLACEMENTS





PATTERNS OF INCLINOMETER DISPLACEMENTS

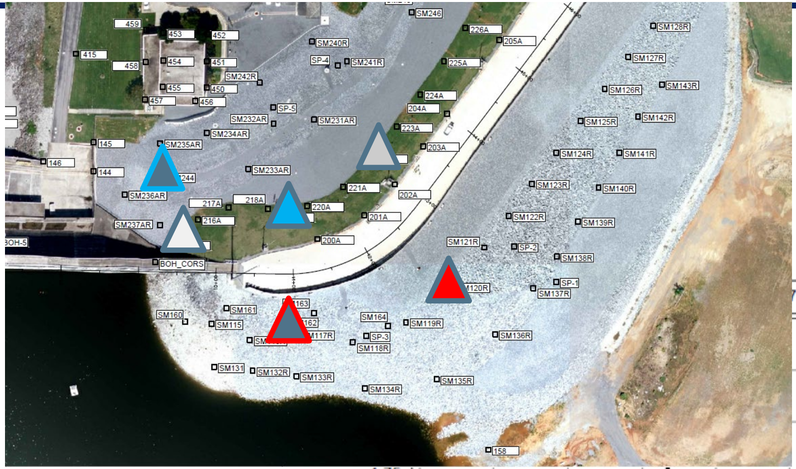


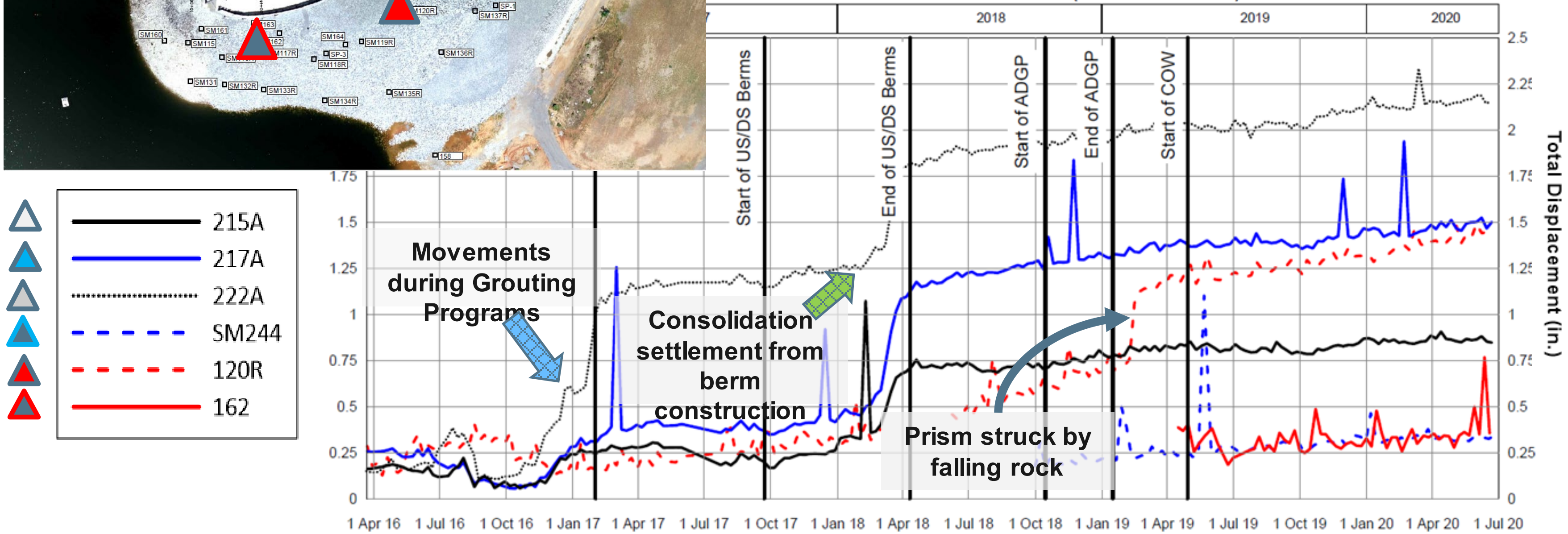
Overall Performance Monitoring

DAM SAFETY PERFORMANCE - DEFORMATIONS

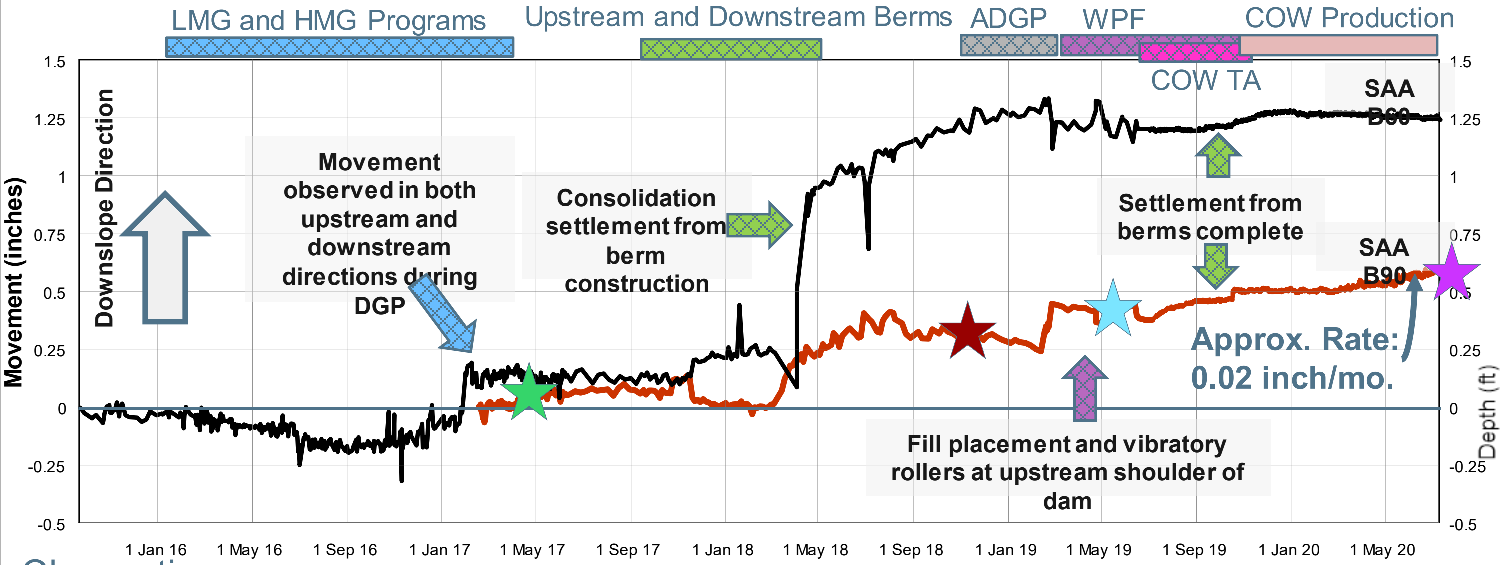
<u>Observations</u>:

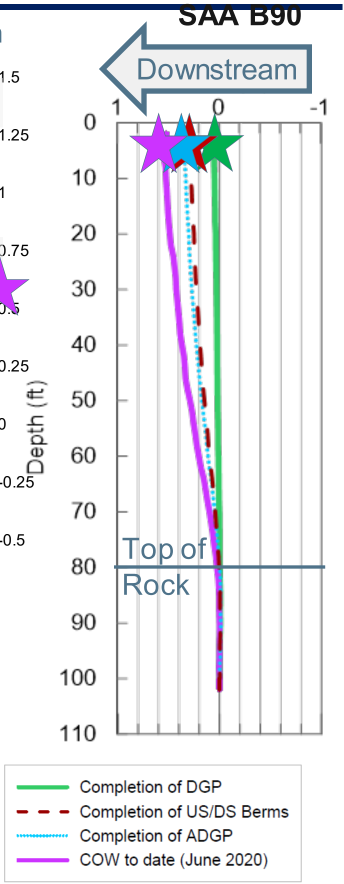
- Largest movement observed during berm construction
- Patterns of deformation appear similar in upstream and downstream directions





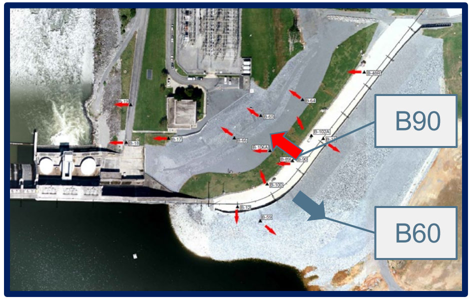
DAM SAFETY PERFORMANCE - DEFORMATIONS



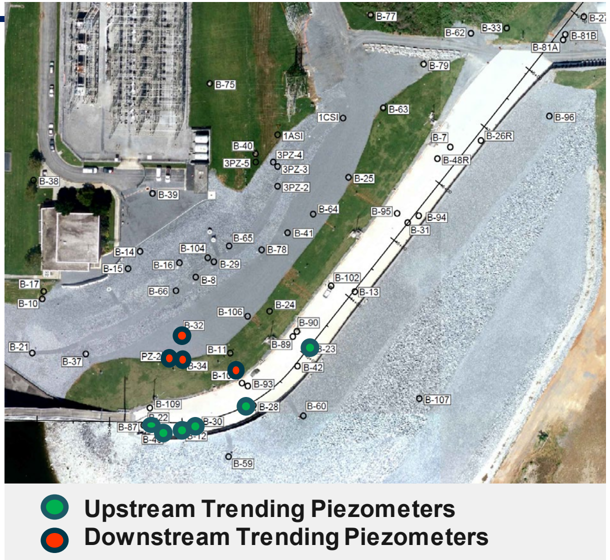


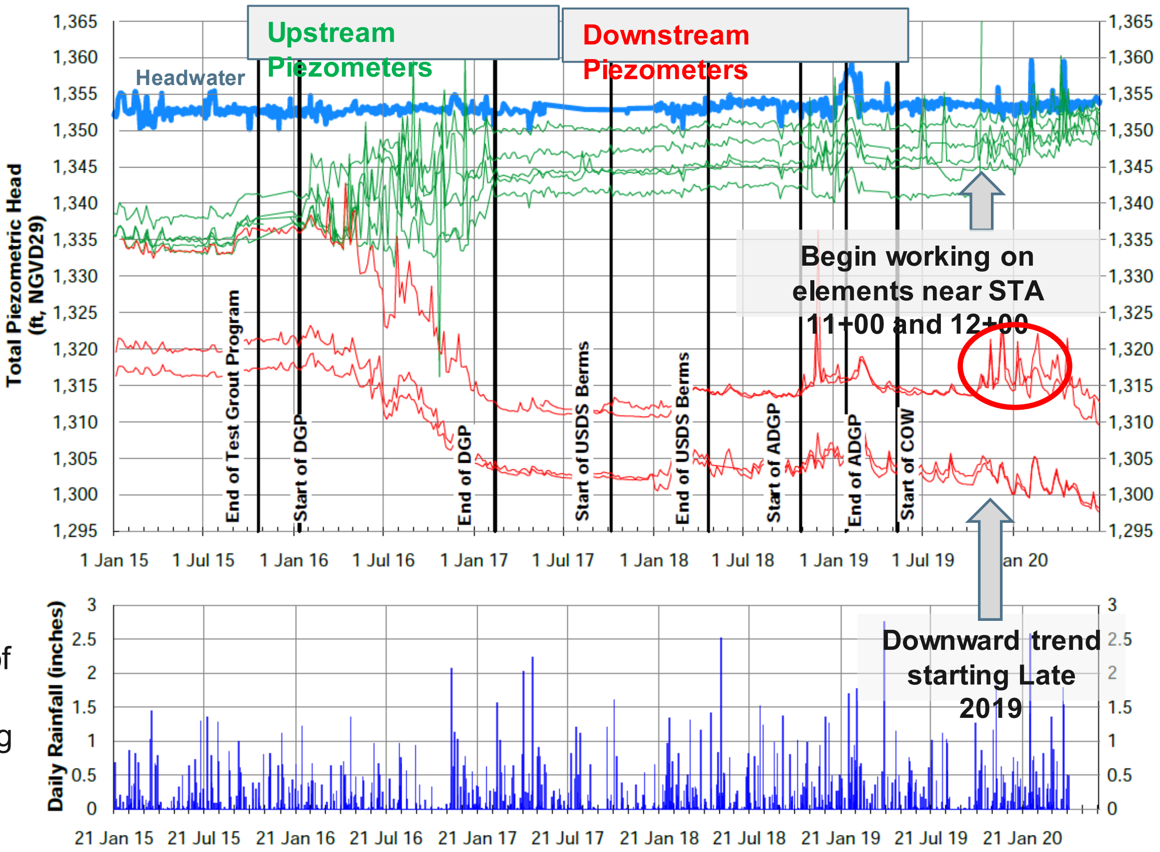
Observations:

- Largest movement observed during berms construction



PORE PRESSURES MONITORING – OVERALL TRENDS





Observations:

- Grouting program was effective at reducing pore pressures downstream of treatment
- Further “sealing” of the epikarst is being observed during COW Element Construction

Conclusions

Instrumentation for Dam Remediation Projects

- **Automated systems are very valuable in remediation projects**
  - **Dam Safety**
  - **Allows for time stamped data to traceable events**
  - **Reduces potential for delays**
  - **Provides understanding of dam behavior**
  - **Verifies design assumptions and informs stage construction**
  - **Reduces construction risk**

Instrumentation for Dam Remediation Projects

- Systems may need to be larger or smaller based on geology, construction techniques, design verification, and PFM's
- Utilize design of instrumentation system to verify your data (differing types of data)
- Design the instrumentation system with the 3 R's in mind
- Make the instrumentation accessible and compatible with Information management systems
- Understand the soil mechanics of the instrumentation

CLOSURE

THE PROJECT IS REMEDIATING A VULNERABILITY TO “INTERNAL EROSION”, WHICH WAS POORLY UNDERSTOOD BY THE ENGINEERING PROFESSION AT THE TIME THE DAM WAS CONSTRUCTED IN 1952. DESPITE THE BEST PRACTICES OF THE DAY, THE PROBLEM BECAME MANIFEST AT BOONE.

SAFETY OF WORKERS ON SITE AND THE DOWNSTREAM PUBLIC ARE OF PARAMOUNT IMPORTANCE DURING COMPLETION OF THE PROJECT. TO MINIMIZE RISK TO DOWNSTREAM PUBLIC, TVA HAS LOWERED THE RESERVOIR DURING THE CONSTRUCTION PERIOD.

THE PROJECT IS ON TARGET TO BE COMPLETED ALONG THE 5- TO 7-YEAR TIMELINE COMMUNICATED BY CEO BILL JOHNSON DURING A PUBLIC MEETING WITH STAKEHOLDERS HELD IN THE SUMMER OF 2015. THE RESERVOIR IS CURRENTLY ON SCHEDULE TO RETURN TO NORMAL OPERATIONS BY AUGUST 2022.

THIS PRESENTATION ONLY TAKES VIEWERS THROUGH THE PRESENT DAY, SUCH THAT THE “CONCLUSION” OF THE PROJECT (i.e., THE IMPLEMENTATION OF THE REMEDIATION) HAS YET TO BE FULLY REALIZED. STAY TUNED FOR FUTURE UPDATES!

INFORMATION HEREIN WAS DEVELOPED SPECIFICALLY FOR THIS PRESENTATION AND AUDIENCE, AND MAY CONTAIN DETAILS WHICH ARE INTERPRETIVE, DELIBERATIVE, OR PROTECTED BY CONTRACTUAL AGREEMENT. REPRODUCTION AND/OR DISTRIBUTION OF THESE CONTENTS IS STRICTLY PROHIBITED.

FOR MORE INFORMATION

Boone monthly newsletter

Boone twitter:

@BooneRepair

Boone website:

https://www.tva.com/Newsroom/Boone-Dam-Project

Boone Community Relations Office:
320 Boone Dam Road / Kingsport, TN 37663

Boone public e-mail program:

boonelake@tva.gov

TENNESSEE
VALLEY
AUTHORITY