BOLIVAR DAM
GROUT CURTAIN CONSTRUCTION
Muskingum River Basin, OH

AEG Annual Meeting
September 2016

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U.S. Army Corps of Engineers, Huntington WV
LRD Dam Safety Production Center
Dam Safety Modification Mandatory Center of Expertise
BOLIVAR DAM GROUTING - OUTLINE

A. SITE CONDITIONS
   1. Project Location
   2. Site Geology
   3. Past Performance - Seepage

B. GROUT CURTAIN CONSTRUCTION

C. GROUT CURTAIN RESULTS
Located in eastern Ohio, within Muskingum River Watershed

System of 16 USACE dams, most built in 1930’s

This system of dams was the nation’s first to impound water for regional flood control

Dam/Levee Reevaluation
- Changing Criteria
- Poor Performance During High-Water Events
- Portfolio of Dams Prioritization based on Risk Assessments
BOLIVAR DAM

- Located on Sandy Creek, a tributary of the Tuscarawas River
- Earthen dam, constructed in 1938
- “Run of River”

BOLIVAR DAM

- Muskingum Watershed
- Tuscarawas River
- Walhonding River
- Muskingum River
- Sandy Creek
- Muskingum Watershed

USACE Dams

OHIO

MI

KY
BOLIVAR DAM

- 6,400’ Dam Length
- 87’ Dam Height (main)
- Founded Mostly on Glacial Outwash
- Left Abutment Founded on Bedrock

Intake Structure

- 6,400’ Dam Length
- 87’ Dam Height (main)
- Founded Mostly on Glacial Outwash
- Left Abutment Founded on Bedrock

Intake Structure

Tailwater El. 906
(backup from Dover Dam Pool)

Spillway Crest
Elev. 962 feet

Top of Dam wall
Elev. 985.5 feet

Pool of Record – El. 951.6
30 year event

Intake Structure

POOL OF RECORD – JAN 2005
Near-horizontal sedimentary rock

Pennsylvanian aged Pottsville Group

Interbedded sandstone, shale, siltstone, claystone with thin seams of coal and limestone

Typically joints are high angled with smooth and planar surfaces.

Solutioned discontinuities are common in thin limestone units.
GLACIAL GEOLOGY

- Unglaciated
- Located near the ice margins of Illinoian and Wisconsin glacial periods
- Site geology Influenced by glacial lakes and outwash.
- Typically, +100 foot thick proglacial soil deposits within valley bottom.
(El. 950 to 920 feet) Onsite Borrow Area for seepage blanket extension/augmentation work – downstream of right abutment
SEEPAGE DURING FLOOD EVENTS

- Downstream Soil
- Rock Toe Seepage
- Terrace Seepage
- Tail Water
- Terrace Piped Sand
SEEPAGE DURING FLOOD EVENTS

- Emergency Filter Placement on Terrace
- Terrace Foundation Sand Eroded Out
- Overflowing relief well nearing inundation by Dover Dam pool
- Artesian flow from piezometer even with extension
- Flow through open joints in bedrock in left abutment of dam
Risk assessment resulted in actionable failure modes (internal erosion through foundation sands)
- DSAC II rating (urgent)
SEEPAGE REMEDIATION MEASURES
SEEPAGE BARRIER & GROUT CURTAIN

SEEPAGE BARRIER
* 4,519 FEET LONG
* UP TO 144 FEET DEEP
* 2 FEET MIN. THICK

GROUT CURTAIN
* DOUBLE LINE
* 394 FEET LONG
* 65 FOOT AVG. DEPTH

COMPLETED REMEDIATION MEASURES
- Slope Filters
- Downstream Filter Berms
- Rehab Relief Wells
- ADAS Instrumentation

INTAKE STRUCTURE
DAM
SPILLWAY
UPSTREAM
DOWNSTREAM
STILLING BASIN
BOLIVAR DAM GROUTING - OUTLINE

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B. GROUT CURTAIN CONSTRUCTION
   1. Potential Failure Mode
   2. Grout Curtain Design
   3. Construction Methods

C. GROUT CURTAIN RESULTS
BEDROCK SEEPAGE – LOCATION

- Spillway
- Stilling Basin
- Flood Event
- Intake Structure
- Hypothetical Seepage Paths
- Approximate Location of Seepage Barrier
- Left Abutment
BEDROCK SEEPAGE – LEFT ABUTMENT

2005 FLOOD EVENT

1991 FLOOD EVENT

LOCATION ABOVE STILLING BASIN
LEFT ABUTMENT – GEOLOGY

- Soil: (colluvium – fines w/ rock frag.) approx. 16’ thick
- Bedrock: Near horizontal, interbedded, sedimentary bedrock
- Two thin limestone units (Upper and Lower Mercer Limestone)
- Limestone Units: thin (3’ to 5’ thick), regionally continuous, very hard, high UCS (as high as 32,000 psi).
- Joints: high angle, solutioned, approx. 5’ spacing, joint set at 90°, interconnected, avenues for groundwater flow.
- Bedding planes: low angle, open, solutioned and continuous.
- Exposed in stilling basin and spillway.
LIMESTONE EXCAVATION / OUTCROP

STILLING BASIN – CONSTRUCTION PHOTO (1936)
BEDROCK SEEPAGE – POTENTIAL FAILURE MODE

- **EXISTING SPILLWAY SILL GROUT CURTAIN (1989)**
- **STILLING BASIN**
- **SCOUR/EROSION OF DAM EMBANKMENT**
- **FLOOD EVENT**
- **INTAKE STRUCTURE**
- **HYPOTHETICAL SEEPAGE PATHS**
- **APPROXIMATE LOCATION OF SEEPAGE BARRIER**

**LEFT ABUTMENT**
BEDROCK SEEPAGE – REMEDIATION

EXISTING SPILLWAY SILL
GROUT CURTAIN (1989)

SPILLWAY

LOCATION OF GROUT CURTAIN

REDUCED GROUNDWATER VELOCITY

STILLING BASIN

FLOOD EVENT

INTAKE STRUCTURE

HYPOTHETICAL SEEPAGE PATHS

LEFT ABUTMENT

APPROXIMATE LOCATION OF SEEPAGE BARRIER

EXTEND SEEPAGE BARRIER KEYED INTO BEDROCK
GROUT CURTAIN – GENERAL DESIGN

- 400’ length grout curtain
GROUT CURTAIN – GENERAL DESIGN

- **400’ length** grout curtain
- **Double line** grout curtain, 10’ spacing between grout lines
- **3” diameter** grout holes
- All **Primary and Secondary** holes were grouted. Higher order grout holes were split spaced, when needed.
GROUT CURTAIN – GENERAL DESIGN

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- **Double line** grout curtain, 10’ spacing between grout lines
- **3” diameter** grout holes
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- **65’ depth**, bottom elev. 924 (below limestone units)
- **Two zones** (treat upper and lower limestones separately)
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- Downstream holes inclined 30° toward spillway (intersect high angled joints)
GROUT CURTAIN – GENERAL DESIGN

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- **Double line** grout curtain, 10’ spacing between grout lines
- **3” diameter grout holes**
- All **Primary and Secondary** holes were grouted. Higher order grout holes were split spaced, when needed.
- **65’ depth**, bottom elev. 924 (below limestone units)
- **Two zones** (treat upper and lower limestones separately)
- Downstream holes inclined **30° toward spillway** (intersect high angled joints)
- Upstream holes inclined **30° toward dam/valley** (intersect high angled joints)
CONSTRUCTION

- Contract awarded to Treviicos
- **Seepage Barrier**: panel method, excavated with hydromill, backfilled with low strength concrete
- **Grout Curtain**: subcontracted to TerraFirm
- Construction Award Cost: $44 million
- Notice to Proceed Date: May 2014
**DRILLING THROUGH SOIL & INSTALL CASING**

- Grouting was subcontracted to Terra Firm
- Hole location and drill mast orientation was surveyed
- Auger drilling method through soil without drilling fluids, used crawler-mounted Davey Kent drills
- Installed temporary casing (PVC pipe)
- Place grout seal and grout annulus in two lifts

<table>
<thead>
<tr>
<th>Soil</th>
<th>Claystone</th>
<th>Upper Limestone</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top of Rock</td>
<td>Interbedded SH/SS/Coal</td>
<td></td>
</tr>
<tr>
<td>Top of Ground</td>
<td>Interbedded SH/SS/Coal</td>
<td>Lower Limestone</td>
</tr>
</tbody>
</table>

![AUGER DRILL RIG](image1)

**TYPICAL GROUT HOLE**

- Temporary Casing
- Grout Seal

![CASING](image2)

![SURVEY](image3)
DRILLING THROUGH BEDROCK

- Water actuated down-hole hammer with crawler-mounted Gill Beetle drills
- Drill 3” diameter hole
- Bottom of grout curtain at elev. 924
- Maximum drill length of 115’
- Inclination 0° to 70° from vertical
- Hole sidewalls were cleaned
- Hole deviation was measured using Boretrak or Gyroshot

![Typical Grout Hole Diagram](image)

- Temporary Casing
- Grout Seal
- Top of Rock
- Soil
- Claystone
- Upper Limestone
- Interbedded SH/SS/Coal
- Lower Limestone
- Interbedded SH/SS/Coal
- Not to Scale

![Down-Hole-Hammer Drill Rig](image)

- Cleaning Nozzle
- Boretrak
- Down-Hole-Hammer Drill Rig
PRESSURE TESTING

- **Two Zones** to treat upper and lower limestone units separately
- **Upstage grouting** – preferred method
- Set double packer within zone
- **Pressure is limited** during pressure testing and grouting to prevent hydraulic jacking
- Computer monitored, using pressure transducers and flow meters

![PRESSURE TEST CART]

![TYPICAL GROUT HOLE Diagram]

- **ZONE 1**
- **ZONE 2**
- **Interbedded SH/SS/Coal**
- **Upper Limestone**
- **Lower Limestone**
- **Claystone**
- **Soil**
GROUTING

- **Six balanced stabilized grout** mixes (range of viscosity and specific gravity, <1% bleed, <0.05 Pressure Filtration, <16hr final set)
- **Computer monitored** grouting and pressure testing (Jean Lutz system)
- Typically start with thinner mixes and incrementally increase viscosity
- Grouting refusal set at 0.5 gal/min
DOWNSTAGE GROUTING

- Downstage grouting if significant **drill water loss** is encountered (+50%), indicating open foundation conditions.

- Stage is pressure tested and grouted prior to deepening the hole.

**TYPICAL GROUT HOLE**

- Temporary Casing
- Top of Rock
- Soil
- Grout Seal
- Top of Ground
- Claystone
- Upper Limestone
- Interbedded SH/SS/Coal
- Void
- Lower Limestone
- Interbedded SH/SS/Coal
- Not to Scale
BOLIVAR DAM GROUTING - OUTLINE

A. SITE CONDITIONS

B. GROUT CURTAIN CONSTRUCTION
   1. Potential Failure Mode
   2. Grout Curtain Design
   3. Construction Methods

C. GROUT CURTAIN RESULTS
   1. Grout Takes
   2. Closure Criteria
   3. Lessons Learned
GROUT RECORDS – UPSTREAM LINE

GROUT PROFILE – PRIMARY & SECONDARY HOLES
(looking downstream)
GROUT RECORDS – UPSTREAM LINE

GROUT PROFILE – PRIMARY & SECONDARY HOLES
(looking downstream)

- Soil (colluvium)
- Shale, Siltstone & Coal
- Sandstone
- Limestone
GROUT RECORDS – DOWNSTREAM LINE

GROUT PROFILE – PRIMARY & SECONDARY HOLES
(looking downstream)
GROUT RECORDS – DOWNSTREAM LINE

GROUT PROFILE – PRIMARY & SECONDARY HOLES
(looking downstream)
GROUT PLACEMENT – DOWNHOLE IMAGES

HOLE P140U - 30°

Shale, Siltstone & Coal
Limestone (colluvium)

Seepage Barrier

GEOLOGIC PROFILE – SHOWING DOWNSTAGE GROUT (looking downstream)

ZONE 1
ZONE 2

LOWER MERCER LIMESTONE
CLAYSTONE

56'
57'
58'
59'
60'
61'

GROUND WATER LEVEL

1000
950
900
GROUT PLACEMENT – DOWNHOLE IMAGES

GEOLOGIC PROFILE – SHOWING DOWNSTAGE GROUTING
(looking downstream)

ZONE 1
ZONE 2

Seepage Barrier

HOLE P190U - 30°

LOWER MERcer LIMESTONE
SHALE
GROUT
GROUT

0+00 -0+50
1+00
2+00
3+00
4+00
5+00
6+00
7+00
8+00
9+00
10+00

53'
54'
55'
56'
57'
58'
59'
60'
61'
62'
63'
64'
65'
66'
67'
68'
69'
70'
71'
72'
73'
74'
75'
76'
77'
78'
79'
80'
81'
82'
83'
84'
85'
86'
87'
88'
89'
90'
91'
92'
93'
94'
95'
96'
97'
98'
99'
100'

Shale, Siltstone & Coal
Sandstone
Limestone

HOLE P190U - 30°
GROUT PLACEMENT – DOWNHOLE IMAGES

HOLE T145U - 30°

GROUT

GROUT

GROUT

CLAYSTONE

UPPER MERCER LIMESTONE

GEOLOGIC PROFILE – SHOWING DOWNSTAGE GROUT
(looking downstream)

ZONE 1

ZONE 2

Seepage Barrier

Downstage Grouting

Shale, Siltstone & Coal

Sandstone

Limestone

1000
950
900
850
800
750
700
650
600
550
500
450
400
350
300
250
200
150
100
50
0
-50
-100
-150
-200

1000
950
900
850
800
750
700
650
600
550
500
450
400
350
300
250
200
150
100
50
0
-50
-100
-150
-200
Grout Curtain - Closure Criteria

- Specified that **Primary and Secondary** holes were to be drilled, pressure tested and grouted (min. 10’ spacing).

- Specified criteria for **refusal** during grouting was **0.5 gallons per minute**.

- Specified criteria for **split-spaced** higher-order grout holes was grout take being greater than **100 gallons**.

- **Consensus from a cadre** of professionals, upon review of data.
  - **Sequential reduction** of grout takes and pressure test values for higher order grout holes (reduction in bedrock permeability).
  - Additional criteria for split-spacing by reviewing **pressure test results** of the highest-order grout holes to determine a risk-based and practical upper bound values (lugeon values).
Review of Pressure Test Results – Zone 2

- Seepage within Zone 2 has a **higher probability of dam failure** than Zone 1.
  - Higher hydraulic gradient
  - Increased frequency of pools
  - Longer pool duration

- **Upper bound Lugeon value of 10** for highest-order, pre-grouted holes (marginally groutable).
- **Final average Lugeon value below 5**
- Resulted in **adding 10 Higher-Order holes.**

Profile - Grout Curtain
Review of Pressure Test Results – Zone 1

- Seepage within Zone 1 has a **lower probability of dam failure** than Zone 2.
  - Lower hydraulic gradient
  - Decreased frequency of pools
  - Shorter pool duration
- **Upper bound Lugeon value of 35** for highest-order grouted holes from sta 0+00G to 2+00G.
- **Final average Lugeon value below 20** (higher than typical criteria)
- Resulted in **adding 12 Higher Order holes**.
Upstream Grout Curtain – All Holes

- Average hole spacing = 4.7’
- **102 Total Holes**, 50 Primary & Secondary, 52 Higher Order Holes
- Primary through Quinary Holes
- Approximately 4,600’ of grouted holes in bedrock
- **115,700 gal of grout**

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**Profile - Upstream Grout Curtain**

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**ZONE 1**

**ZONE 2**

**SOIL**

**TOP OF GROUND**

**TOP OF ROCK**

**ZONE BOUNDARY 950**

**SPILLWAY**

**DAM**
Upstream Curtain – Zone 2 – Closure – Higher Risk

LUGEON VALUES FROM PRE-GROUTED PRESSURE TESTS

<table>
<thead>
<tr>
<th>Foundation Condition</th>
<th>Median (Lu)</th>
<th>Average (Lu)</th>
<th>Standard Deviation</th>
<th>Hydraulic Conductivity (cm/sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Before Grouting (U/S primary holes)</td>
<td>15.5</td>
<td>30.8</td>
<td>35</td>
<td>$4 \times 10^{-4}$</td>
</tr>
<tr>
<td>Nearly Completed Grouting (highest-order grout holes)</td>
<td>2.4</td>
<td>3.9</td>
<td>3.7</td>
<td>$5 \times 10^{-5}$</td>
</tr>
</tbody>
</table>

Profile - Upstream Curtain – Highest-Order Grout Holes Only
Upstream Curtain – Zone 1 – Closure – Low Risk

LUGEON VALUES FROM PRE-GROUTED PRESSURE TESTS

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<tr>
<td>Before Grouting (U/S primary holes)</td>
<td>56.6</td>
<td>441</td>
<td>1,123</td>
<td>$5 \times 10^{-3}$</td>
</tr>
<tr>
<td>Nearly Completed Grouting (highest-order grout holes)</td>
<td>16.9</td>
<td>18.4</td>
<td>16.4</td>
<td>$2 \times 10^{-4}$</td>
</tr>
</tbody>
</table>

Primary (20’)
Secondary (10’)
Tertiary (5’)
Quaternary (2.5’)
Quinary (1.25’)

Before Grouting (U/S primary holes): 56.6, 441, 1,123, $5 \times 10^{-3}$
Nearly Completed Grouting (highest-order grout holes): 16.9, 18.4, 16.4, $2 \times 10^{-4}$

Profile - Upstream Curtain – Highest-Order Grout Holes Only

Upper Bound Criteria = 35 Lu
Downstream Grout Curtain – All Holes

- Average hole spacing = 7.7’
- 68 Total Holes, 46 Primary & Secondary, 22 Higher Order Holes
- Primary through Quaternary Holes
- Approximately 3,100’ of grouted hole in bedrock
- 12,800 gal of grout
### Lugeon Values from Pre-GROUTED Pressure Tests

<table>
<thead>
<tr>
<th>Foundation Condition</th>
<th>Median (Lu)</th>
<th>Average (Lu)</th>
<th>Standard Deviation</th>
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<td>35</td>
<td>$4 \times 10^{-4}$</td>
</tr>
<tr>
<td>Nearly Completed Grouting (highest-order grout holes)</td>
<td>2.6</td>
<td>4.5</td>
<td>4.7</td>
<td>$6 \times 10^{-5}$</td>
</tr>
</tbody>
</table>

**Profile - Downstream Curtain – Highest-Order Grout Holes Only**

**Primary (20')**
- Secondary (10')
- Tertiary (5')
- Quaternary (2.5')
- Quinary (1.25')

**Lugeon Values**
- 0 – 5 Lugeon
- 5 - 10 Lugeon
- 10 – 15 Lugeon
- + 15 Lugeon
Downstream Curtain – Zone 1 – Closure – Low Risk

### Lugeon Values from Pre-Gрутовed Pressure Tests

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<td>1,123</td>
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</tr>
<tr>
<td>Nearly Completed Grouting (highest-order grout holes)</td>
<td>11.9</td>
<td>15.8</td>
<td>16.0</td>
<td>$2 \times 10^{-4}$</td>
</tr>
</tbody>
</table>

Profile - Downstream Curtain – Highest-Order Grout Holes Only

Upper Bound Criteria = 35 Lu
**Grout Placed – All Holes**

**GROUT PLACED - All Holes (gal)**

<table>
<thead>
<tr>
<th></th>
<th>Upstream</th>
<th>Downstream</th>
<th>subtotal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary</td>
<td>78,627</td>
<td>8,453</td>
<td>87,081</td>
</tr>
<tr>
<td>Secondary</td>
<td>33,953</td>
<td>3,412</td>
<td>37,365</td>
</tr>
<tr>
<td>Tertiary</td>
<td>2,421</td>
<td>857</td>
<td>3,278</td>
</tr>
<tr>
<td>Quaternary</td>
<td>588</td>
<td>80</td>
<td>668</td>
</tr>
<tr>
<td>Quinary</td>
<td>81</td>
<td>81</td>
<td></td>
</tr>
</tbody>
</table>

**subtotal:** 115,671 12,802

**128,473: Total Grout Placed (gal)**

**GROUT PLACED PER LINEAR FOOT (gal/lf)**

<table>
<thead>
<tr>
<th></th>
<th>Upstream</th>
<th>Downstream</th>
<th>subtotal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary</td>
<td>63.66</td>
<td>7.61</td>
<td>37.12</td>
</tr>
<tr>
<td>Secondary</td>
<td>30.89</td>
<td>3.13</td>
<td>17.07</td>
</tr>
<tr>
<td>Tertiary</td>
<td>1.64</td>
<td>1.43</td>
<td>1.58</td>
</tr>
<tr>
<td>Quaternary</td>
<td>0.89</td>
<td>0.27</td>
<td>0.80</td>
</tr>
<tr>
<td>Quinary</td>
<td>0.80</td>
<td></td>
<td>0.80</td>
</tr>
</tbody>
</table>

**subtotal:** 25.26 4.13

**16.73: Grout Placed Per Linear Foot (gal/lf)**

- Total Cement Placed (cf): 8,659
- Cement Placed per LF (cf/lf): 1.13 (estimated 0.33)
- Grout Placed: 54% Zone 1, 46% Zone 2
- Grout Placed: 90% Upstream Line, 10% Downstream
Pressure Test & Downstages

PRESSURE TEST - MEDIAN LUGEON

<table>
<thead>
<tr>
<th></th>
<th>Upstream</th>
<th>Downstream</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary</td>
<td>41.5</td>
<td>17.4</td>
</tr>
<tr>
<td>Secondary</td>
<td>28.5</td>
<td>15.0</td>
</tr>
<tr>
<td>Tertiary</td>
<td>8.9</td>
<td>8.6</td>
</tr>
<tr>
<td>Quaternary</td>
<td>7.9</td>
<td>1.5</td>
</tr>
<tr>
<td>Quinary</td>
<td>2.3</td>
<td></td>
</tr>
</tbody>
</table>

Pre-grouted Pressure Test (Median Lu)

Total Number of Downstages (ea)

<table>
<thead>
<tr>
<th></th>
<th>Upstream</th>
<th>Downstream</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary</td>
<td>57</td>
<td>7</td>
</tr>
<tr>
<td>Secondary</td>
<td>18</td>
<td>5</td>
</tr>
<tr>
<td>Tertiary</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Quaternary</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Quinary</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

subtotal: 78 12

90:Total Number of Downstages (ea)

- 80% of grout placed during downstaging
# Grout Placed – Grout Mix

**GROUT PLACED - UPSTREAM LINE - BY MIX (gal/lf)**

<table>
<thead>
<tr>
<th></th>
<th>Mix A</th>
<th>Mix B</th>
<th>Mix C</th>
<th>Mix D</th>
<th>Mix E</th>
<th>Mix F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary</td>
<td>23.42</td>
<td>13.50</td>
<td>7.75</td>
<td>5.47</td>
<td>1.93</td>
<td>11.58</td>
</tr>
<tr>
<td>Secondary</td>
<td>10.46</td>
<td>5.25</td>
<td>2.97</td>
<td>1.75</td>
<td>1.25</td>
<td>9.21</td>
</tr>
<tr>
<td>Tertiary</td>
<td>1.60</td>
<td>0.04</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quaternary</td>
<td>0.89</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quinary</td>
<td>0.80</td>
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</tr>
</tbody>
</table>

- **36 sec**
- **41 sec**
- **58 sec**
- **127 sec**
- **high gum**
- **sanded**

**GROUT PLACED - DOWNSTREAM LINE - BY MIX (gal/lf)**

<table>
<thead>
<tr>
<th></th>
<th>Mix A</th>
<th>Mix B</th>
<th>Mix C</th>
<th>Mix D</th>
<th>Mix E</th>
<th>Mix F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary</td>
<td>5.11</td>
<td>1.70</td>
<td>0.59</td>
<td>0.10</td>
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</tr>
<tr>
<td>Secondary</td>
<td>1.90</td>
<td>0.44</td>
<td>0.19</td>
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<tr>
<td>Tertiary</td>
<td>1.43</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Quaternary</td>
<td>0.27</td>
<td></td>
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</tbody>
</table>

- **36 sec**
- **41 sec**
- **58 sec**
- **127 sec**
- **high gum**
- **sanded**
### Grouting Quantities

<table>
<thead>
<tr>
<th>DESCRIPTION</th>
<th>UNIT</th>
<th>ORIGINAL QUANTITY (+ mod 28)</th>
<th>FINAL ESTIMATED QUANTITY</th>
<th>PERCENT (+/-)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drilling and Grouting - Mobilization and Demobilization</td>
<td>JOB</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Hole Drilling in Overburden and Casing Installation</td>
<td>LF</td>
<td>2,200</td>
<td>2,122</td>
<td>-4</td>
</tr>
<tr>
<td>Hole Drilling in Rock</td>
<td>LF</td>
<td>7,070</td>
<td>8,889</td>
<td>26</td>
</tr>
<tr>
<td>Hole Re-Drilling</td>
<td>LF</td>
<td>2,100</td>
<td>1,071</td>
<td>-49</td>
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<tr>
<td>Reconnections for Downstaging</td>
<td>EA</td>
<td>55</td>
<td>86</td>
<td>56</td>
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<tr>
<td>Pressure Testing</td>
<td>EA</td>
<td>321</td>
<td>446</td>
<td>39</td>
</tr>
<tr>
<td>Optical Televiewer Survey</td>
<td>LF</td>
<td>580</td>
<td>243</td>
<td>-58</td>
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<tr>
<td>Placing Grout</td>
<td>HR</td>
<td>240</td>
<td>426</td>
<td>78</td>
</tr>
<tr>
<td>Stand-by Time for Grouting</td>
<td>HR</td>
<td>17</td>
<td>0</td>
<td>-100</td>
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<tr>
<td>Portland Cement In Grout</td>
<td>CF</td>
<td>2,400</td>
<td>8,712</td>
<td>263</td>
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<tr>
<td>Sand in Grout</td>
<td>LBS</td>
<td>4,465</td>
<td>84,365</td>
<td>1789</td>
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<tr>
<td>Bentonite in Grout</td>
<td>LBS</td>
<td>5,850</td>
<td>22,397</td>
<td>283</td>
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<tr>
<td>Admixtures in Grout</td>
<td>GAL</td>
<td>510</td>
<td>4,790</td>
<td>839</td>
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</tbody>
</table>

Modification 0028 expanded the scope of the grout curtain, as a result of IEPR comments. Quantities are approximate and have not been finalized at the time of this presentation.
Lessons Learned

- “Been There – Done That” doesn’t always apply to “Being Here – Doing This”

- “We’ve rarely use a sanded mix” (estimating quantities)

- “You’re done when you’re done” (need for closure criteria)

- “I don’t need no stinking Microsoft Access” (need for data management)
SEEPAGE BARRIER & GROUTING: STATUS

FINALIZING SITE WORK

SEEPAGE BARRIER COMPLETED APRIL 2016

GROUT CURTAIN COMPLETED NOVEMBER 2015