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
Background: Sinkholes and Turbid Discharge

2012 Sinkhole

Oct. 2014 Sinkhole

Oct. 2014 Muddy Discharge
Muddy Seep in Tailrace

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

11/03/14 • 14:32 • Units Off • HW 1367.4
Idealized Cross Section and Foundation Treatment

Raised to 1408.5 in 1983
Cut Off Trench Alignment

Grout Curtain Alignment

Cut Off Trench Excavation
Site Geology - The Underlying Issue
Elements of the Geologic Model

Complex Structure
Elements of the Geologic Model

Complex Structure
Elements of the Geologic Model

Complex Structure
Elements of the Geologic Model

• Bedrock
  – Competent rock
  – Epikarst
Elements of the Geologic Model

- Foundation
- Soils
- Epikarst
Elements of the Geologic Model

Foundation Soils

- Alluvial Cap
- Residual
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

Exposed Top of Epikarst
Alluvial Deposit in Foundation Soils
Geological Elements

Photographic Definitions

Competent Rock
- Foundation Soils
- Epikarst
- Embankment Fill
Geological Elements

Photographic Definitions

Competent Rock
- Foundation Soils
- Epikarst
- Embankment Fill
Figure 10 - Placing Clay in Core Trench Section
Investigations – Exploration Borings
Investigations – Geophysics
Hydro-Geologic Model Overview

Seepage Flows at Boone Dam
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

1. Drainage Network
2. Right Rim Contribution
3. Reservoir Contribution

Preexisting topographic draw

Elev. 1260’
Elev. 1275’
Elev. 1330’
Elev. 1425’
Elev. 1500’
Preexisting Drainage Network

1. Drainage Network
2. Right Rim Contribution
3. Reservoir Contribution

Preexisting sinkholes and natural springs

Spring prior to construction

Depressions prior to construction
Preexisting Drainage Network

Consolidation Grouting Required
Preexisting Drainage Network
• 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

Karstic Vadose Zone

Measured Head in Right Rim 1384’

Current HW 1352’
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.
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.
Piezometers with response to high infiltration event

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

- Drainage Network
- Right Rim Contribution
- Reservoir Contribution

Approximate Location of Seepage Piping Outlet
Approximate Location of Sink Hole
Right Rim Contribution

Piezometers at downstream toe respond to high infiltration event
Right Rim Contribution

1. Drainage Network
2. Right Rim Contribution
3. Reservoir Contribution

A French drain was required during construction to deal with excessive flows from springs in the area shown below. Piezometer elevations following high infiltration event fluctuates at higher elevations following high infiltration event. Piezometer elevations during dry period.
Right Rim Contribution

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

Piezometer elevations during dry period.

Piezometer 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.

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

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

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

1. Drainage Network
2. Right Rim Contribution
3. Reservoir Contribution

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.

B-30 Boring
Grout Show Location
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

1. Drainage Network
2. Right Rim Contribution
3. Reservoir Contribution
Pipe and Tank Illustration

- 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
Remediation Plans
Remediation Plans

Boone Dam Seepage Remediation
Stage 2 – Platform Construction and Rock Grouting

- Earthen Embankment
- Control Building
- Muddy Seepage Point
- Blanket Drain
- Rock Grouting
- Epikarst – Intermixed Soil and Rock
- Karst Limestone Bedrock

TVA
Remediation Plans

Boone Dam Seepage Remediation
Stage 3 – Diaphragm Wall Construction

- Control Building
- Earth Embankment
- Blanket Drain
- Foundation Soils
- Diaphragm Wall
- Epi-Karst – Intermixed Soil and Rock
- Karst Limestone Bedrock

TVA
Remediation Plans
Current and Upcoming Activities

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