Boone Dam Hydro-Geo Model and Seepage Remediation

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Presentation Overview

I. Background

II. Elements of the Geologic Model

III. The Boone Dam Hydro-Geo Model

IV. Remediation Strategy

Background: Sinkholes and Turbid Discharge

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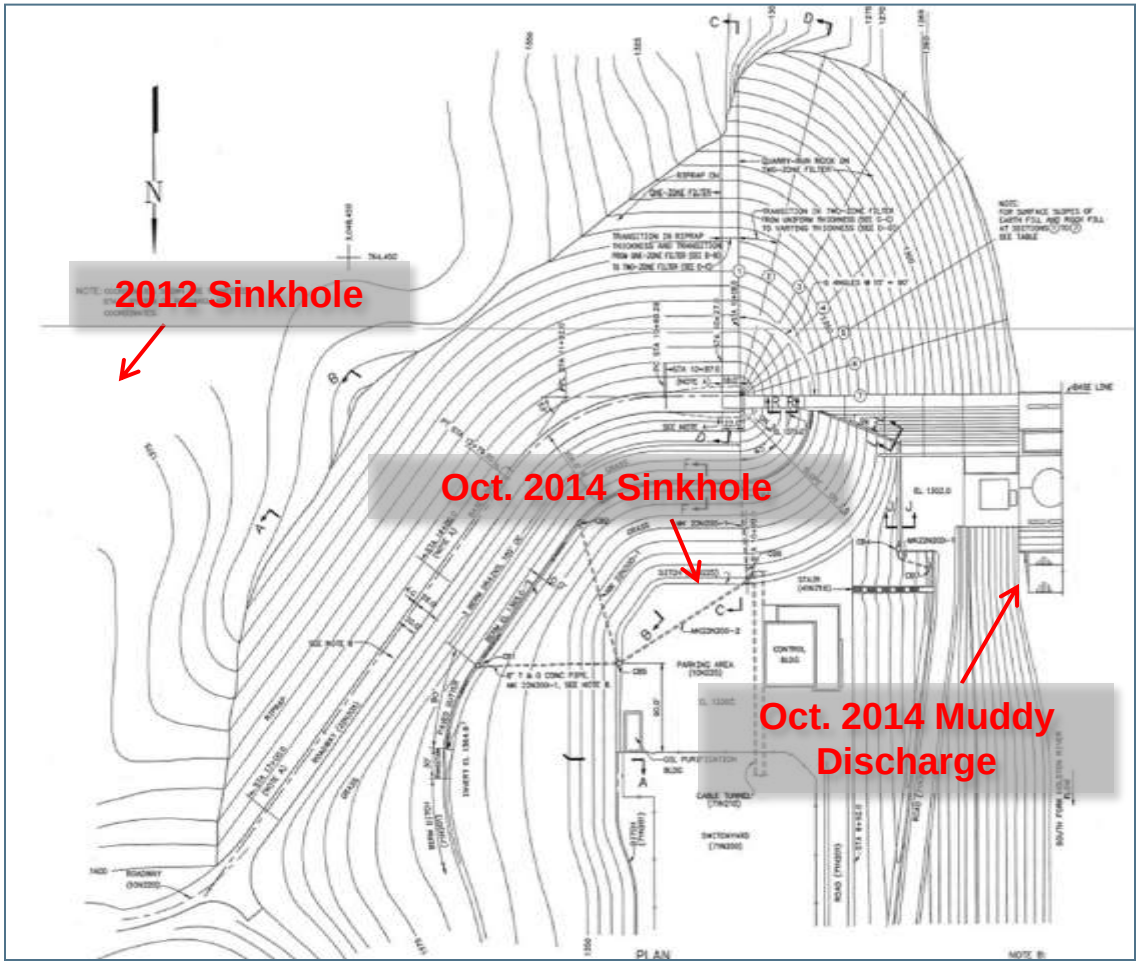
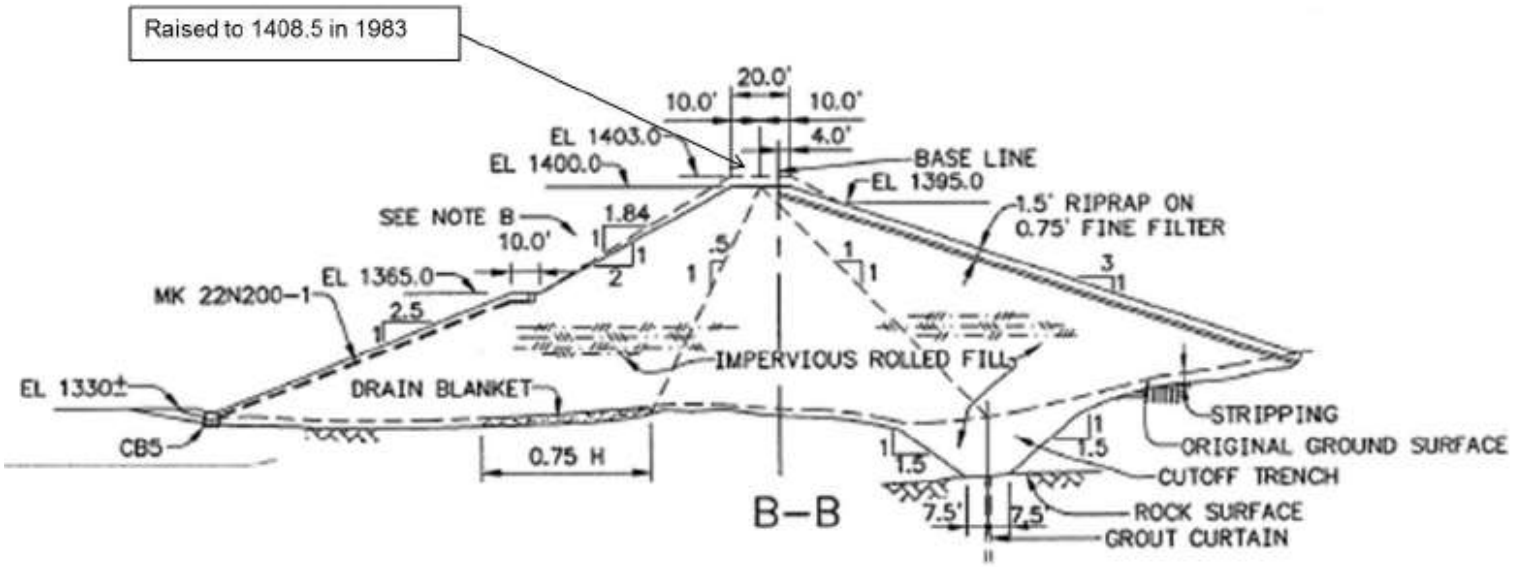
Muddy Seep in Tailrace

10/30/14 ▪ 18:42 ▪ Units Off ▪ HW 1372.7

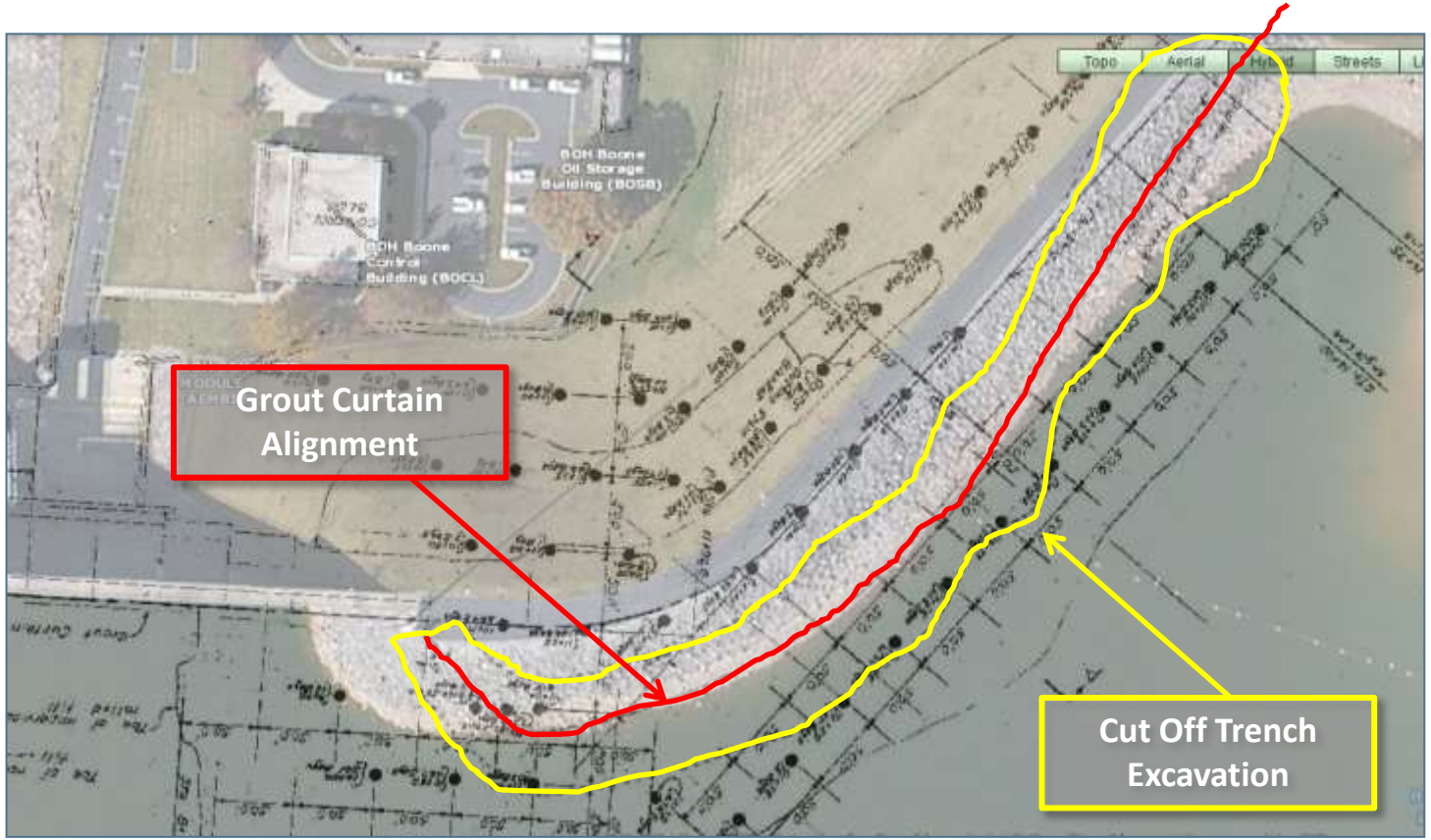
11/03/14 ▪ 14:32 ▪ Units Off ▪ HW 1367.4


2012 Sinkhole
Oct. 2014 Sinkhole
Oct. 2014 Muddy Discharge
PLAN

Idealized Cross Section and Foundation Treatment



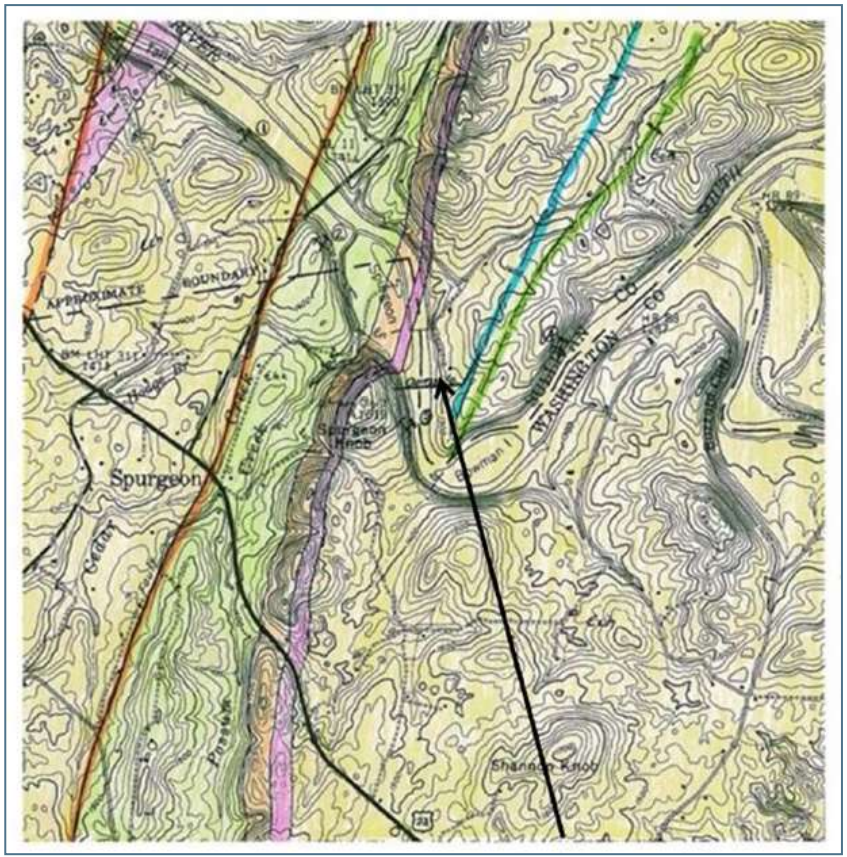
Cut Off Trench Alignment

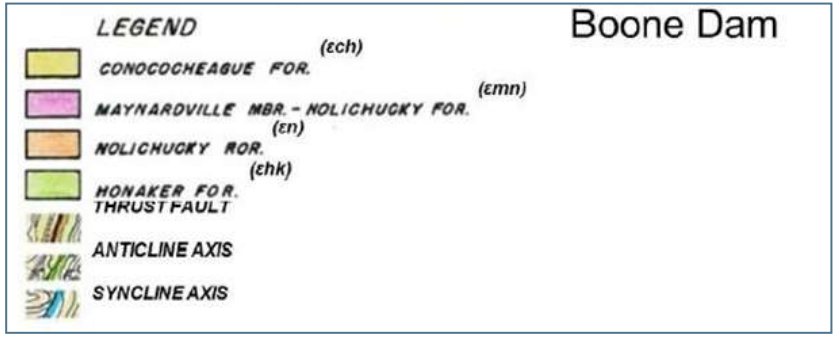


Site Geology - The Underlying Issue

Elements of the Geologic Model

Complex Structure





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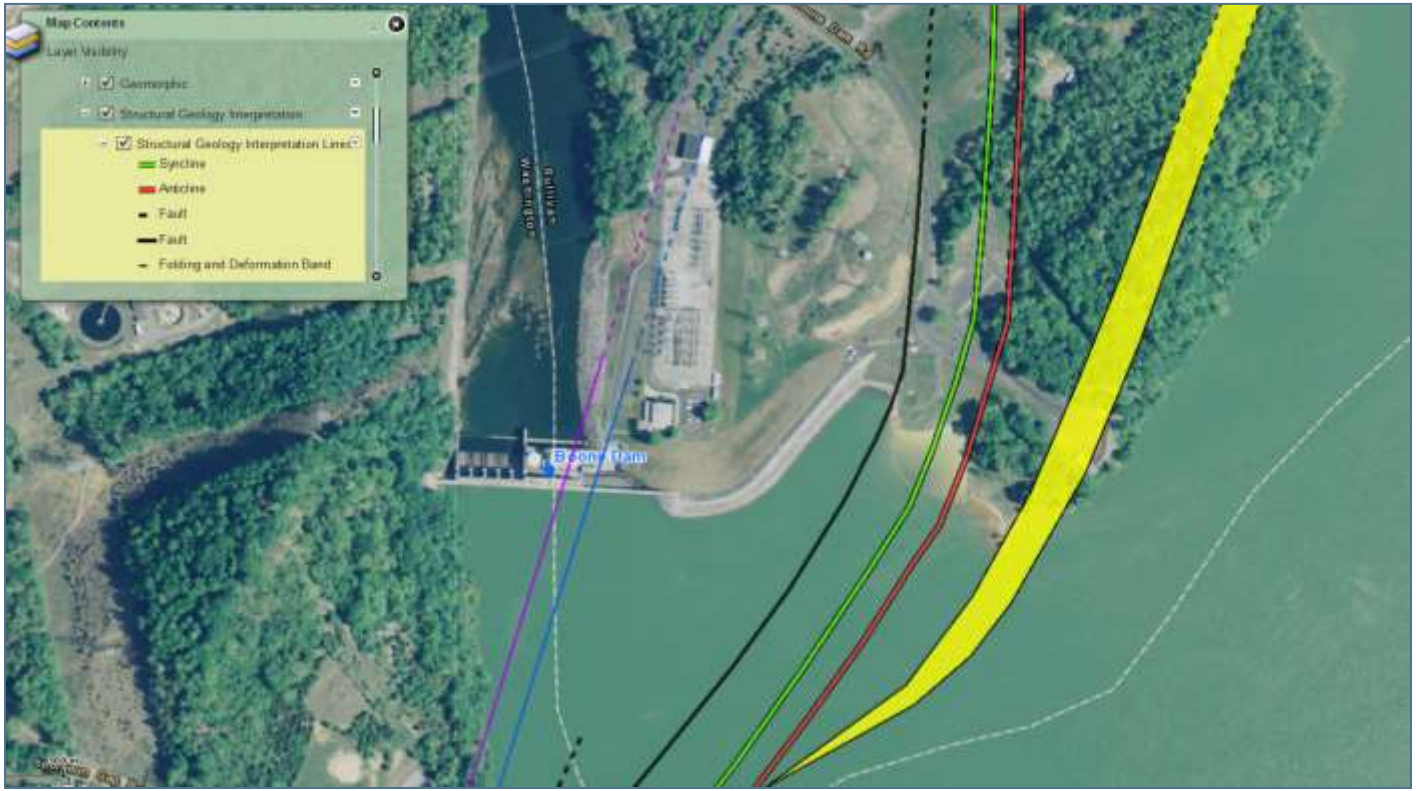

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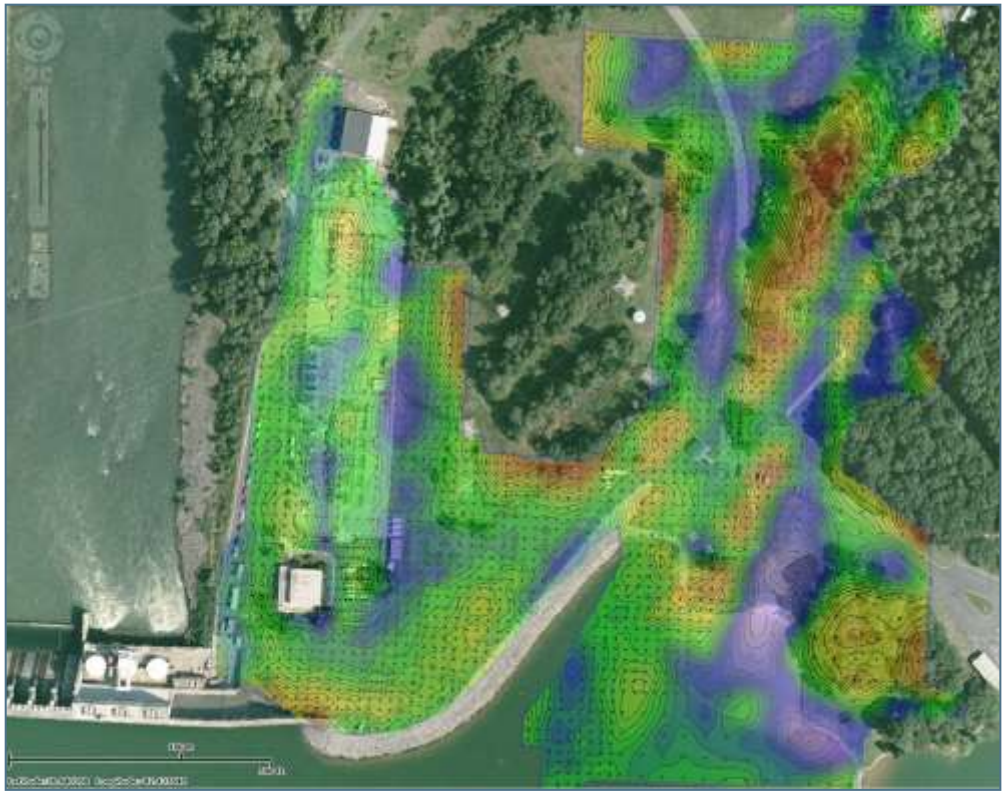
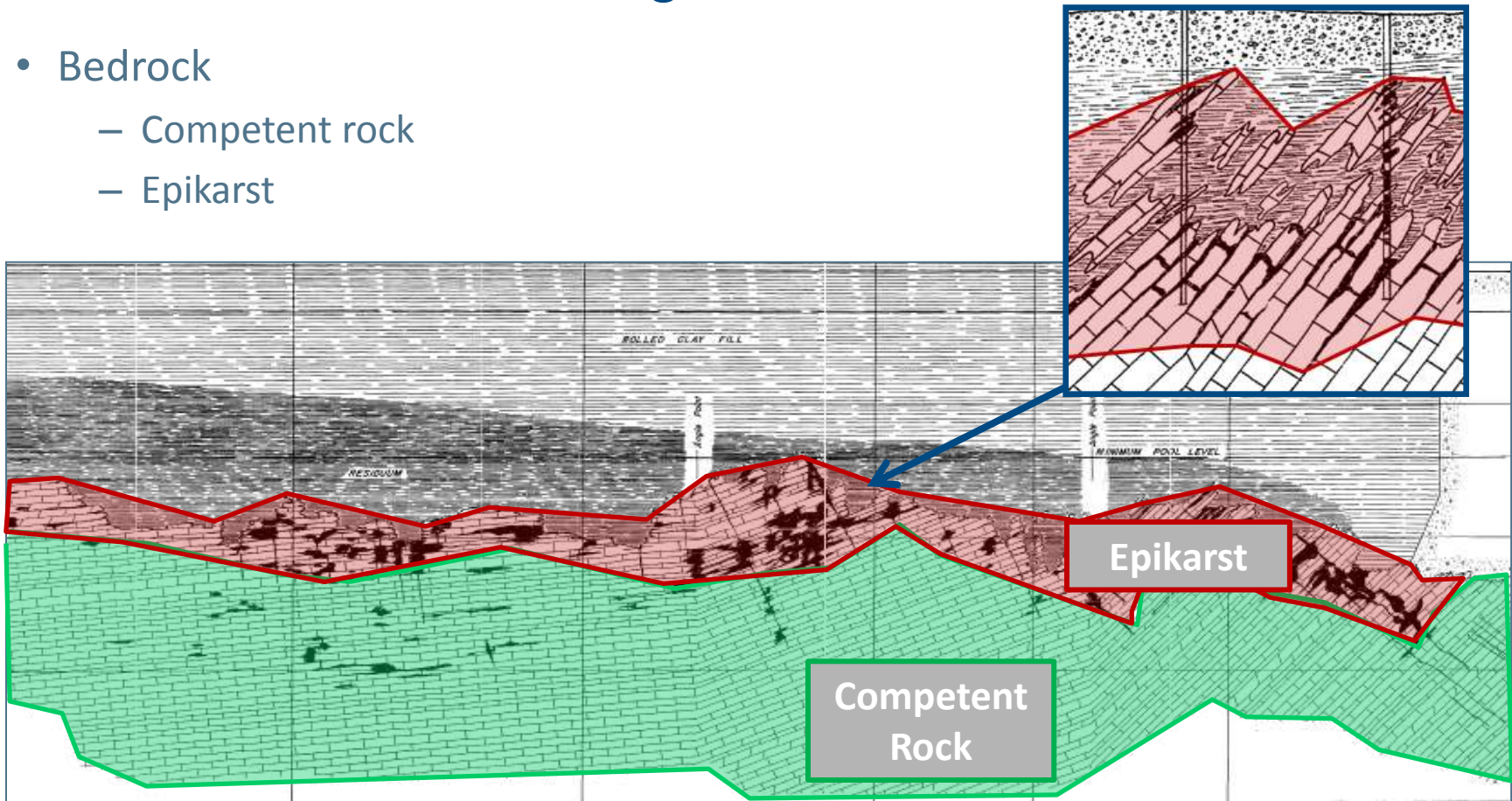


Elements of the Geologic Model

- Bedrock
  - Competent rock
  - Epikarst



Elements of the Geologic Model

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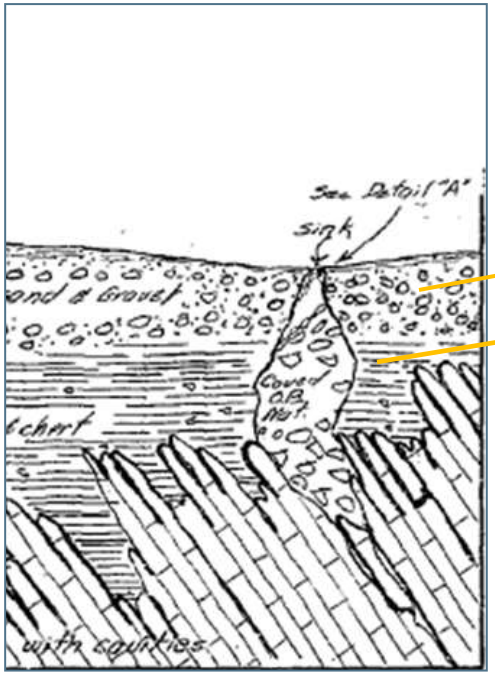
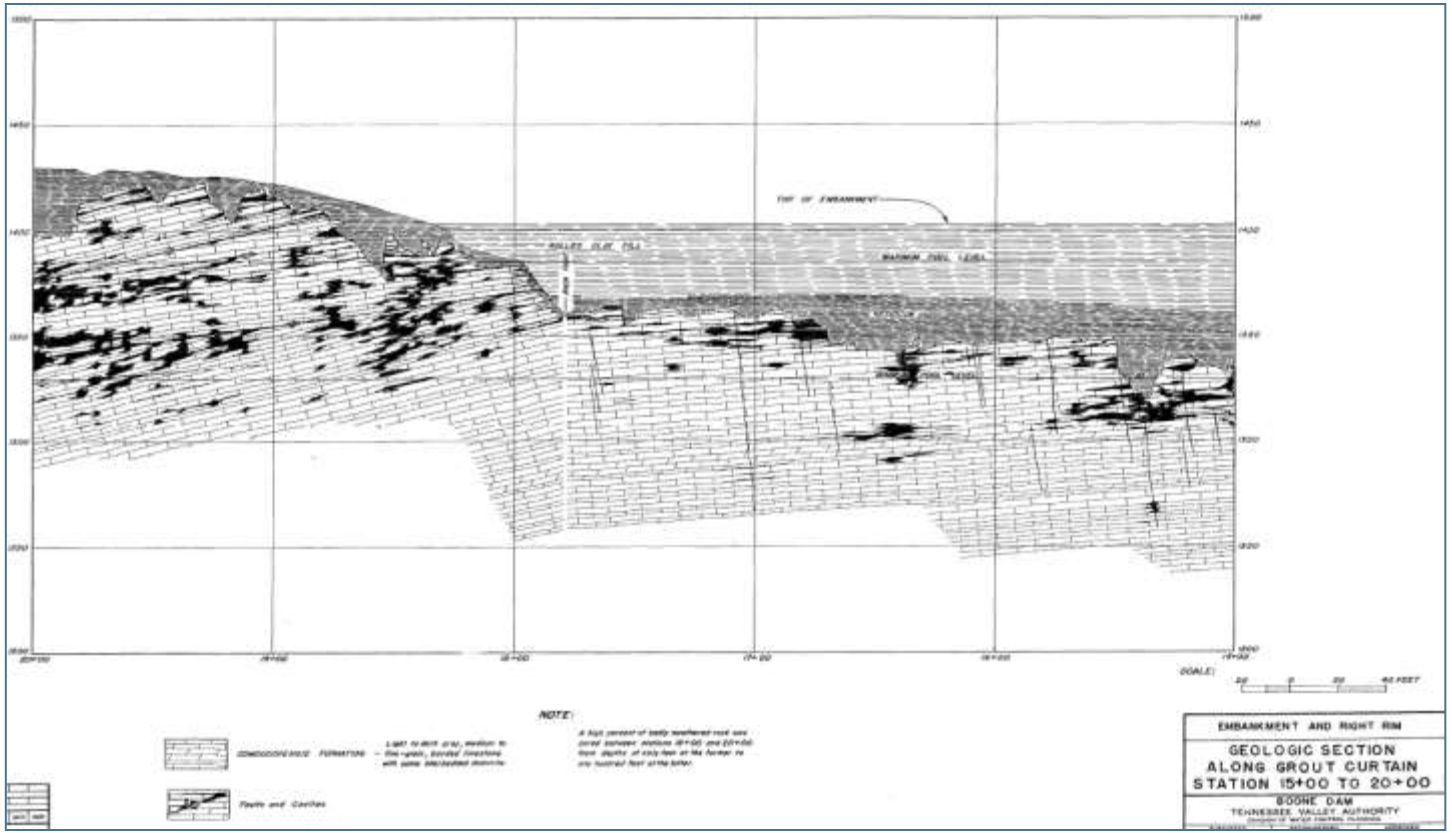
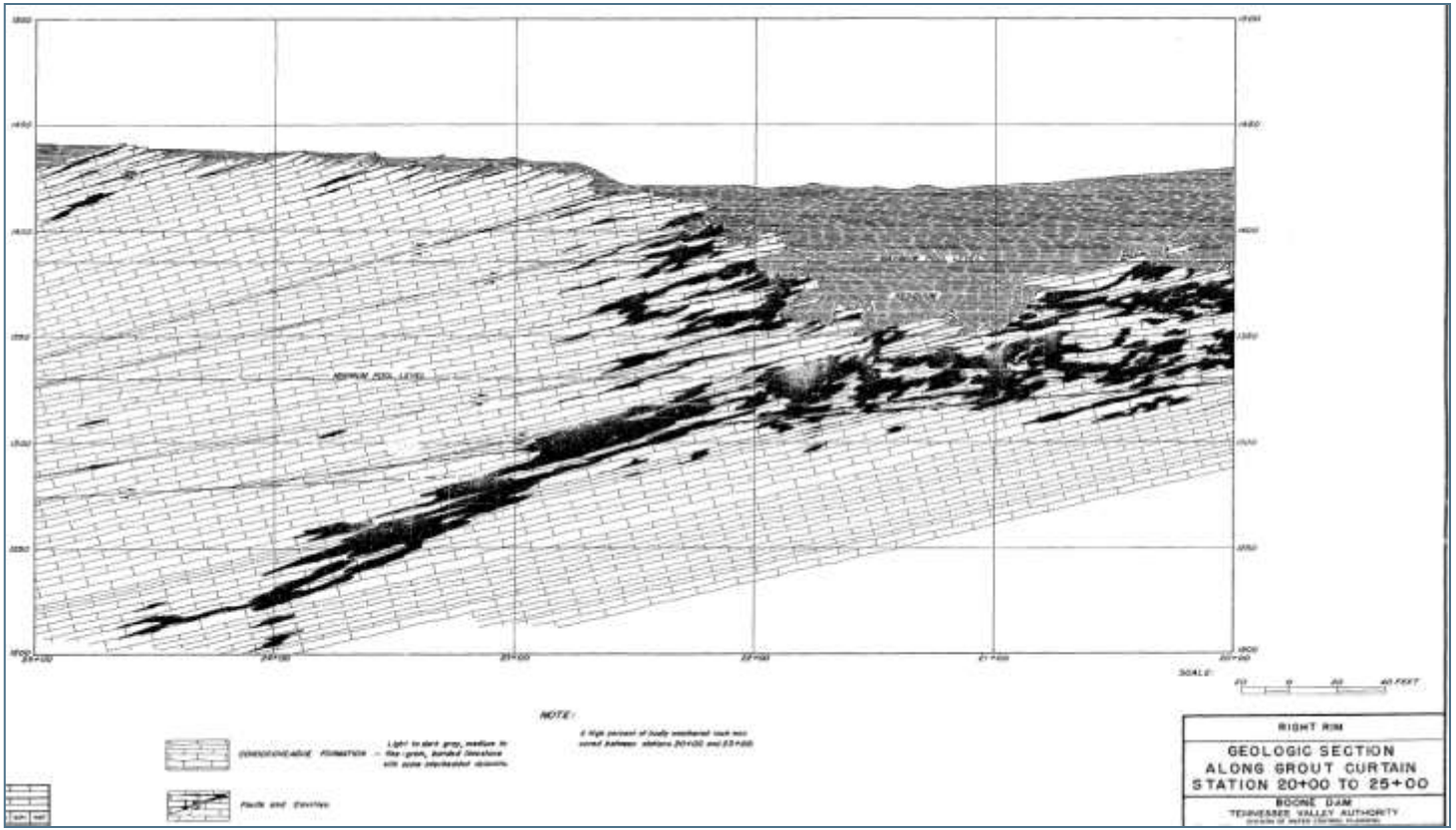
Foundation Soils



Right Abutment Section along Grout Curtain



Right Rim – Station 20+00 to 25+00

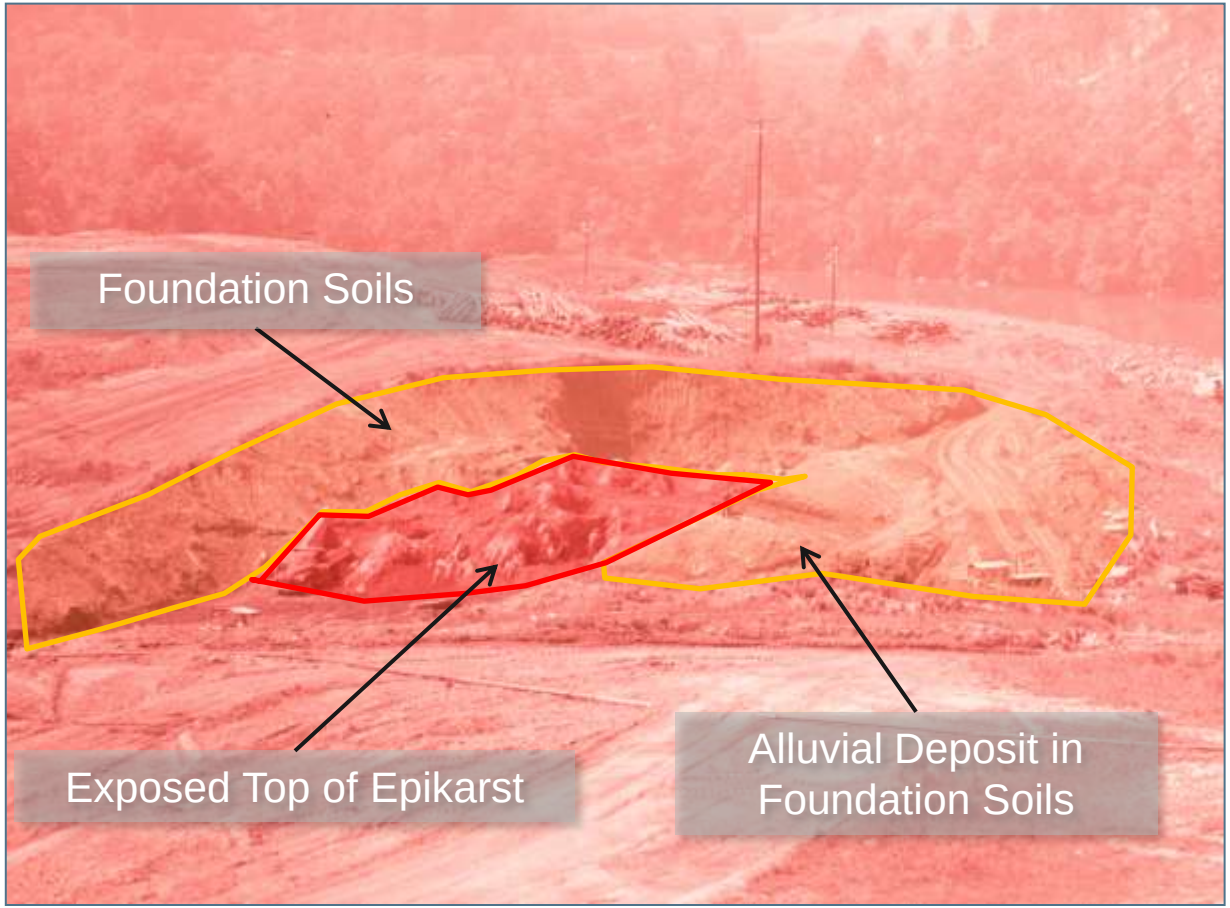


Geological Elements

Photographic Definitions

Competent Rock

- **Foundation Soils**
- **Epikarst**
- **Embankment Fill**



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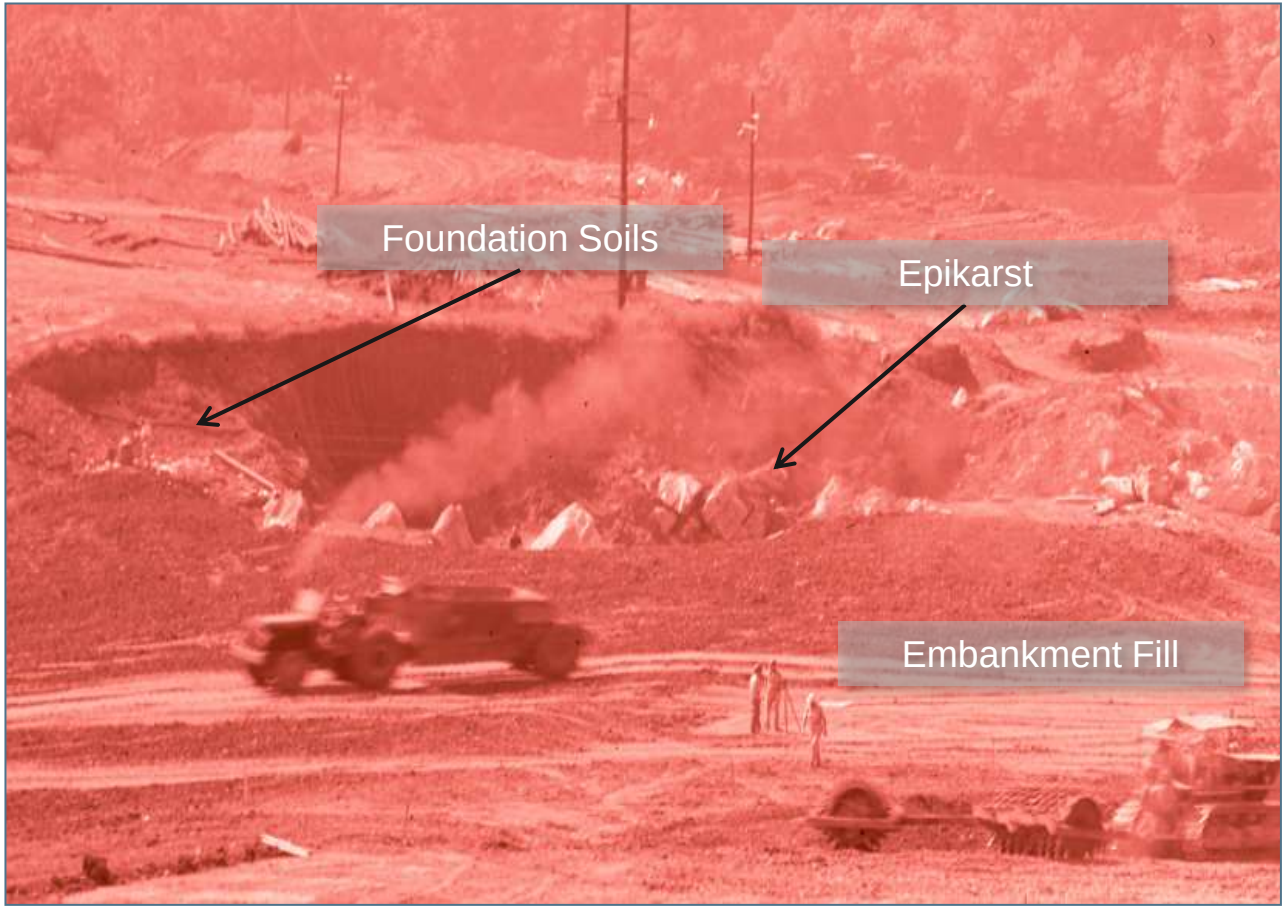


Core Trench Placing Clay

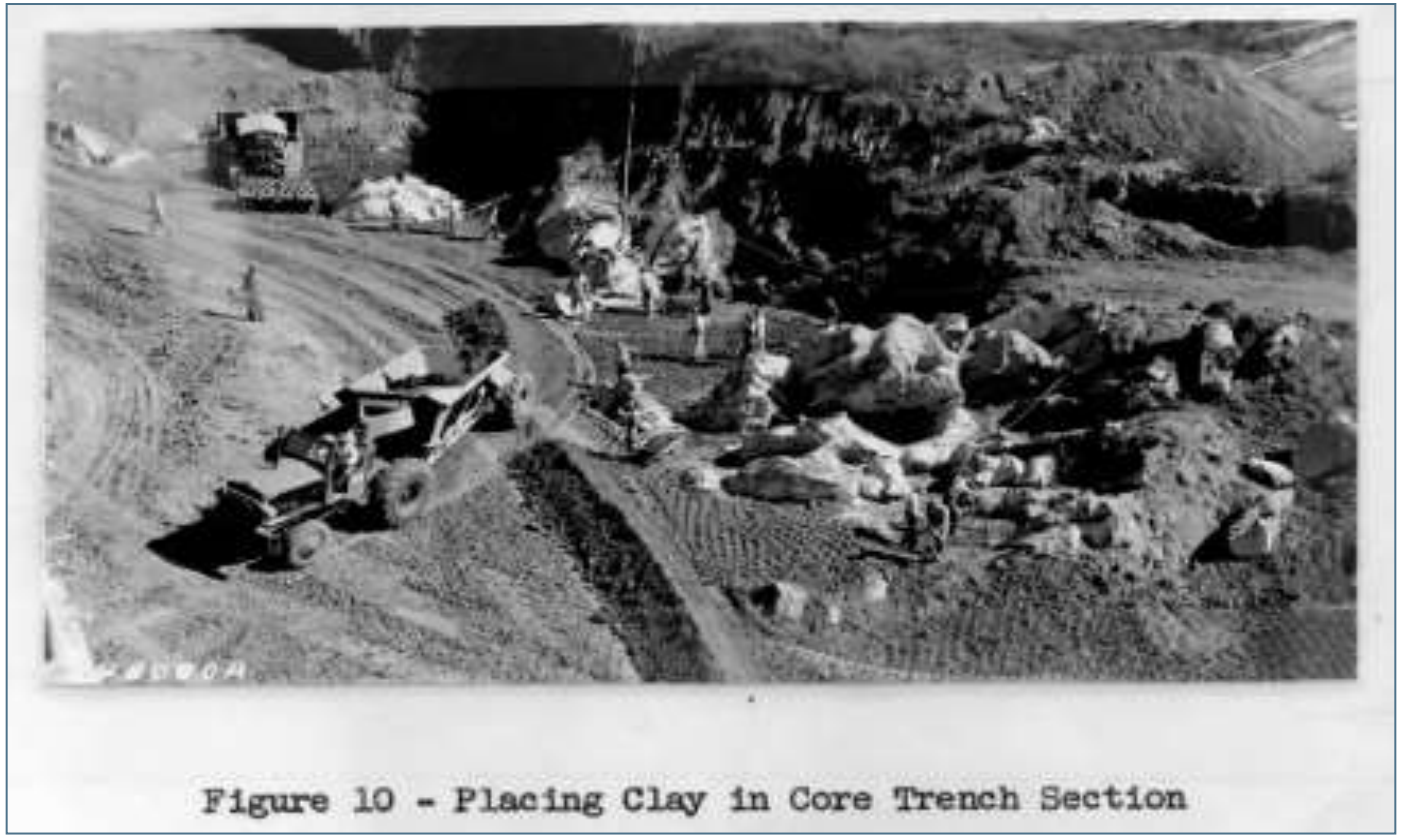
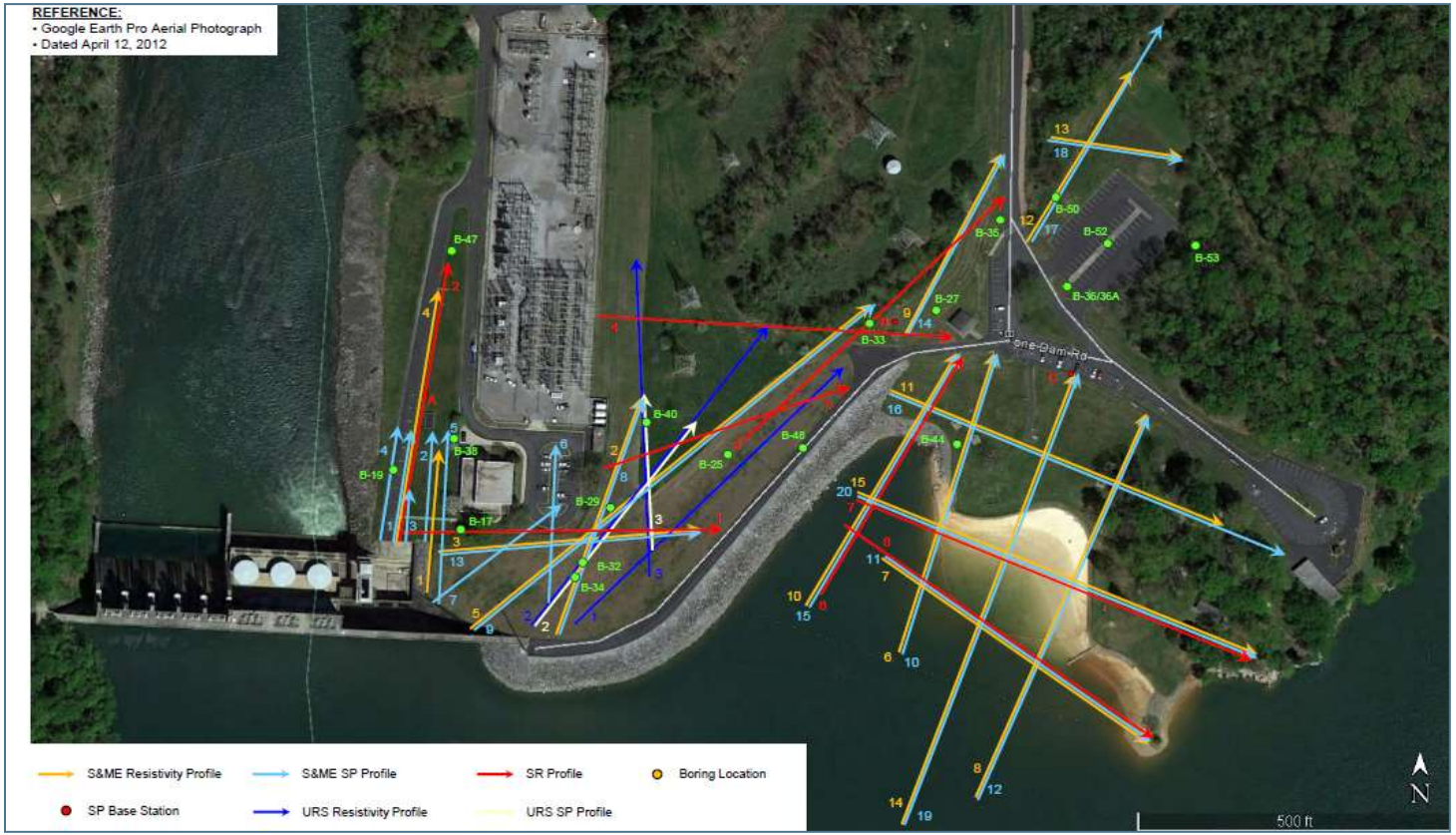


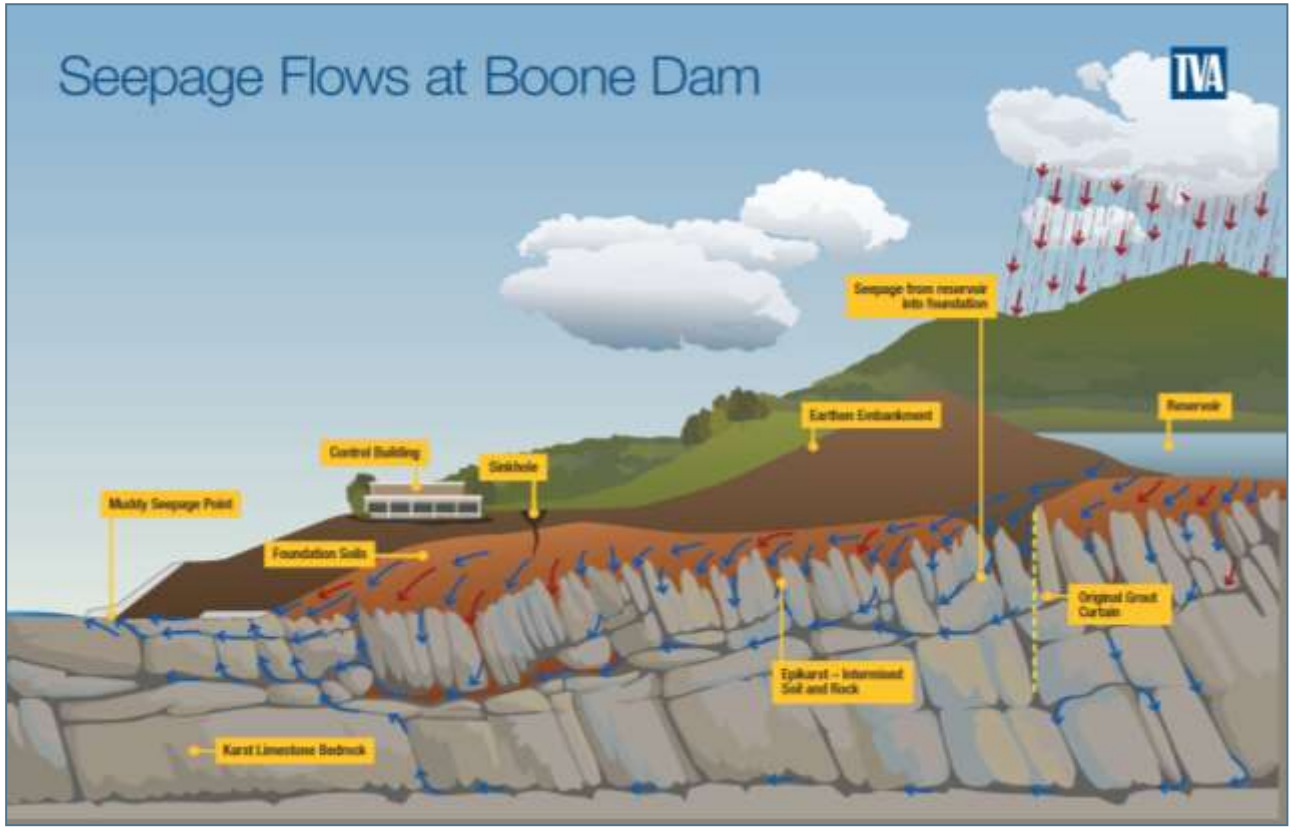
Figure 10 - Placing Clay in Core Trench Section

Investigations – Exploration Borings

Investigations – Geophysics



Hydro-Geologic Model Overview



Boone Hydro-Geo Model Thesis Statements

1. An extensive, subsurface drainage network existed in the epikarst prior to construction of Boone Dam.

2. The right rim provides a constant source of head under the embankment. Recharge in the right rim causes surges in volume and pressure to the epikarst and foundation, which have continued to develop the drainage network.

3. Increased gradients from the reservoir have exploited weaknesses in the cutoff trench and tied headwater to the drainage network.

Preexisting Drainage Network

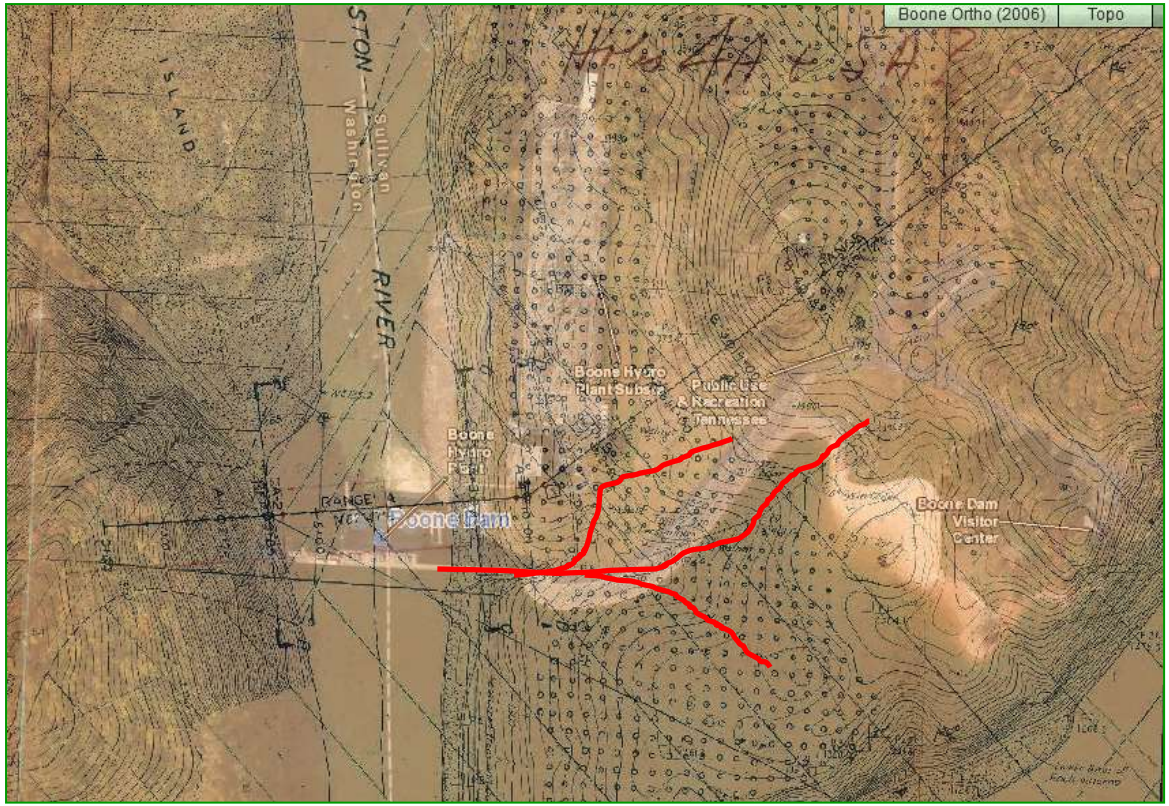
1

- An extensive, subsurface drainage network existed in the epikarst prior to construction of Boone Dam.

Supporting Evidence:
Preconstruction site topography and geologic mapping indicate features of a well developed drainage network including draws, alluvial deposits, springs, and sinkholes.

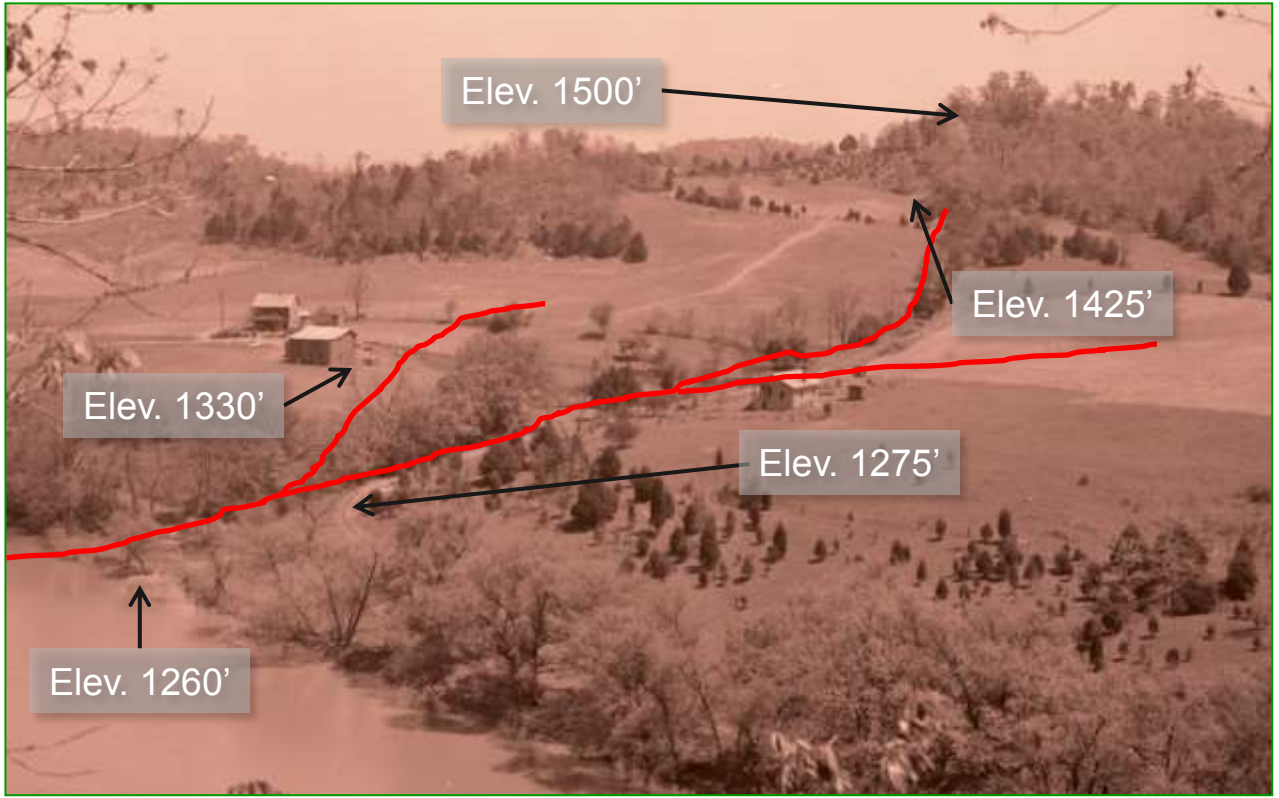
Preexisting Drainage Network

Preconstruction site topography and geologic mapping indicate features of a well developed drainage network including draws, alluvial deposits, springs, and sinkholes.

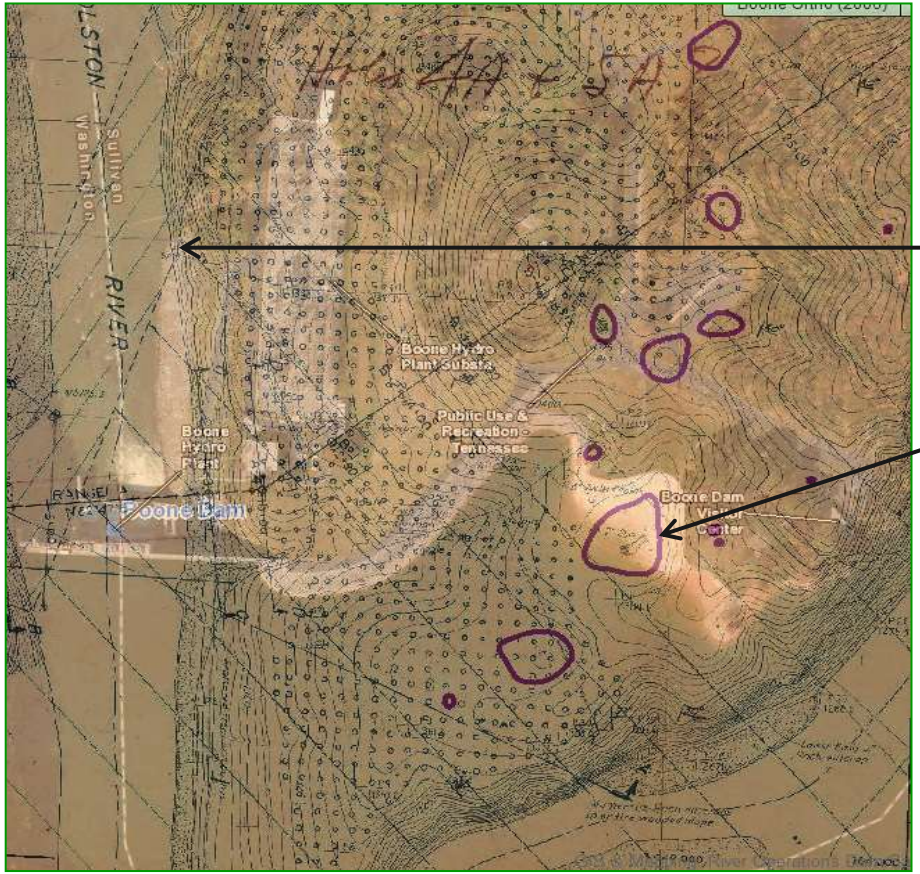


Preexisting Drainage Network

Preexisting topographic draw



Preexisting Drainage Network

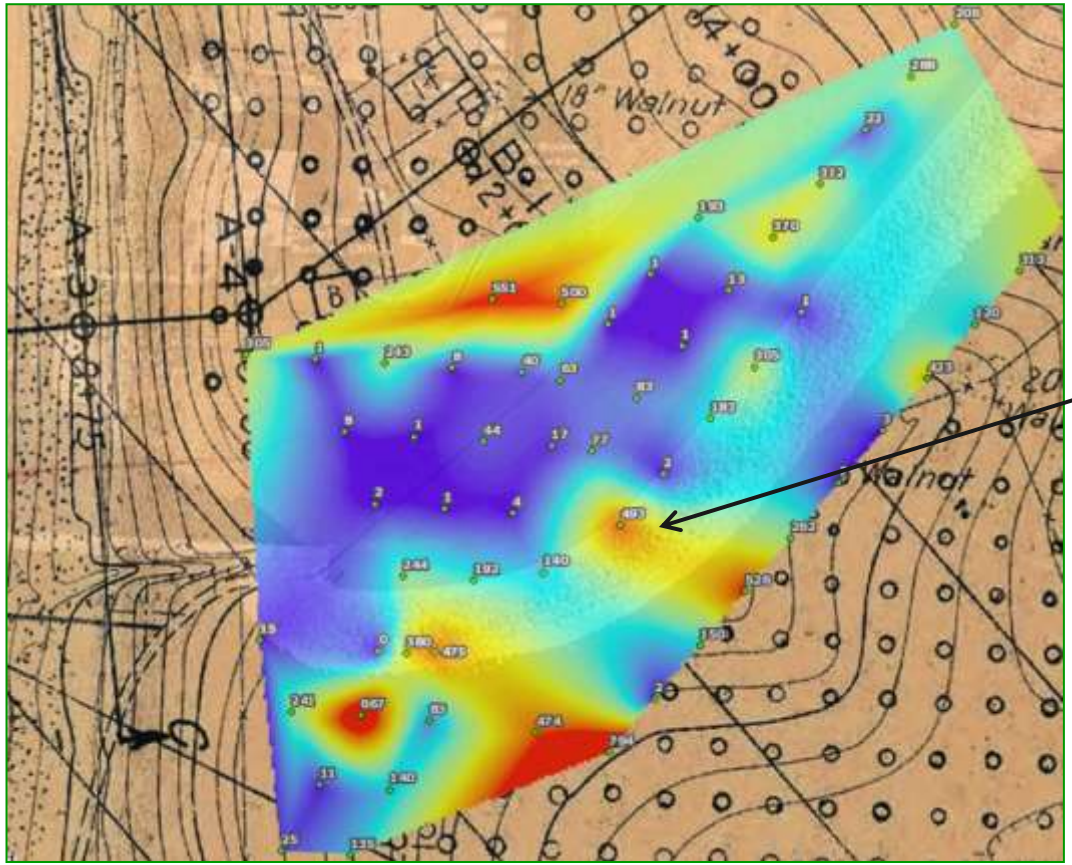


Preexisting sinkholes and natural springs

Spring prior to construction

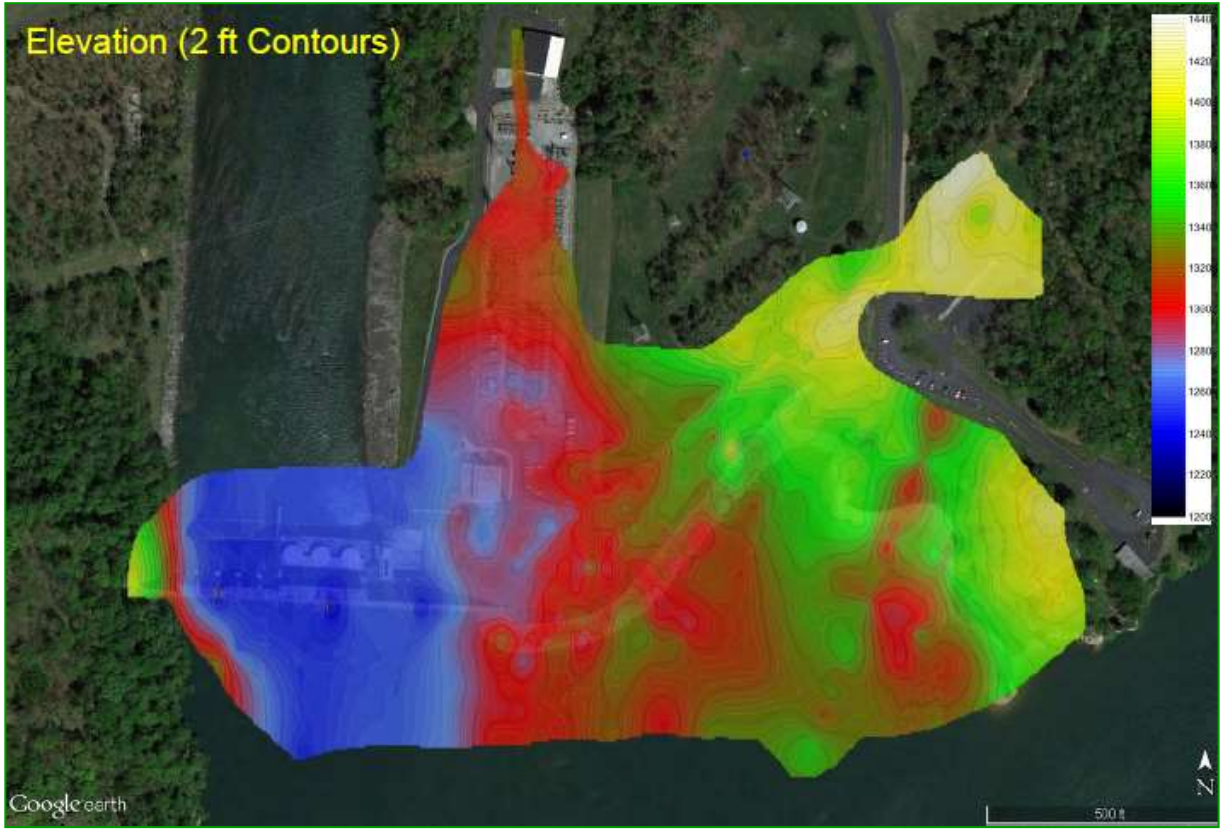
Depressions prior to construction

Preexisting Drainage Network



Consolidation Grouting Required

Preexisting Drainage Network



Right Rim Contribution

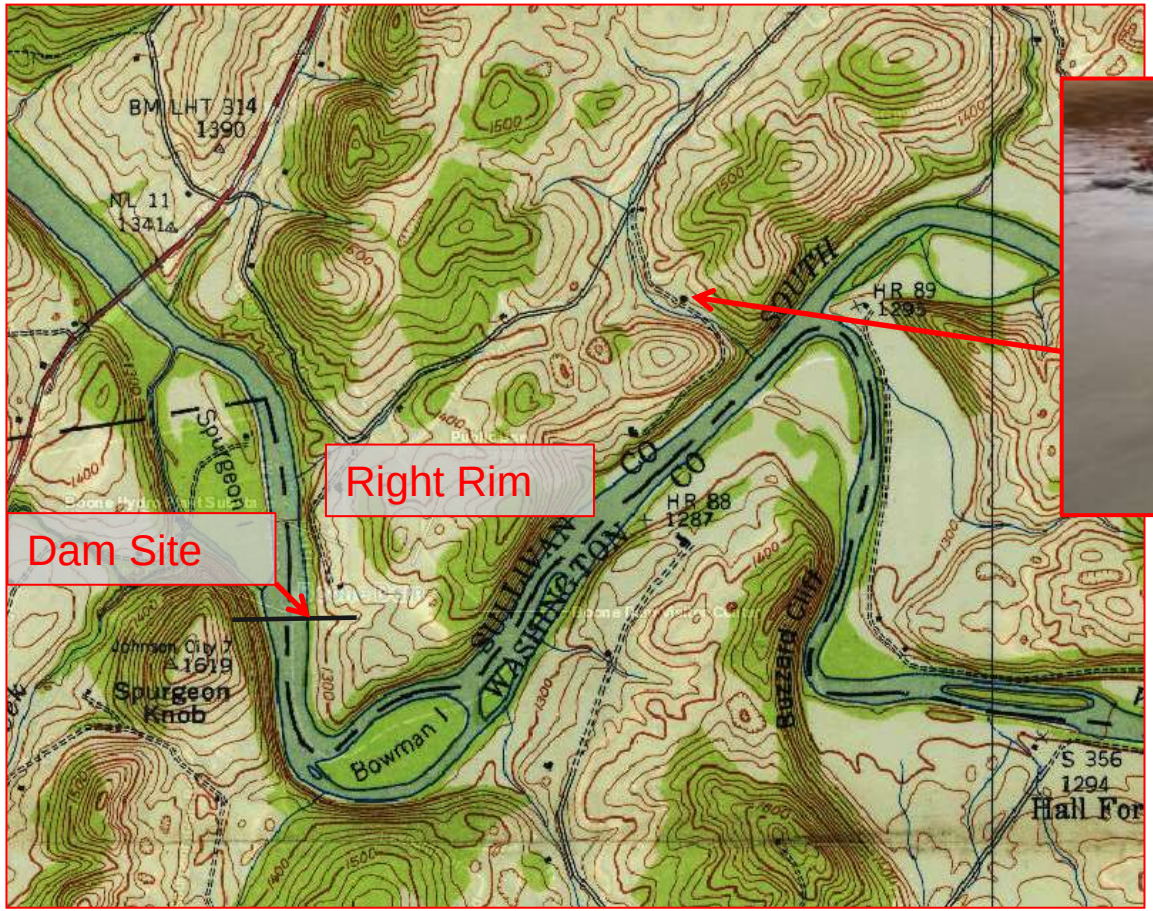
2

- The right rim provides a constant source of head under the embankment. Recharge (high infiltration) in the right rim causes surges to the epikarst and foundation, which have continued to develop the drainage network.

Supporting Evidence:

- Extensive weathering present in right abutment
- Piezometric data indicates heads significantly higher than headwater in the right rim and flow paths toward the toe.
- A French drain was required during construction to deal with excessive flows from springs
- Confined aquifer like behavior observed during drilling of several boreholes.
- A number of piezometers increase in total head following high infiltration events.
- Following high infiltration event on March 5, 2015 muddy seeps were observed along the upstream face of the dam

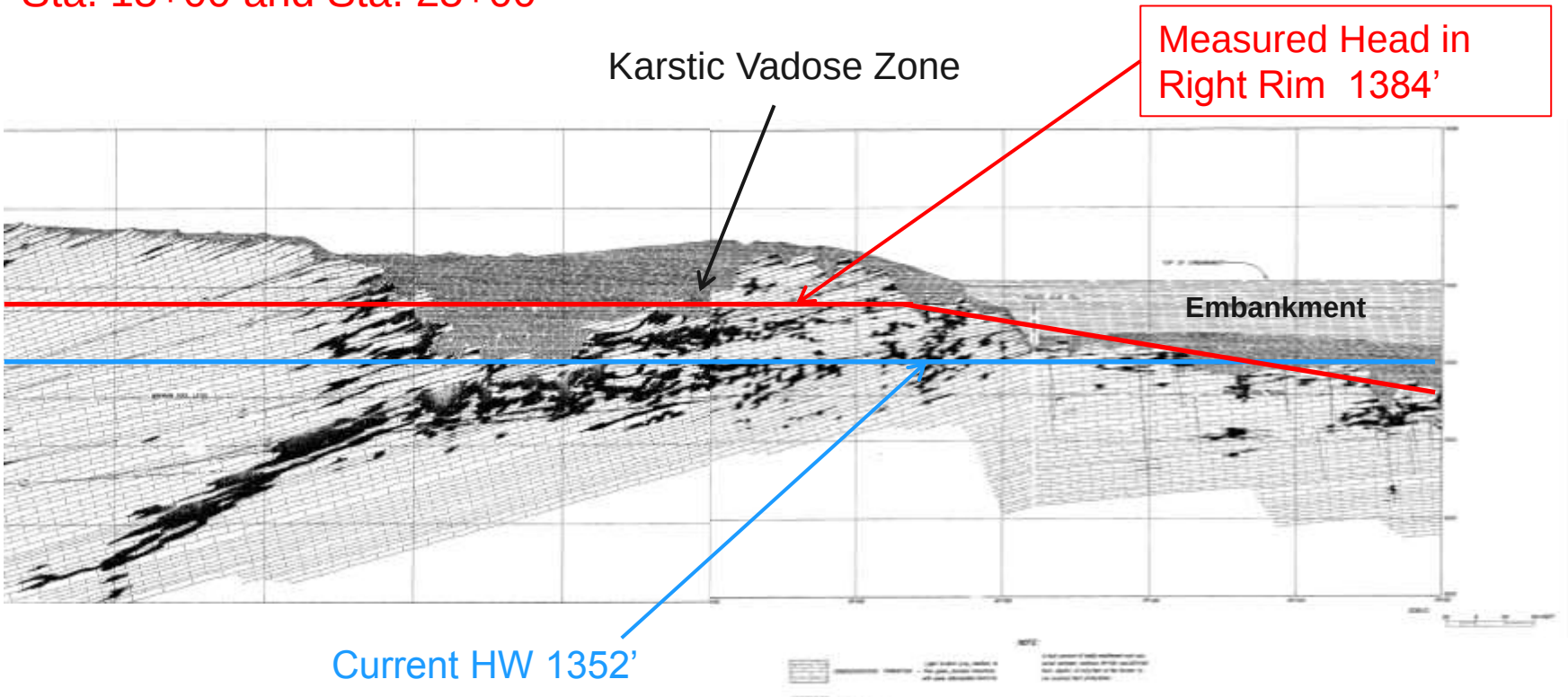
Right Rim Contribution



Artesian well in reservoir indicates higher head from regional groundwater recharge

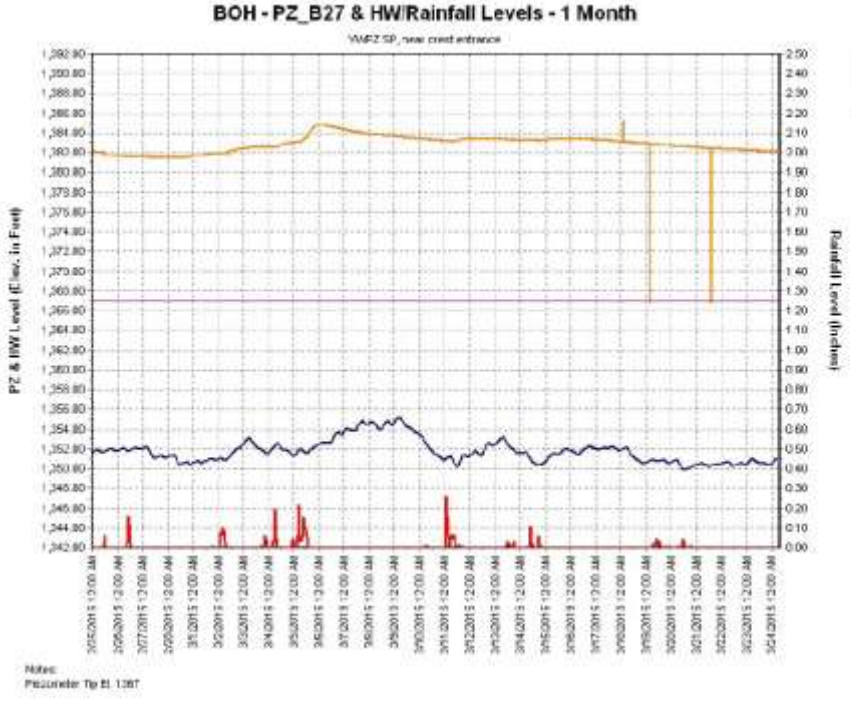
Right Rim Contribution

Extensive weathering in right abutment, Section along grout curtain between Sta. 15+00 and Sta. 25+00



Right Rim Contribution

Piezometric data indicates heads significantly higher than headwater in the right rim and flow paths toward the toe. B-27, shown below, is ~ 20 feet higher than the current headwater.



Upstream of cutoff
Tip in Epikarst from Elev. 1389 to 1364

Right Rim Contribution

The piezometric contours indicate flow paths in the epikarst from the right rim toward the toe

Right Rim Contribution

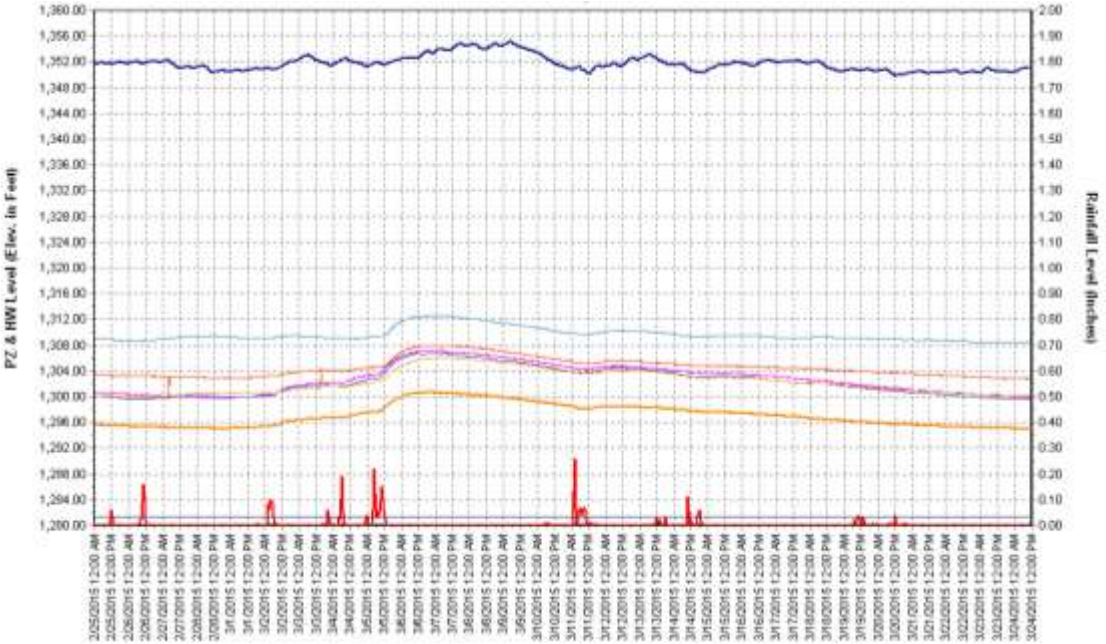
A French drain was required during construction to deal with excessive flows from springs in the area shown below.

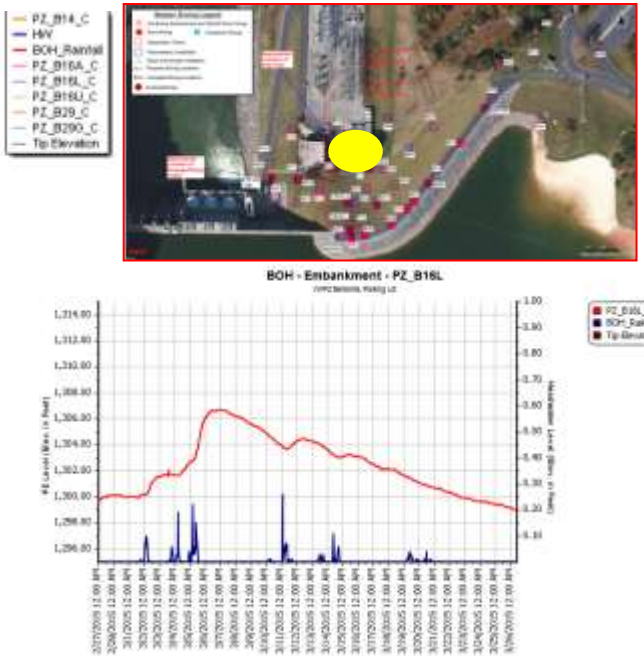
Right Rim Contribution

Piezometers with response to high infiltration event

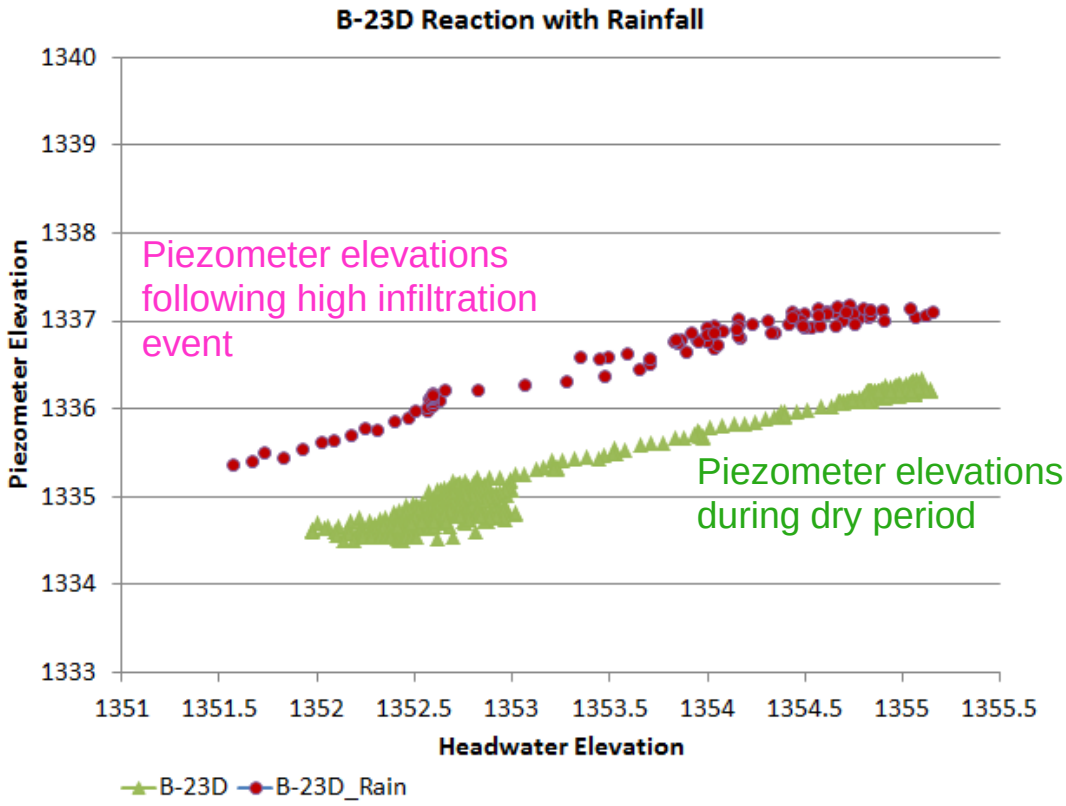
Right Rim Contribution

Piezometers at downstream toe respond to high infiltration event



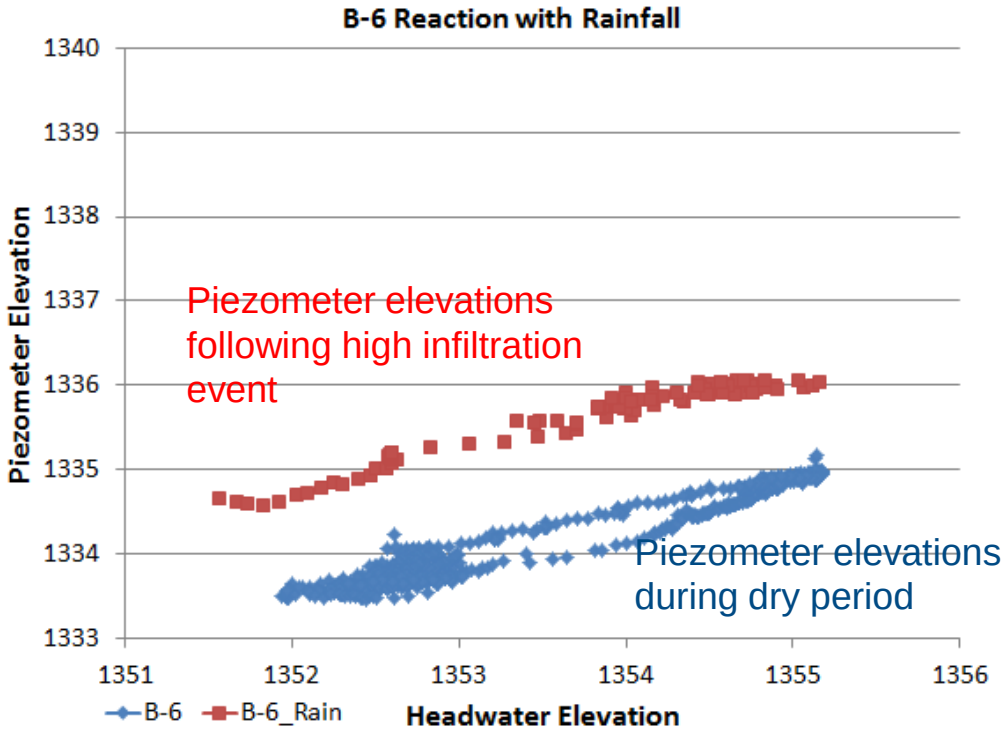


Right Rim Contribution



Vibrating wire piezometer B-23D fluctuates at higher elevations following high infiltration event

Right Rim Contribution



Open standpipe piezometer B-6 fluctuates at higher elevations following high infiltration event

Right Rim Contribution

Following a high infiltration event on March 5, 2015 muddy seeps were observed along the upstream face of the dam

Right Rim Contribution

Following a high infiltration event on March 5, 2015 muddy seeps were observed along the upstream face of the dam

Right Rim Contribution

Seep #2 Video

Reservoir Contribution

3

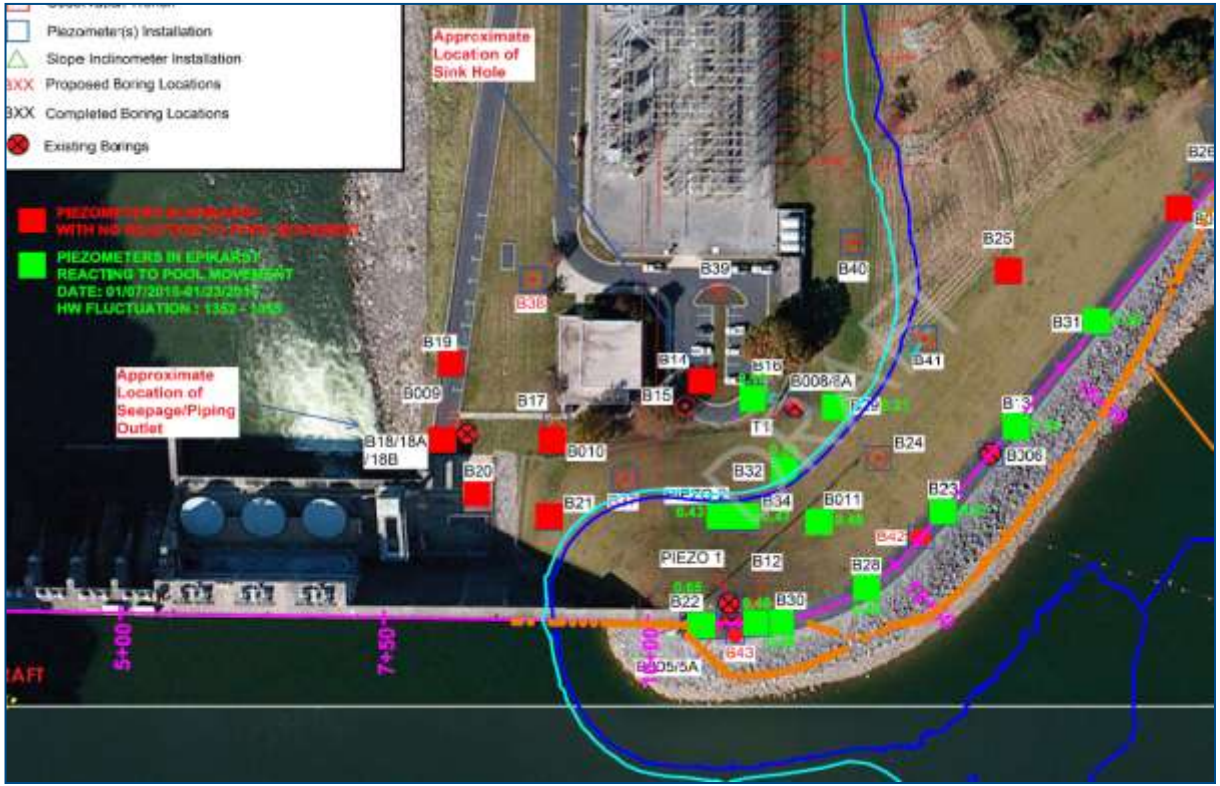
- Increased gradients to the reservoir have exploited weaknesses in the cutoff trench and tied headwater to the drainage network.

Supporting Evidence:

- Several PZs respond to changes in HW with small lag times
- B28 dye test pushed dye from downstream of cutoff to the upstream of the cutoff
- Grouting of the B30 instrument likely pushed grout from D/S of the cutoff to the reservoir
- B-44 dye test (U/S) resulted in dye in B-28 (D/S), B-42 (D/S), and H/W
- PZs temperatures and water conductivity testing indicate that reservoir water and right rim groundwater are intermixing underneath the dam
- PZ temperatures indicate water under the embankment is colder than regional groundwater but warmer than reservoir.
- Conductivity indicates the same
- Open soil pipe at the U/S Toe of the dam

Reservoir Contribution

Instrumentation Response to HW

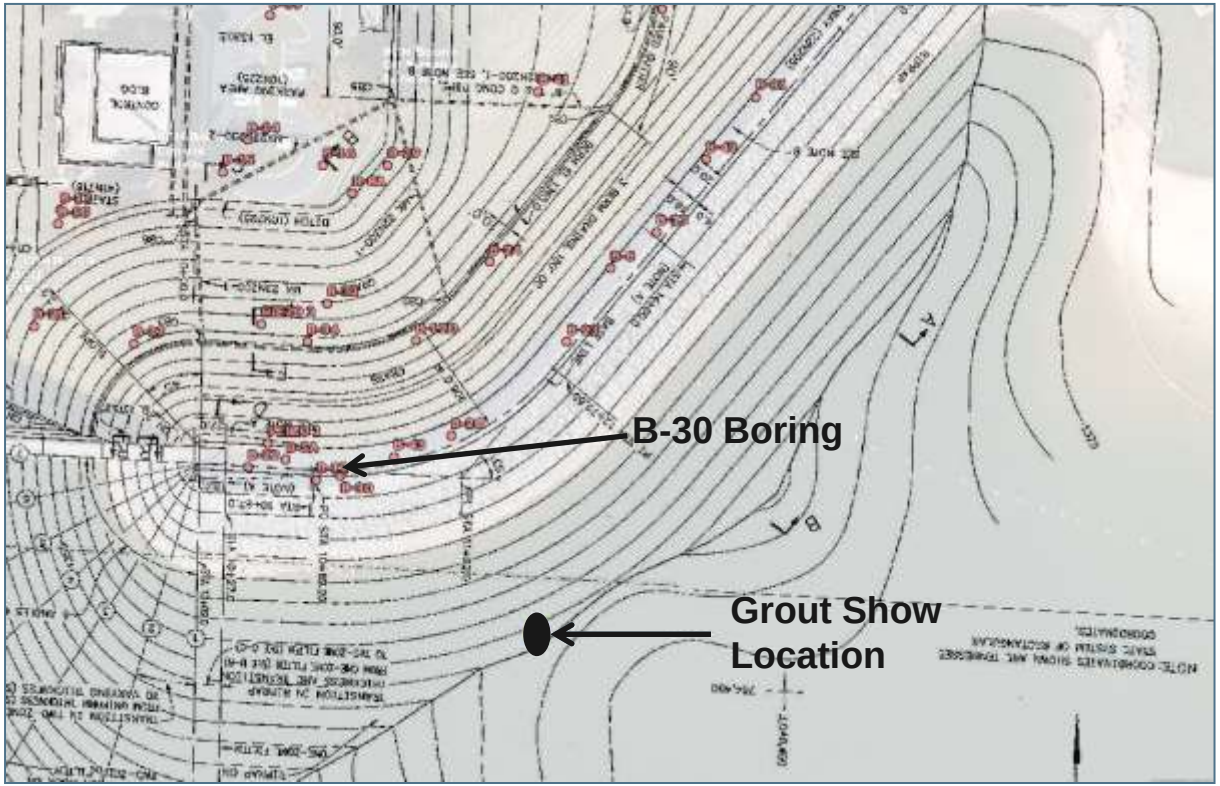


PZs respond to changes in HW with small lag times

Reservoir Contribution

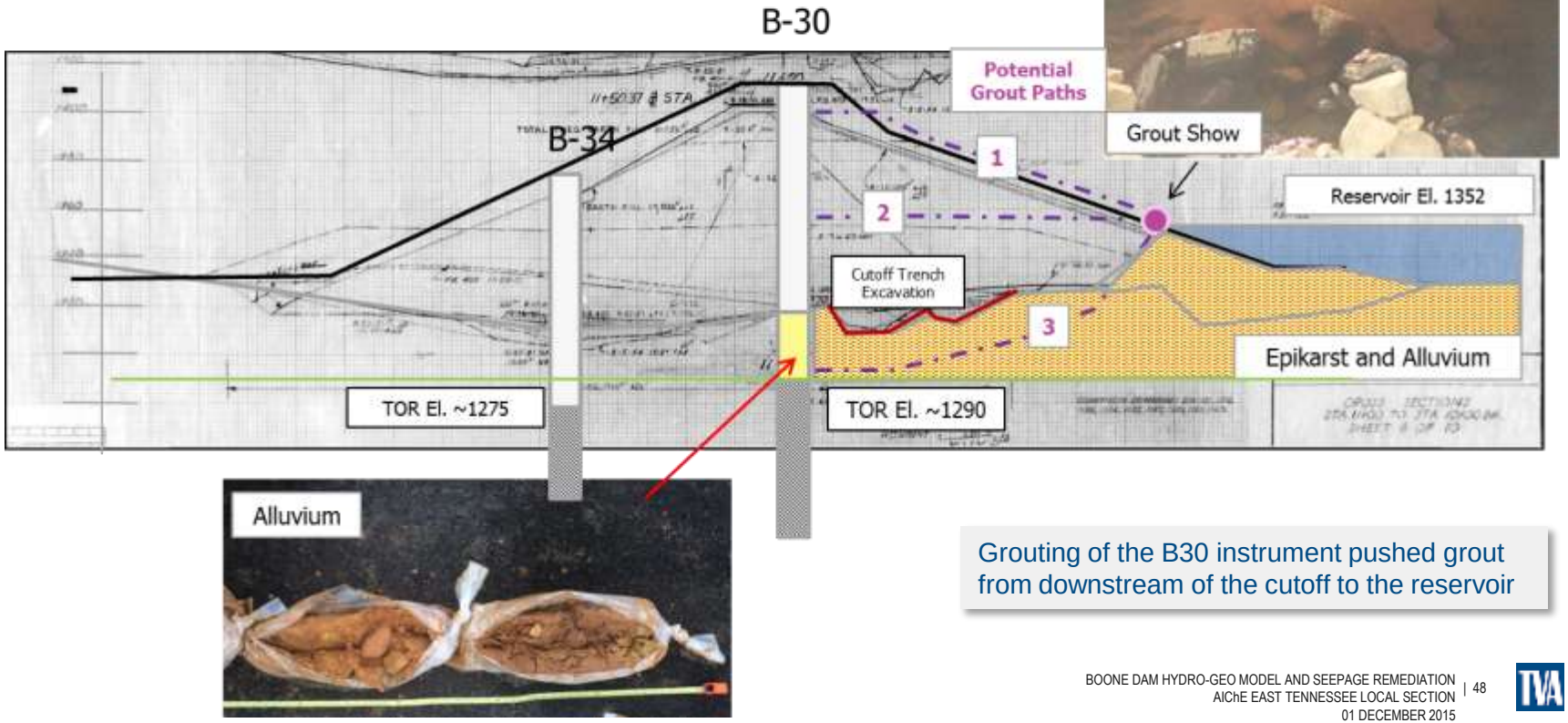
B-30 Grout Event

Grouting of the B30 instrument pushed grout from downstream of the cutoff to the reservoir



Reservoir Contribution

B-30 Grout Event



Grouting of the B30 instrument pushed grout from downstream of the cutoff to the reservoir

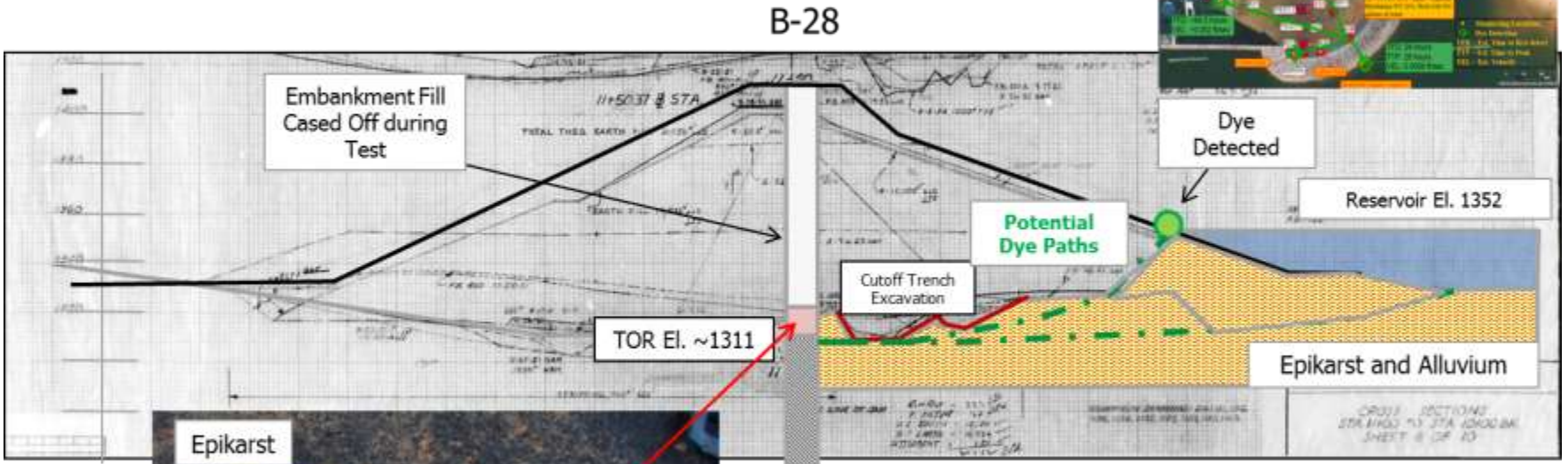
Reservoir Contribution

B-28 Dye Test

B28 dye test from downstream of cutoff had a detect to the upstream of the cutoff

Reservoir Contribution

B-28 Dye Test



B28 dye test pushed dye from downstream of cutoff to the upstream of the cutoff

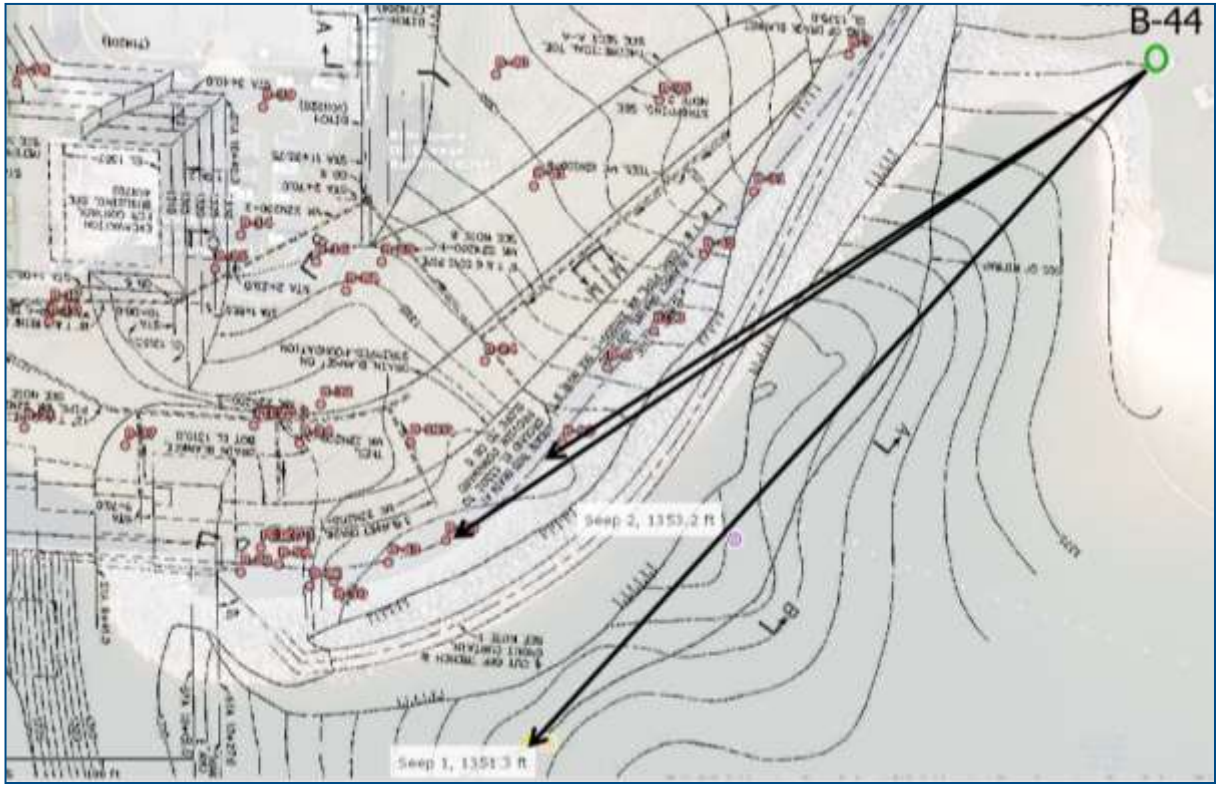
Reservoir Contribution

B-44 Dye Test

B-44 dye test (U/S) resulted in dye in B-28 and B-42 (D/S) epikarst and headwater

Reservoir Contribution

B-44 Dye Test



B-44 dye test (U/S) resulted in dye in B-28 and B-42 (D/S) epikarst

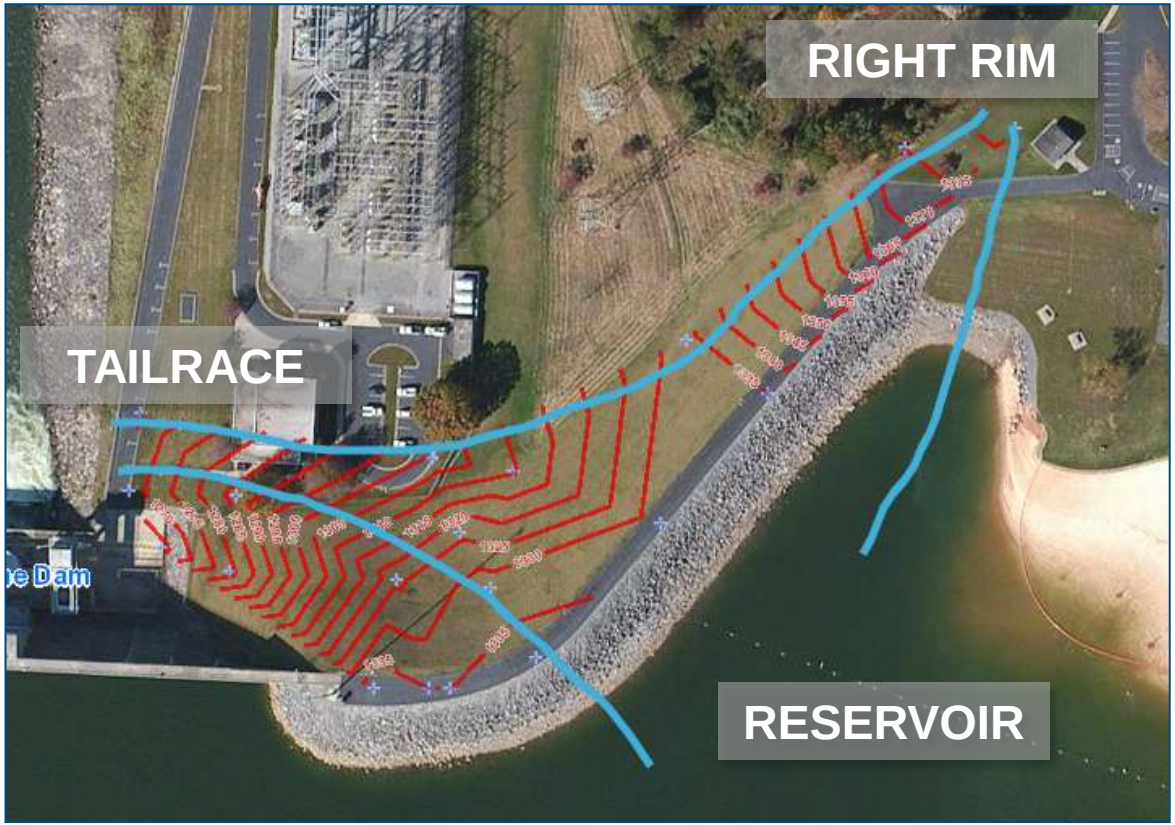
Reservoir Contribution

Temperatures in Embankment Soils

Temperature closely matches regional ground temperature and indicates very little flow through the embankment soils

Normal ground temperature in the project area is 57°F
Reservoir Temperature is 43°F

Pipe and Tank Illustration



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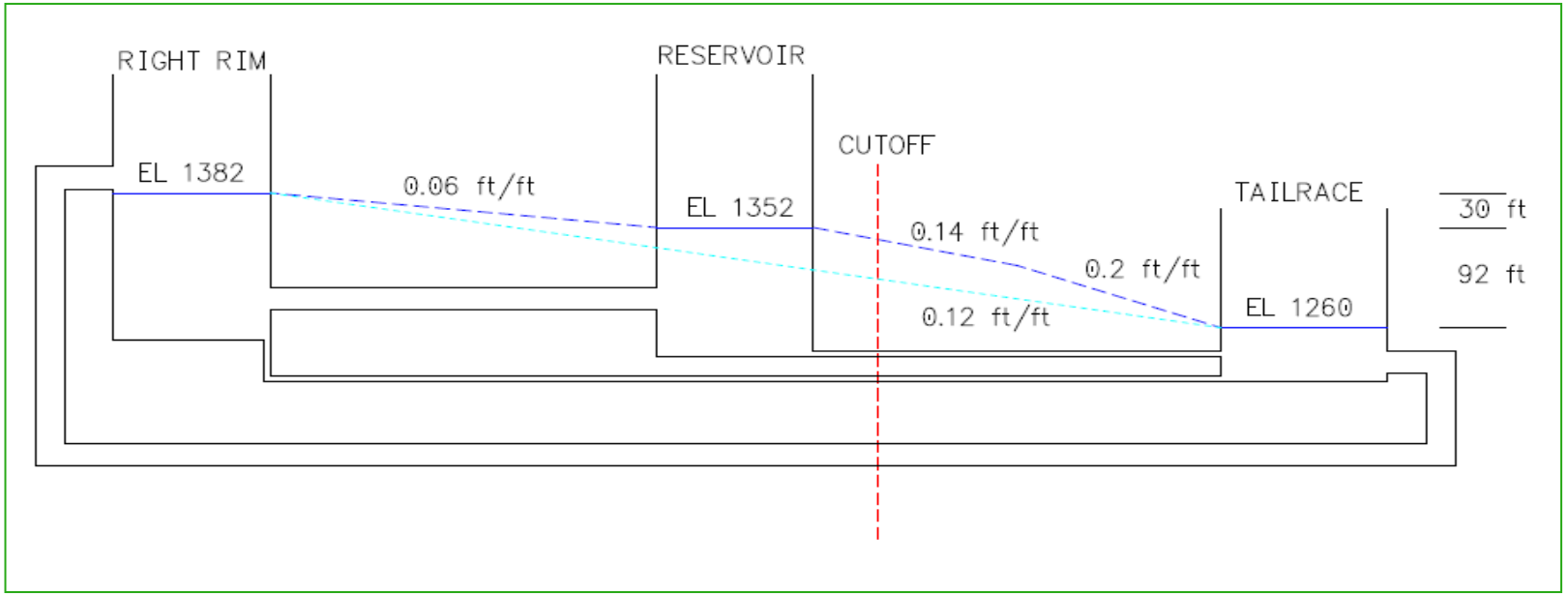


- Simplified model of the existing drainage network
- Demonstrates the constant source of head from the Right Rim
- Exhibits the potential for large fluctuations in the system dependent on water surface elevation in both Right Rim and Reservoir
- Illustrates the increased gradients due to the Reservoir

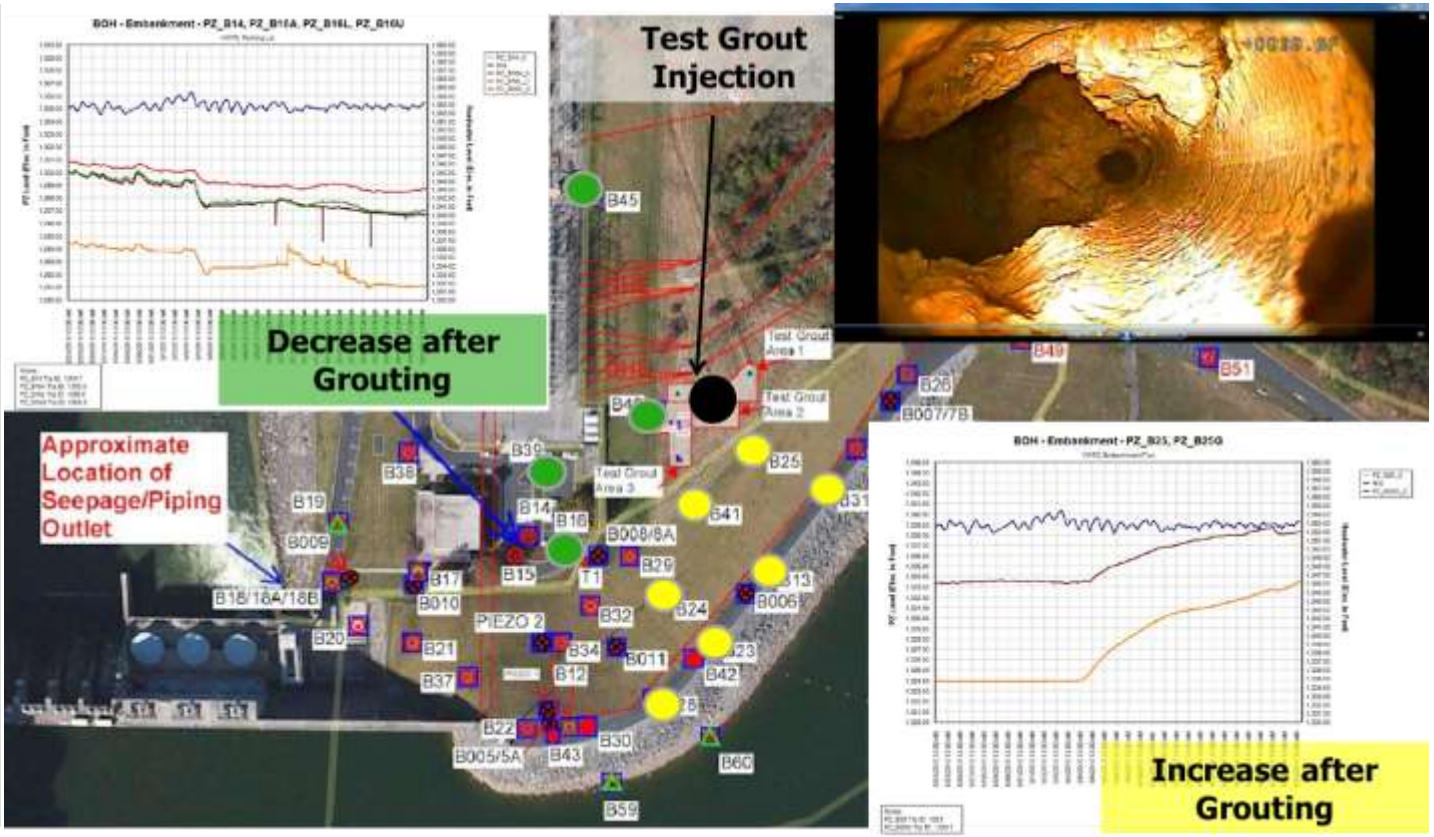
Potentially Active Failure Modes

Erosion through an open channel or pipe that connects to the reservoir, through the epikarst or embankment soils, with a resulting flowrate that quickly undercuts the embankment.

Erosion channels transmit high water pressures from the upstream lake to the downstream dam face, inducing a large slope failure in the embankment.

Sinkholes develop under the downstream face causing a series of slope failures that leave a deep gap in the embankment crest.

Recent Conformations of Hydro-Geo Model Right Rim

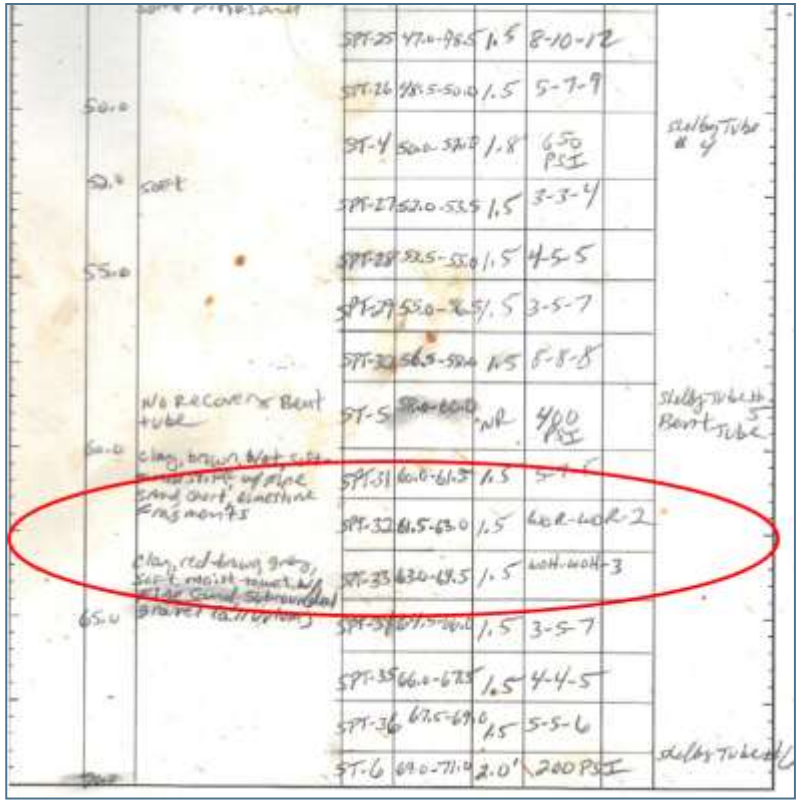


Recent Conformations of Hydro-Geo Model

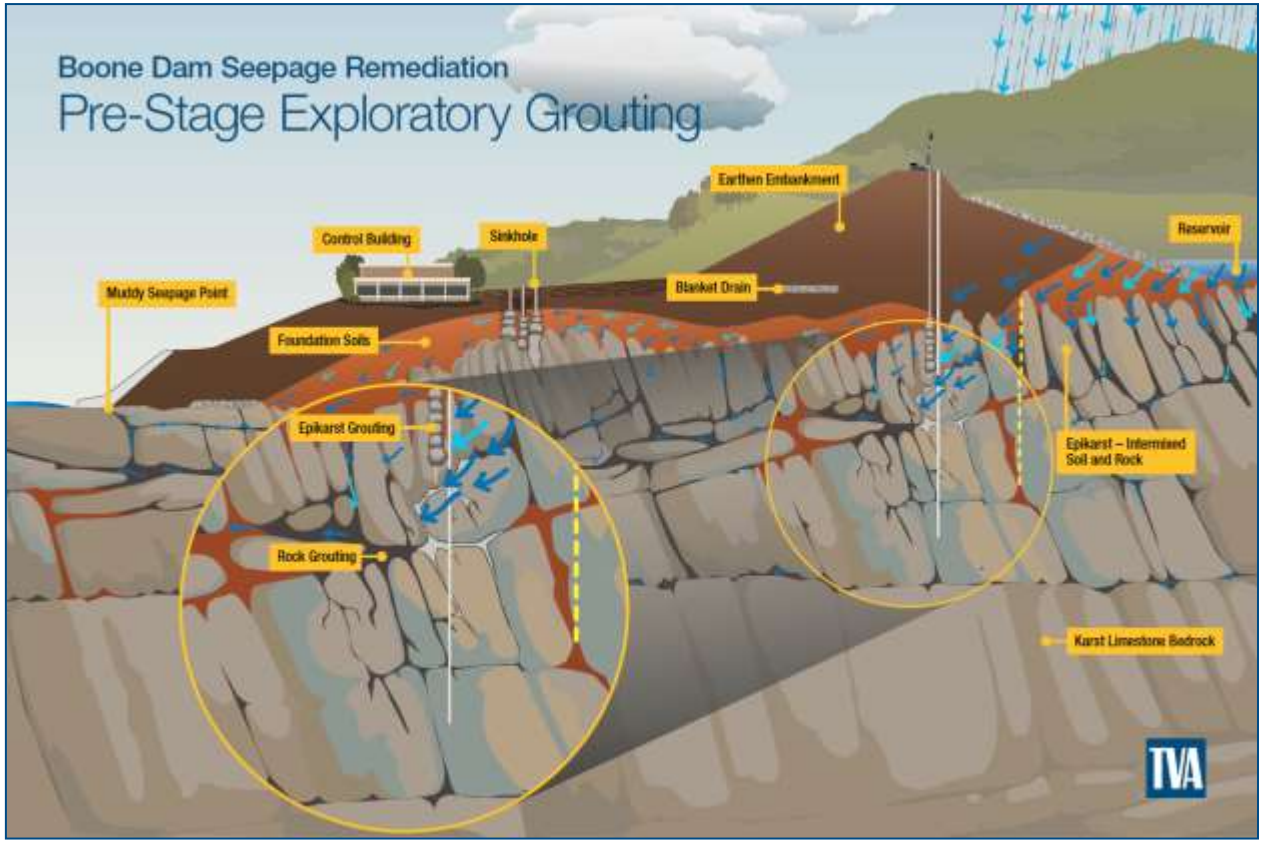
Reservoir Connections – B-60

Recent Conformations of Hydro-Geo Model

Reservoir Connections – B-60



Remediation Plans



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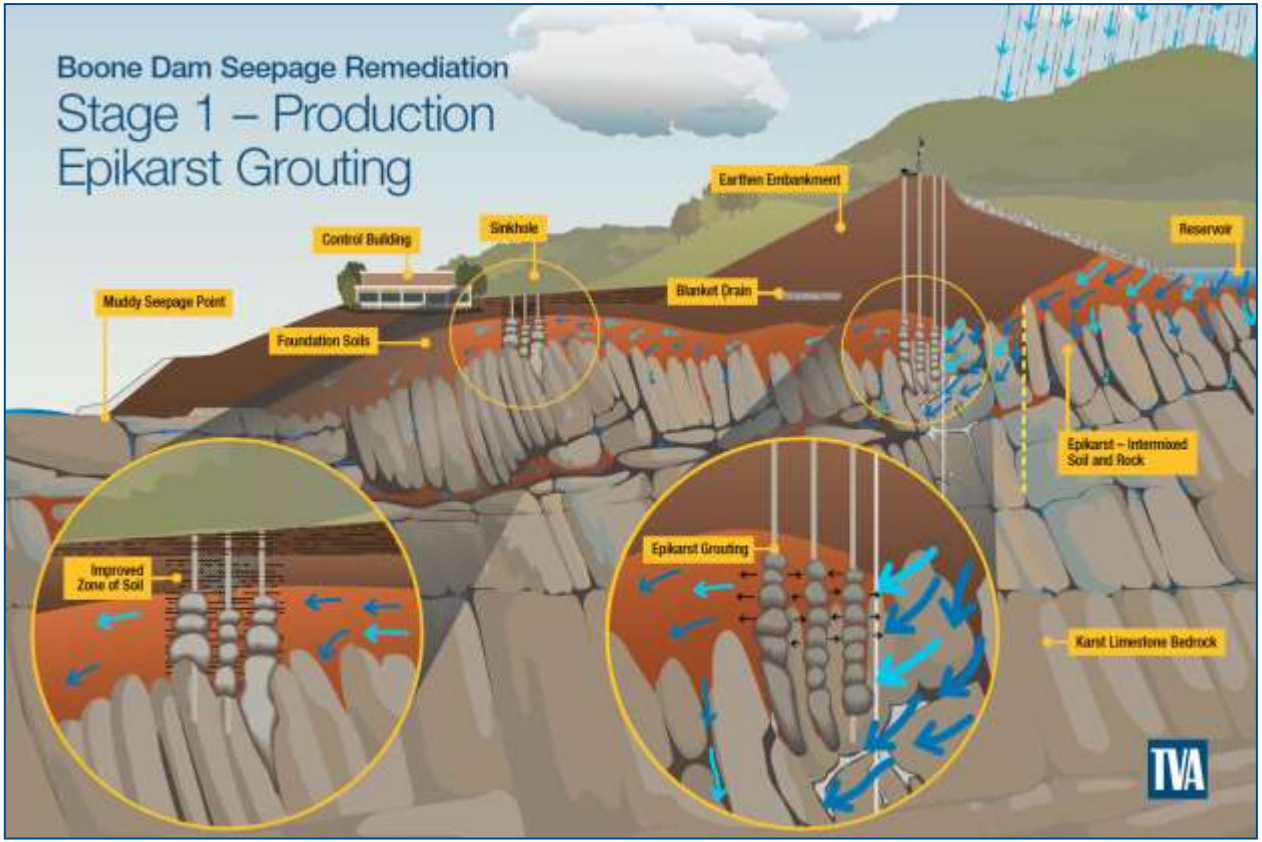

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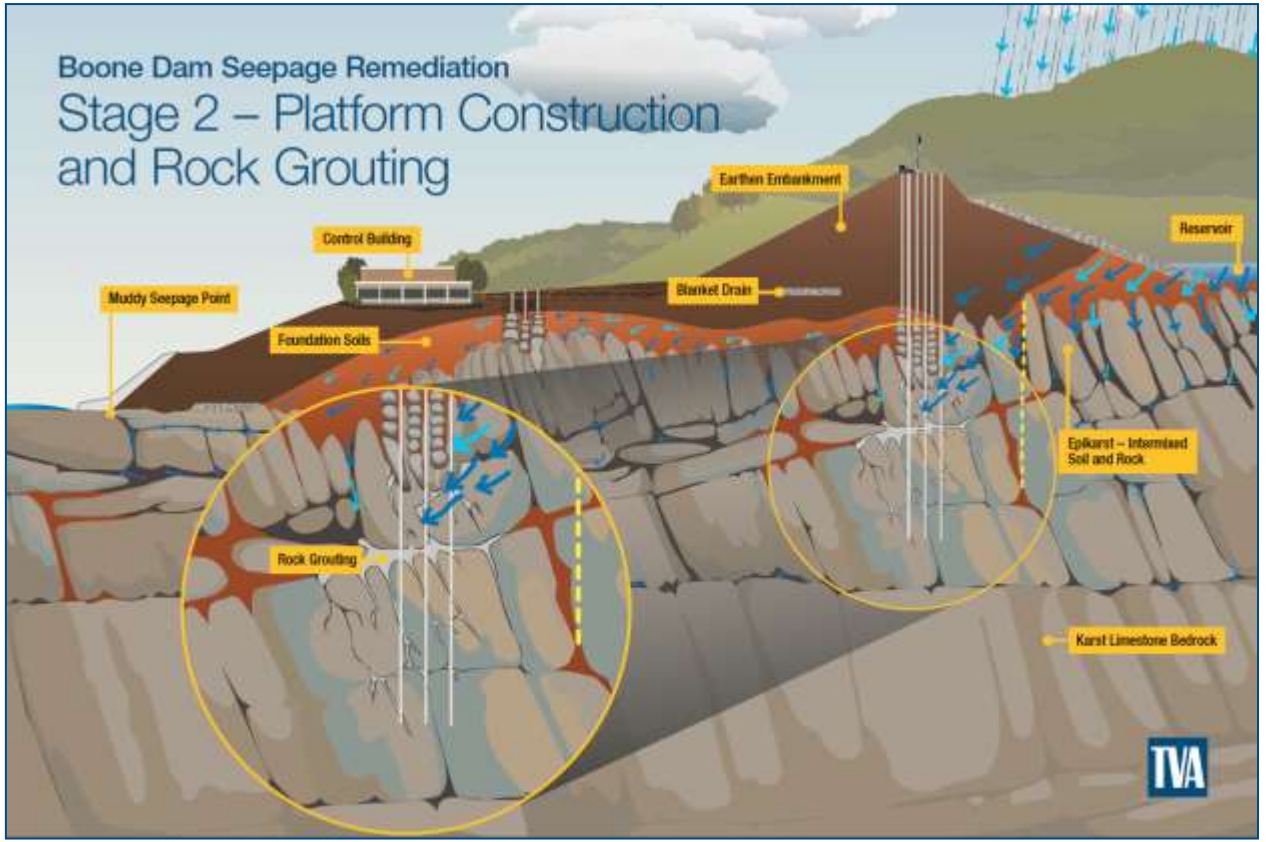

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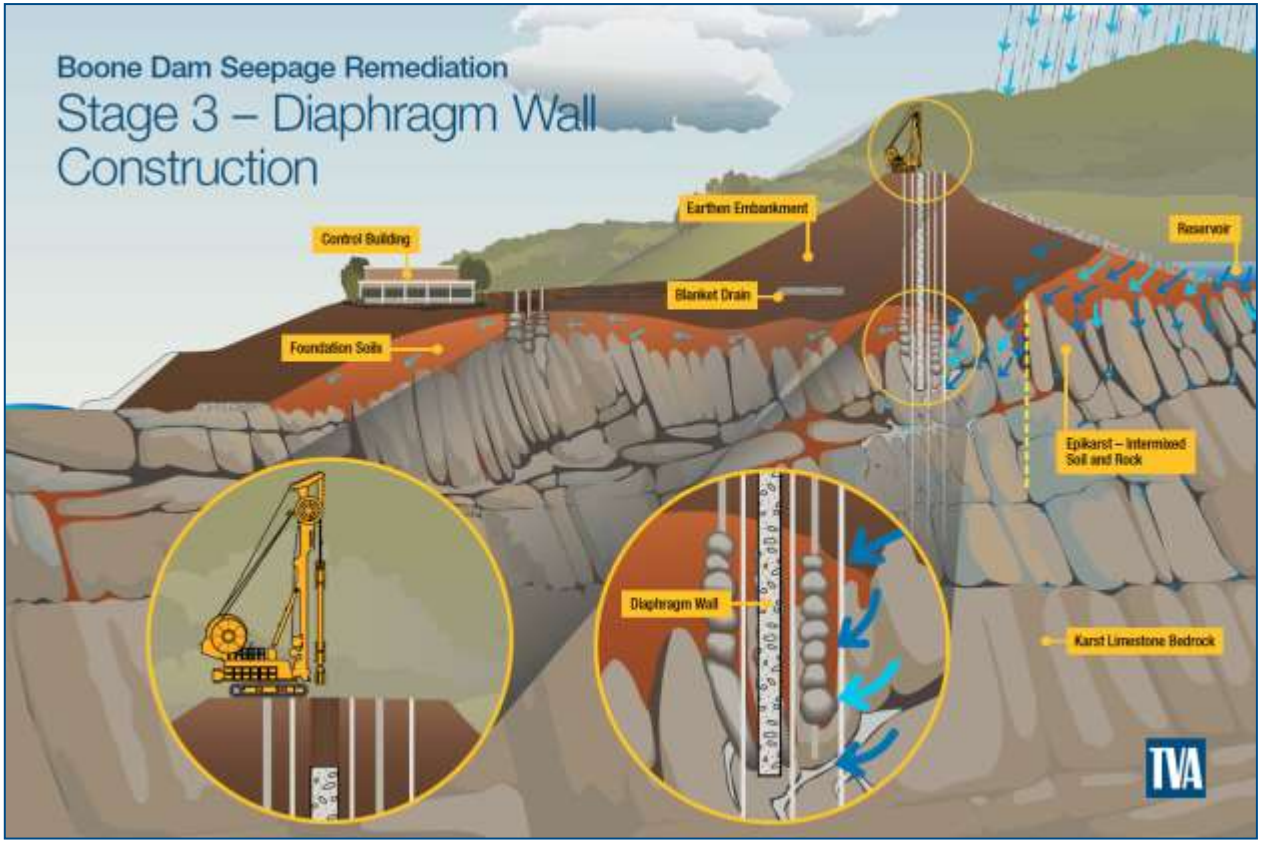

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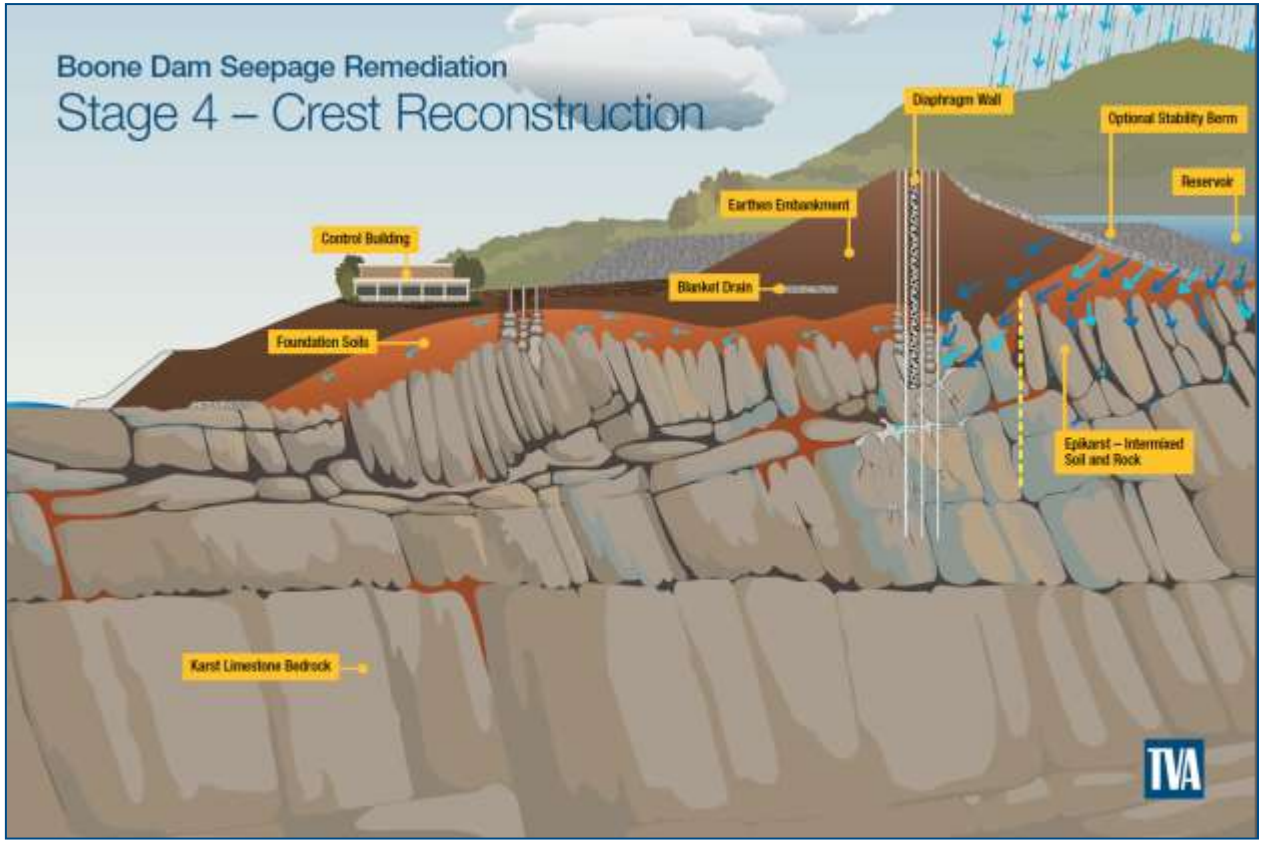

Current and Upcoming Activities

- Test Grouting Program
- Exploration Grouting Program
- Composite Wall Design
- Environmental Assessment Completion

Questions