Tale of Three Projects

Addressing Dam Safety Concerns within the Muskingum River Basin, OH

AEG Annual Meeting
September 2015

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TALE OF THREE PROJECTS - OUTLINE

A. MUSKINGUM REGION

1. **Project Locations**
2. **Project Descriptions**
3. **Local Geology**

B. DOVER DAM (foundation anchors)

C. BOLIVAR DAM (seepage barrier & grouting)

D. ZOAR LEVEE (risk assessment)

MUSKINGUM WATERSHED

- Located in eastern Ohio, within Muskingum River Watershed
- System of 16 USACE dams, mostly built in 1930's, within Muskingum River Watershed for flood control, recreation and water quality
- Dam/Levee Reevaluation
  - Changing Criteria
  - Poor Performance During High-Water Events
  - Portfolio of Dams Prioritization based on Risk Assessments

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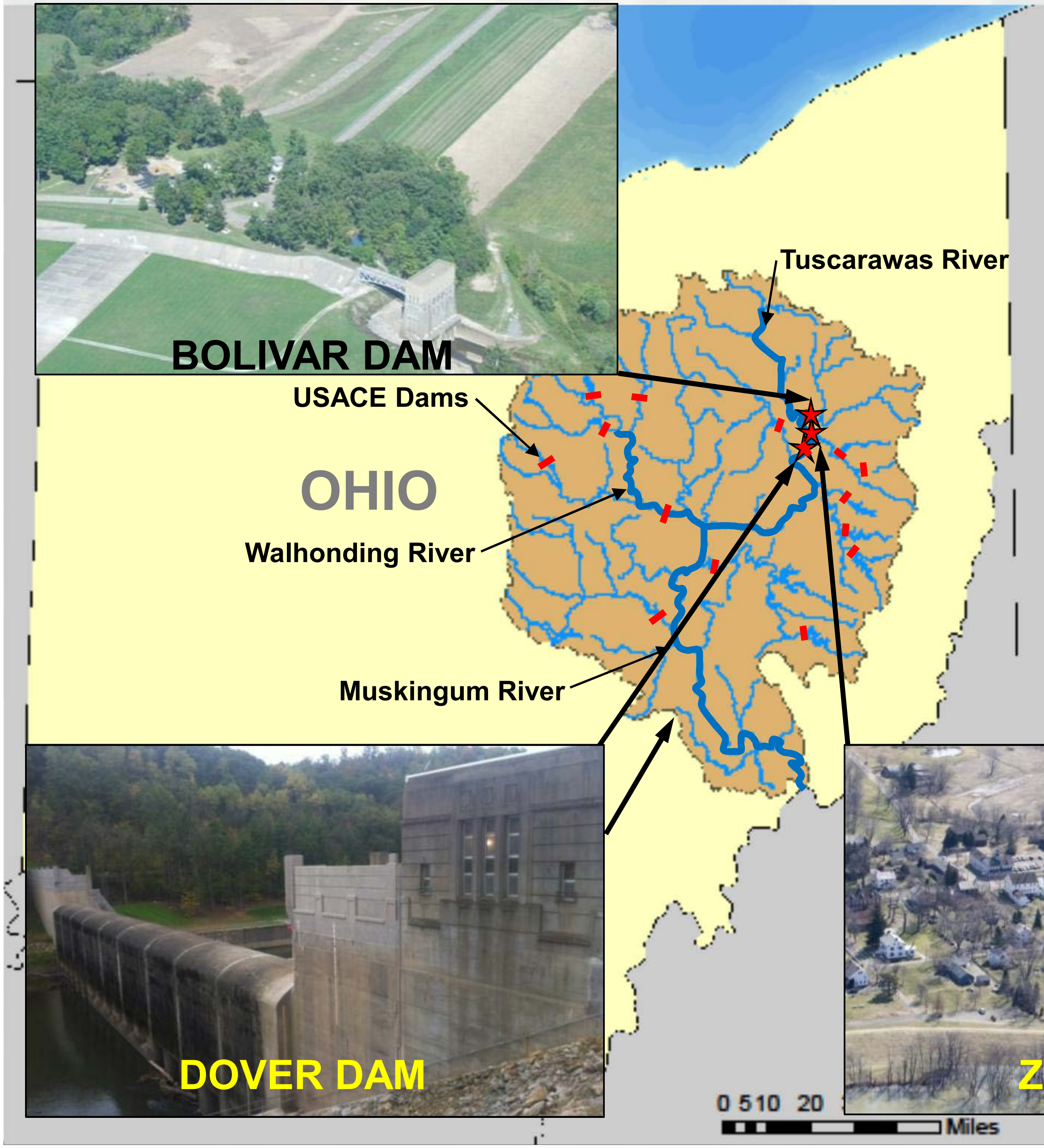
PROJECT LOCATIONS



Three Projects

1. Dover Dam: Concrete gravity dam, founded on bedrock, run-of-river

2. Bolivar Dam: Earthen dam, founded mostly on glacial outwash, run-of-river

3. Zoar Levee: Earthen levee, founded mostly on glacial outwash, located within Dover pool.

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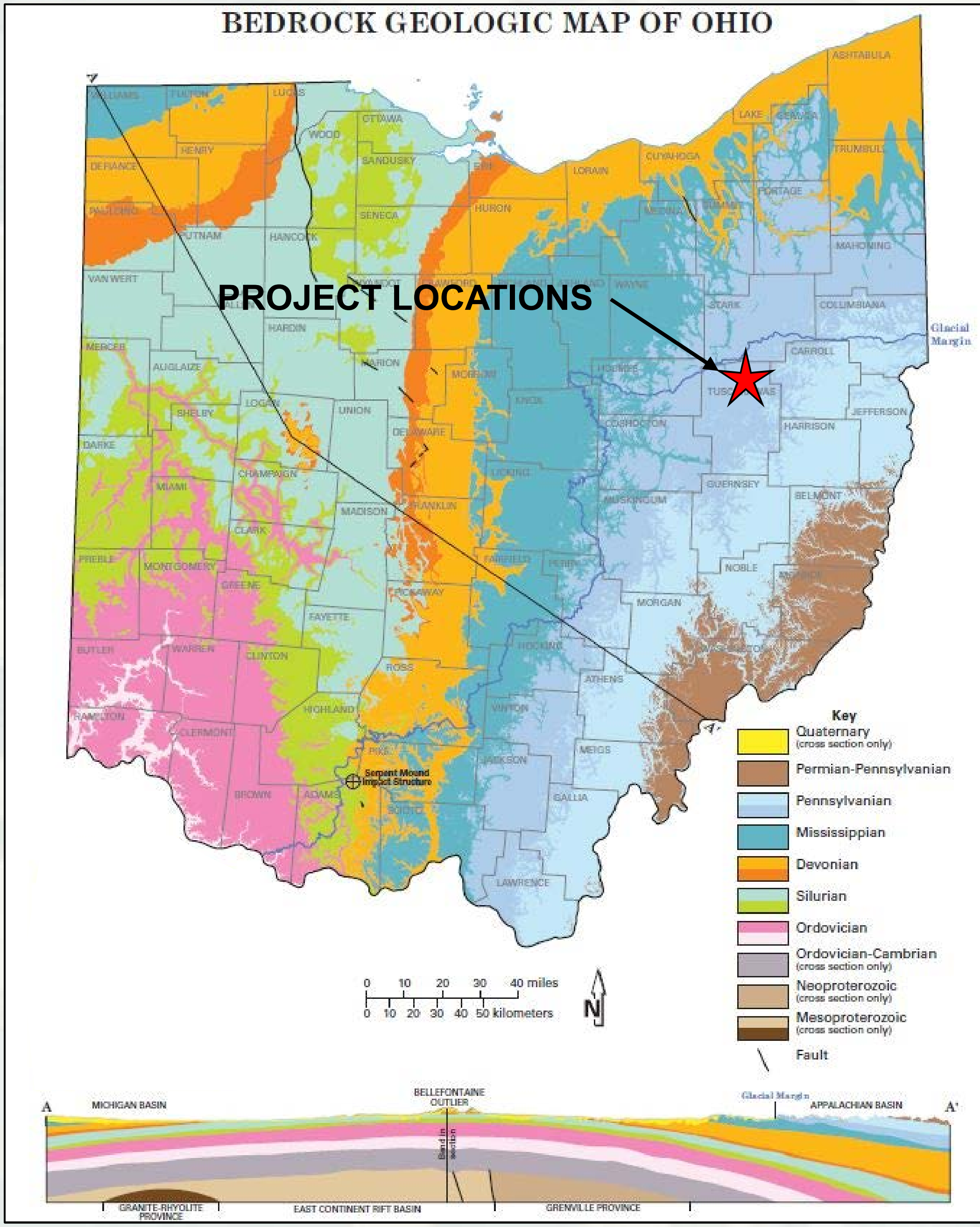
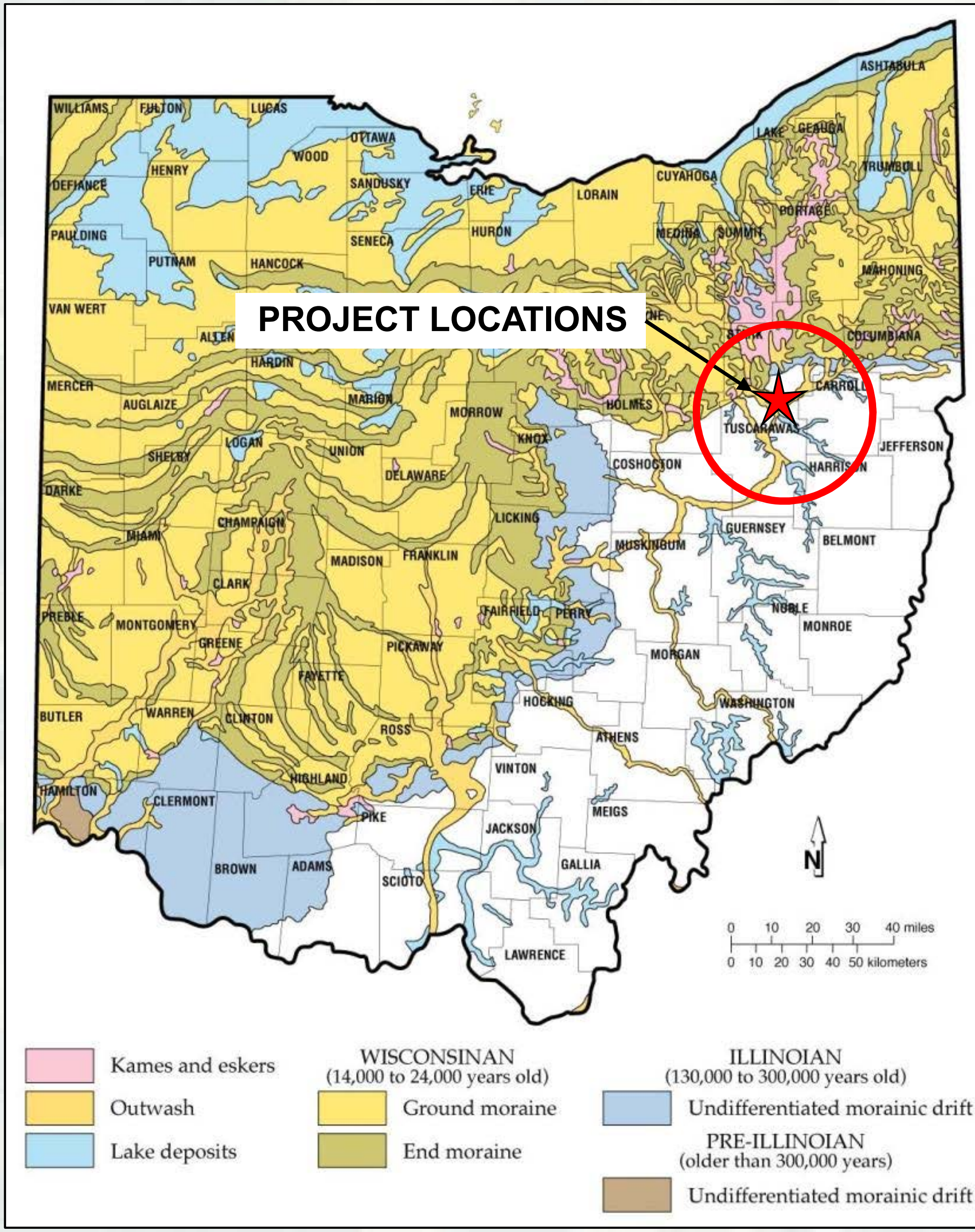
GEOLOGY



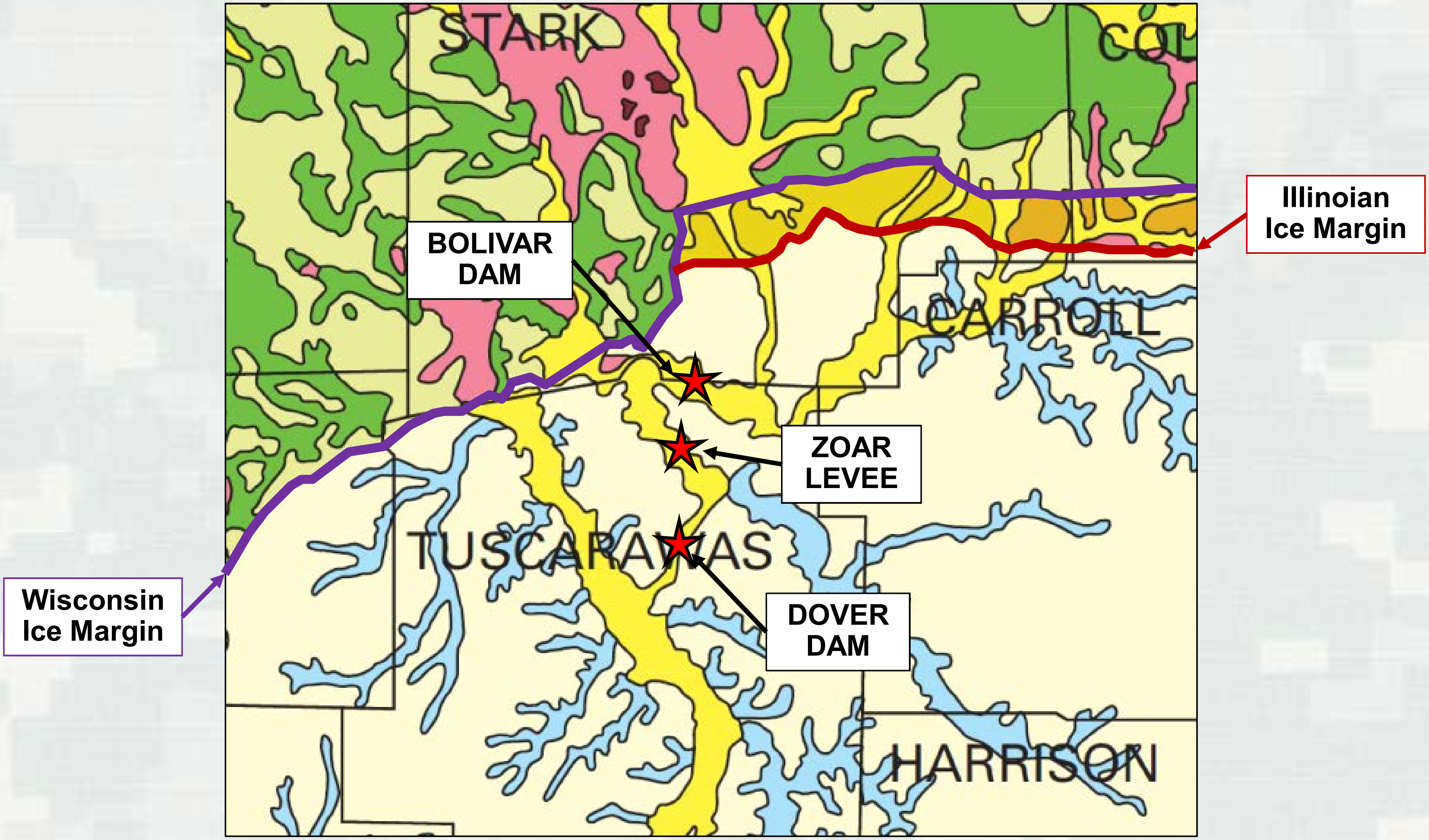
- Near-horizontal sedimentary rock (bedding)
- Pennsylvanian aged Pottsville Group
- Interbedded sandstone, shale, siltstone, claystone with thin seams of coal and limestone
- Typically joints are high angled with smooth and planar surfaces.
- Solutioned discontinuities are common in thin limestone units.

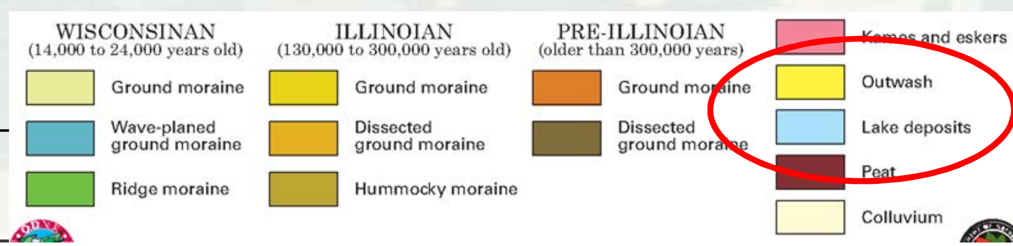
GLACIAL GEOLOGY



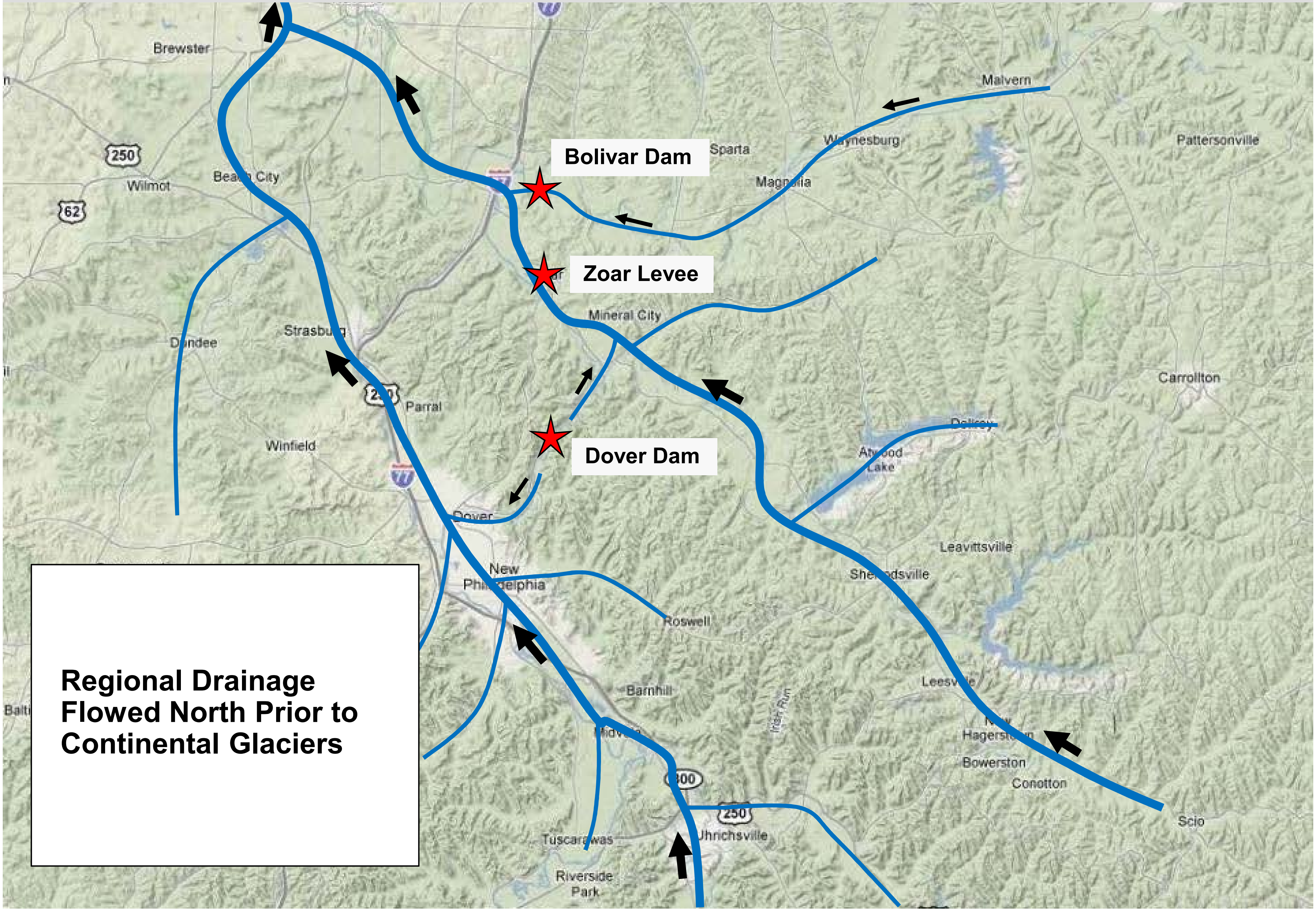
- Unglaciated
- Located near the ice margins of Illinoian and Wisconsin glacial periods
- Site geology Influenced by glacial lakes and outwash.
- Typically, +100' proglacial soil deposits within valley bottom.

LOCAL GLACIAL GEOLOGY



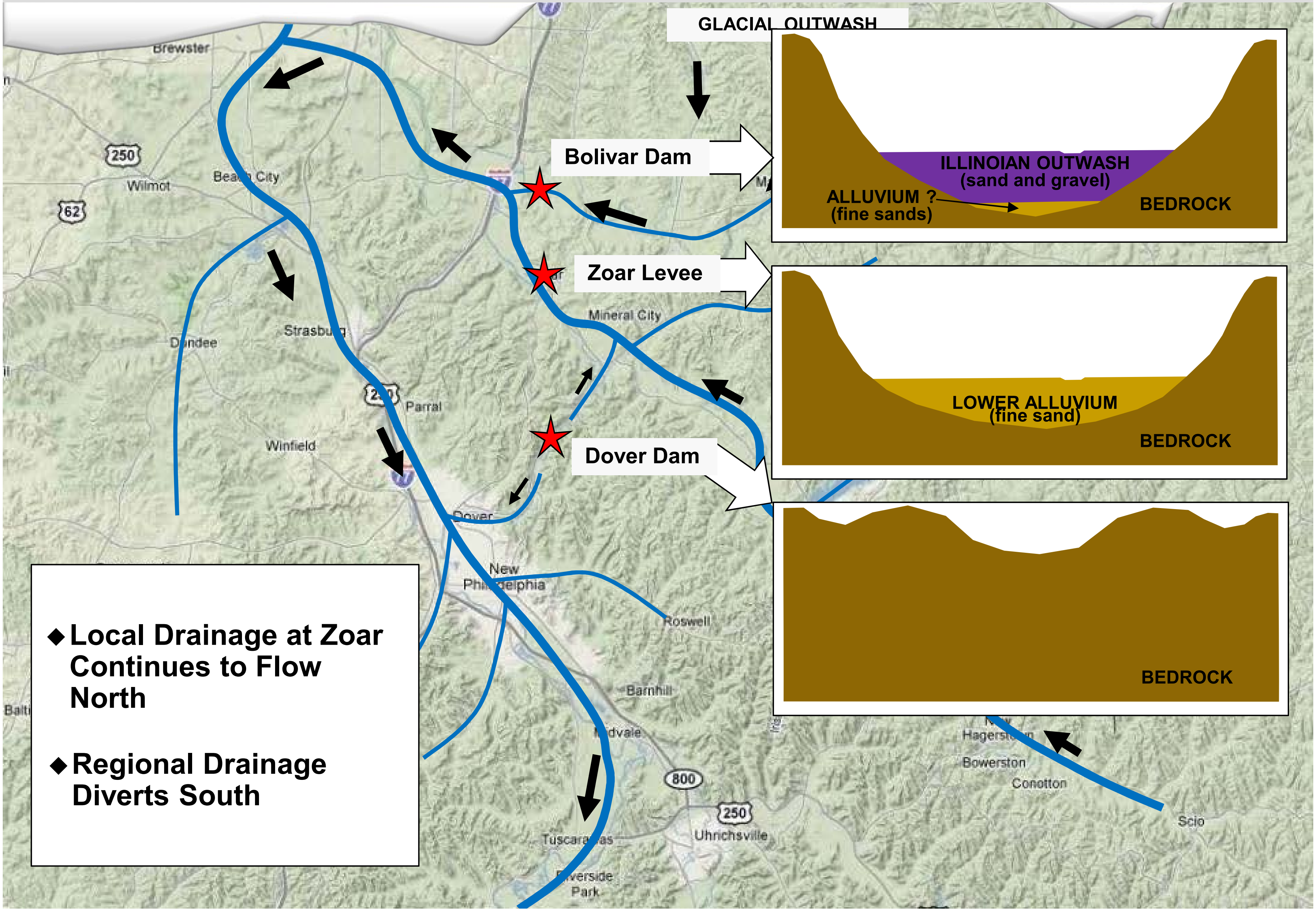


PRE GLACIAL DRAINAGE



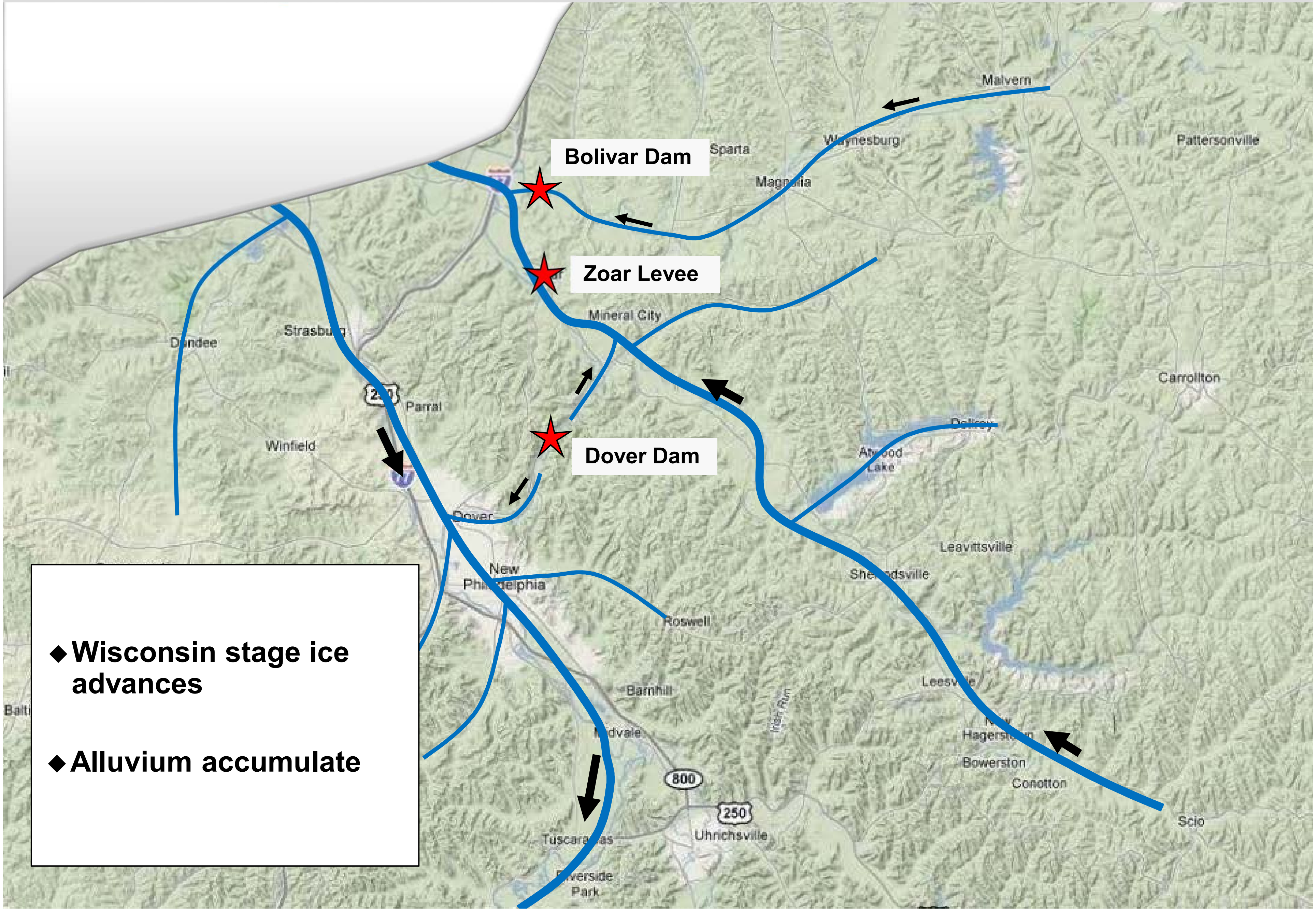
Regional Drainage Flowed North Prior to Continental Glaciers

ILLINOIAN ICE ADVANCE



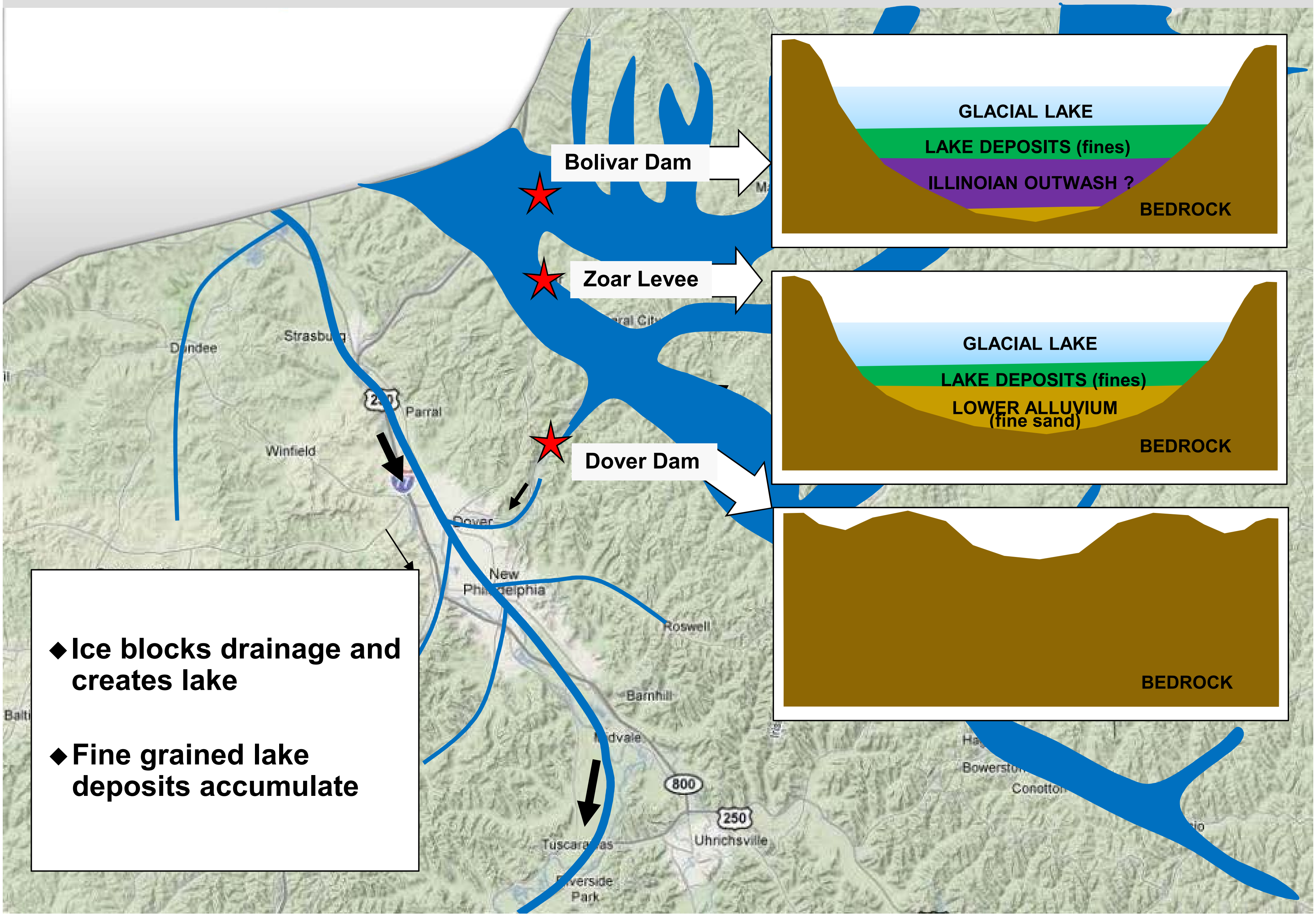
- Local Drainage at Zoar Continues to Flow North
- Regional Drainage Diverts South

WISCONSIN STAGE ICE ADVANCE



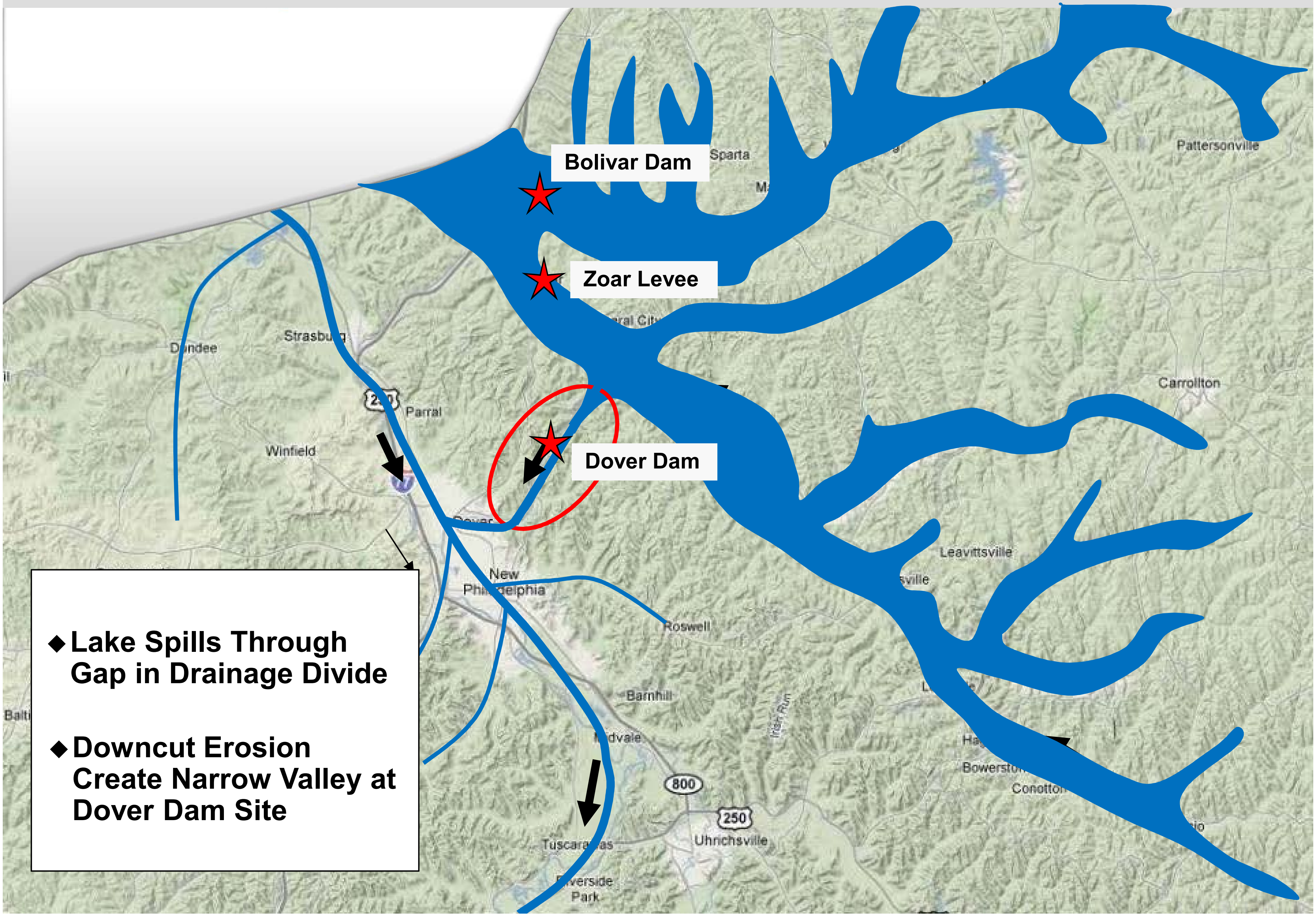
- Wisconsin stage ice advances
- Alluvium accumulate

WISCONSIN STAGE – GLACIAL LAKE



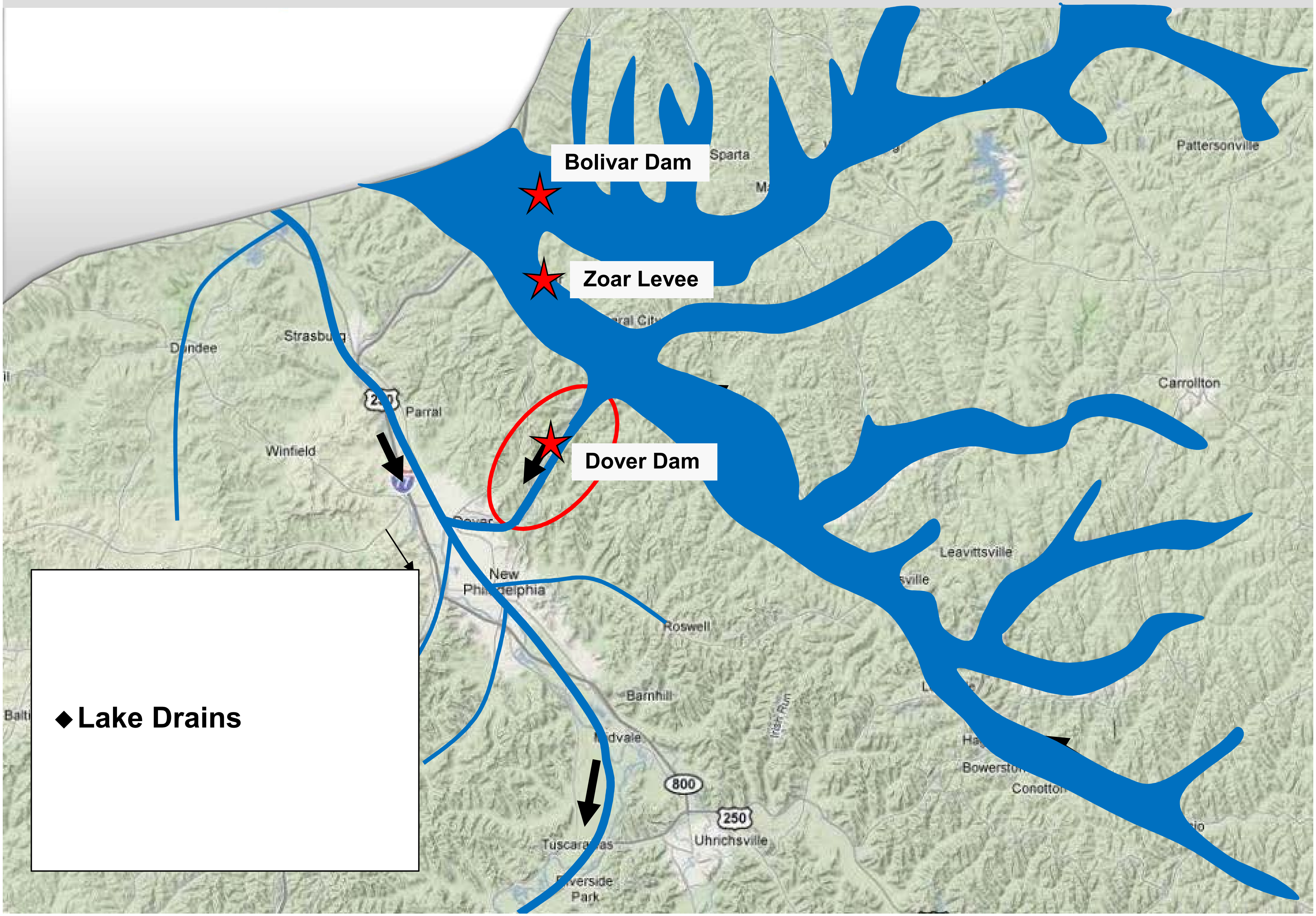
- Ice blocks drainage and creates lake
- Fine grained lake deposits accumulate

WISCONSIN ICE ADVANCE – GLACIAL LAKE



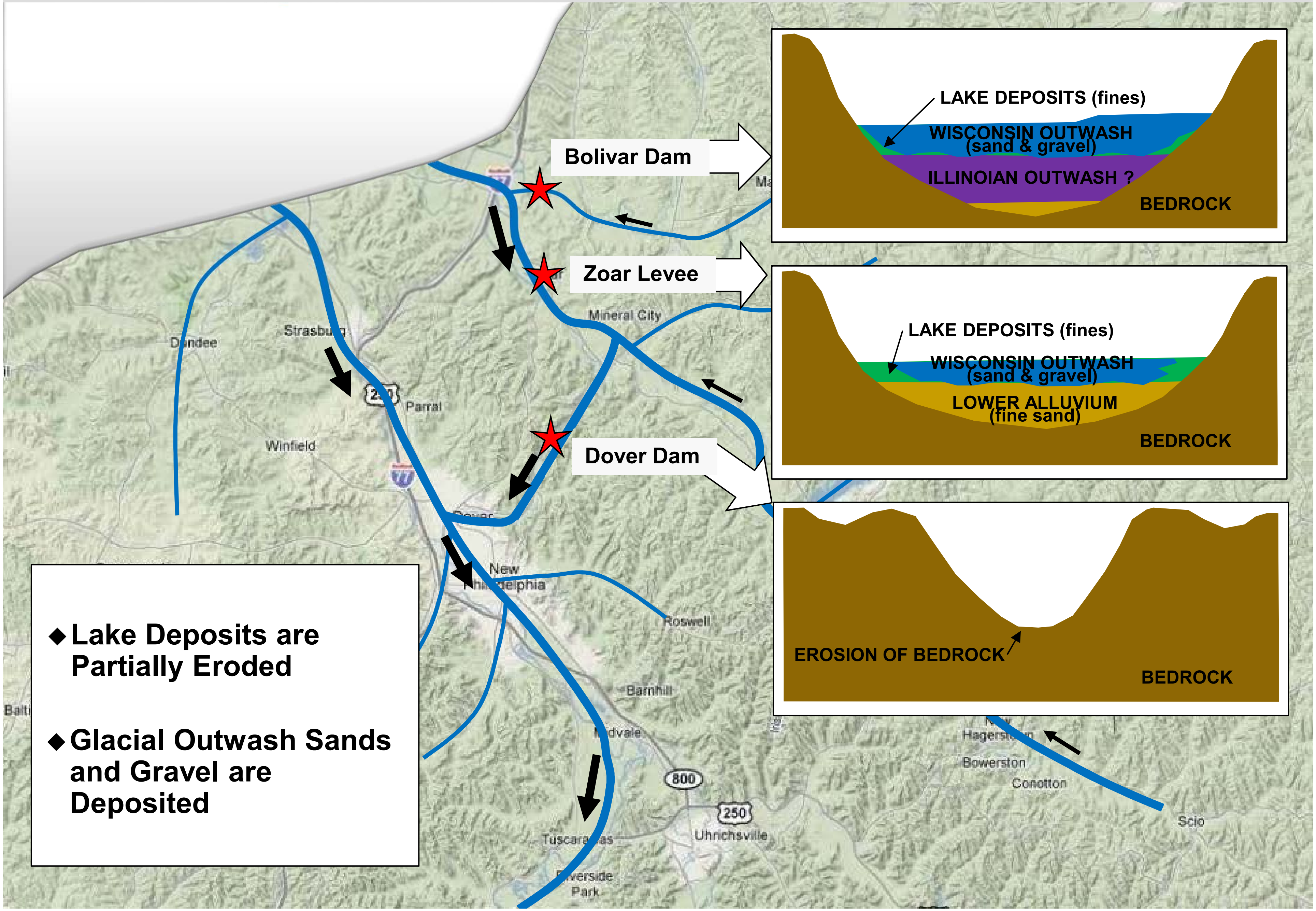
- ◆ Lake Spills Through Gap in Drainage Divide
- ◆ Downcut Erosion Create Narrow Valley at Dover Dam Site

WISCONSIN ICE ADVANCE – LAKE DRAINS



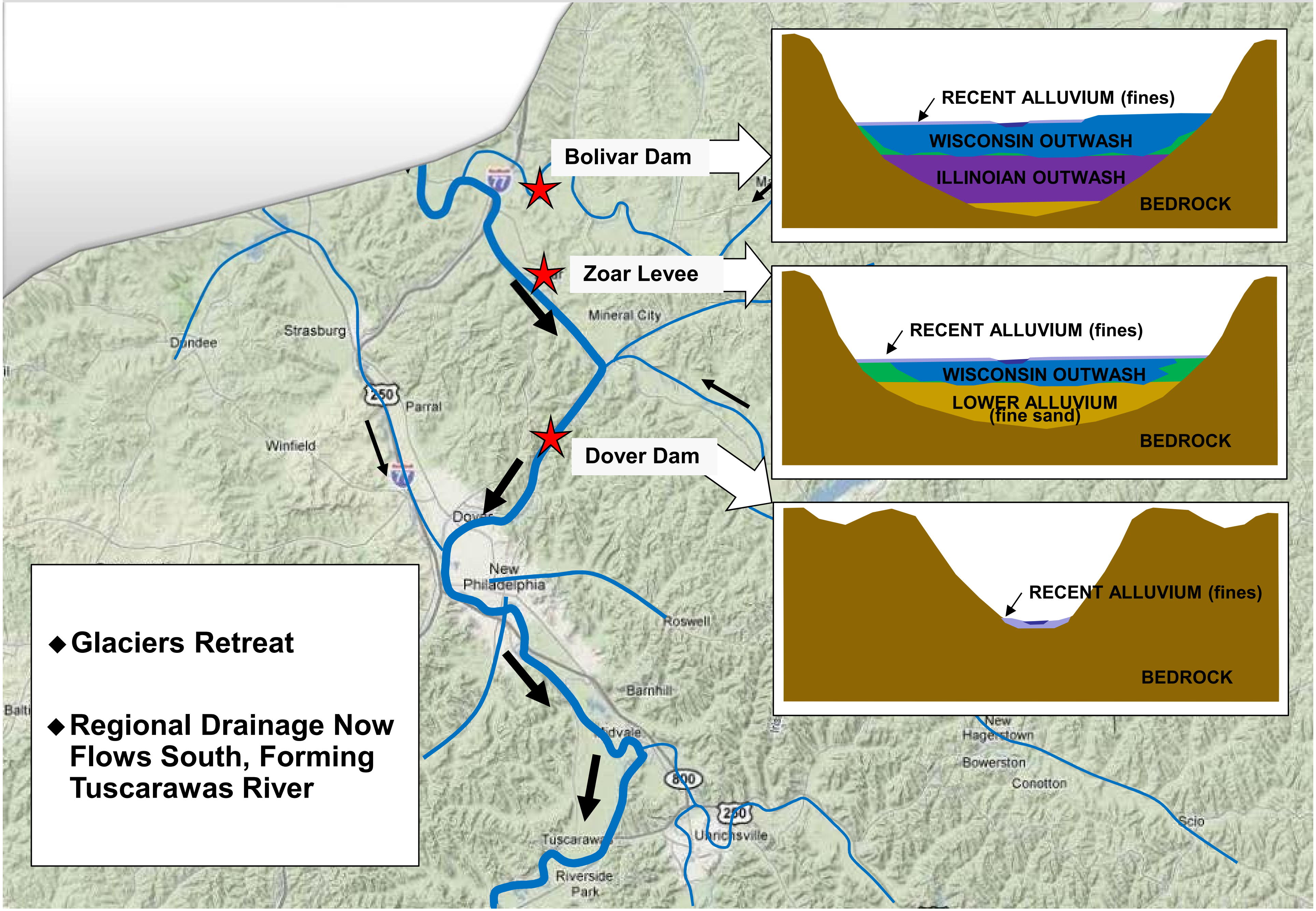
- Lake Drains

WISCONSIN ICE ADVANCE – GLACIAL OUTWASH



- Lake Deposits are Partially Eroded
- Glacial Outwash Sands and Gravel are Deposited

CURRENT DRAINAGE CONDITION



- Glaciers Retreat
- Regional Drainage Now Flows South, Forming Tuscarawas River

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- **2. Project Descriptions**
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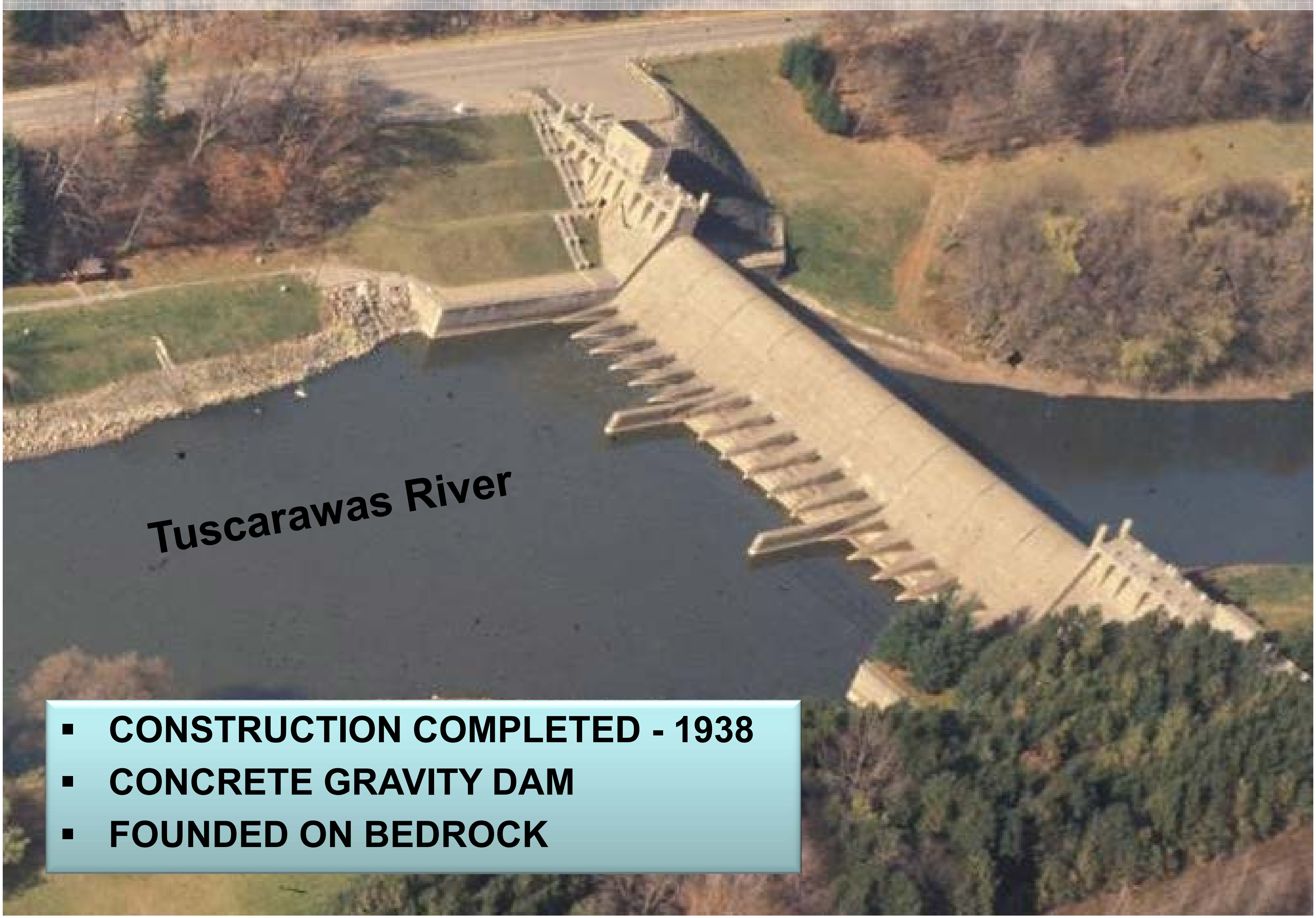
B. Dover Dam (foundation anchors)

- **1. Potential Bedrock Sliding Failure**
- **2. Rock Anchor Design**
- **3. Rock Anchor Installation**

C. Bolivar Dam (seepage barrier & grouting)

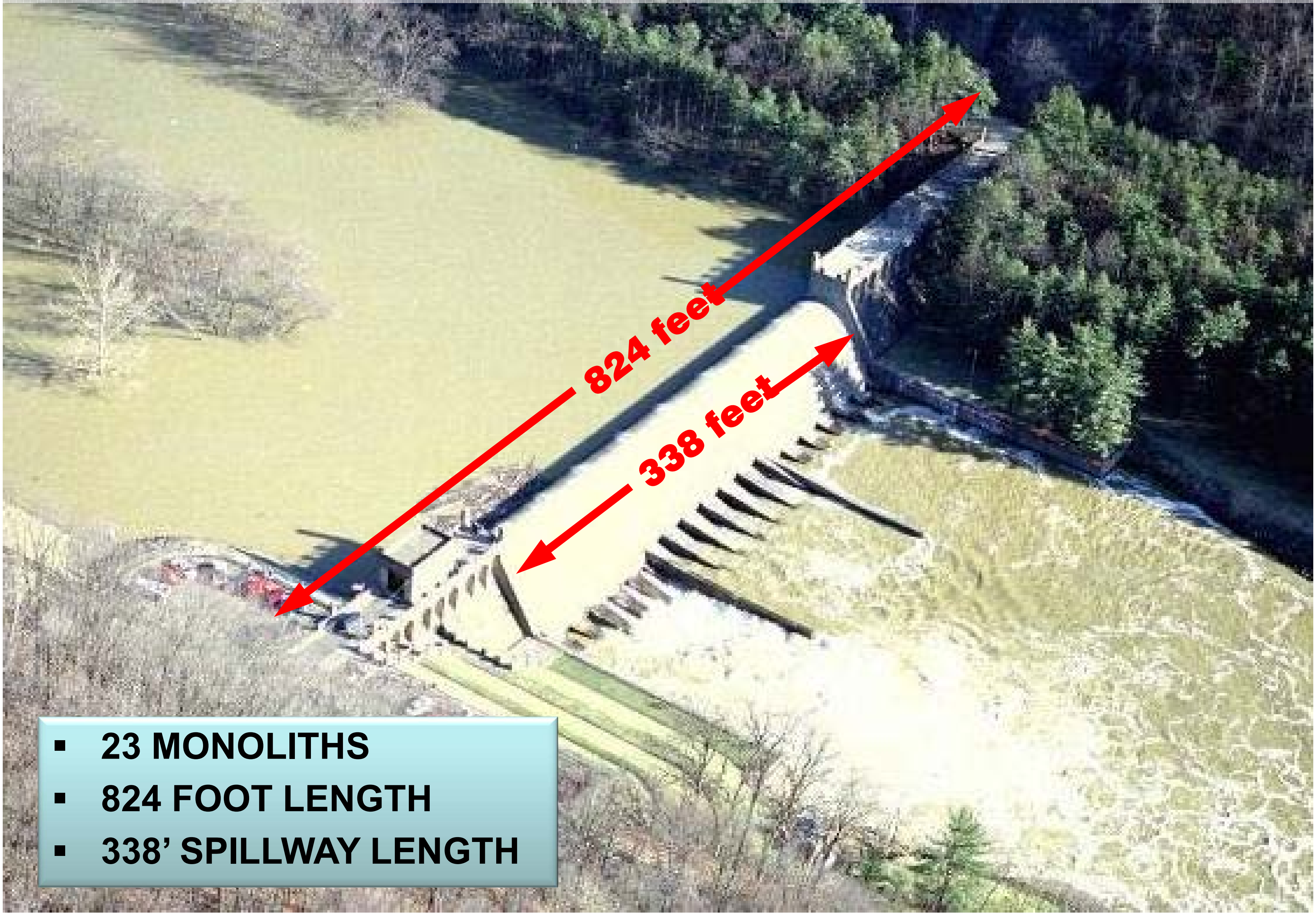
D. Zoar Levee (risk assessment)

DOVER DAM

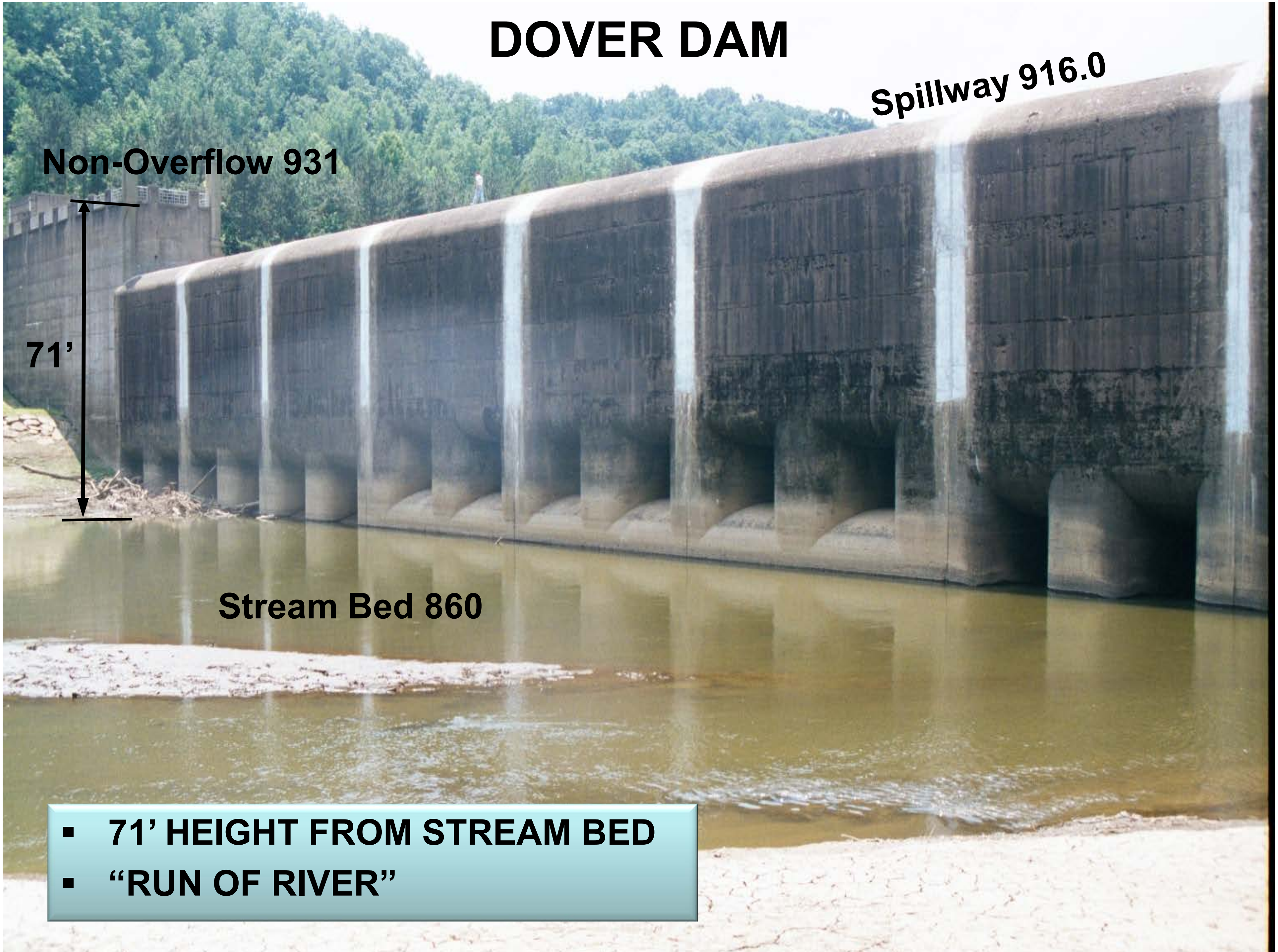


- CONSTRUCTION COMPLETED - 1938
- CONCRETE GRAVITY DAM
- FOUNDED ON BEDROCK

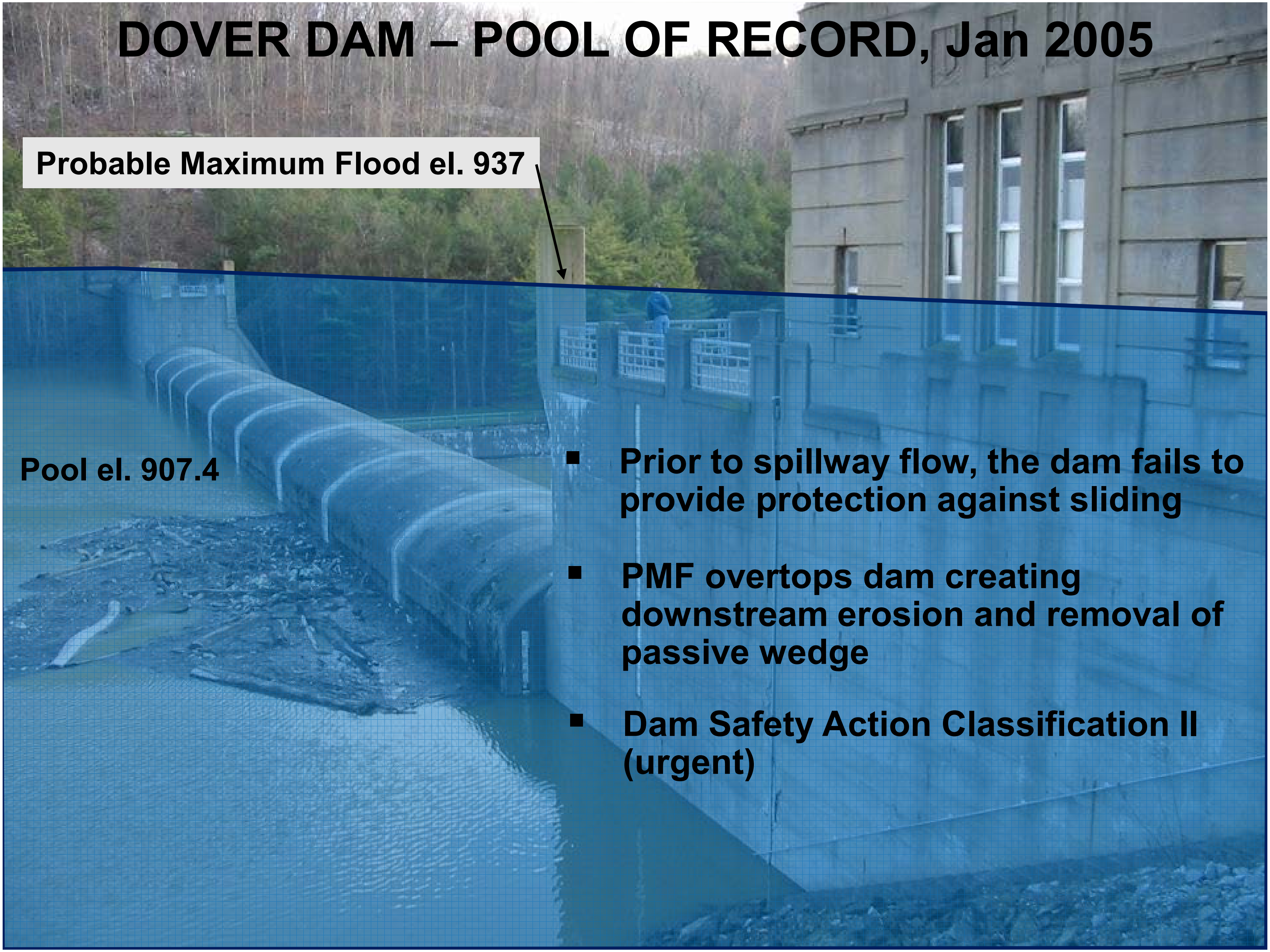
DOVER DAM



- 23 MONOLITHS
- 824 FOOT LENGTH
- 338’ SPILLWAY LENGTH

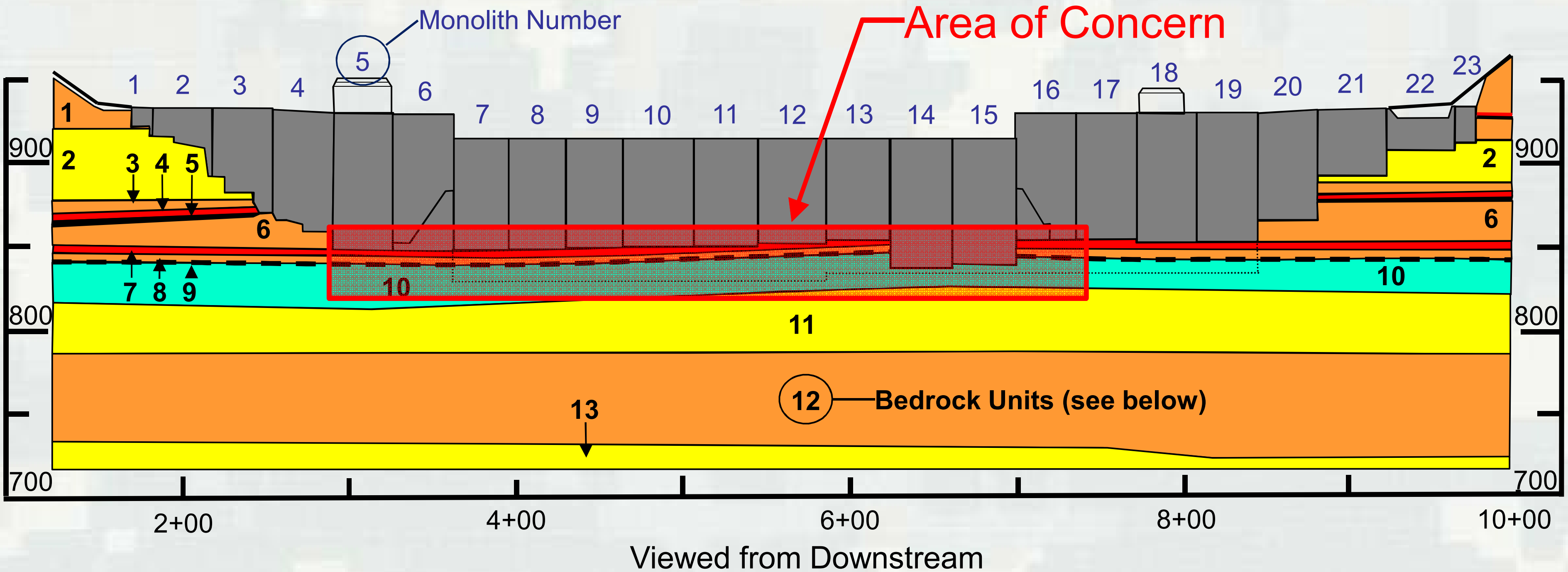

DOVER DAM
Spillway 916.0
Non-Overflow 931
71’
Stream Bed 860
▪ 71’ HEIGHT FROM STREAM BED
▪ “RUN OF RIVER”

DOVER DAM – POOL OF RECORD, Jan 2005



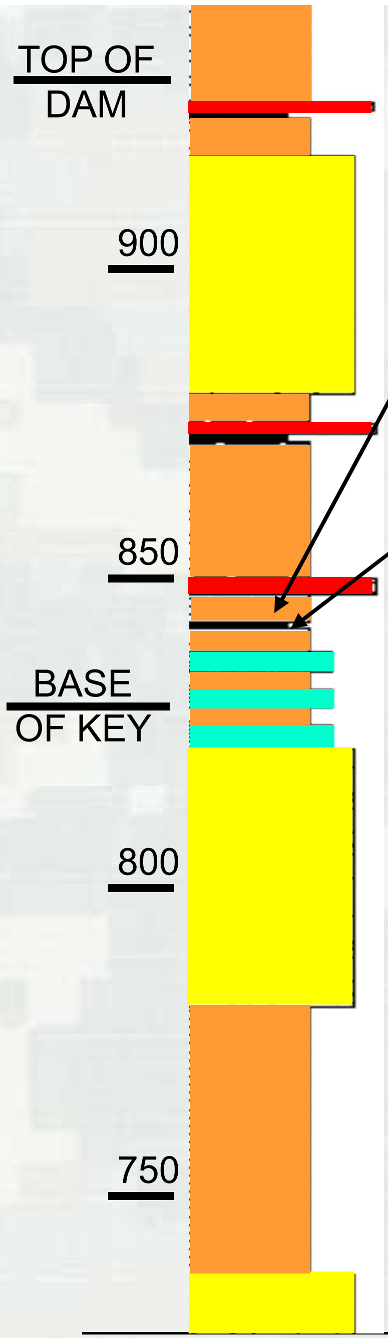
- Prior to spillway flow, the dam fails to provide protection against sliding
- PMF overtops dam creating downstream erosion and removal of passive wedge
- Dam Safety Action Classification II (urgent)

GEOLOGIC PROFILE



1. Upper Silty Shale
2. Upper Sandstone
3. Shale
4. Upper Mercer Limestone
5. Bedford Coal
6. Lower Silty Shale
7. Lower Mercer Limestone
8. Carbonaceous Shale
9. Middle Mercer Coal/CLS
10. Interbedded Siltstone and Shale
11. Middle Sandstone
12. Interbedded Shales
13. Lower Sandstone

BEDROCK UNITS



GEOLOGIC COLUMN

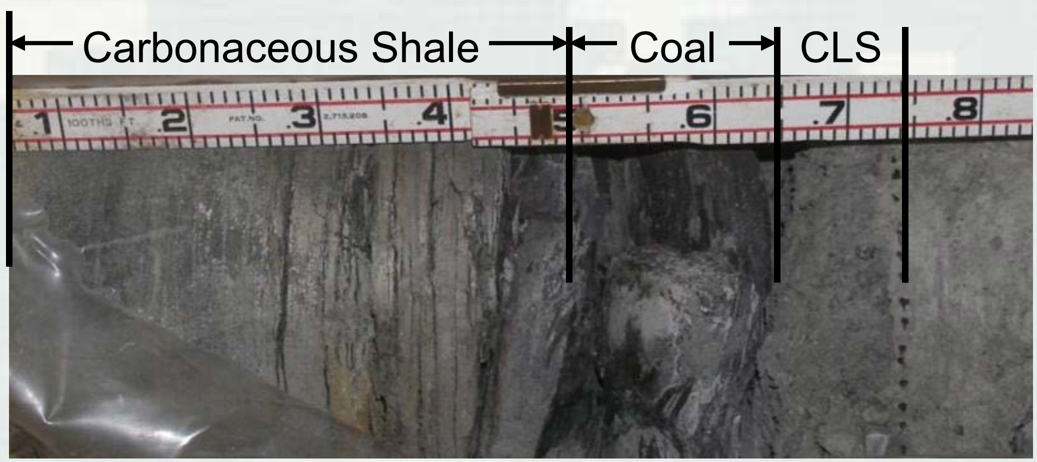
Unit #8 Carbonaceous Shale

- 3'-6' thick
- Dark gray, soft to mod. hard, carbonaceous

Unit #9 Middle Mercer Coal/Claystone

- <1' thick
- Black, blocky, occ. shaly

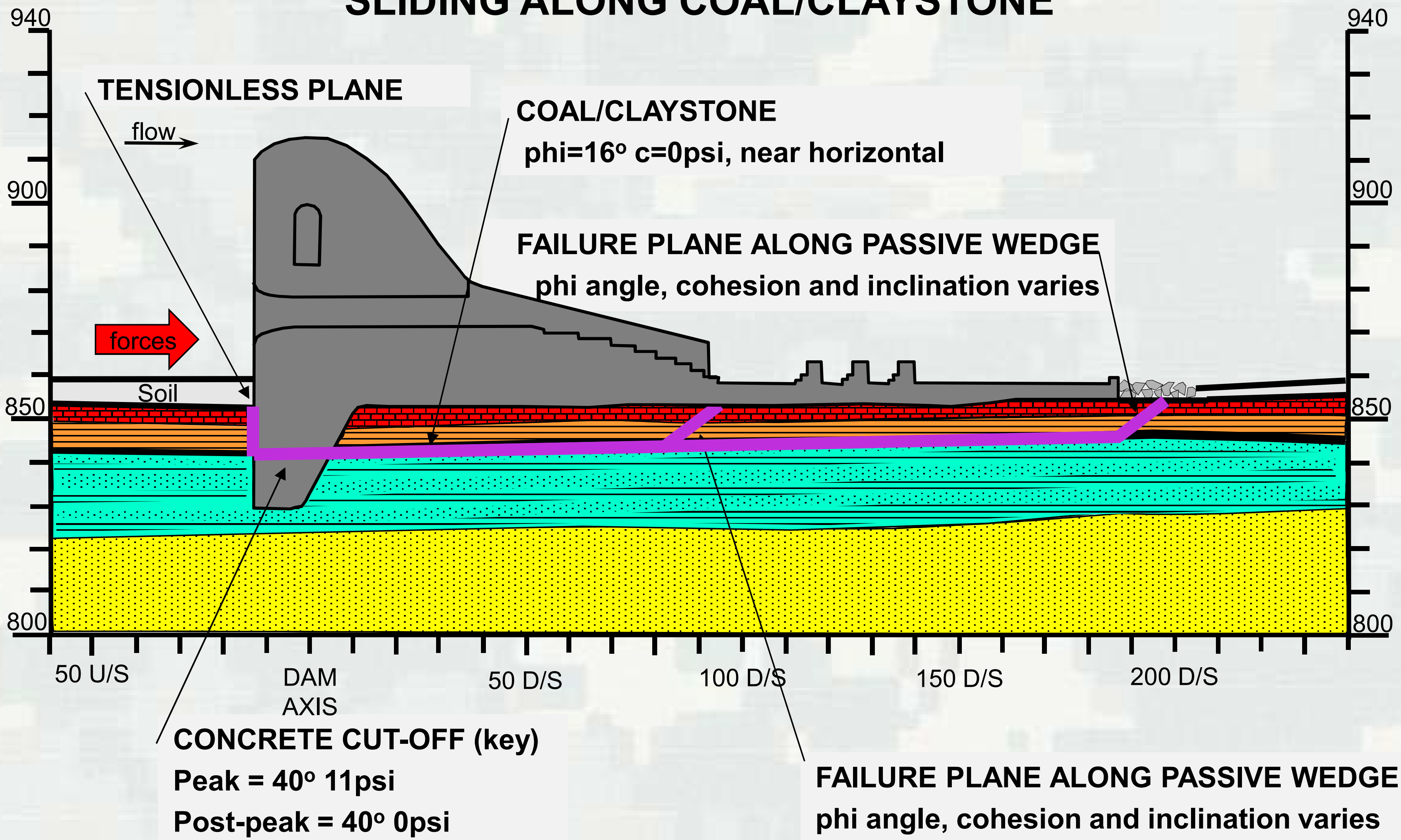
Potential sliding failure plane under valley monoliths



POTENTIAL SLIDING FAILURE PLANES

TYPICAL VALLEY MONOLITH

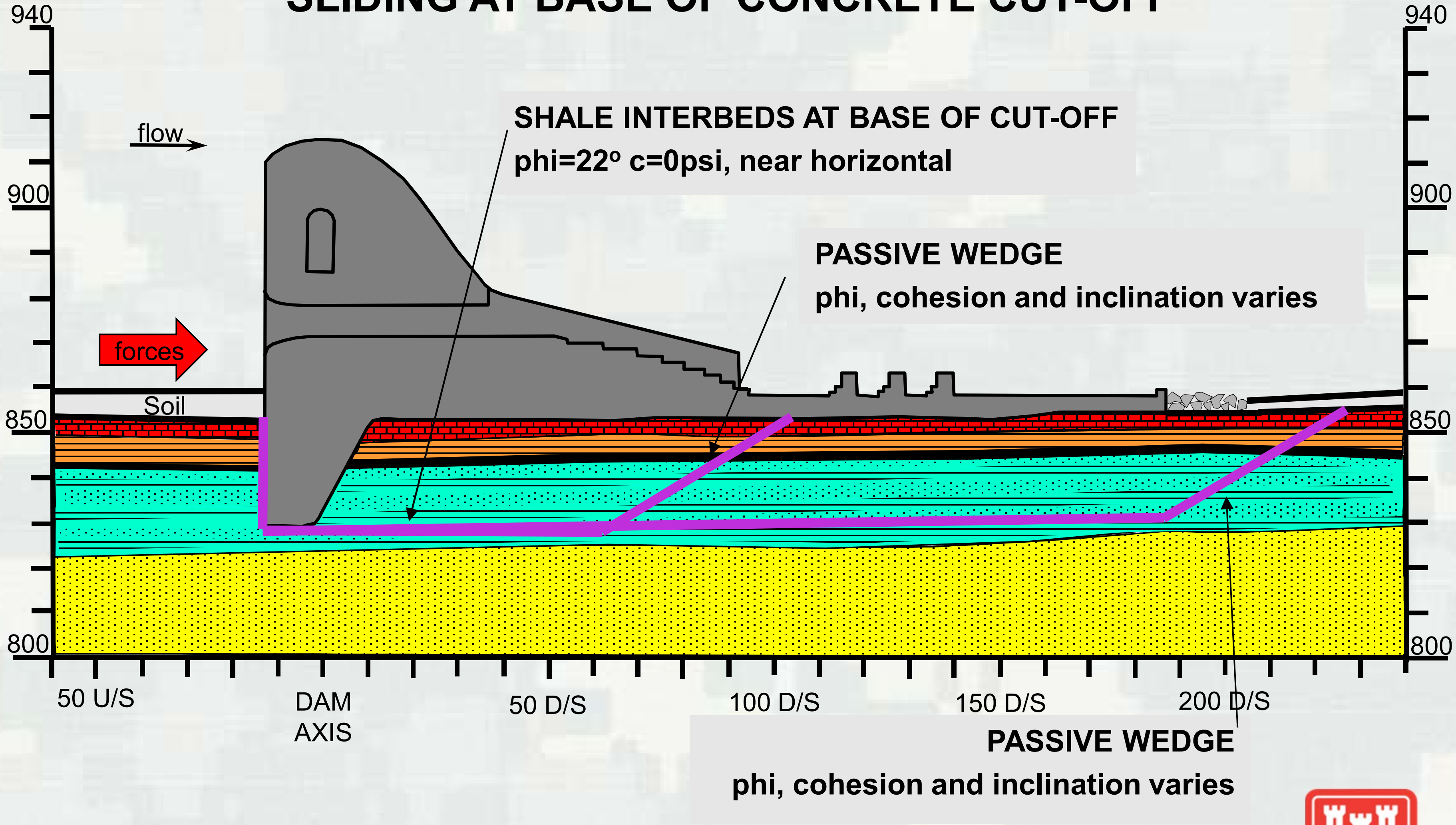
SLIDING ALONG COAL/CLAYSTONE



POTENTIAL SLIDING FAILURE PLANES

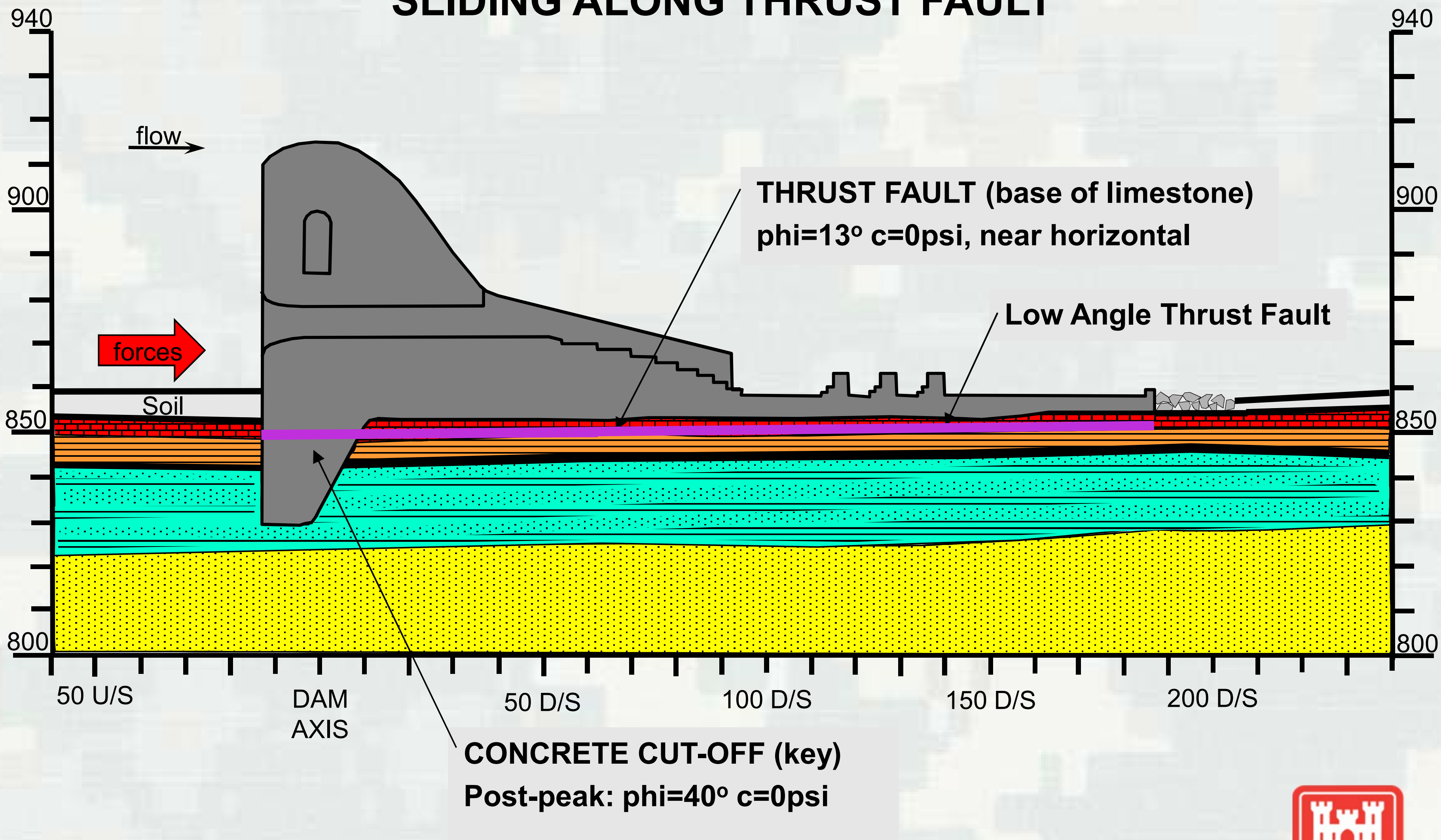
TYPICAL VALLEY MONOLITH

SLIDING AT BASE OF CONCRETE CUT-OFF



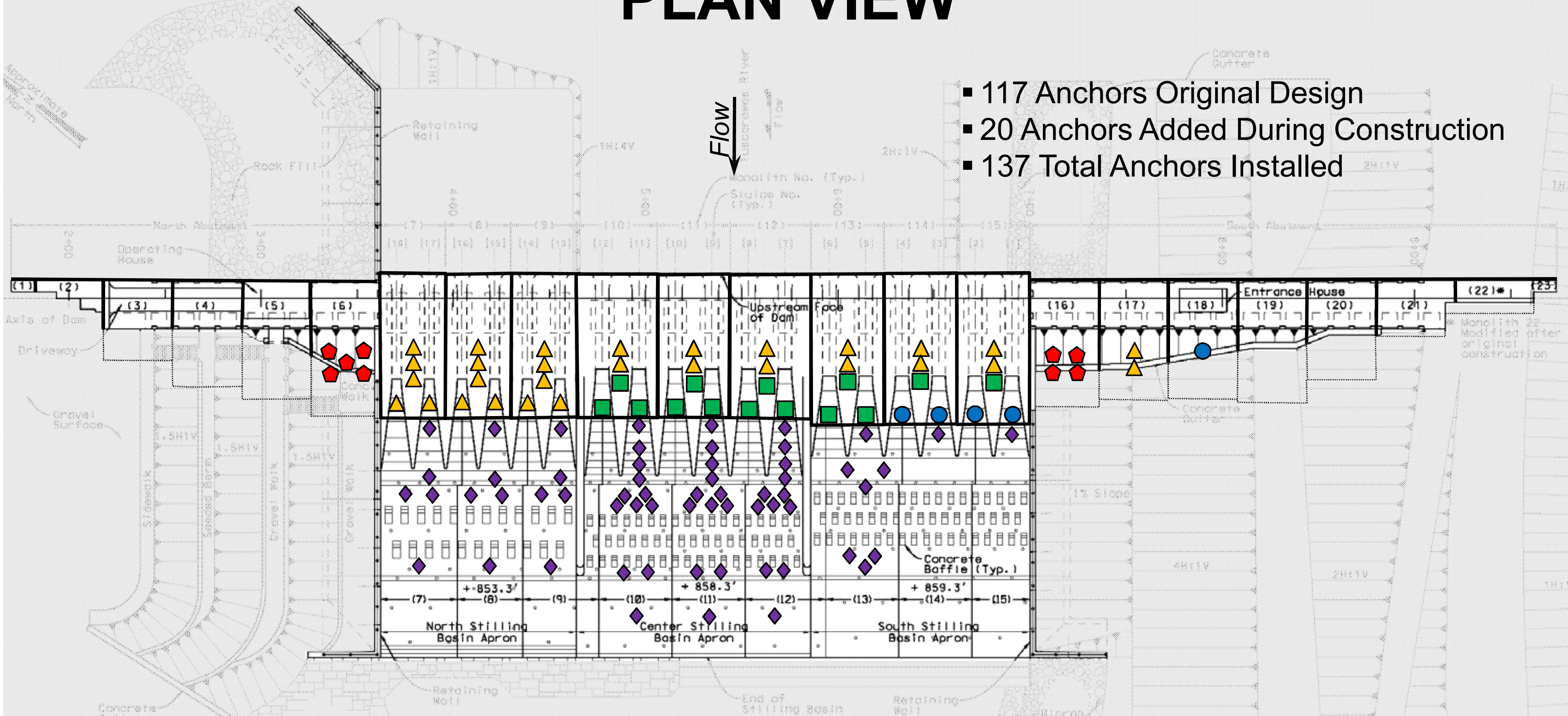
POTENTIAL SLIDING FAILURE PLANES

VALLEY MONOLITHS 12 & 13
SLIDING ALONG THRUST FAULT



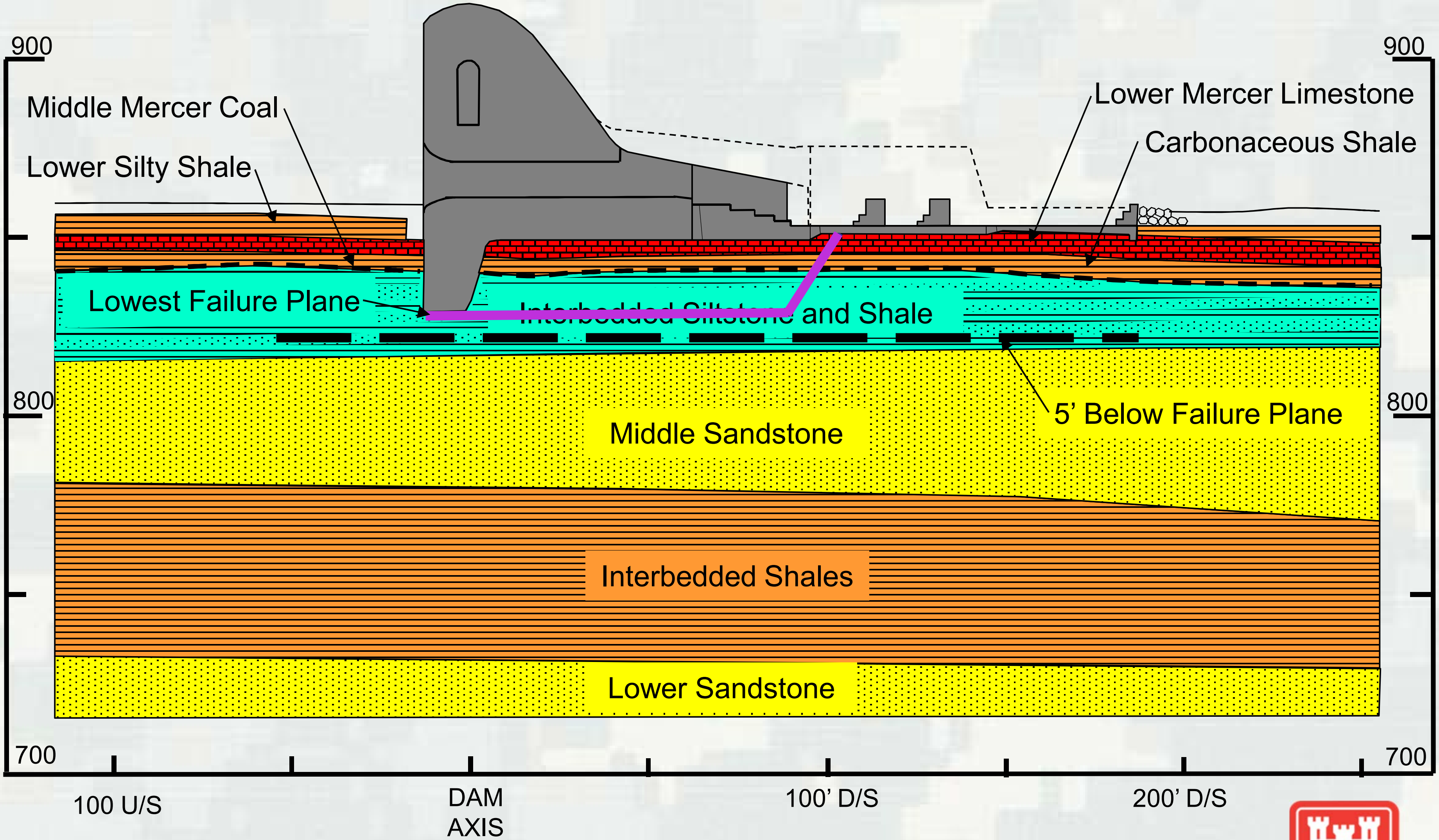
FOUNDATION ANCHOR SYSTEM
PLAN VIEW

- 117 Anchors Original Design
- 20 Anchors Added During Construction
- 137 Total Anchors Installed



Symbol	# of Anchors	Anchor Size	Anchor Length
⬟	9	54 Strands	124' – 167'
▲	29	48 Strands	120' – 163'
■	14	37 Strands	119' – 138'
●	5	19 Strands	103' – 110'
◆	60	2.5" Bars	63' – 108'

ANCHOR LENGTH
GEOLOGIC CROSS SECTION



Monolith M-9

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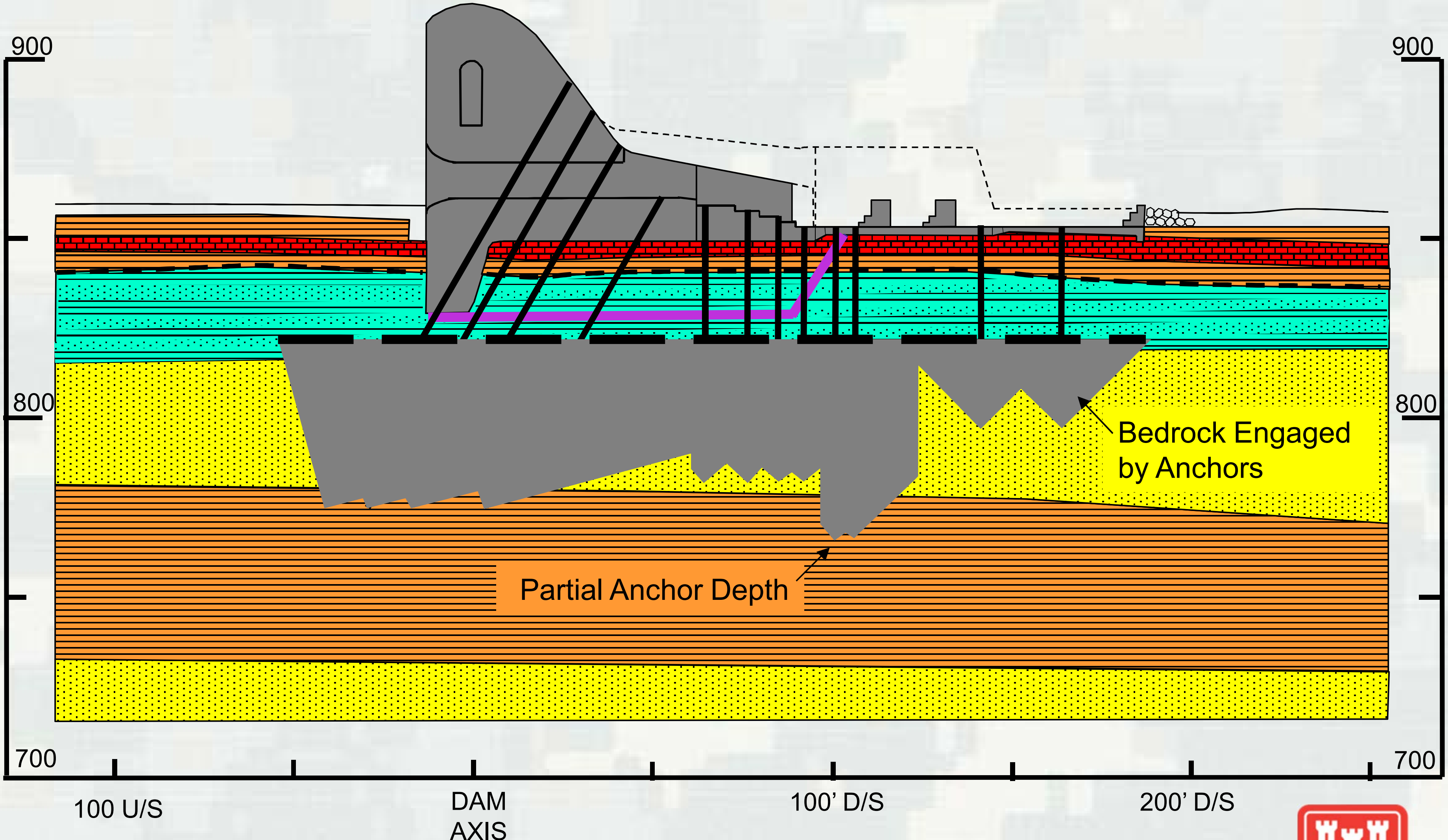
ANCHOR LENGTH
GEOLOGIC CROSS SECTION



Monolith M-9

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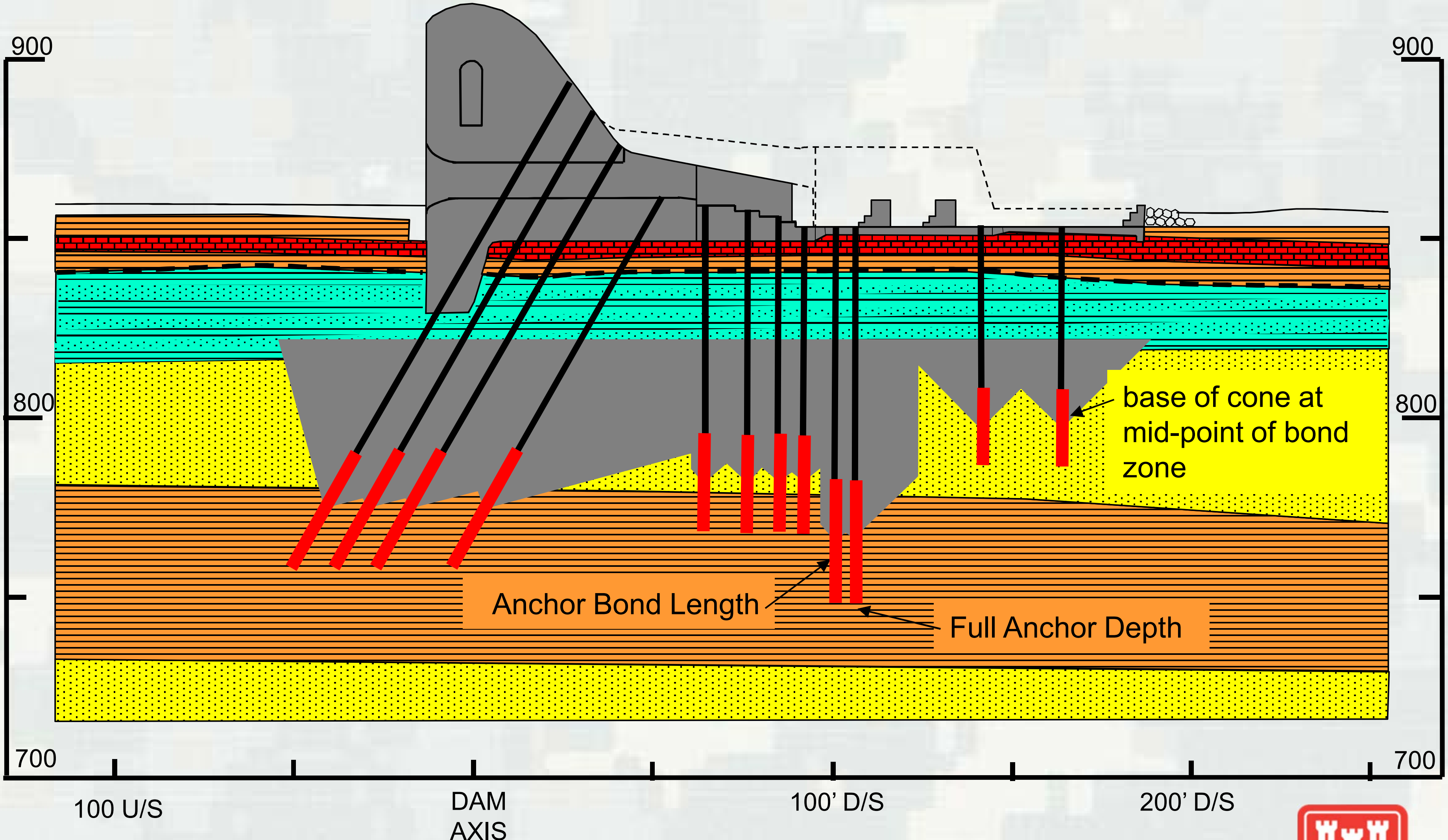
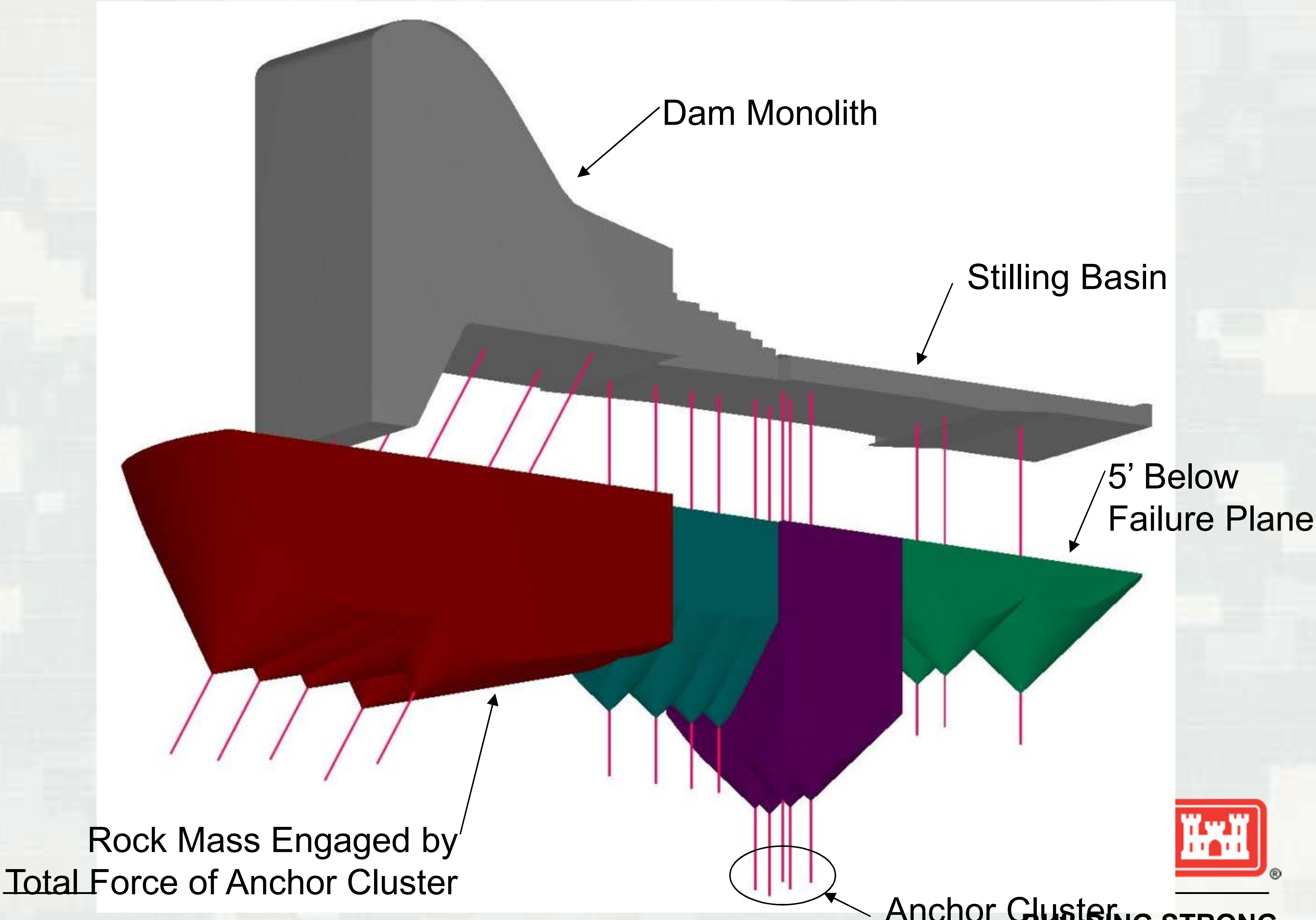
ANCHOR LENGTH
GEOLOGIC CROSS SECTION



Monolith M-9

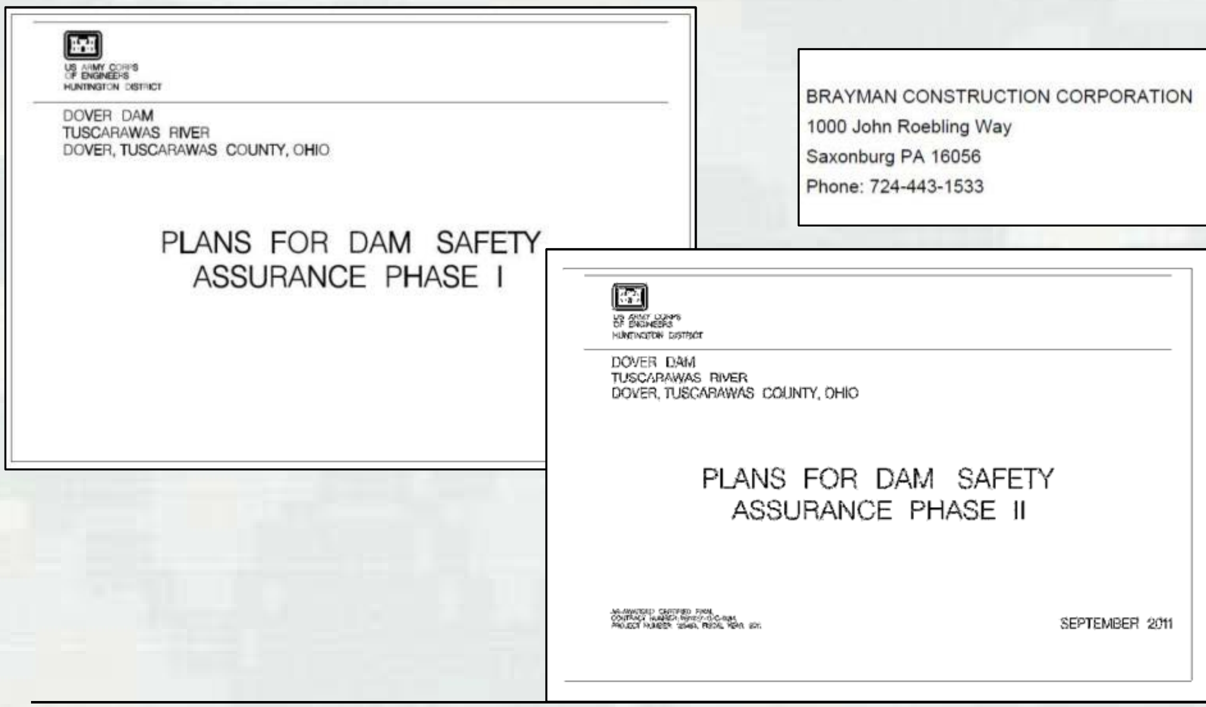
ANCHOR EMBEDMENT DEPTH



BUILDING STRONG®

CONSTRUCTION

- Phase I was awarded to Brayman Construction Corp in Sep 2010
- Phase II was awarded to Brayman Construction Corp in Sep 2011
- Phase I completed in Aug 2013
- Phase II nearly all work was completed in Dec 2014
- Construction Cost (Phases I & II): approx. $40 million
- Total Number of Anchors: 137


US ARMY CORPS OF ENGINEERS
HUNTINGTON DISTRICT

DOVER DAM
TUSCARAWAS RIVER
DOVER, TUSCARAWAS COUNTY, OHIO

PLANS FOR DAM SAFETY
ASSURANCE PHASE I

US ARMY CORPS OF ENGINEERS
HUNTINGTON DISTRICT

DOVER DAM
TUSCARAWAS RIVER
DOVER, TUSCARAWAS COUNTY, OHIO

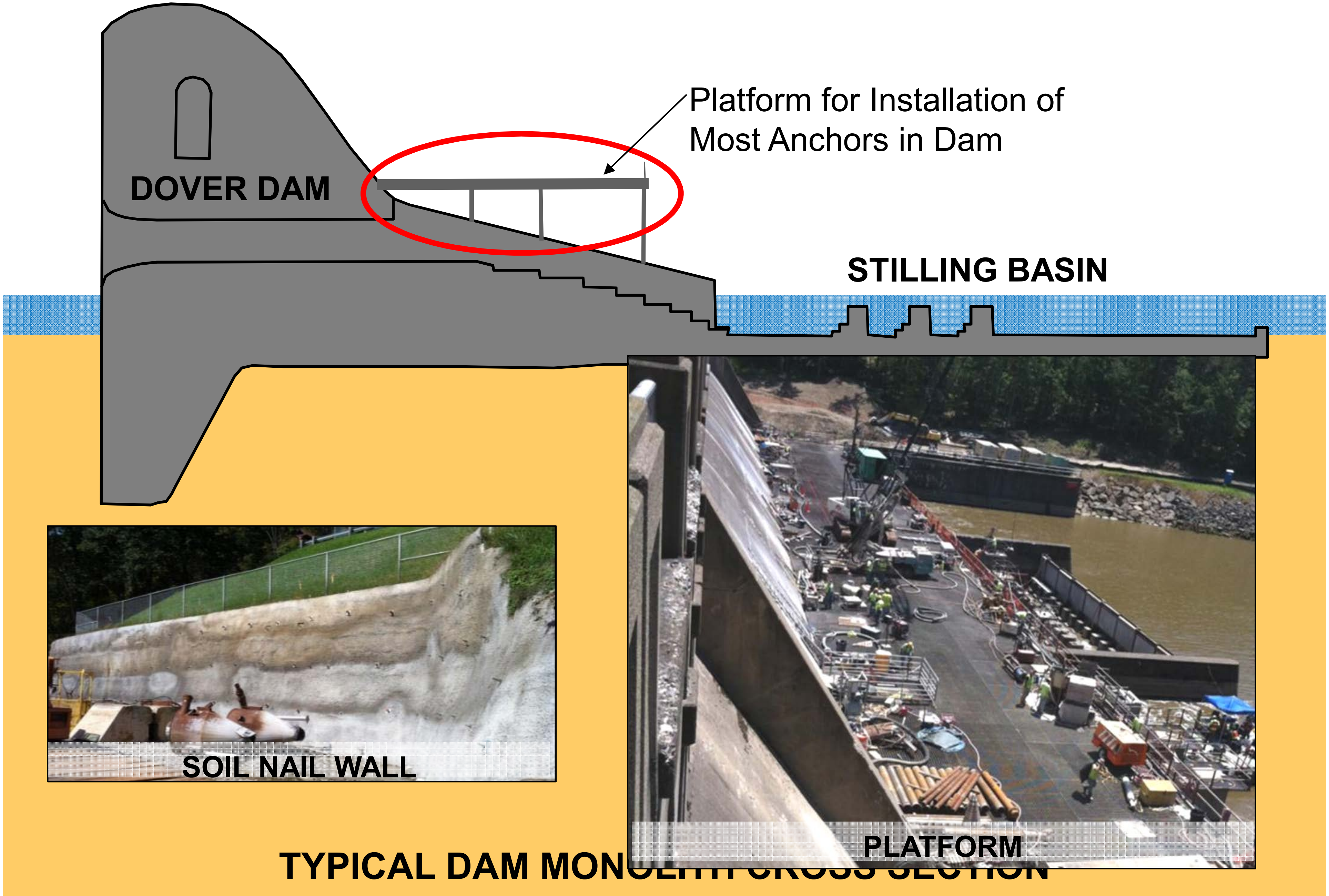
PLANS FOR DAM SAFETY
ASSURANCE PHASE II

SEPTEMBER 2011

BRAYMAN CONSTRUCTION CORPORATION
1000 John Roebling Way
Saxonburg PA 16056
Phone: 724-443-1533

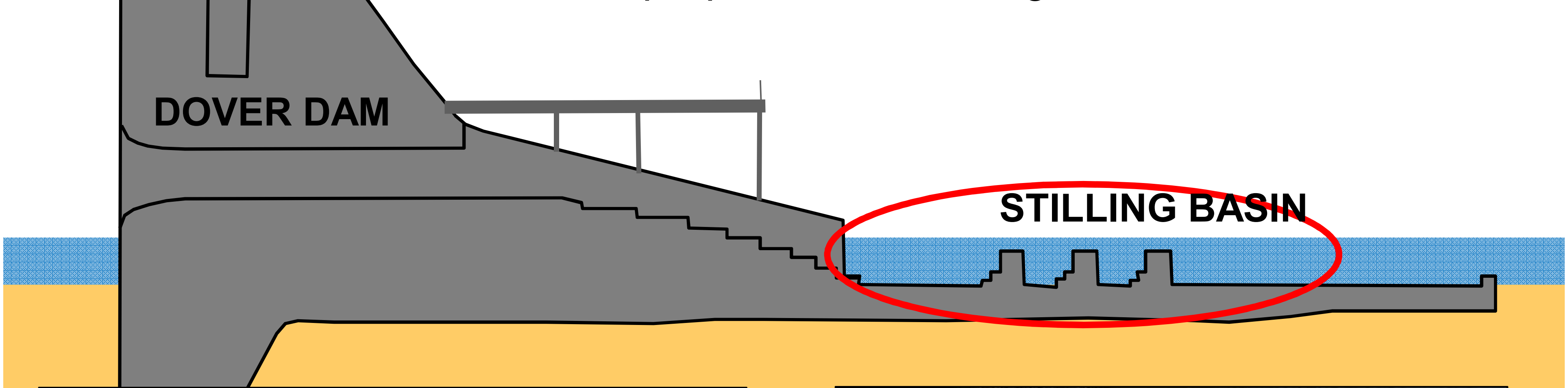
BRAYMAN construction corporation

ANCHOR INSTALLATION – ACCESS (Dam)

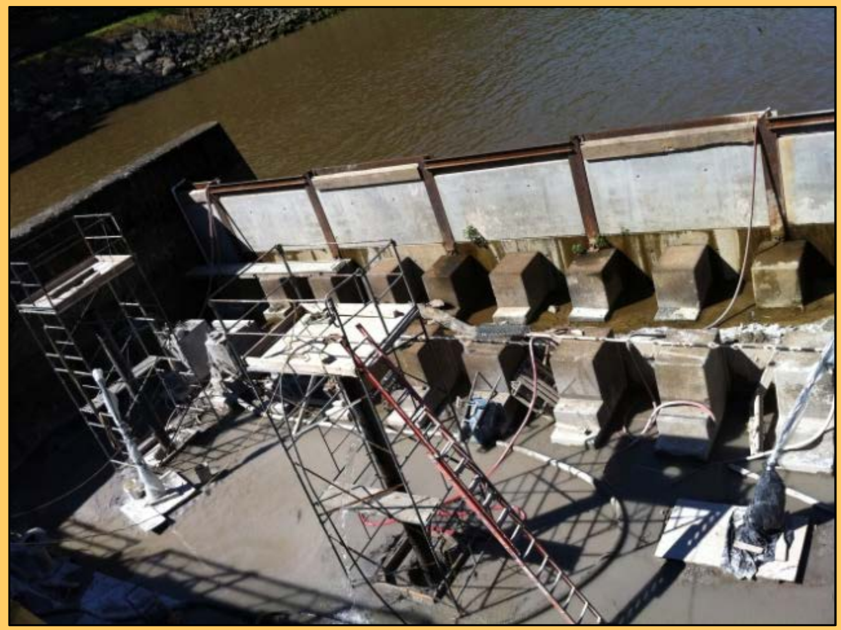


ANCHOR INSTALLATION – ACCESS (Stilling Basin)

- Contract included in-the-wet construction and bar anchors.
- Contractor proposed dewatering and strand anchors.



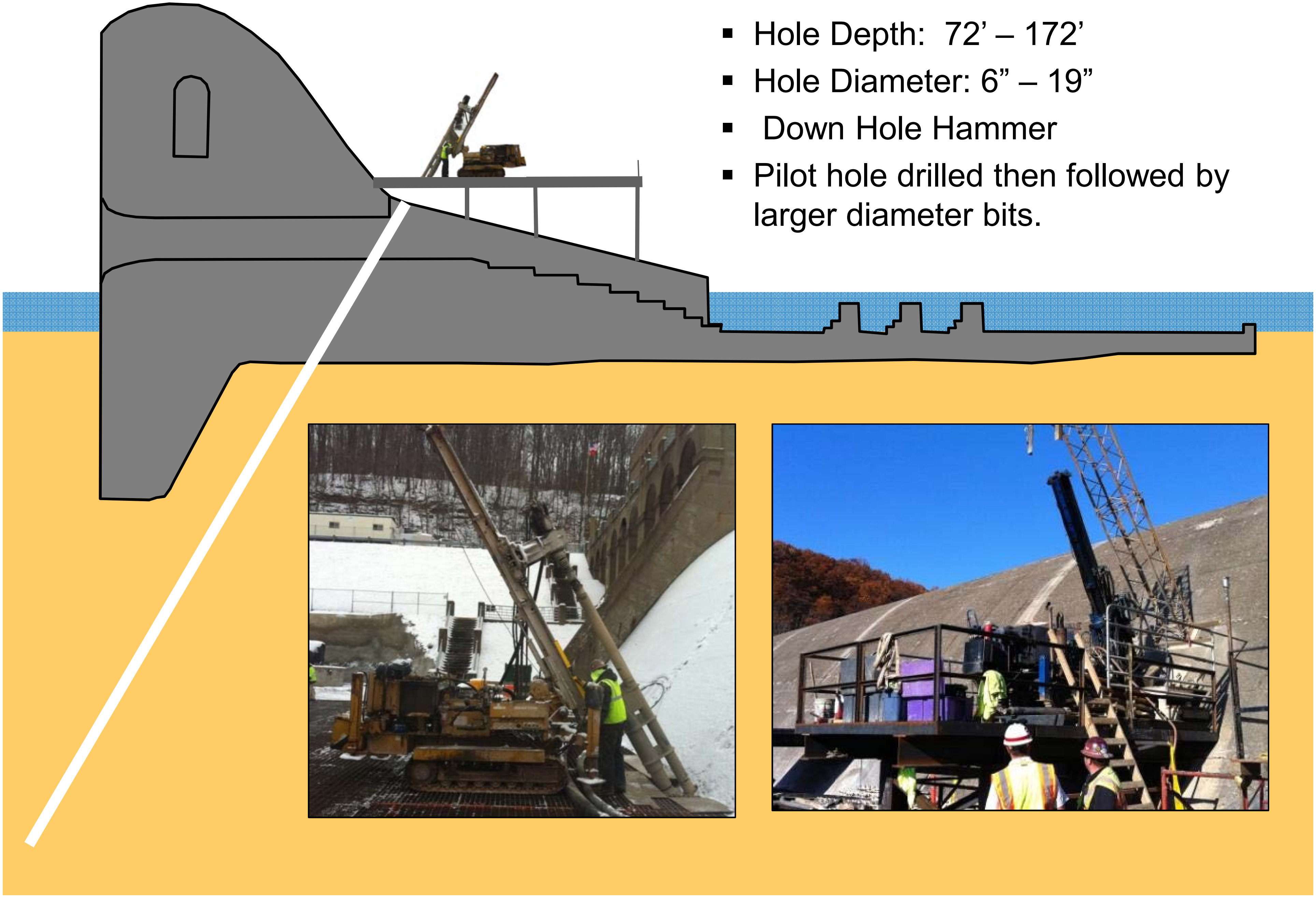
COFFER BOX



DEWATERED STILLING BASIN

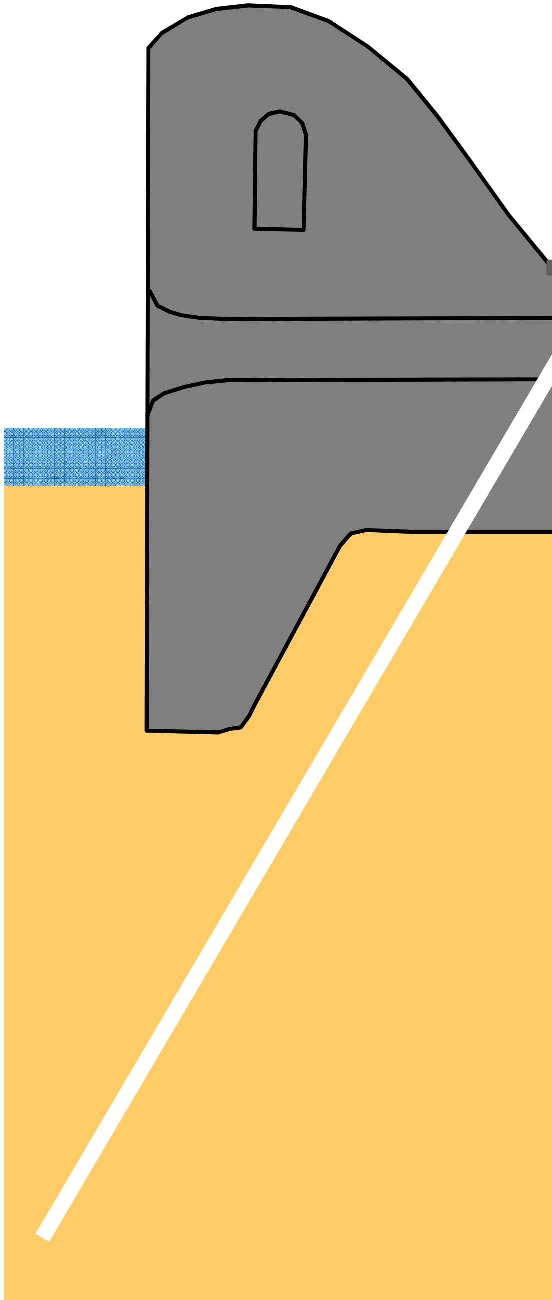
ANCHOR INSTALLATION - DRILLING

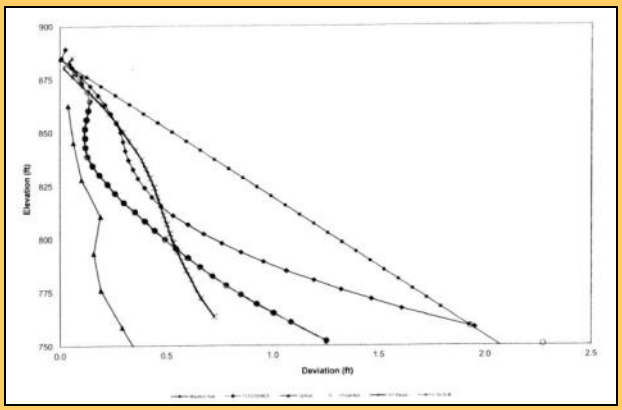
- Hole Depth: 72’ – 172’
- Hole Diameter: 6” – 19”
- Down Hole Hammer
- Pilot hole drilled then followed by larger diameter bits.

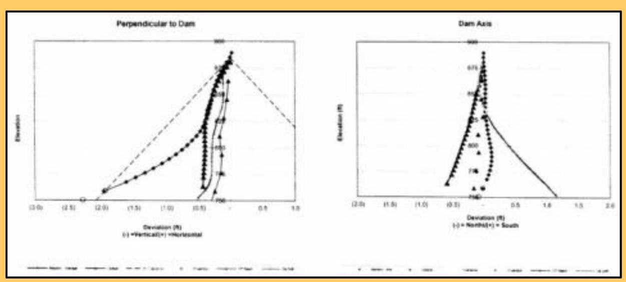


ANCHOR INSTALLATION – HOLE ALIGNMENT

- Drill Tolerance 1:30 – 1:75
- Directional drilling methods used on select holes. Optical readings on pilot hole.
- Maxibor or Bortrak instruments used for alignment check on final hole.

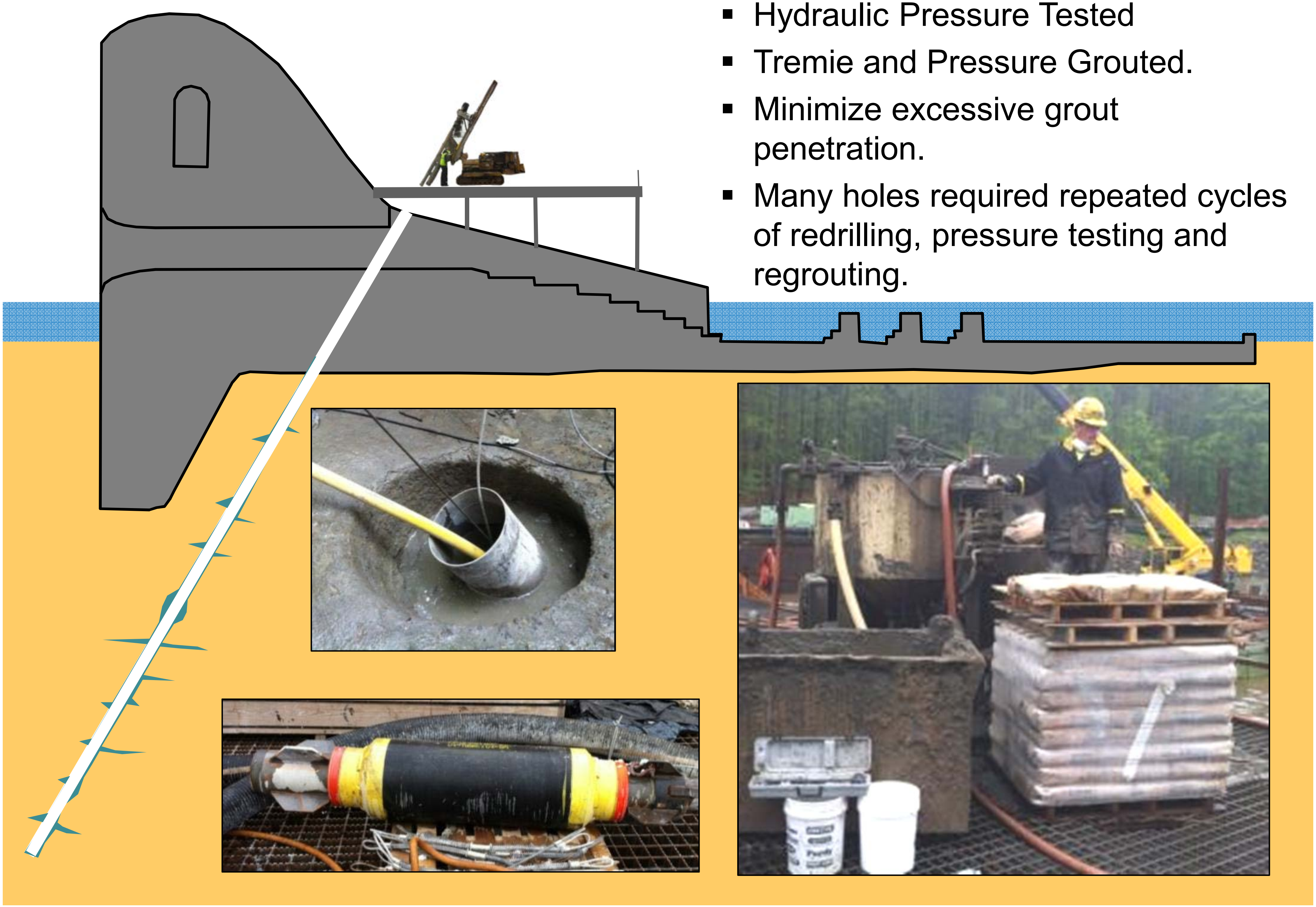




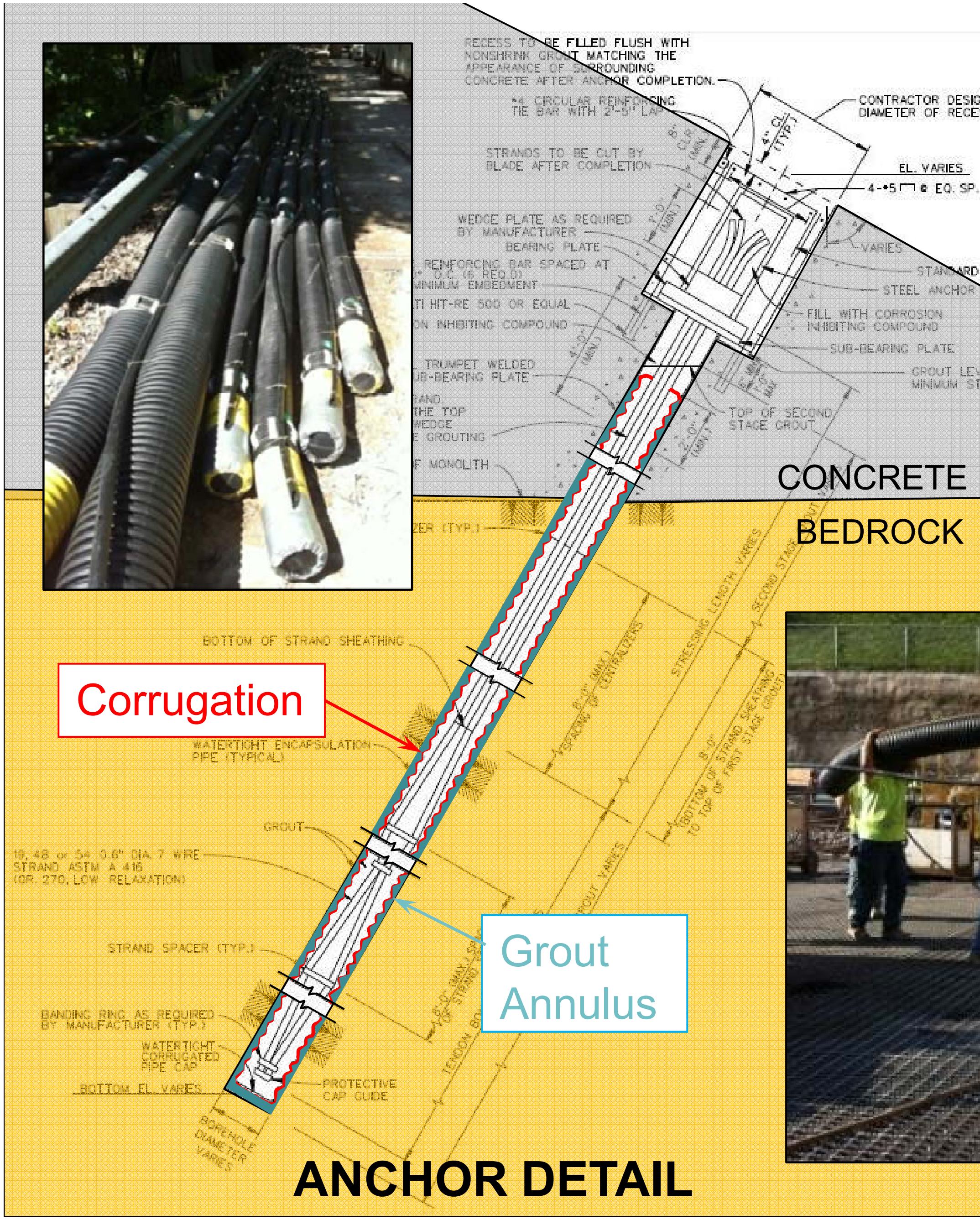


ANCHOR INSTALLATION - WATERTIGHTNESS

- Hydraulic Pressure Tested
- Tremie and Pressure Grouted.
- Minimize excessive grout penetration.
- Many holes required repeated cycles of redrilling, pressure testing and regrouting.



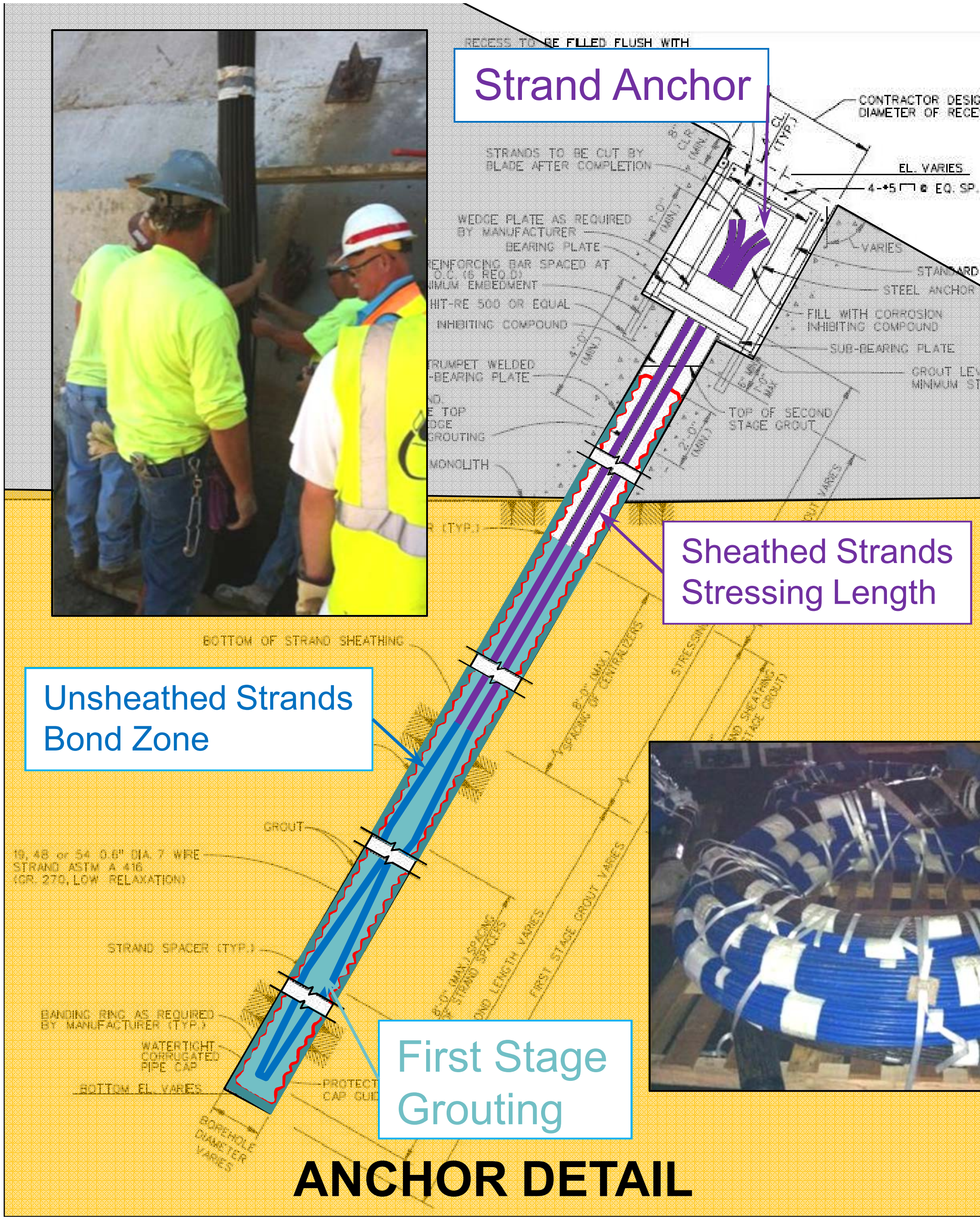
ANCHOR INSTALLATION – ENCAPSULATION

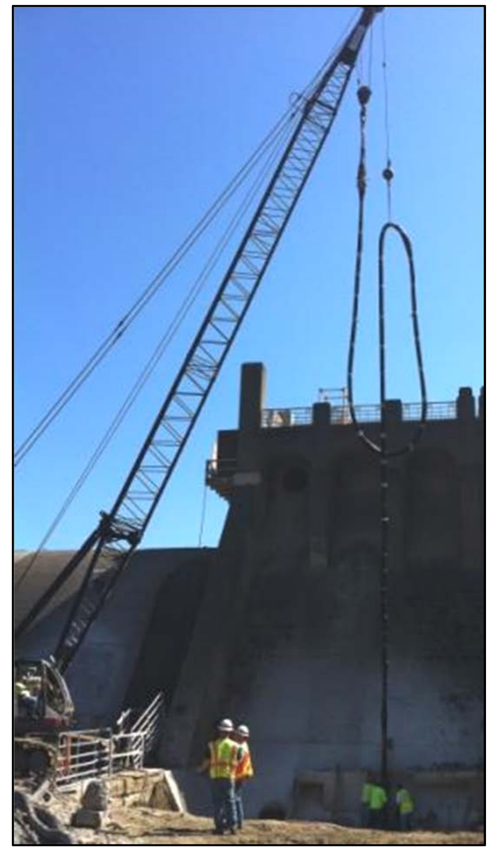


- Double corrosion protection
- Corrugated Tubing: 100 mil thick if ≥ 10”, 60 mil for smaller tubing.
- Water Tested: <2.75 gal in 10 min.
- Grout annulus between corrugated tubing and drilled hole in multiple lifts.

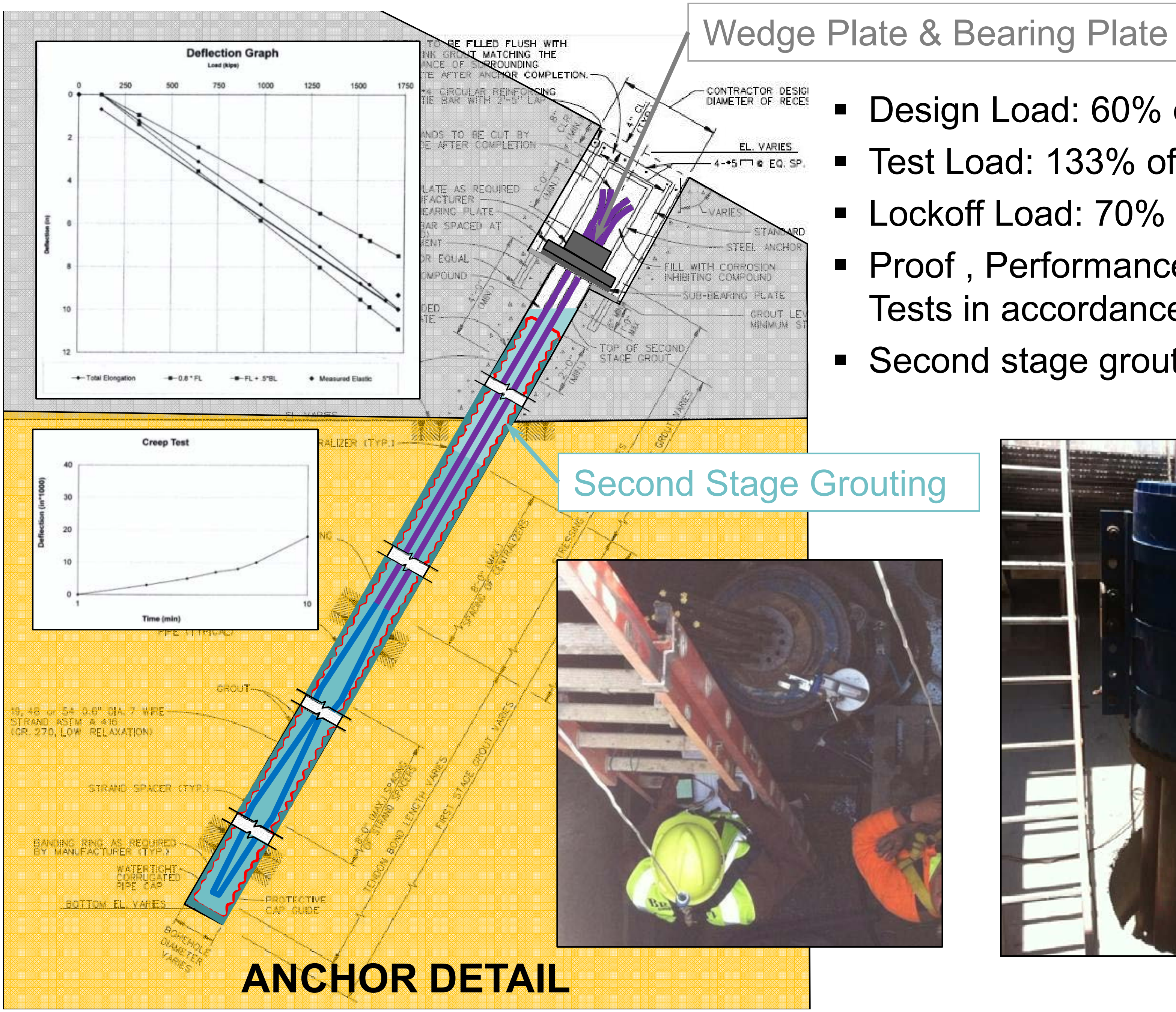
ANCHOR INSTALLATION – INSTALL STRANDS

- Number of Strands: 5 - 54
- Inspect and repair smooth polyethylene extruded strands.
- Greased and extruded strands in stressing length.
- Bare strands in bond length.
- First Stage Grouted



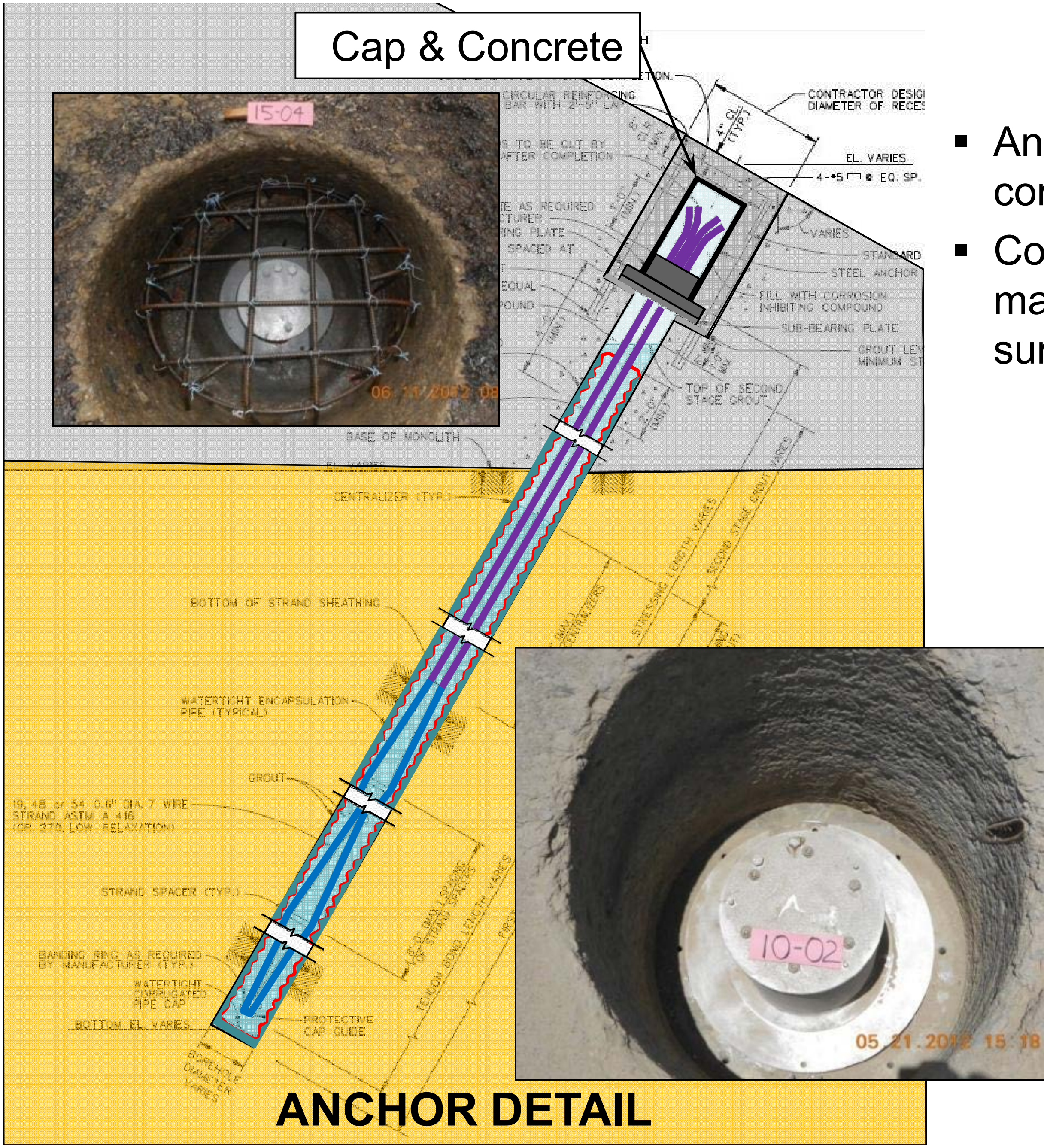


ANCHOR INSTALLATION – STRESSING



- Design Load: 60% of MUTS
- Test Load: 133% of Design Load
- Lockoff Load: 70% of Design Load
- Proof , Performance and Creep Tests in accordance with PTI.
- Second stage grouted.

ANCHOR INSTALLATION – COMPLETION



ANCHOR DETAIL

- Anchor capped and filled with corrosion inhibiting compound.
- Concrete filled recess designed to match the appearance of the dam surface.

OTHER ASPECTS OF DOVER PROJECT

DRILLED SHAFT FOUNDATION

PARAPET WALL

STONE SLOPE PROTECTION

BEDROCK TIE-IN
GATE STRUCTURE

CHALLENGES DURING CONSTRUCTION

- **Multiple cycles of redrilling, pressure testing and regrouting anchor hole.**
  - *Utilized different grout mixes, varied grouting pressures (safely), isolated zones of high grout takes with packers.*

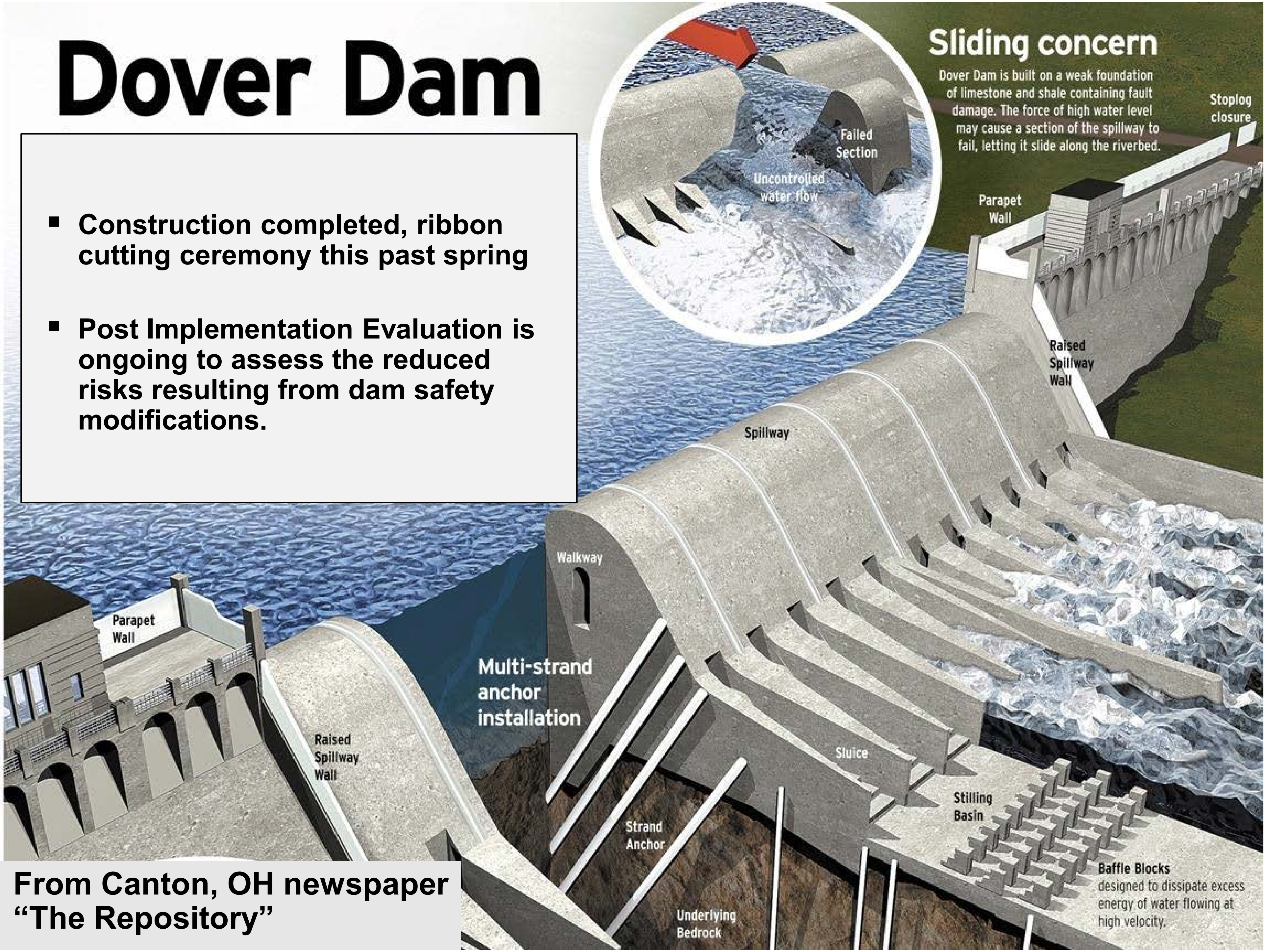
- **Some anchors slightly exceeded deformation tolerance during creep tests.**
  - *Extended creep test from 10 min to 60 min (PTI), additional liftoff tests at extended times (24 hrs, 48 hrs, 1 week), account for steel elongation based on elastic modulus of steel.*

- **Two anchors (48 & 37 strand), during lockoff/liftoff procedures, had several wedges that failed to properly engage, resulting in broken individual wires and complete 7-wire strand failure.**
  - *Both anchors were replaced and an investigation was completed. Possible cause: wedge geometry, cleanliness of pockets, rust on teeth*

- **Stilling basin slab concrete was thinner than original drawings.**
  - *Increased number of smaller anchors (5 strand) used to better distribute load.*

Dover Dam

- Construction completed, ribbon cutting ceremony this past spring
- Post Implementation Evaluation is ongoing to assess the reduced risks resulting from dam safety modifications.



From Canton, OH newspaper "The Repository"

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A. MUSKINGUM REGION

B. DOVER DAM (foundation anchors)

1. **Potential Bedrock Sliding Failure**
2. **Rock Anchor Design**
3. **Rock Anchor Installation**

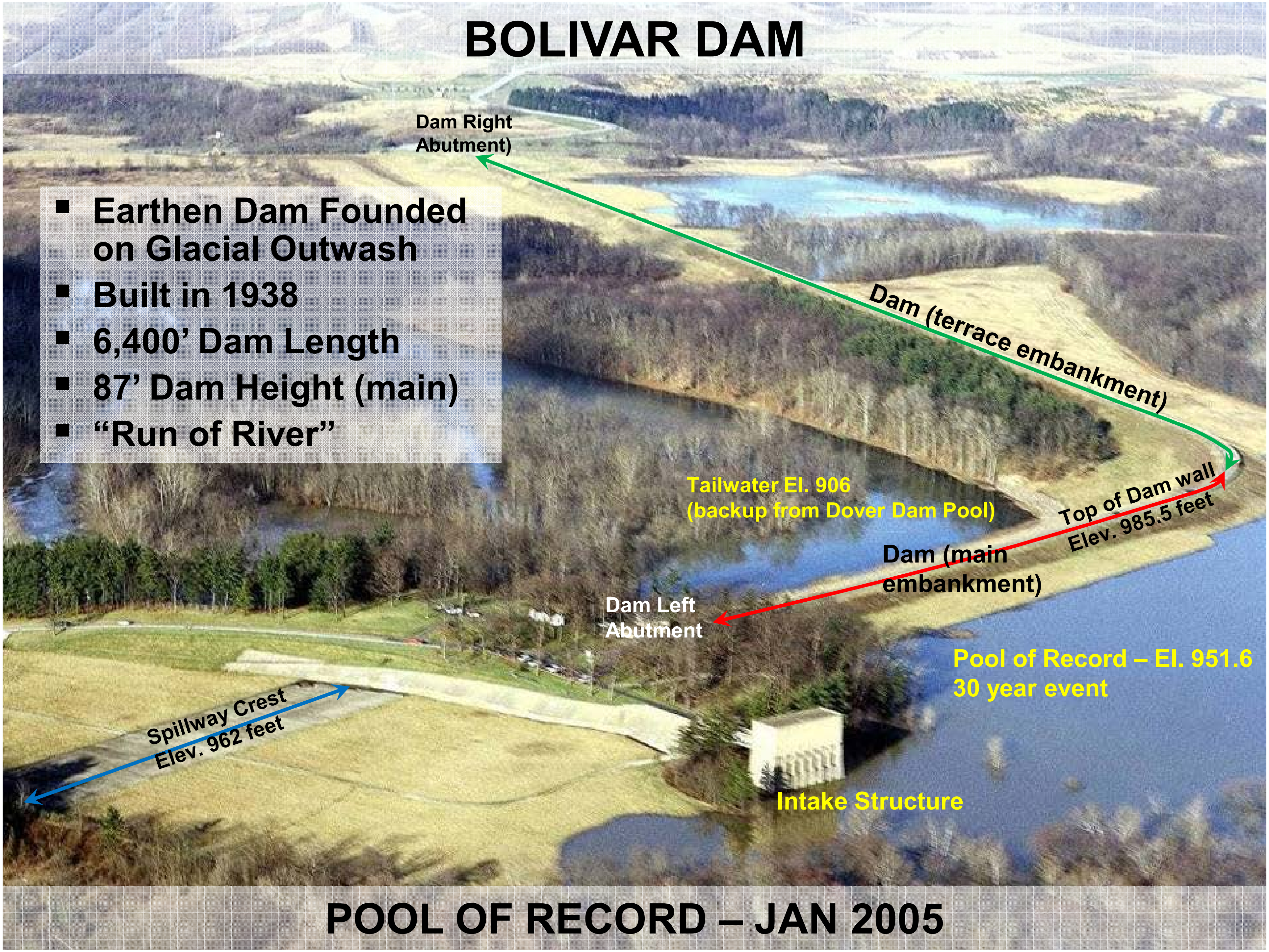
C. BOLIVAR DAM (seepage barrier & grouting)

1. **Seepage Through Soil Foundation**
2. **Seepage Wall Construction**
3. **Bedrock Abutment Seepage**
4. **Grout Curtain Construction**

D. Zoar Levee (risk assessment)

BOLIVAR DAM

- Earthen Dam Founded on Glacial Outwash
- Built in 1938
- 6,400’ Dam Length
- 87’ Dam Height (main)
- “Run of River”



POOL OF RECORD – JAN 2005

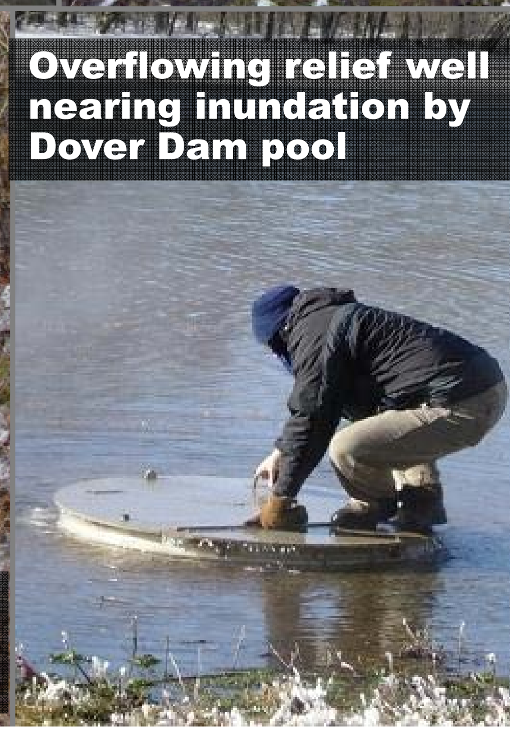
SEEPAGE DURING FLOOD EVENTS

SEEPAGE DURING FLOOD EVENTS

Emergency Filter Placement on Terrace

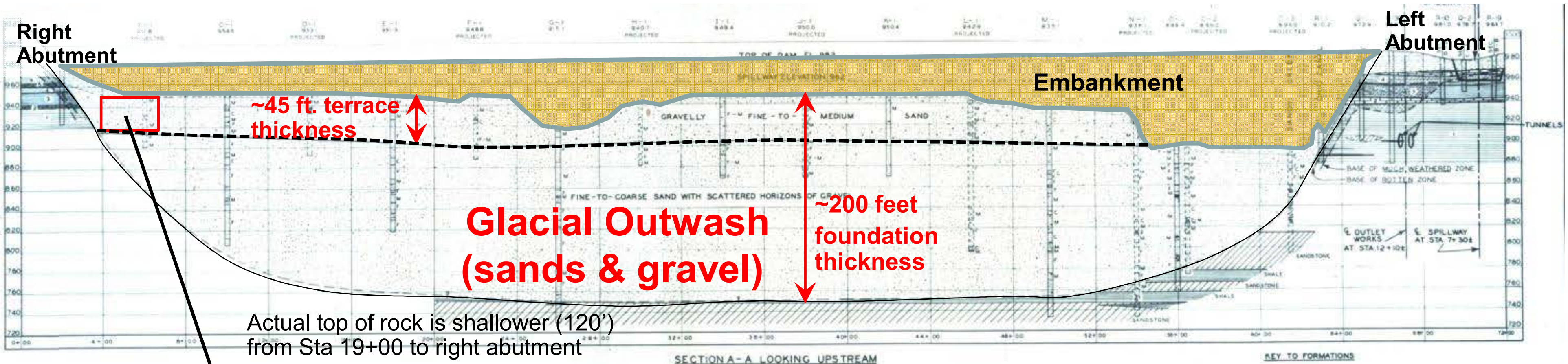
Terrace Foundation Sand Eroded Out


Flow through open joints in bedrock in left abutment of dam

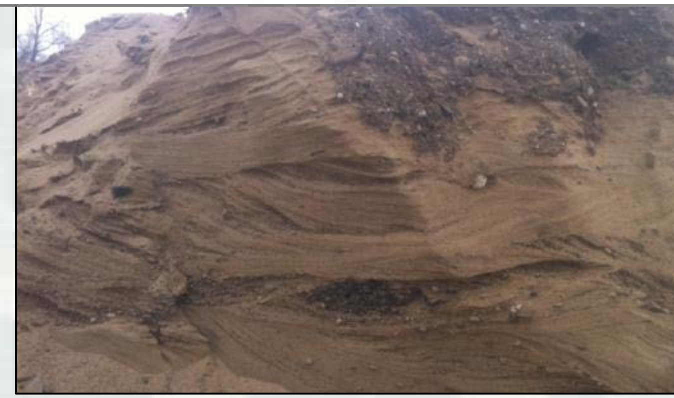

Overflowing relief well nearing inundation by Dover Dam pool


Artesian flow from piezometer even with extension

DAM FOUNDATION - PROFILE




(El. 950 to 920 feet) **Onsite Borrow Area for seepage blanket extension/augmentation work – downstream of right abutment**



DAM FOUNDATION CHARACTERISTICS

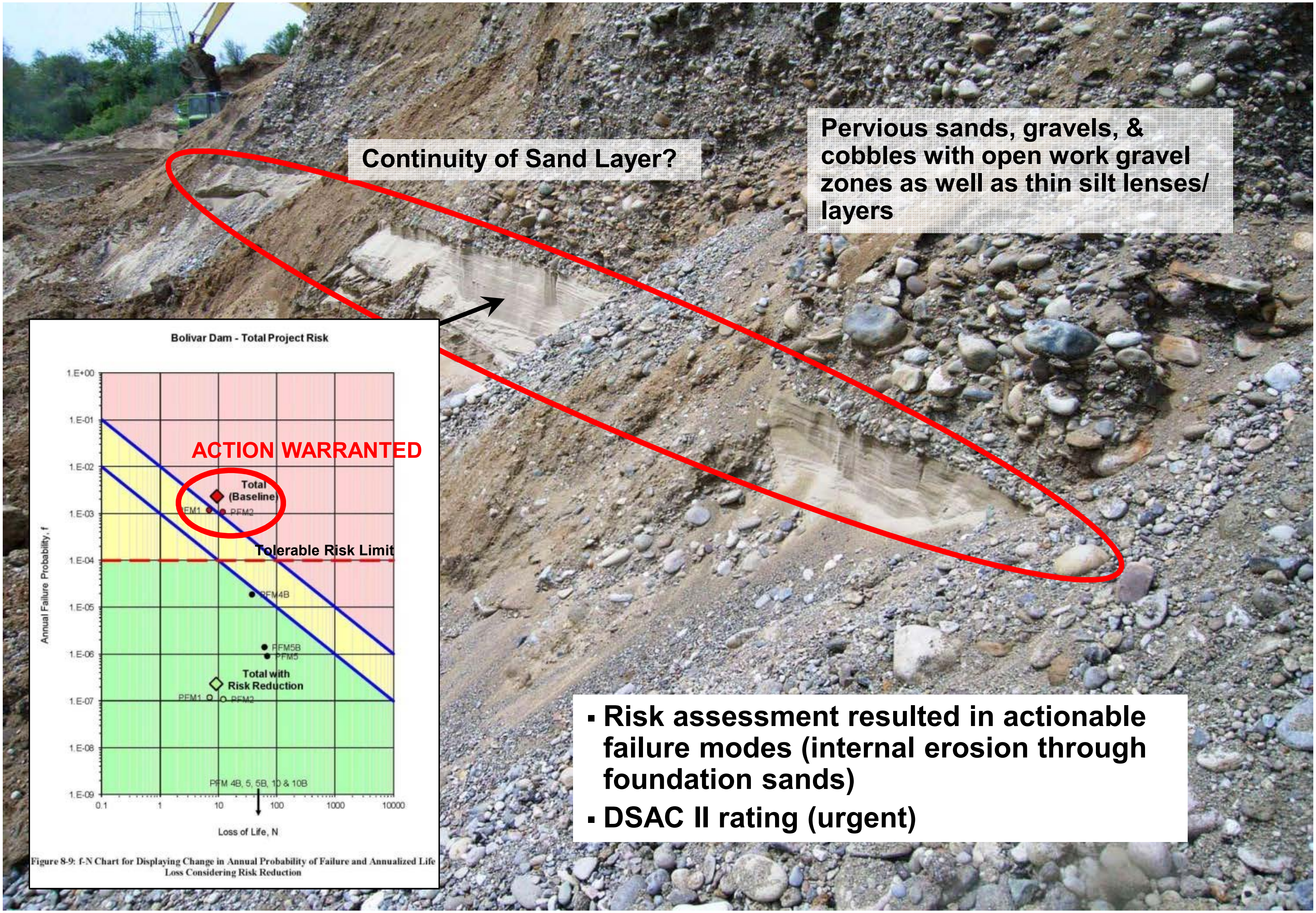
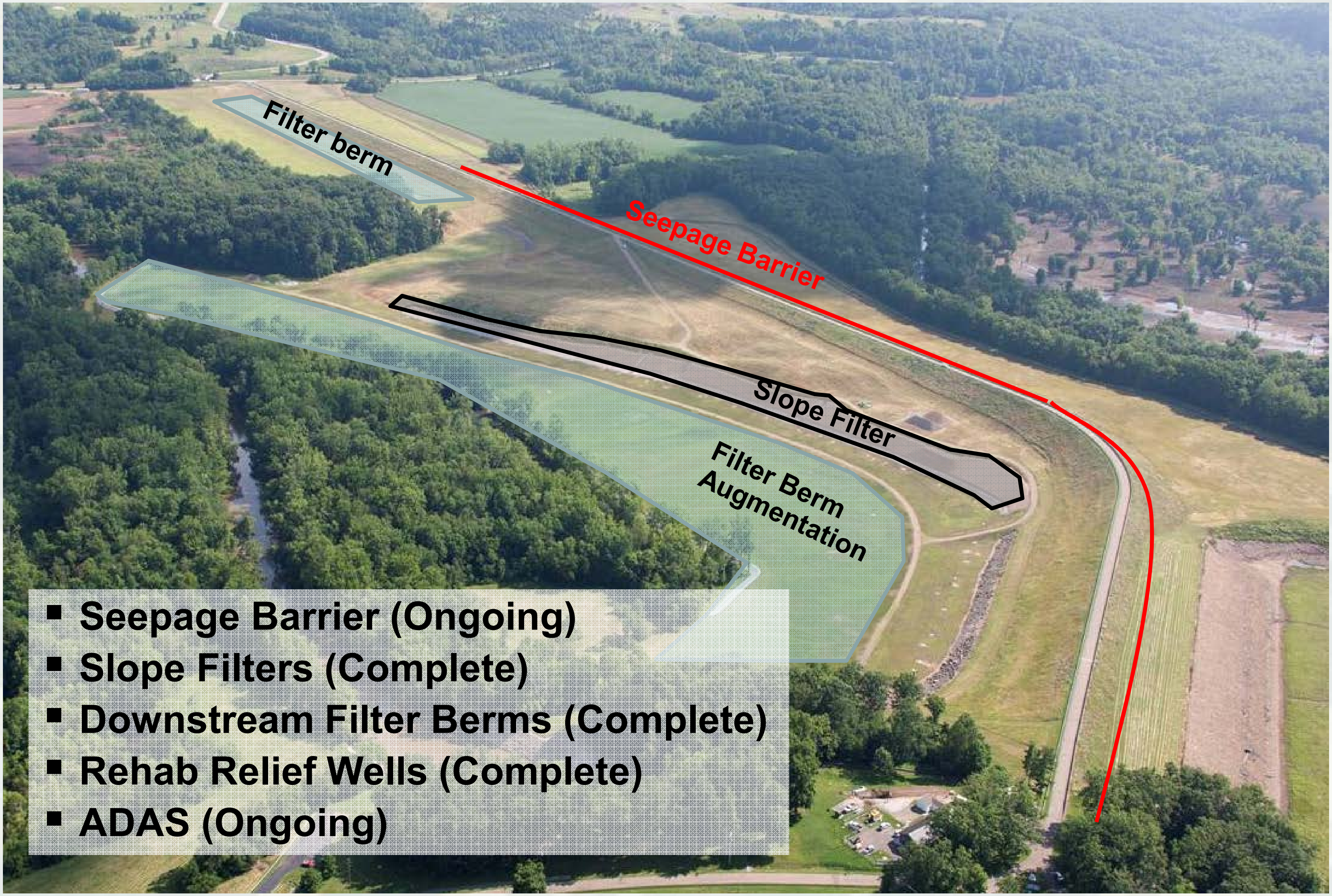


Figure 8-9: f-N Chart for Displaying Change in Annual Probability of Failure and Annualized Life Loss Considering Risk Reduction

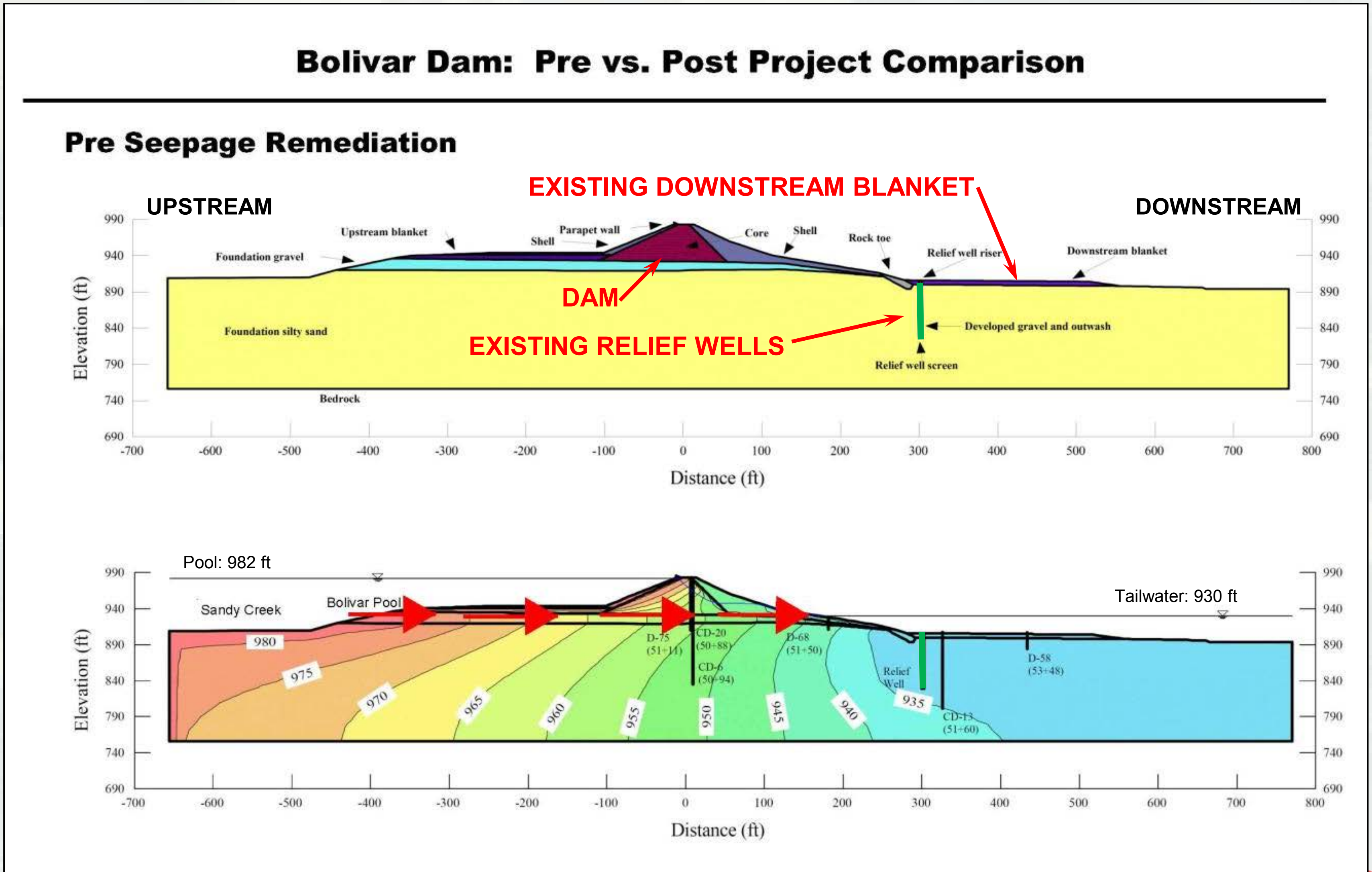
- Risk assessment resulted in actionable failure modes (internal erosion through foundation sands)
- DSAC II rating (urgent)

SEEPAGE REMEDIATION MEASURES



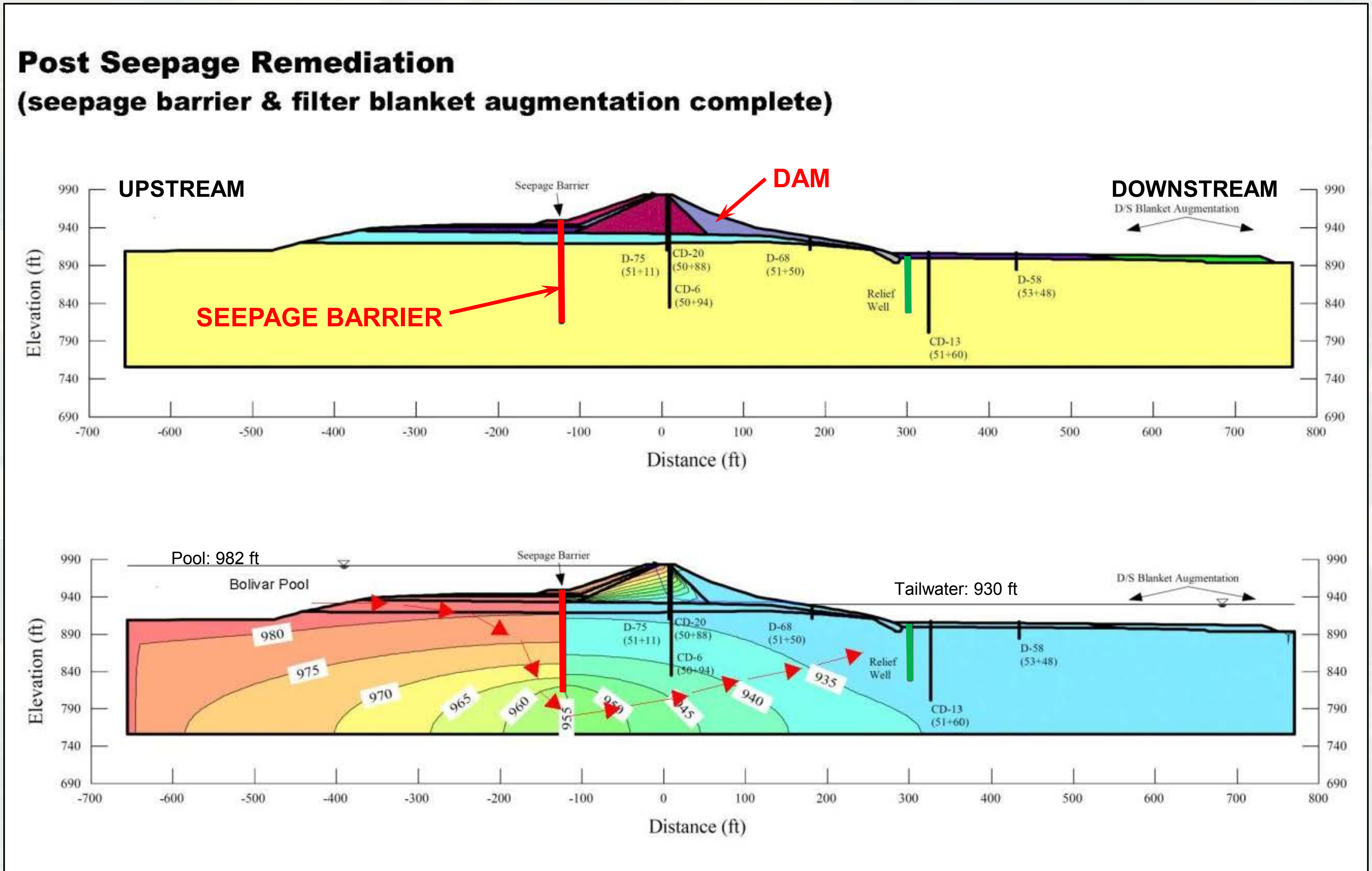
- Seepage Barrier (Ongoing)
- Slope Filters (Complete)
- Downstream Filter Berms (Complete)
- Rehab Relief Wells (Complete)
- ADAS (Ongoing)

SEEPAGE ANALYSIS – W/O SEEPAGE BARRIER



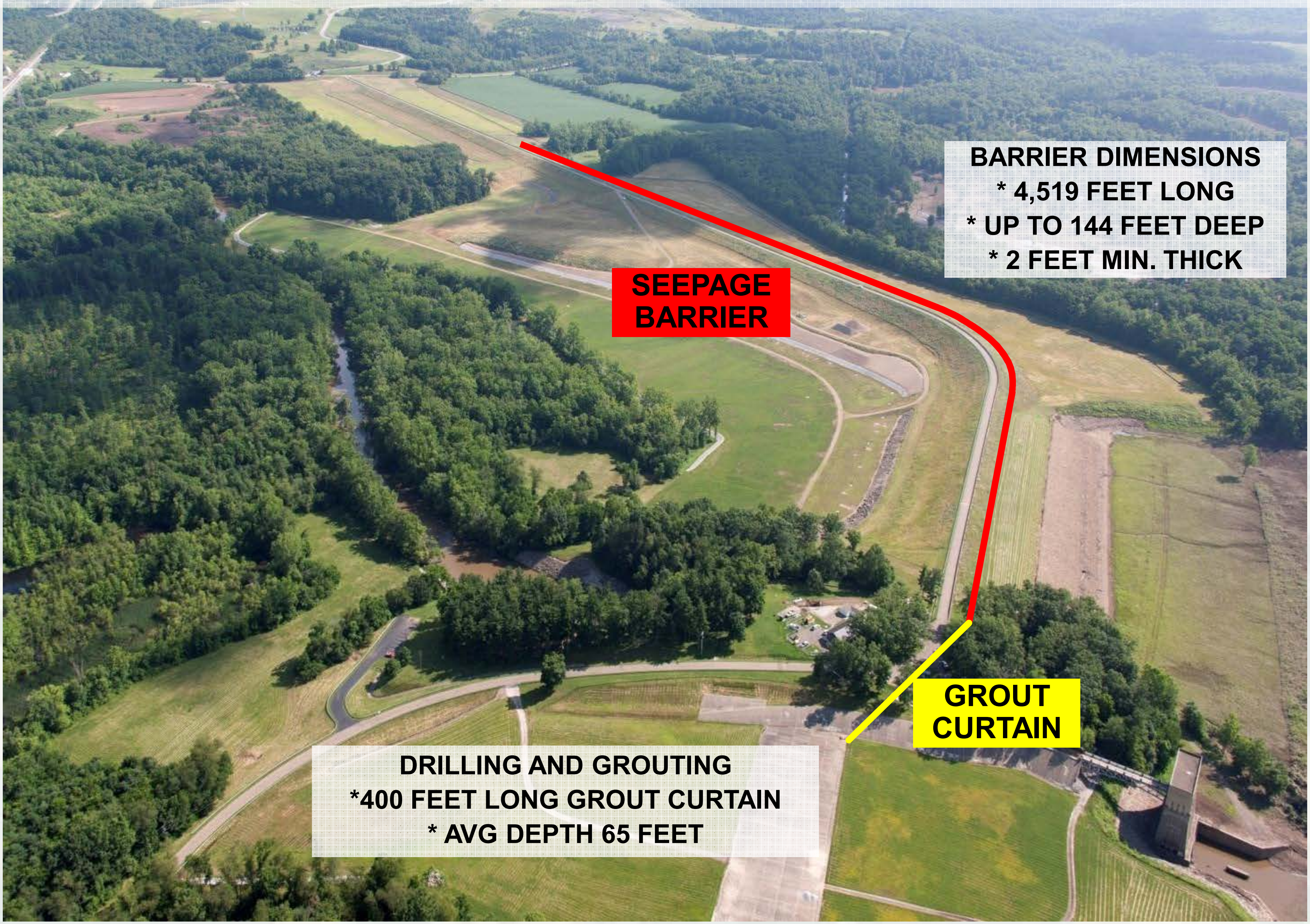
<u>Pre Seepage Remediation</u>*:* There is a direct path of seepage from Sandy Creek into the pervious foundation of the dam. The 1980's relief wells and blanket are somewhat effective in reducing head, extending the seepage path, and providing resistance to uplift but are not effective at all pool and tailwater conditions and locations below the dam.

SEEPAGE ANALYSIS – WITH SEEPAGE BARRIER

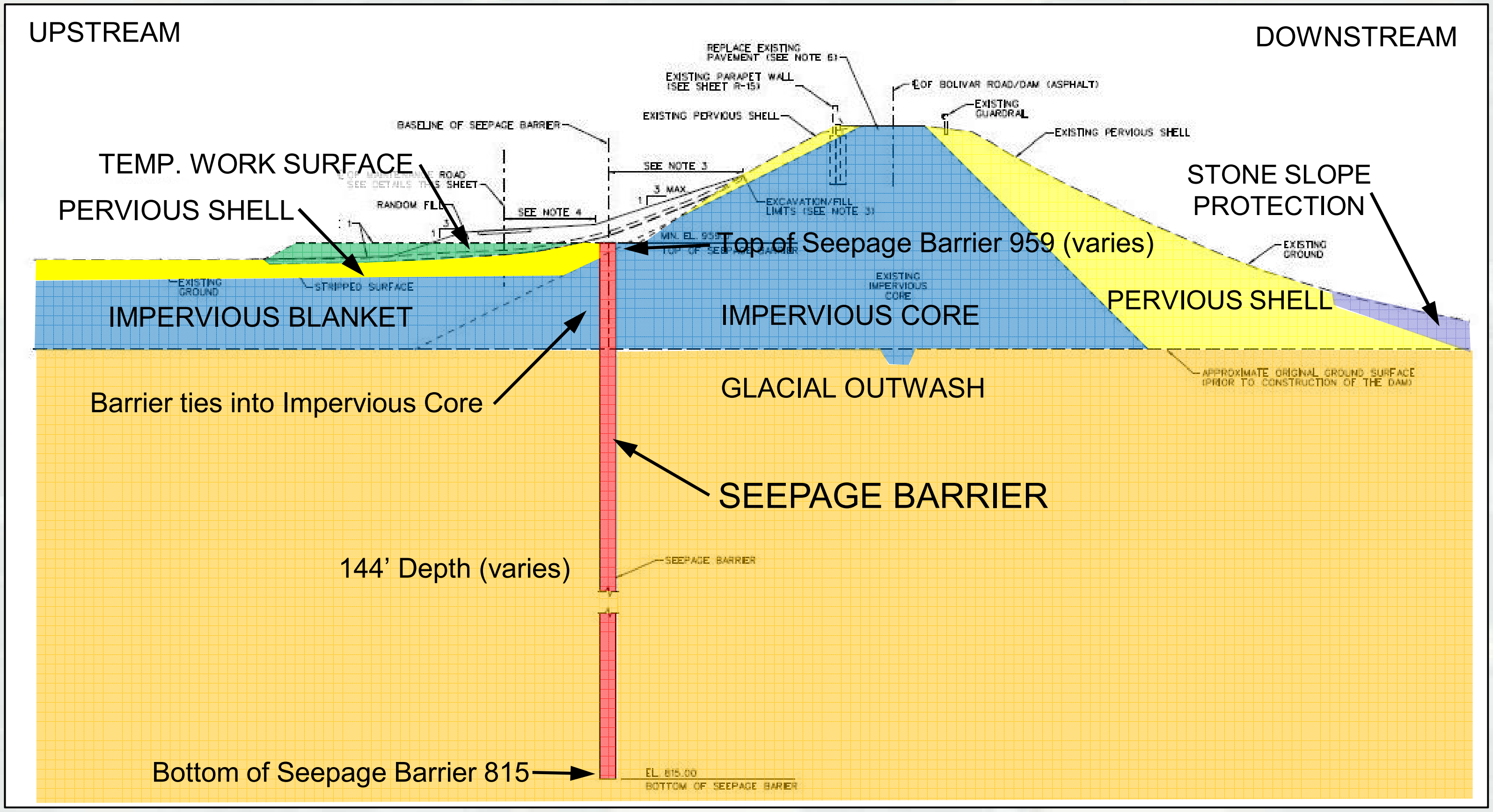


<u>Post Seepage Remediation</u>: Seepage exit gradients are greatly reduced downstream of the dam and the potential piping pathway is cut off reducing the risk of failure of the project to an acceptable level.

SEEPAGE BARRIER & GROUT CURTAIN



SEEPAGE BARRIER - CROSS SECTION



CONSTRUCTION

- Performance based specs. Procured based on best value procedures. Firm fixed price contract.
- Contract awarded to Treviicos
- Panel method using hydromill with low strength concrete backfill
- Foundation drilling and grouting subcontracted to TerraFirm
- Construction Award Cost: $44 million
- Notice to Proceed Date: May 2014
- Scheduled Completion Date: Feb 2017


US ARMY CORPS
OF ENGINEERS
HUNTINGTON DISTRICT

SANDY CREEK OF TUSCARAWAS RIVER
BOLIVAR, OH
BOLIVAR DAM

FEBRUARY 2014

CONSTRUCTION PLANS
SEEPAGE BARRIER

PROJECT NUMBER: 125381
AS-AWARDED CERTIFIED FINAL
W91237-14-C-0003

THIS PROJECT WAS DESIGNED BY THE HUNTINGTON DISTRICT OF THE U.S. ARMY CORPS OF ENGINEERS. THE INITIALS OR SIGNATURES AND REGISTRATION DESIGNATIONS OF INDIVIDUALS APPEAR ON THESE PROJECT DOCUMENTS WITHIN THE SCOPE OF THEIR EMPLOYMENT AS REQUIRED BY ER 1110-1-8152.

William A. Miller, P.E.
Chief, Engineering &
Construction Division

TREVIICOS SOUTH
38 Third Avenue, 3rd Floor
Boston National Historic Park
Charlestown, MA 02129
Tel: 617-241-4800
Fax: 617-241-4801

TERRA FIRM
CONSTRUCTION, LLC
8334 Ruby Avenue - Kansas City - Kansas - 66111

BARRIER WALL CONSTRUCTION - GUIDE WALL

- Prepare temporary work surface
- Install concrete guide walls
- Survey panel locations

SEEPAGE BARRIER – CONCEPTUAL PROFILE ALONG CENTERLINE

(looking upstream - not to scale)

PANEL EXCAVATION - CLAMSHELL

TOP OF BARRIER 959 (varies)

- 3’ Wide Panels (2’ min. specified)
- Initiate panel excavation with clamshell.
- Maintain bentonite slurry level during excavation.

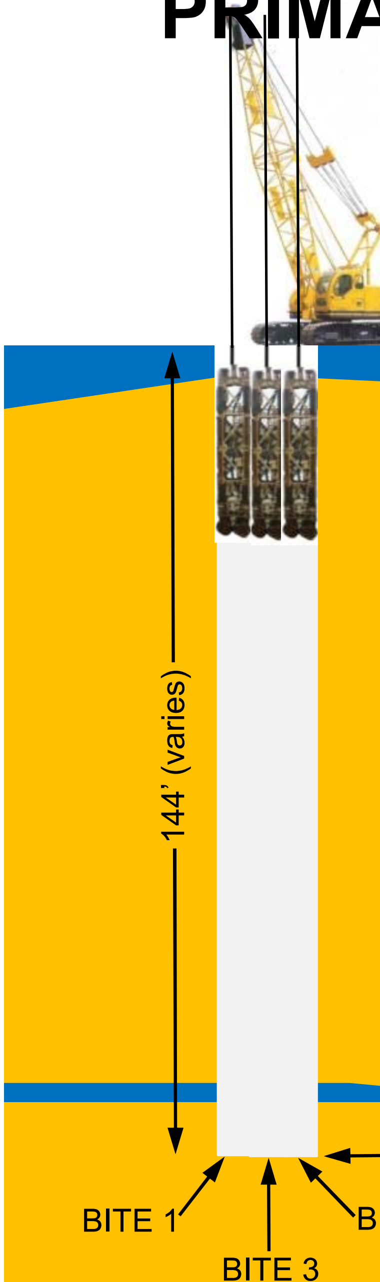
Bentonite Slurry

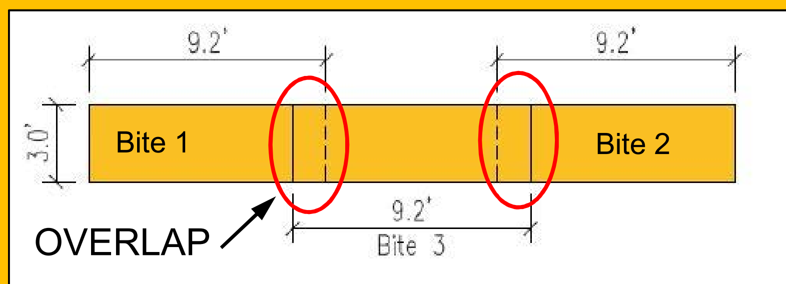
BENTONITE MIXING DE-SANDING PLANT

CLAMSHELL

PRIMARY PANEL EXCAVATION - HYDROMILL

- 144' depth (varies)
- 3 & 5 bite primary panels
- Overlapping excavation to assure no gaps between bites





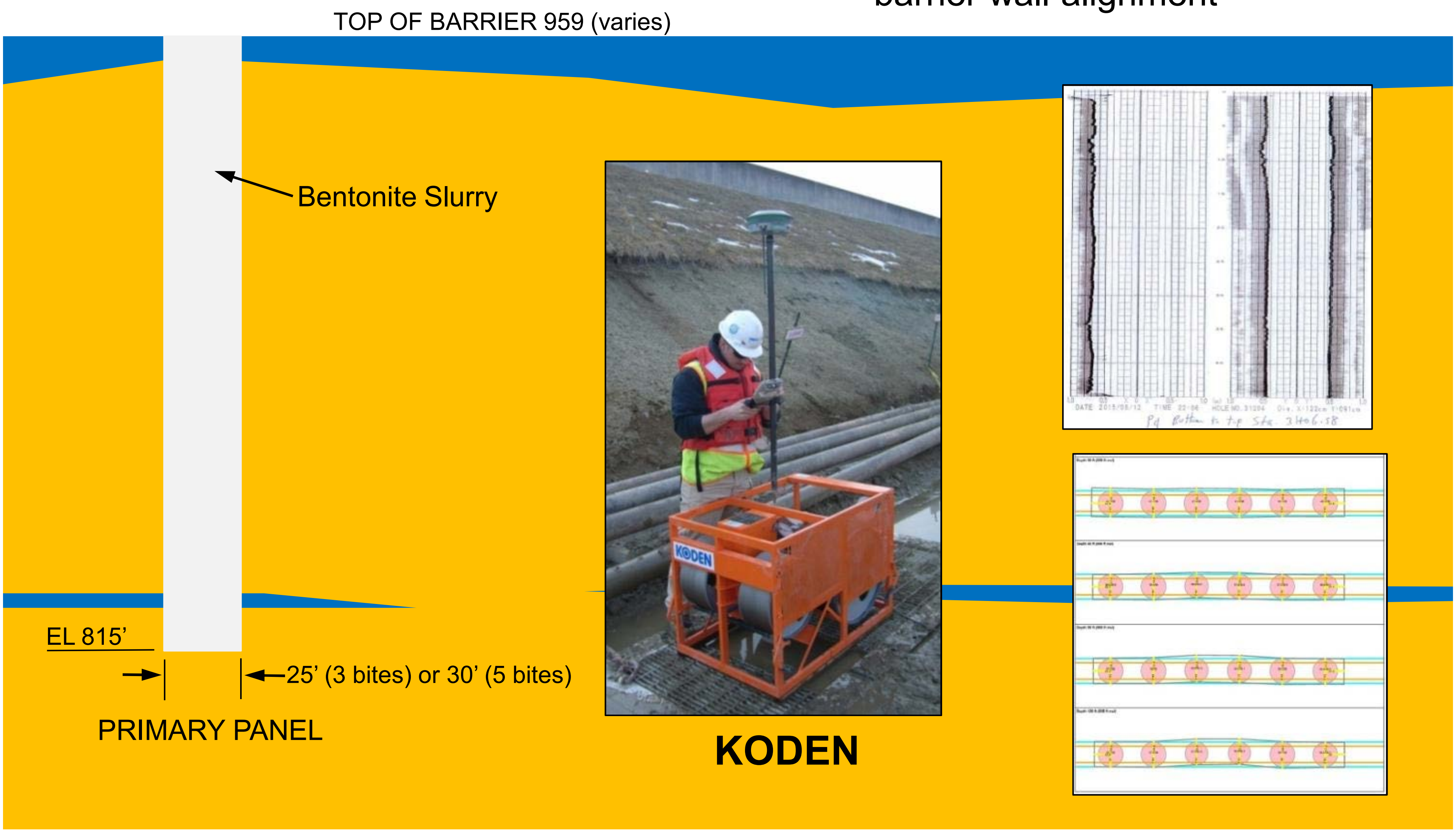
PLAN VIEW – PRIMARY PANEL

HYDROMILL

CUTTER HEAD

SURVEY PANEL ALIGNMENT

- Koden used to measure verticality and panel thickness
- Multiple measurements determine barrier wall alignment



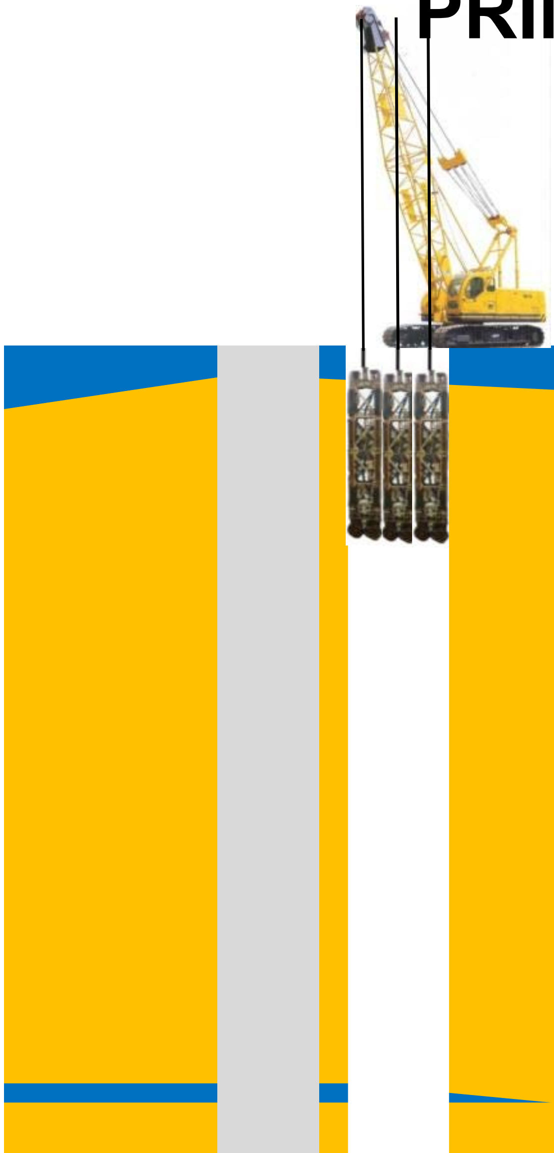
PANEL BACKFILL

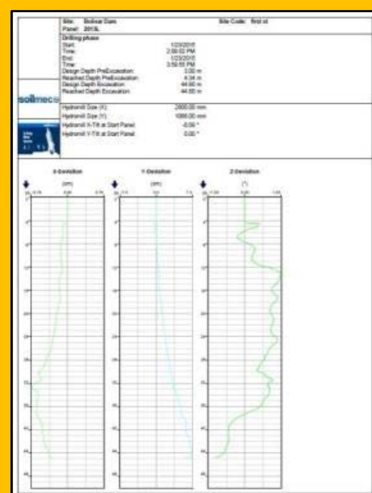
- Continuous and homogenous
- Minimum UCS 750 psi at 28 days (based on 10 point moving average with no test below 500 psi)
- Plastic, high slump concrete mix (not specified)

Tremie Placement

PRIMARY PANEL EXCAVATION

- Drill Mate System measures verticality.
- Adjustments can be made with the hydromill during excavation.



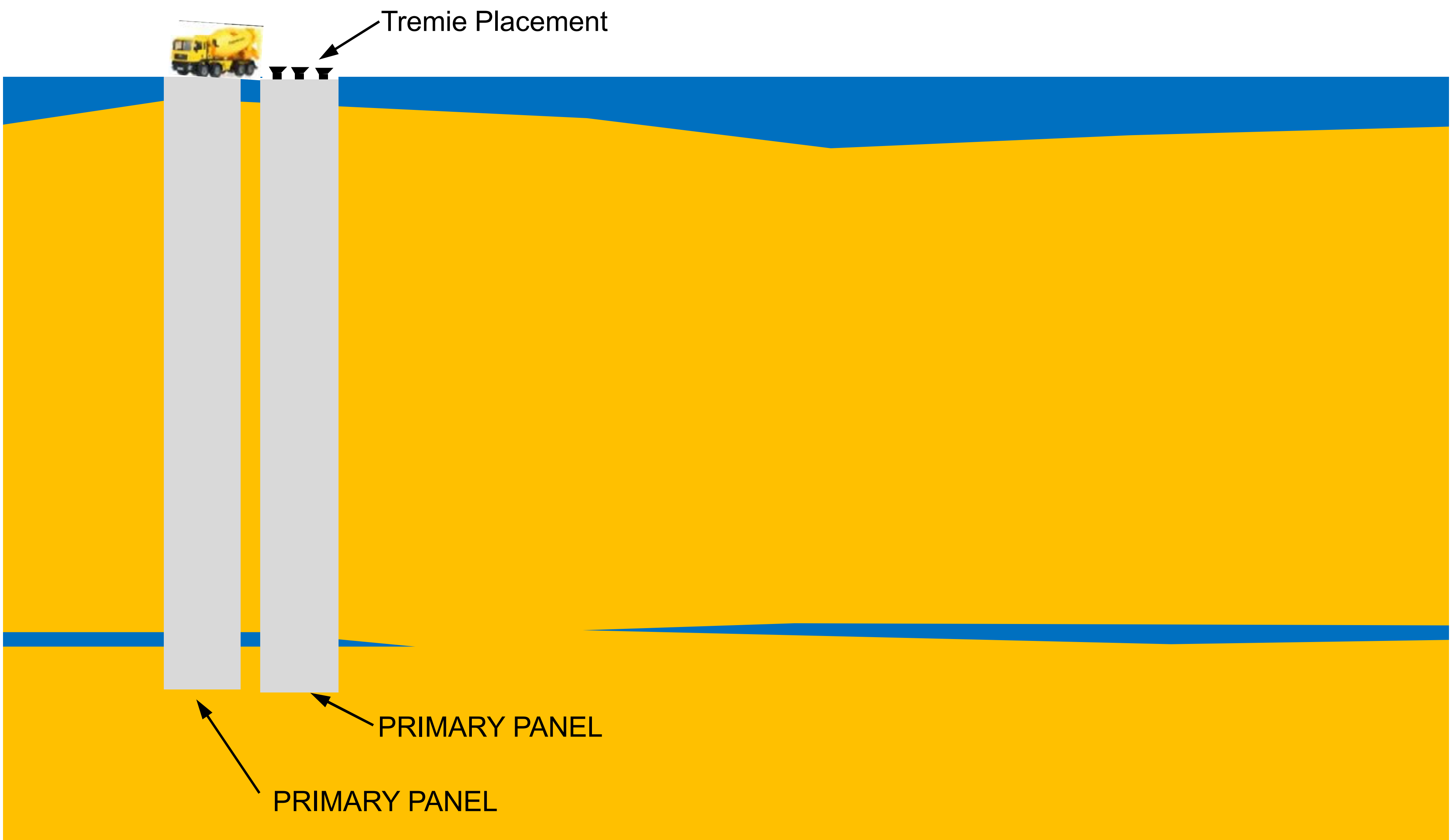


DRILL MATE SYSTEM

PRIMARY PANEL

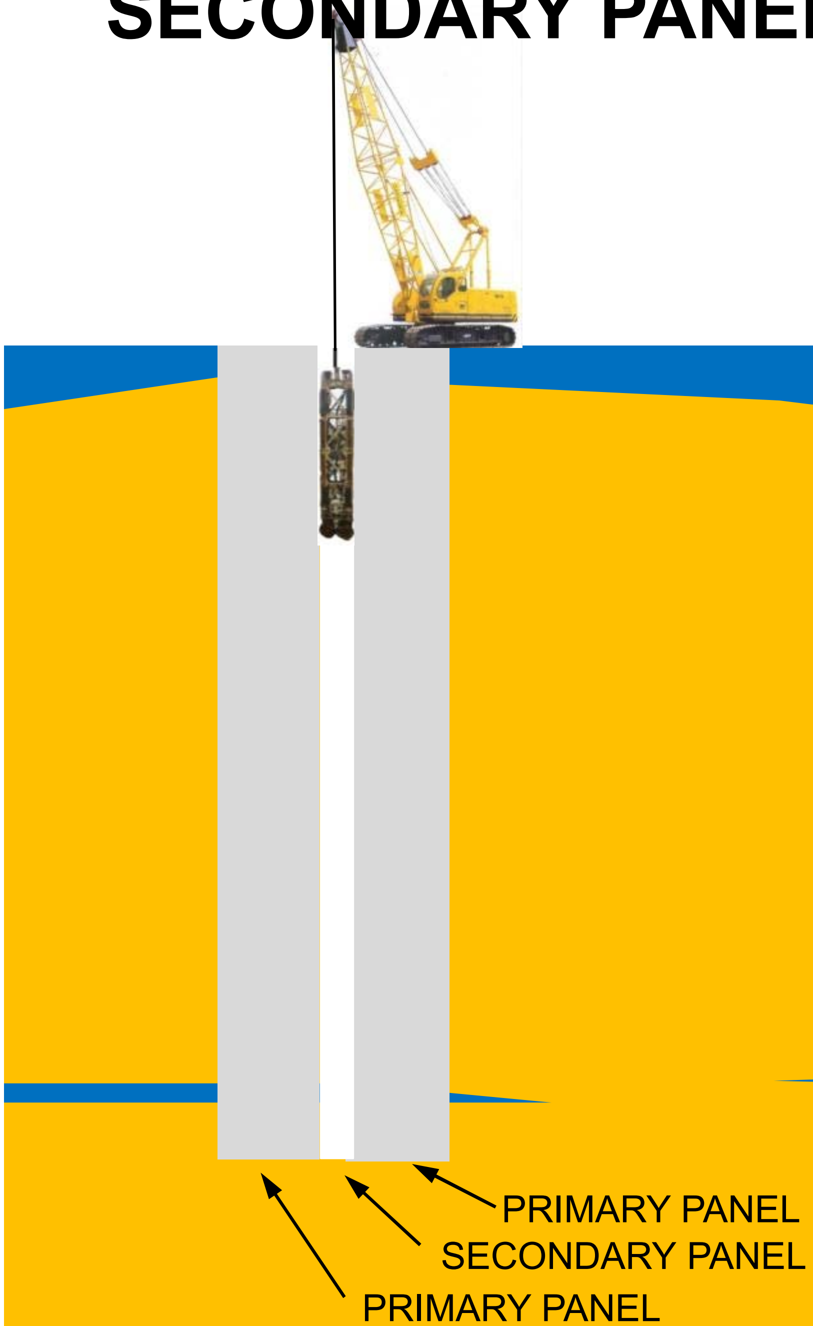
PRIMARY PANEL

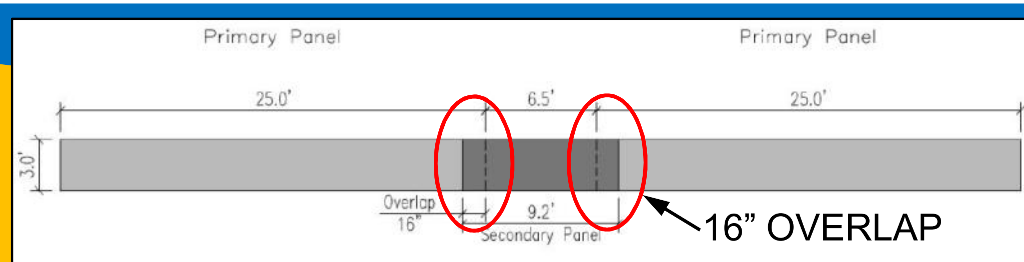
PRIMARY PANEL BACKFILL



SECONDARY PANEL EXCAVATION & CLEANING

- Koden measurements taken
- Clean sidewalls of bentonite buildup
- Replace bentonite slurry prior to backfill

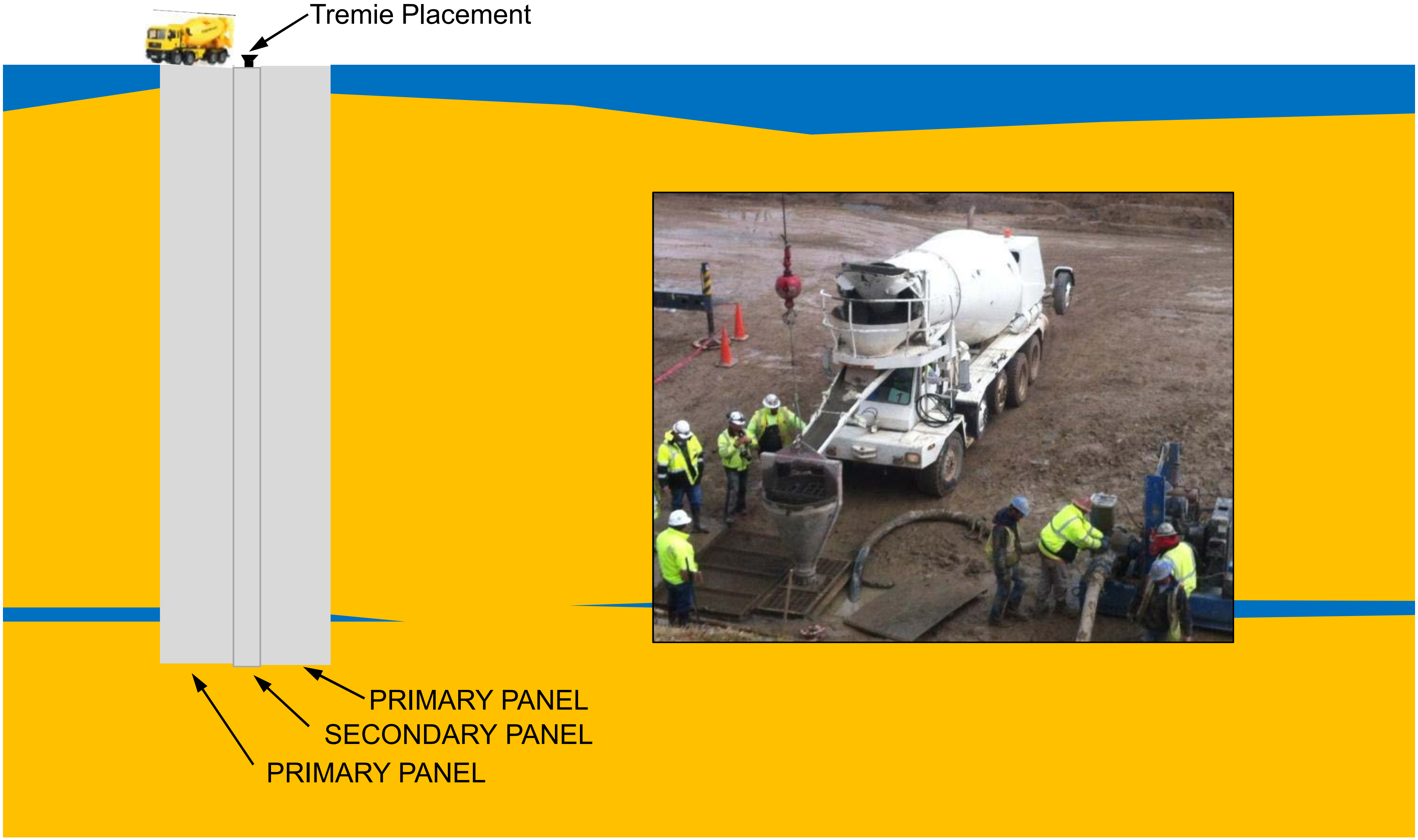




PLAN VIEW
PRIMARY & SECONDARY PANELS

CLEANING PANEL SIDEWALLS

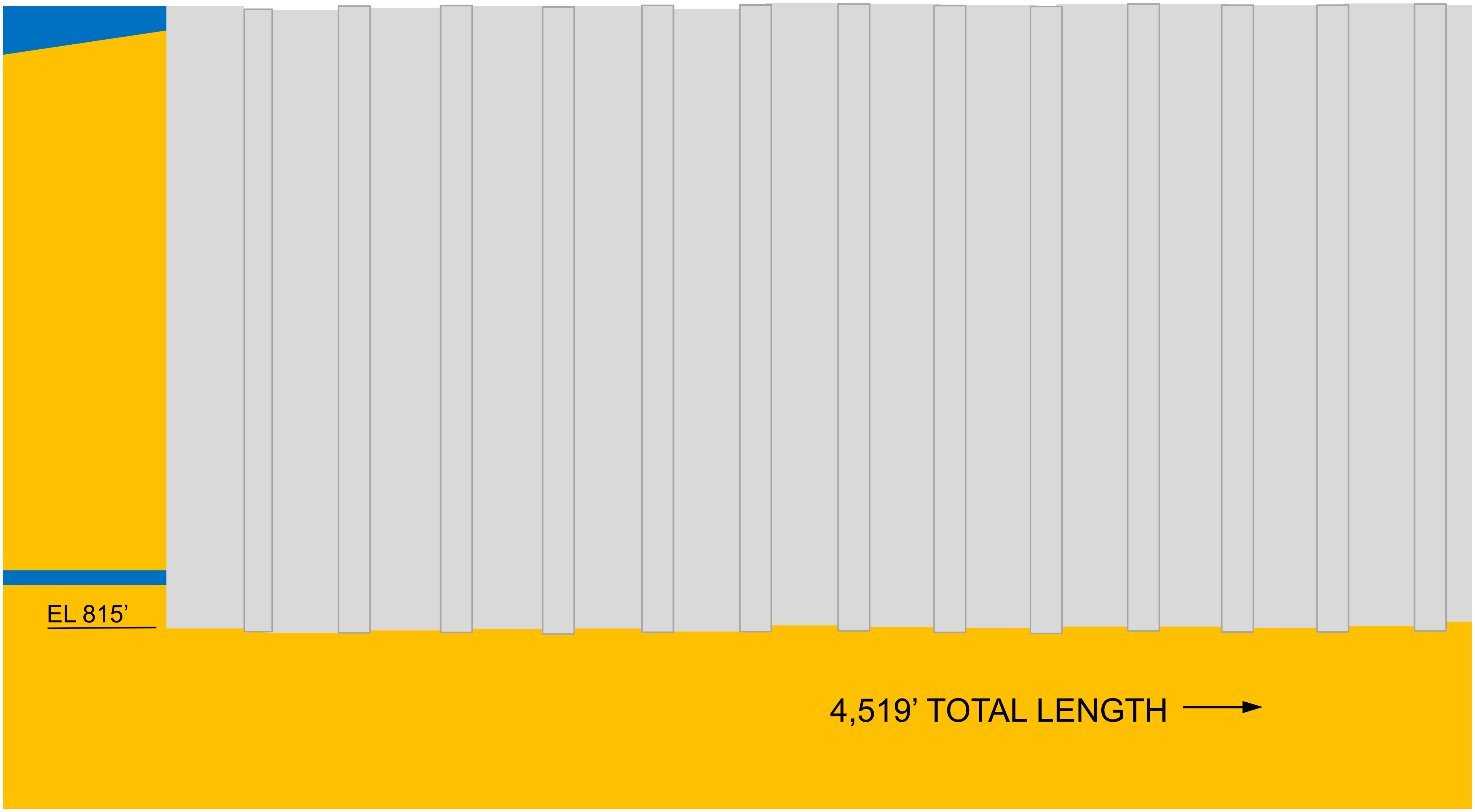
SECONDARY PANEL BACKFILL



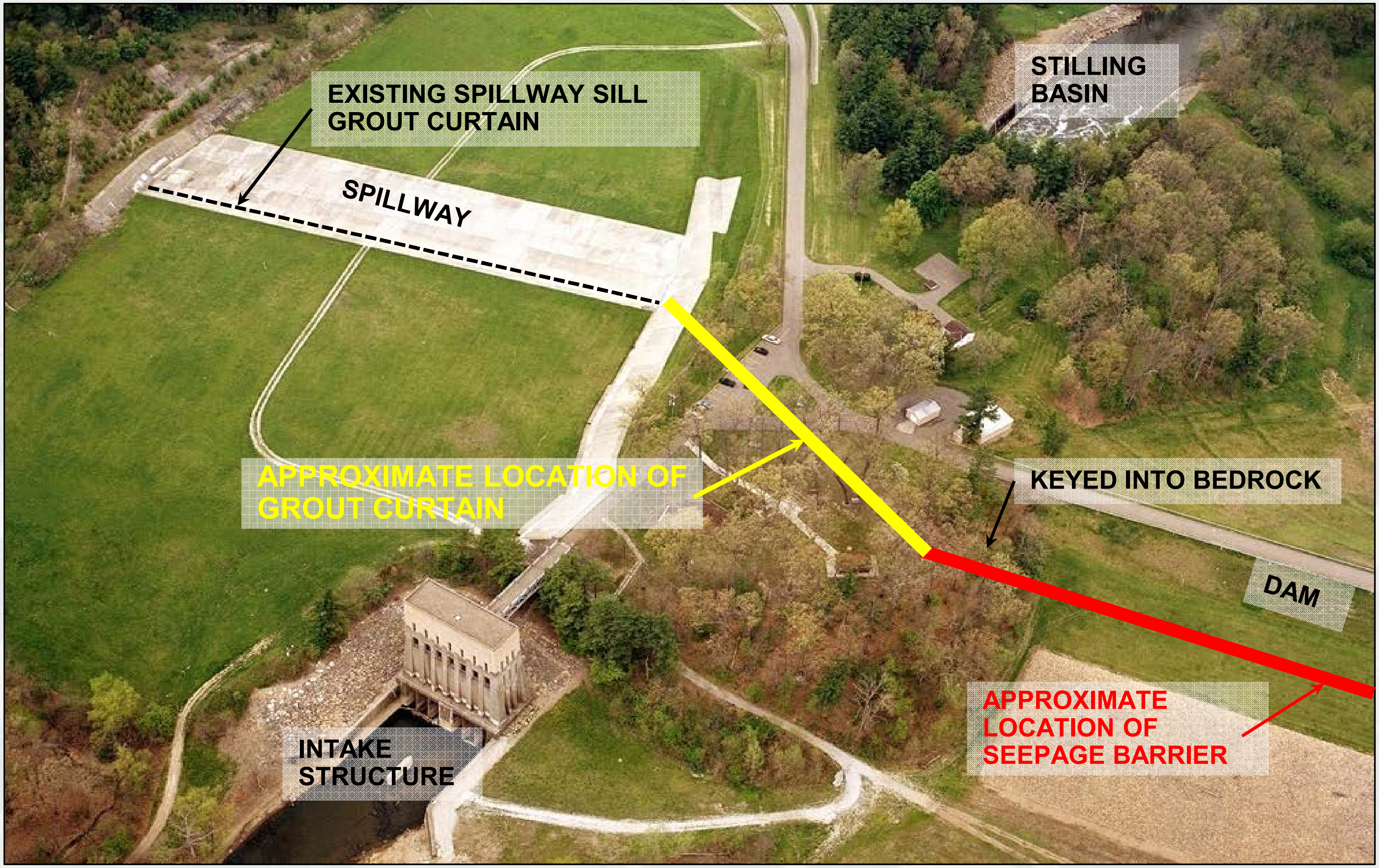
DEMONSTRATION SECTION

- Verification Drilling with down-hole-camera.
- In-place permeability ≤1 x 10^{-6} cm/s at 28 days.

SEEPAGE BARRIER WALL COMPLETION



GROUT CURTAIN - LOCATION



LEFT ABUTMENT

LEFT ABUTMENT – BEDROCK SEEPAGE

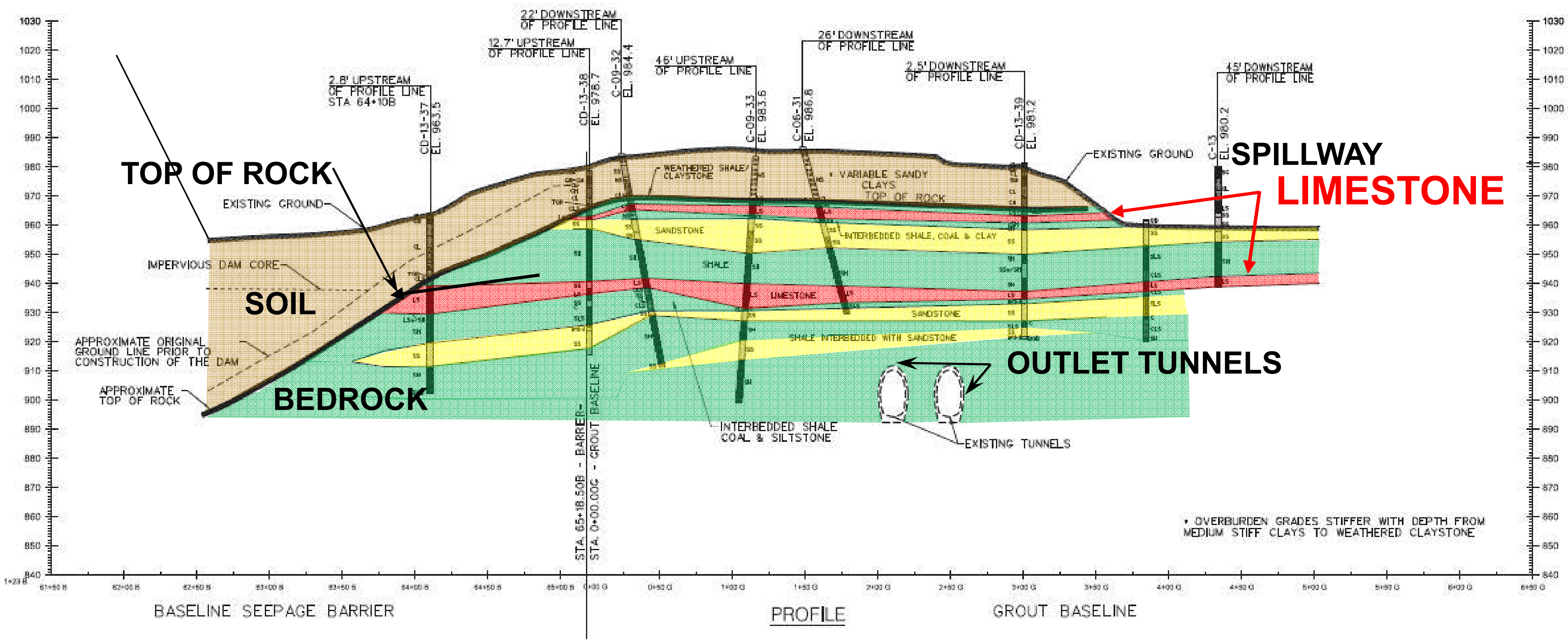
2005 FLOOD EVENT

1991 FLOOD EVENT

LOCATION ABOVE STILLING BASIN

LEFT ABUTMENT – GEOLOGY

- Soil: (colluvium – fines w/ rock frag.) 16’ thick
- Bedrock: Near horizontal, interbedded, sedimentary bedrock
- Two thin (3’-5’ thick) limestone units (Upper and Lower Mercer Limestone)

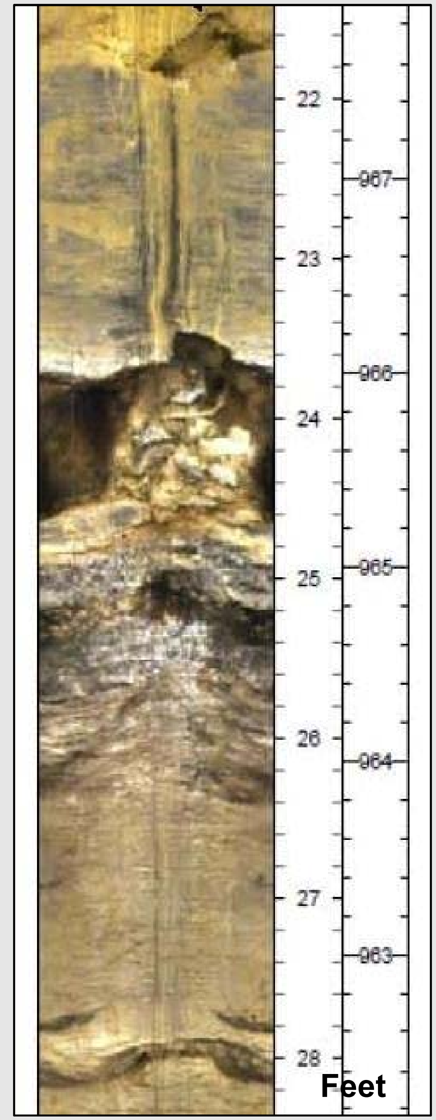


Profile Along Grout Curtain Centerline – Looking Upstream

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^{o}, interconnected, avenues for groundwater flow.
- Bedding planes: low angle, open, solutioned and continuous.
- Exposed in stilling basin and spillway.

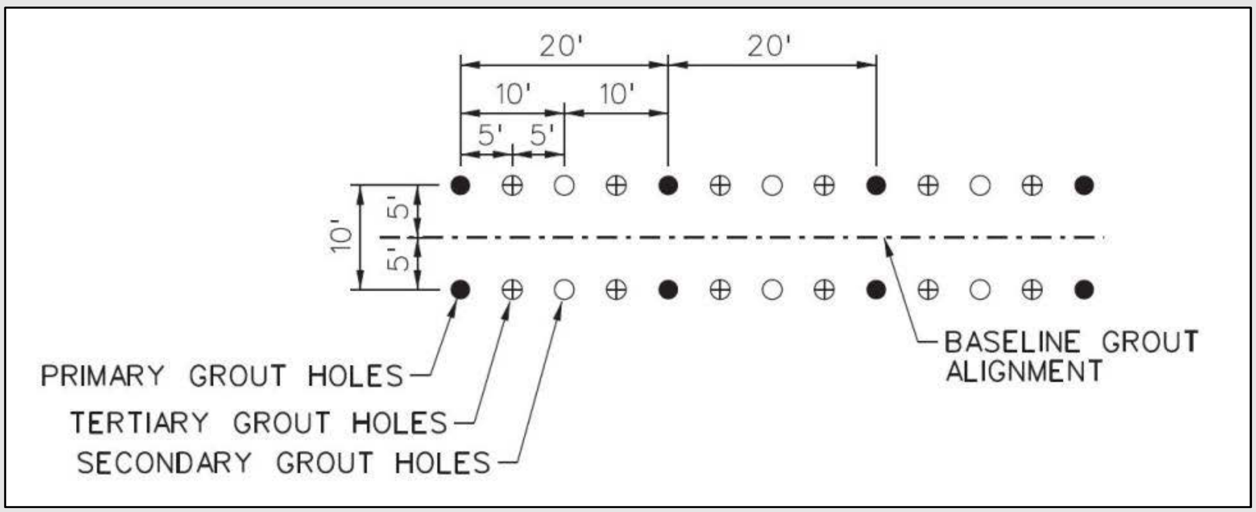
OPEN FRACTURES AT SURFACE



DOWN-THE-HOLE CAMERA IMAGES

GROUT CURTAIN – GENERAL INFORMATION

- Double line grout curtain, 10’ spacing between grout lines.
- Grout curtain is approx. 400’ long, 65’ deep with 3” dia. holes
- 20’ Spacing between Primary holes
- All Primary and Secondary holes will be drilled and pressure tested. Higher order grout holes will be split spaced, if needed.



GROUT CURTAIN – GENERAL INFORMATION

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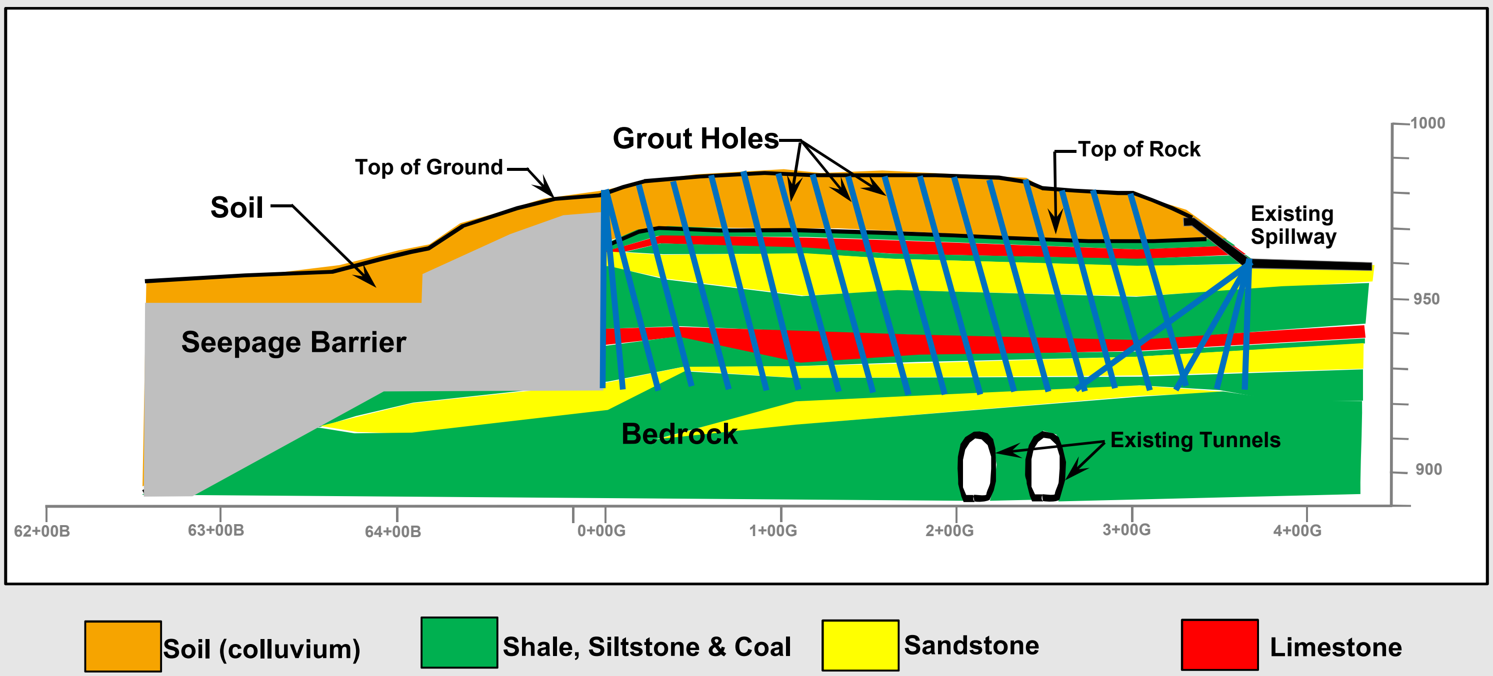
- 20’ Spacing between Primary holes
- All Primary and Secondary holes will be drilled and pressure tested. Higher order grout holes will be split spaced, if needed.
- Downstream grout line hole are mostly inclined 30º toward the spillway



GROUT CURTAIN – GENERAL INFORMATION

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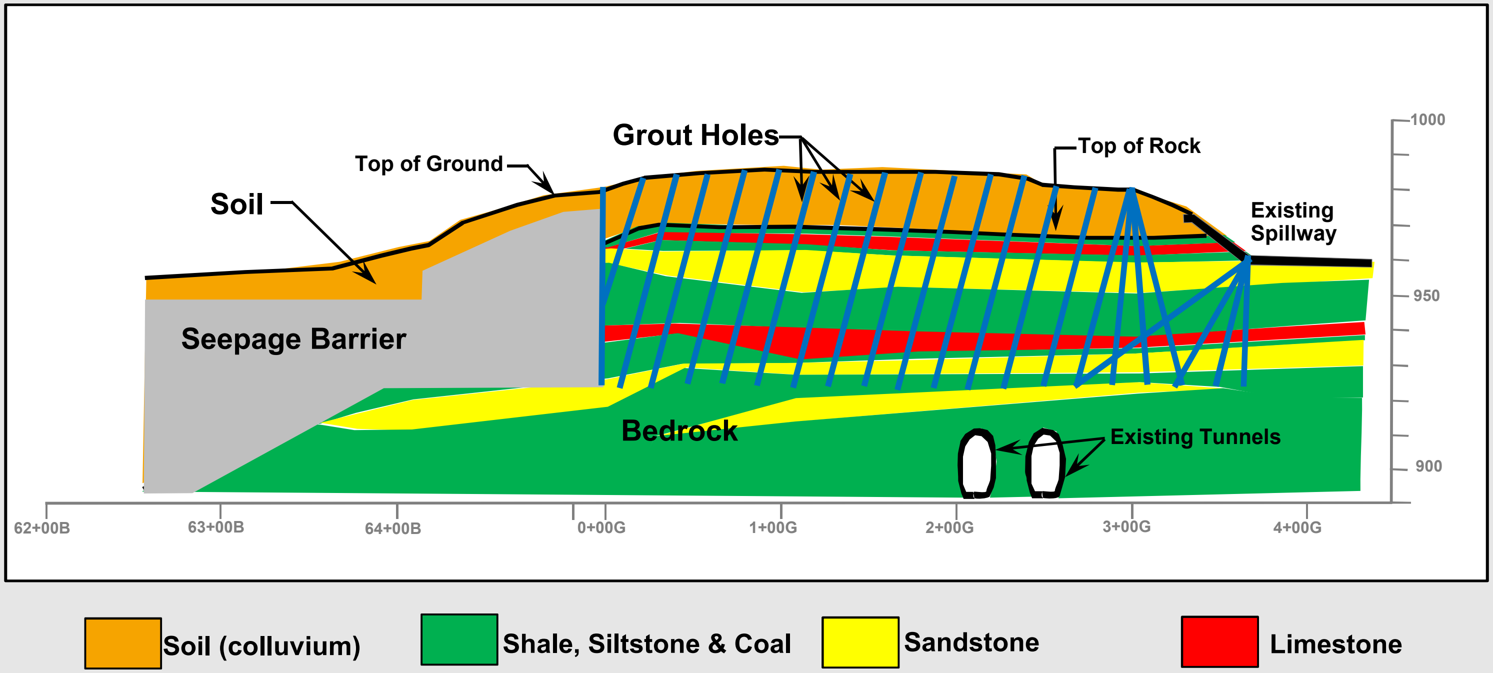
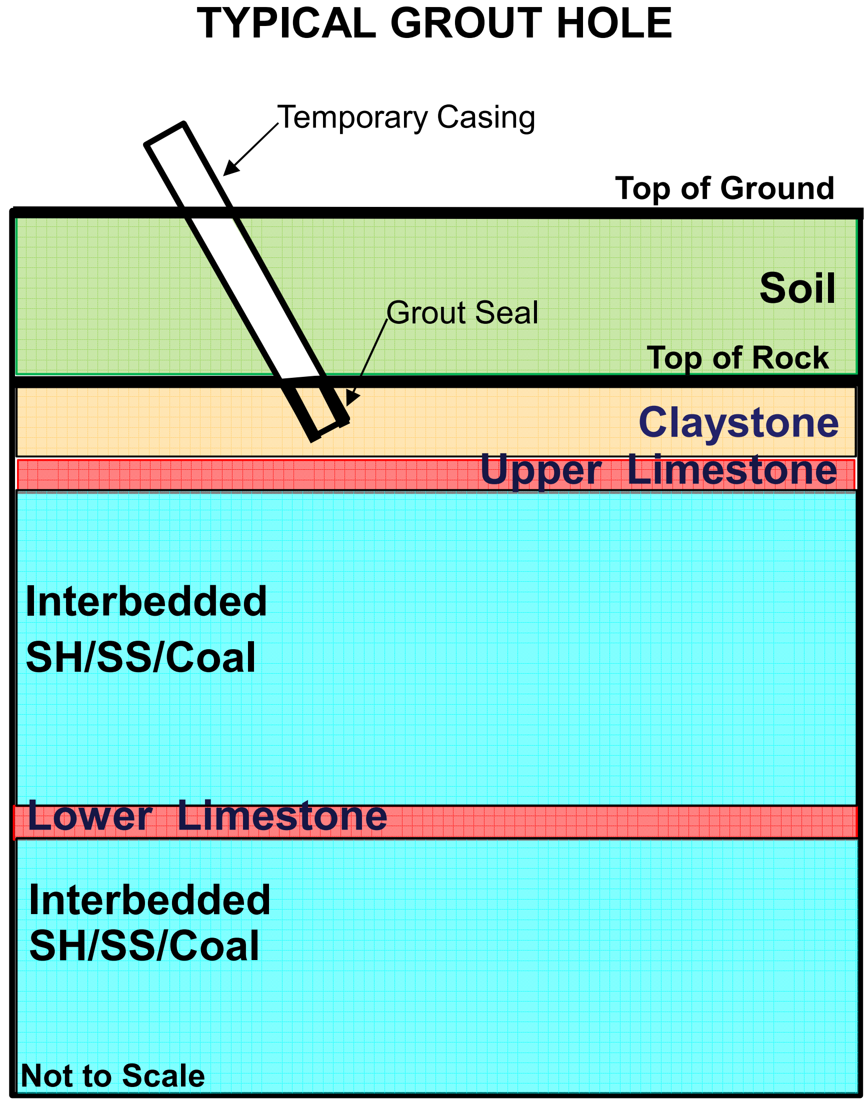
- 20’ Spacing between Primary holes
- All Primary and Secondary holes will be drilled and pressure tested. Higher order grout holes will be split spaced, if needed.
- Downstream grout line hole are mostly inclined 30º toward the spillway
- Upstream grout line holes are mostly inclined 30º toward the dam/valley



DRILLING THROUGH SOIL & INSTALL CASING

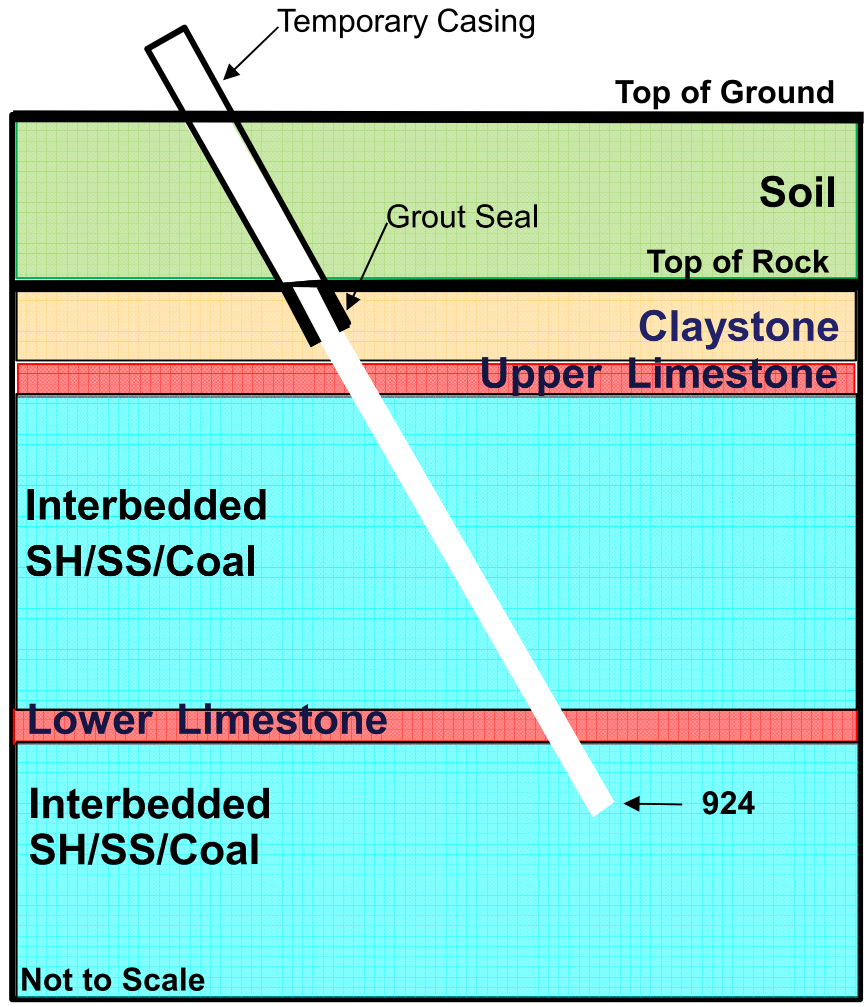
- Hole location and drill mast orientation is surveyed
- Auger drilling method
- Install temporary casing through soil without use of drilling fluids.
- Place grout seal and grout annulus



DRILLING THROUGH BEDROCK

- Drill 3” diameter hole
- Bottom of grout curtain at elev. 924
- Maximum drill length of 115’
- Vertical to 70º from vertical
- Water actuated down-hole hammer
- Hole sidewalls are cleaned
- Bottom of hole deviation magnitude and orientation is measured

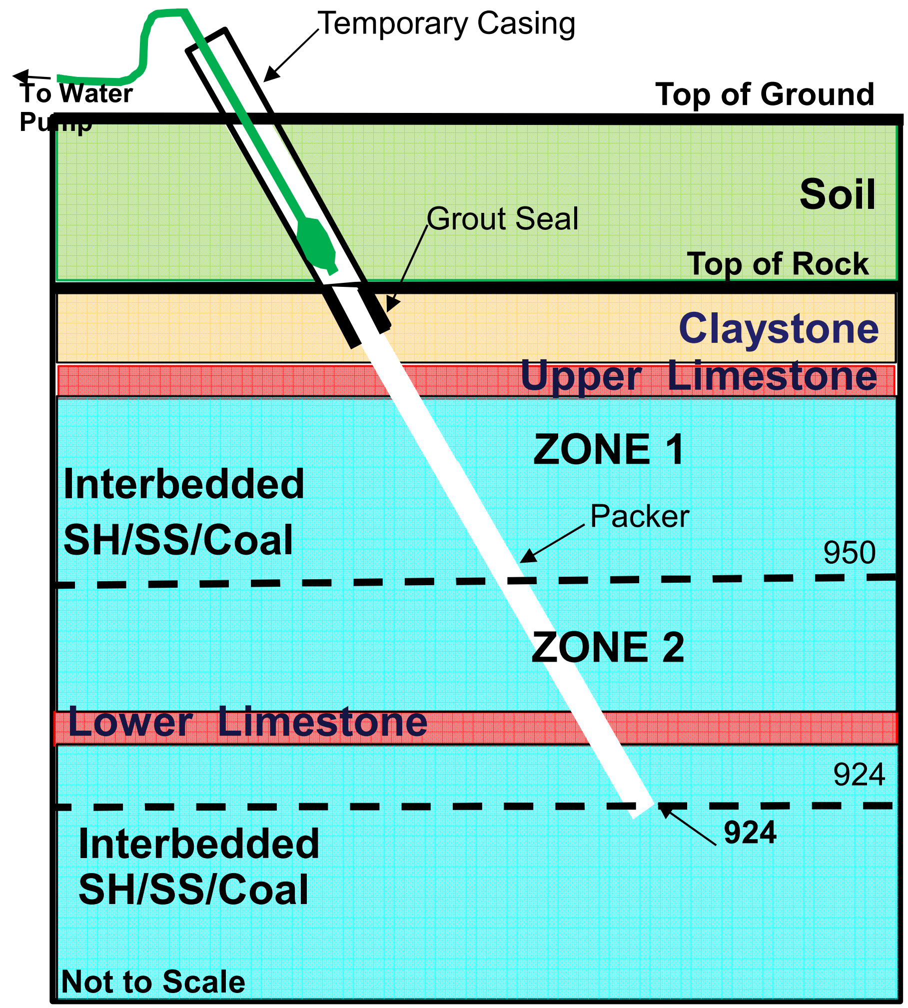
TYPICAL GROUT HOLE



PRESSURE TESTING

- Two Zones to treat upper and lower limestone units separately
- Upstage grouting
- Set packer at top of zone
- Pressure is limited during pressure testing and grouting to prevent hydraulic Jacking

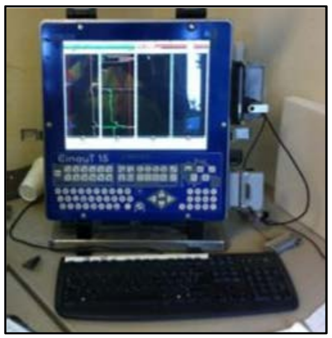
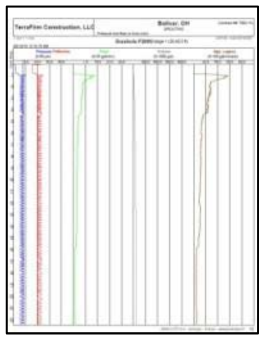
TYPICAL GROUT HOLE



PRESSURE TESTING & GROUT CART

GROUTING

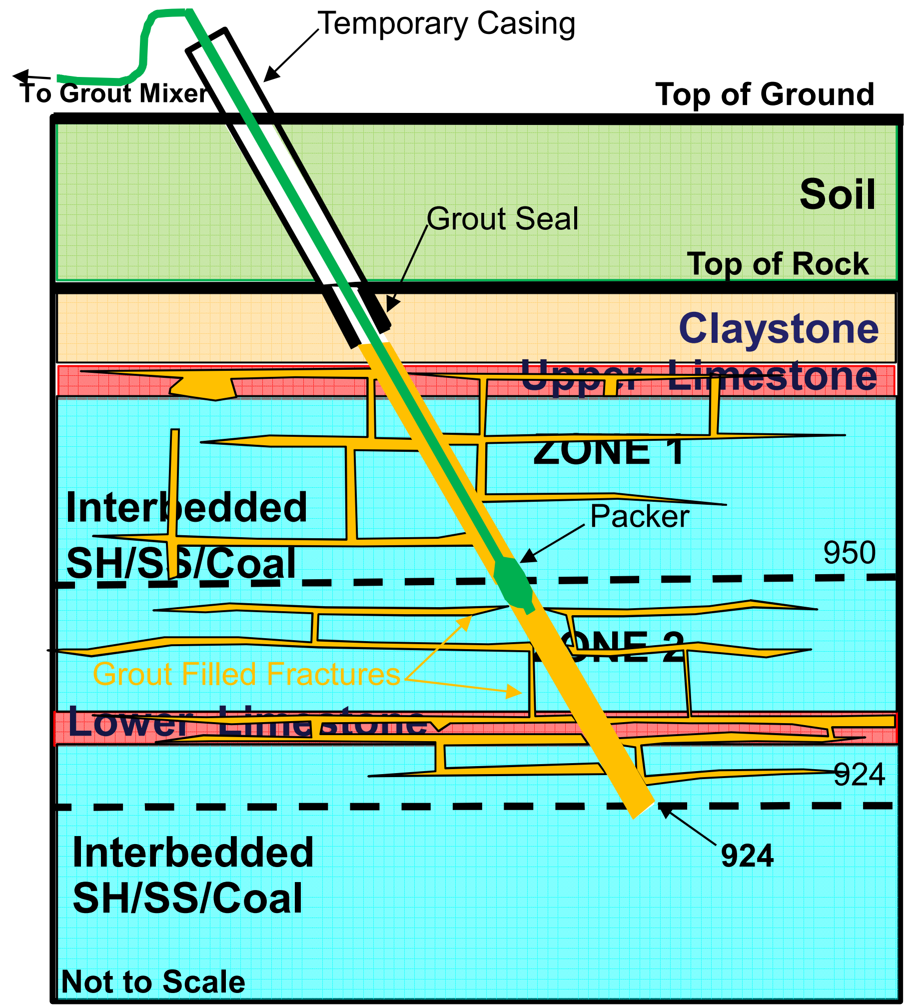
- Six balanced stabilized grout mixes
- Computer monitored grouting and pressure testing
- Typically start with thinner mixes and incrementally increase viscosity
- Upstage grouting
- Grouting refusal set at 0.5 gal/min

GROUT MONITORING

GROUT PLANT

TYPICAL GROUT HOLE

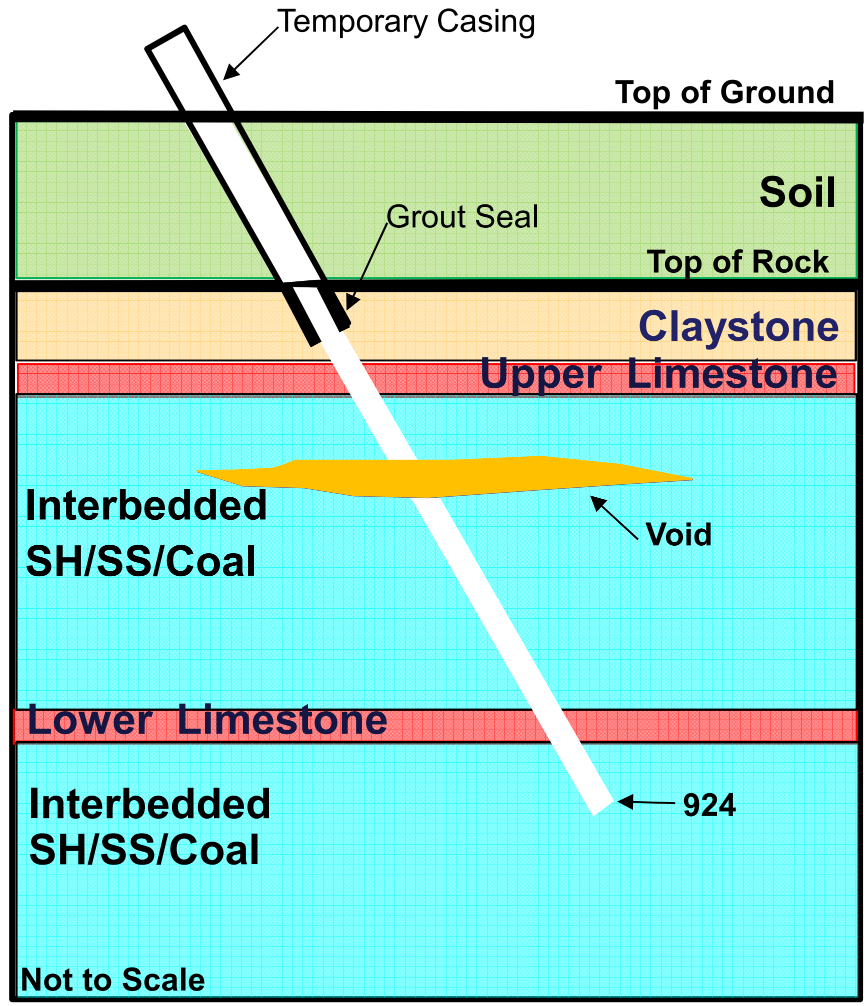


DOWNSTAGE GROUTING

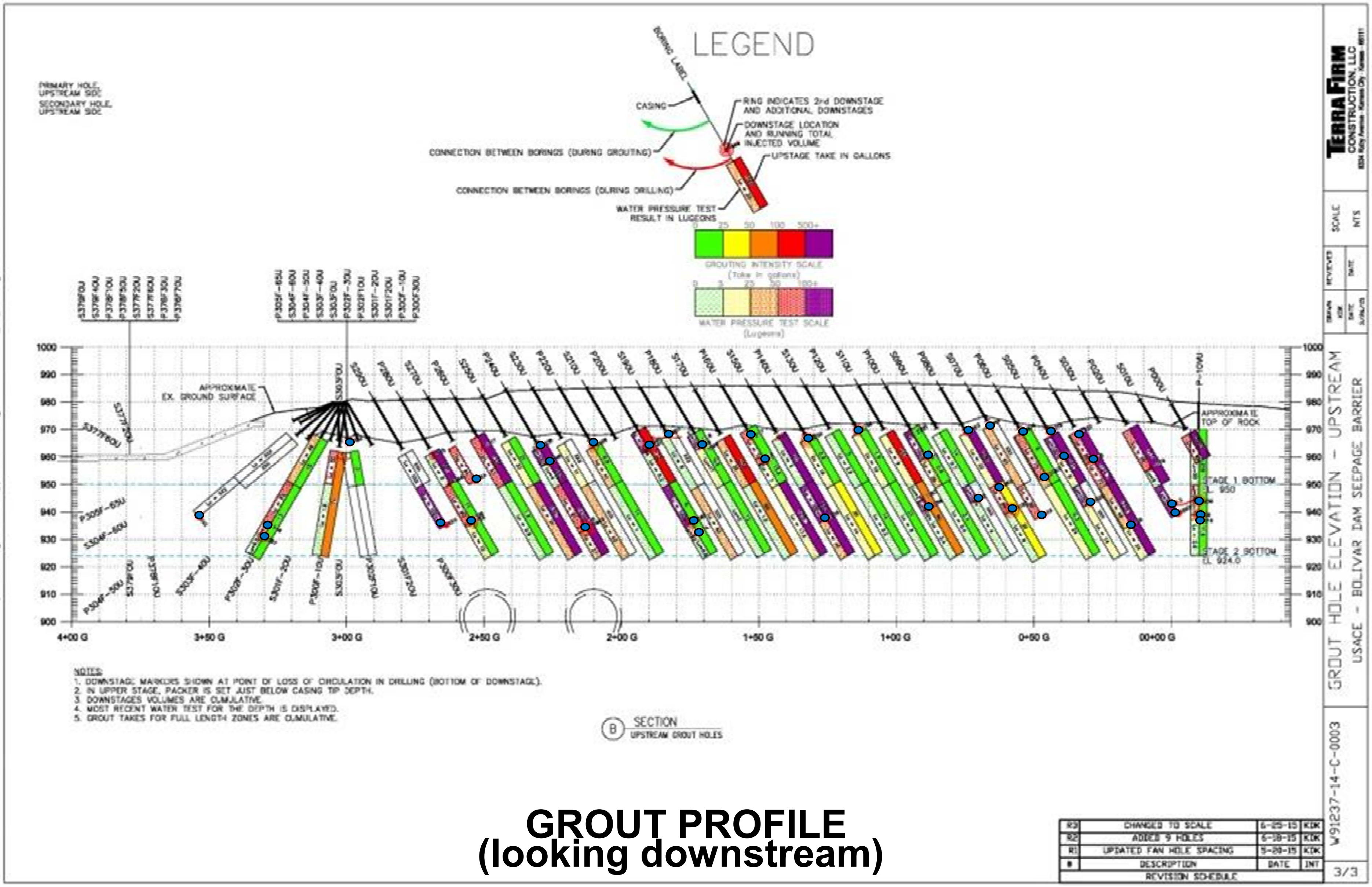
- Downstage grouting if significant drill water loss is encountered (+50%), indicating open foundation conditions.

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

TYPICAL GROUT HOLE

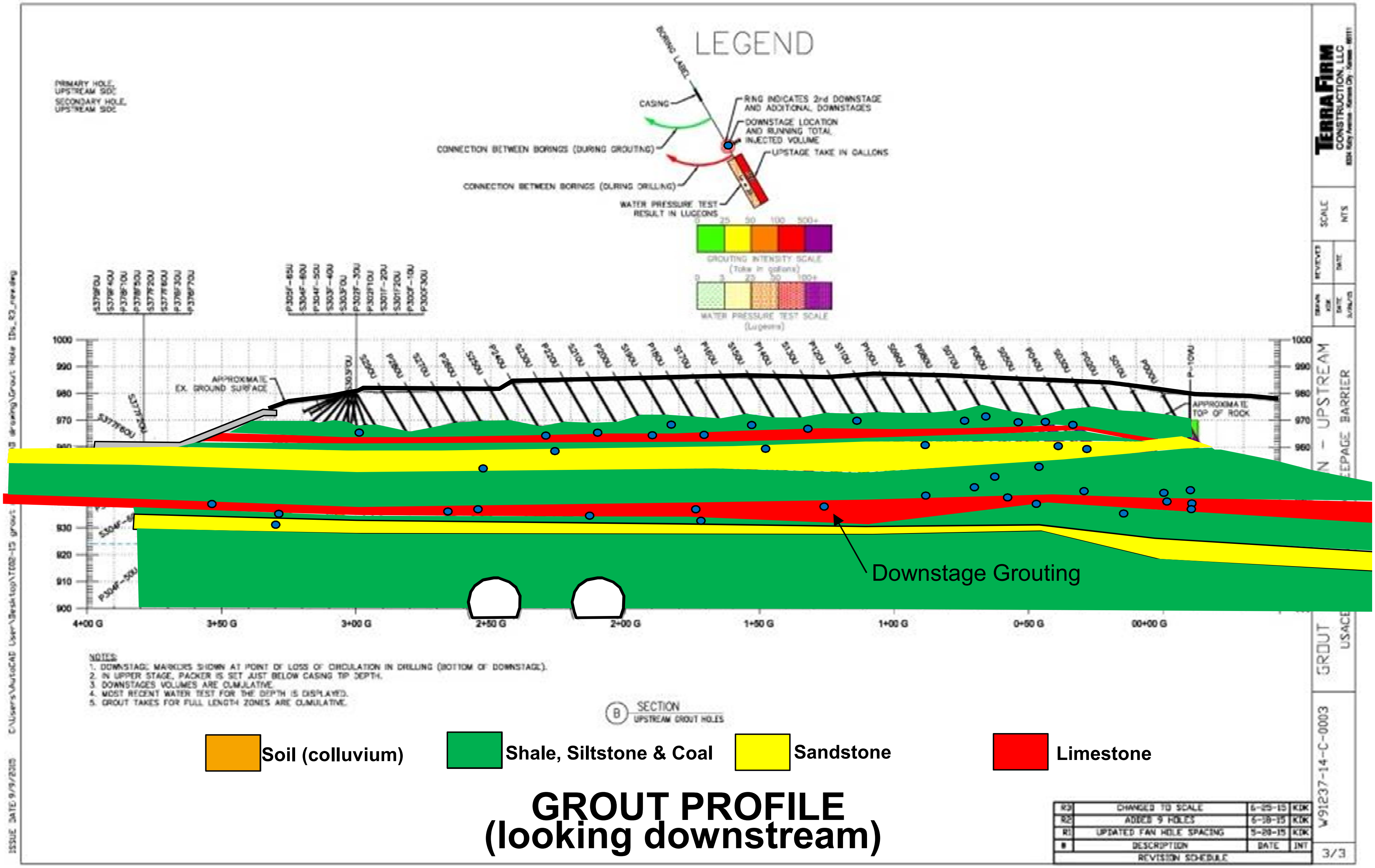


GROUT RECORDS – UPSTREAM LINE



GROUT PROFILE
(looking downstream)

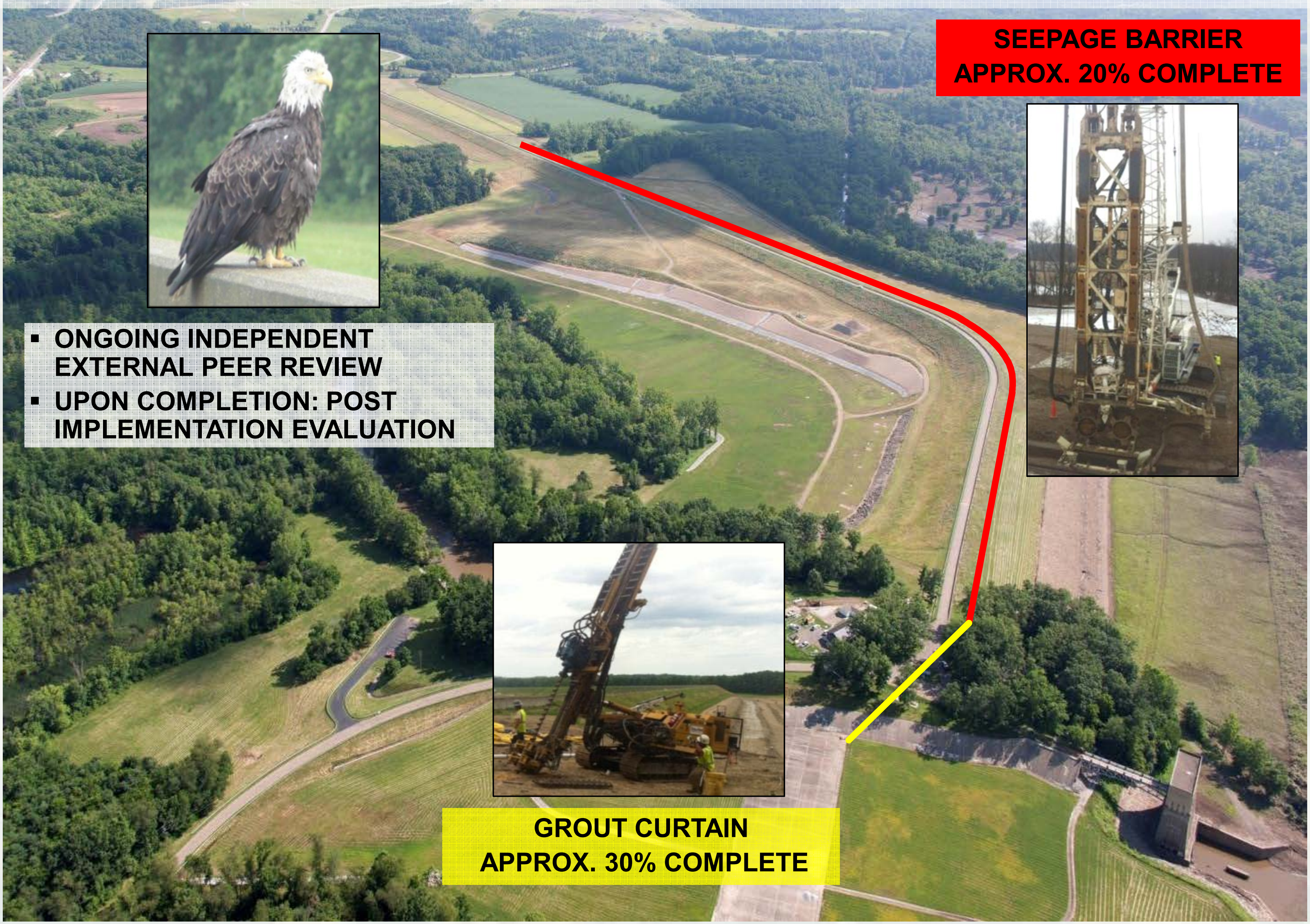
GROUT TAKES – UPSTREAM LINE



Soil (colluvium)
Shale, Siltstone & Coal
Sandstone
Limestone

GROUT PROFILE
(looking downstream)

BOLIVAR DAM: SEEPAGE BARRIER & GROUTING



TALE OF THREE PROJECTS - OUTLINE

A. MUSKINGUM REGION

B. DOVER DAM (foundation anchors)

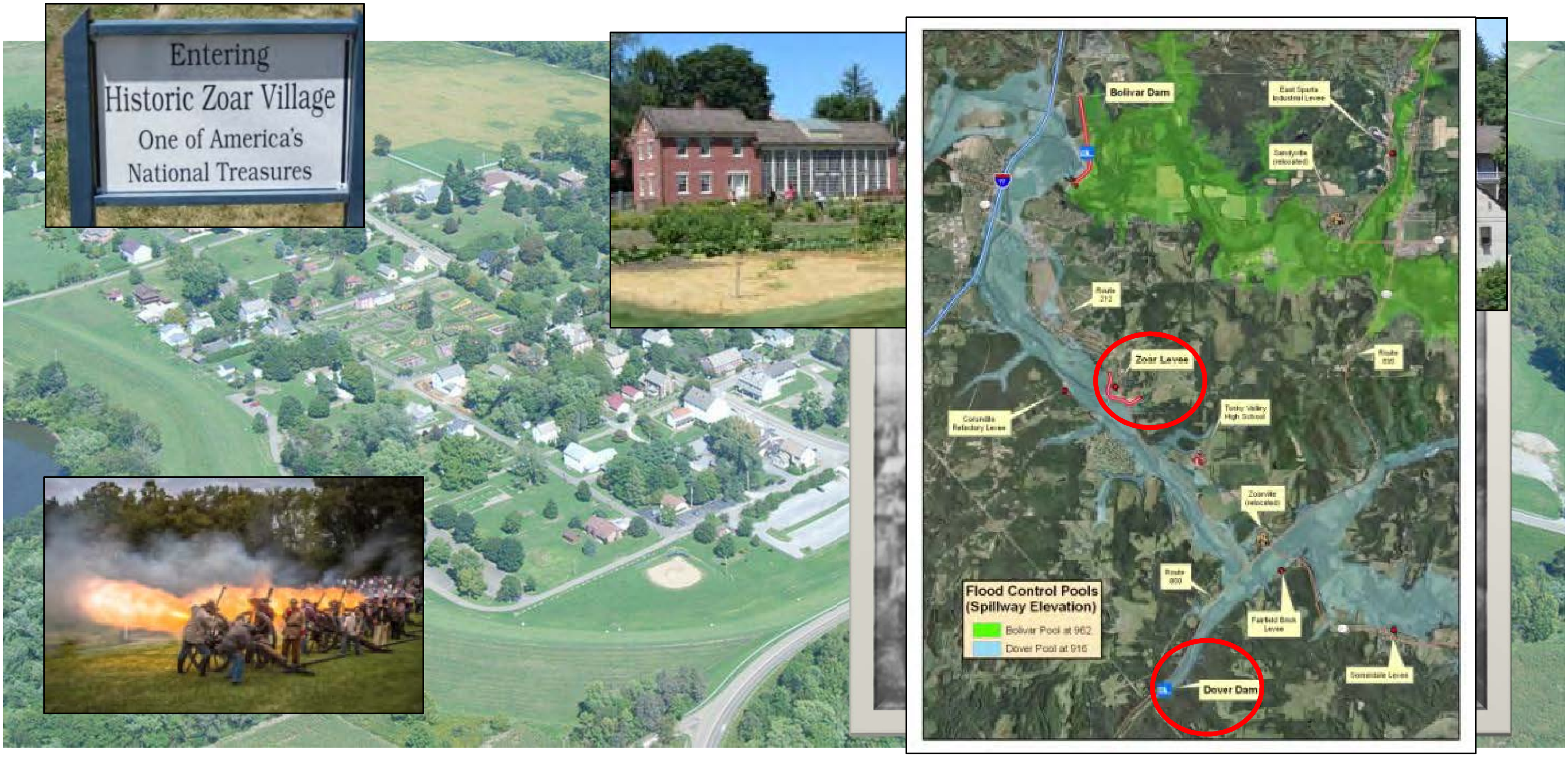
C. BOLIVAR DAM (seepage barrier & grouting)

1. **Internal Erosion in Soil Foundation**
2. **Seepage Wall Construction**
3. **Bedrock Abutment Seepage**
4. **Grout Curtain Construction**

D. ZOAR LEVEE (risk assessment)

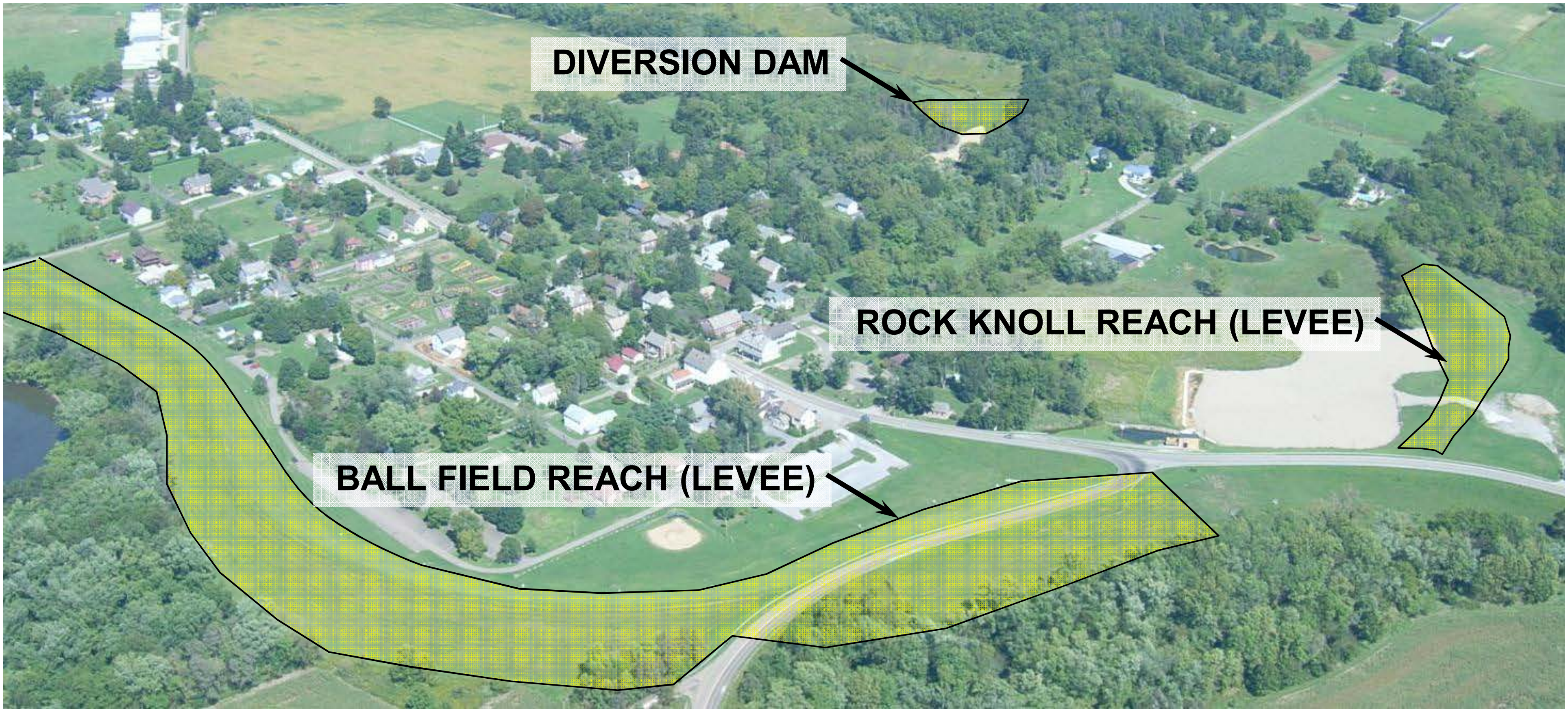
1. **Diversion Dam**
2. **Rock Knoll - Levee**
3. **Ball Field - Levee**

ZOAR LEVEE



- Historic Village (est 1817, German separatist, communal lifestyle)
- Located within Dover Pool
- Earthen Embankment Founded Primarily on Glacial Outwash
- Built in 1938
- Levee Raised 9.5’ in 1951
- Poor Performance During Flood Events – DSAC I (after 2008 event)

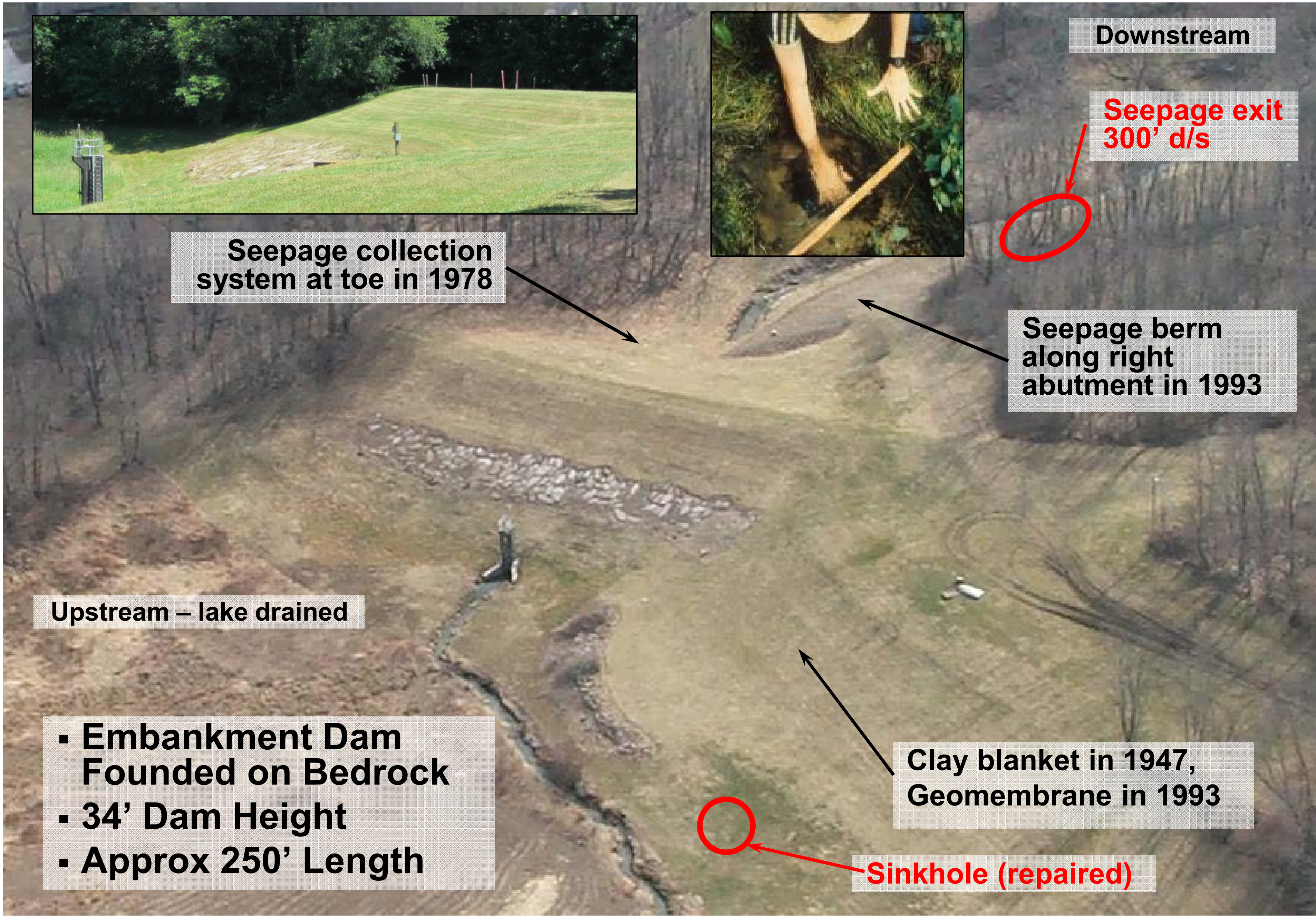
ZOAR LEVEE – THREE AREAS OF CONCERN



1. Diversion Dam
2. Rock Knoll Reach (Levee)
3. Ball Field Reach (Levee)

Several additional areas of concern are not addressed in this presentation

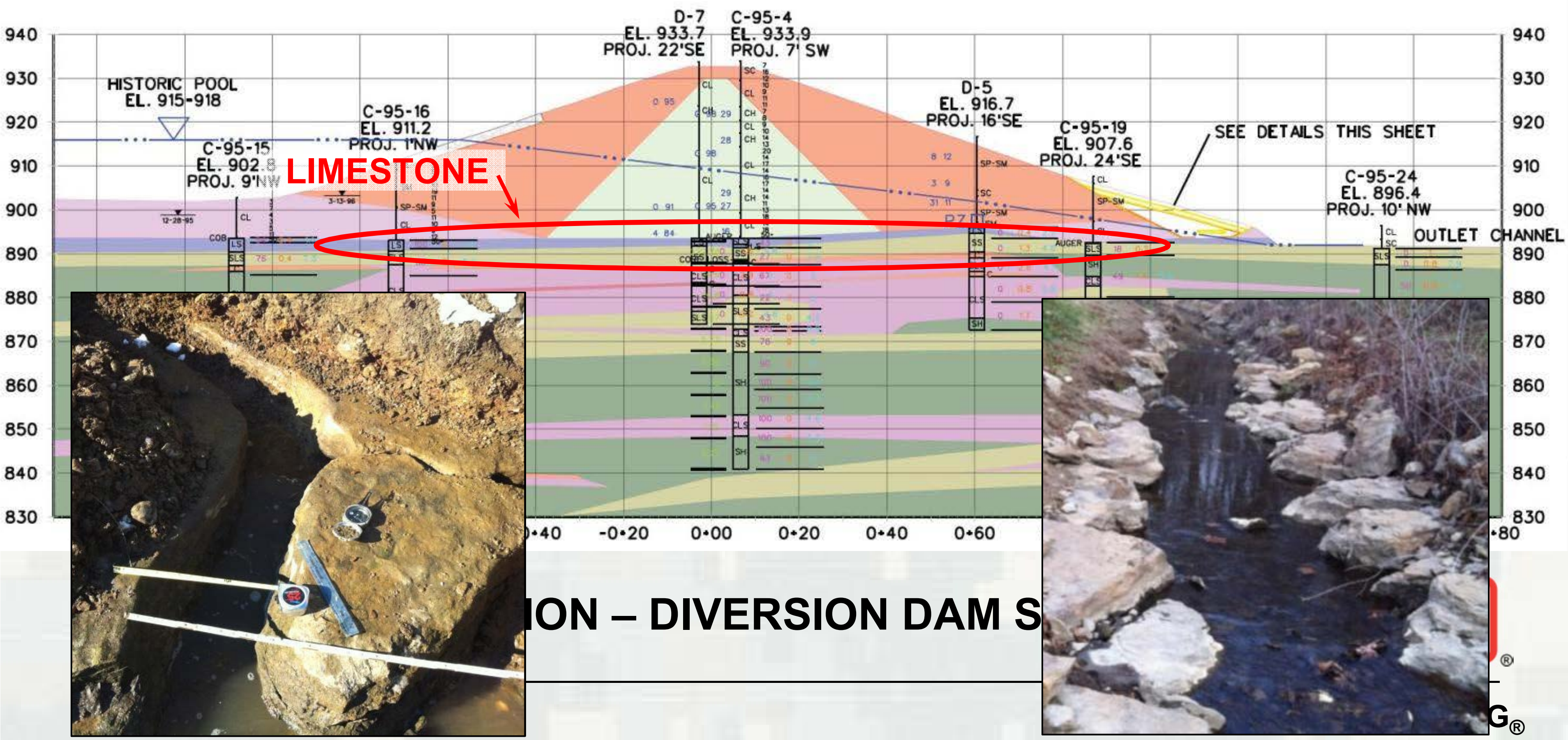
ZOAR DIVERSION DAM – AERIAL VIEW



ZOAR DIVERSION DAM – GEOLOGIC PROFILE

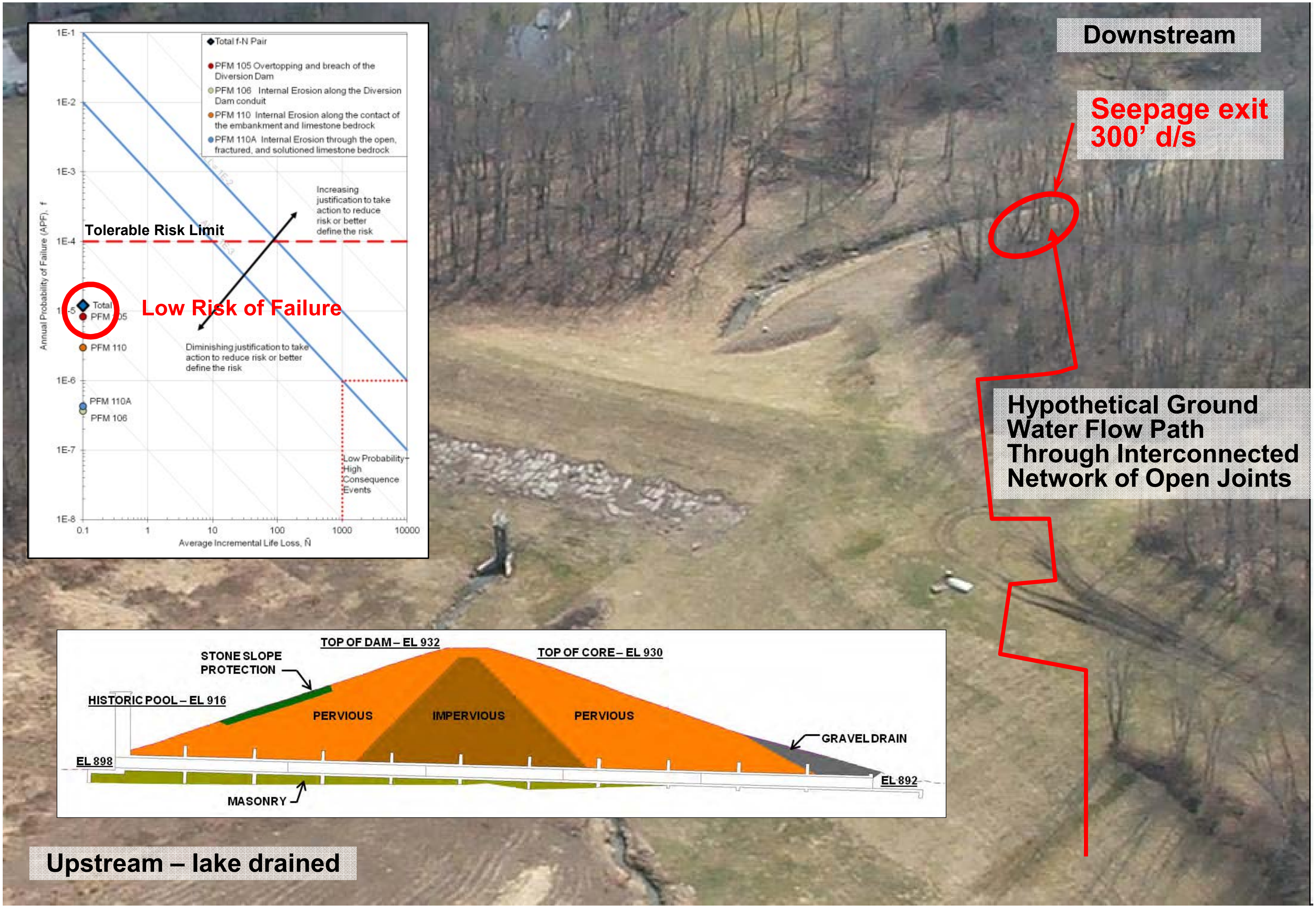
LOWER MERCER LIMESTONE

- Thin, typically 3 to 4 foot thick
- Solutioned high angled joints and low angled bedding planes create avenues for groundwater seepage
- Limestone is missing in portions of dam footprint

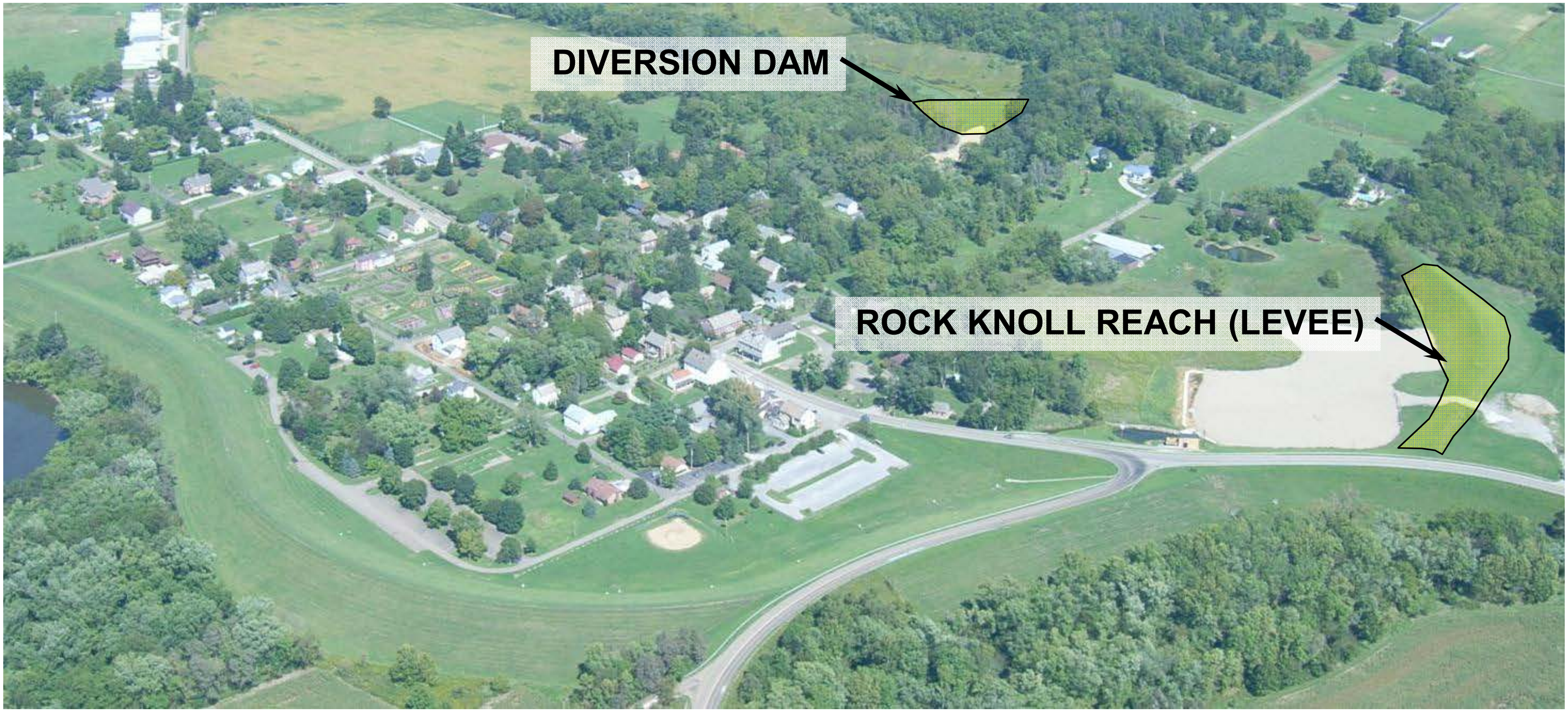


ION – DIVERSION DAM S

ZOAR DIVERSION DAM – RISK ASSESSMENT

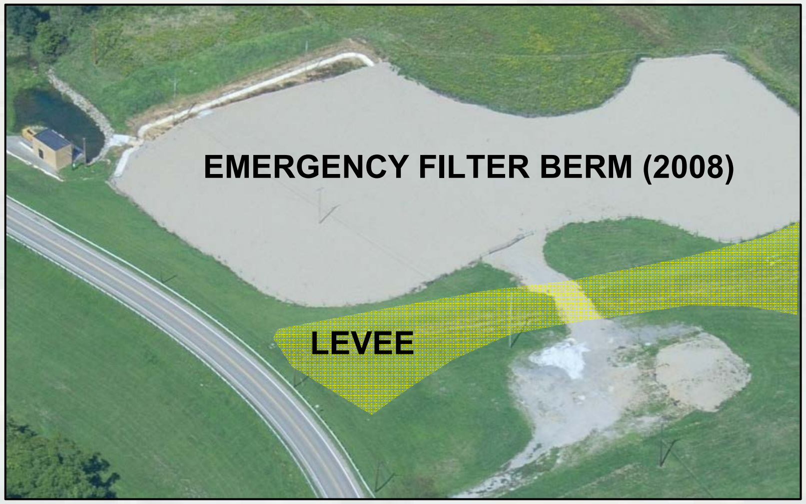


ZOAR LEVEE – THREE AREAS OF CONCERN



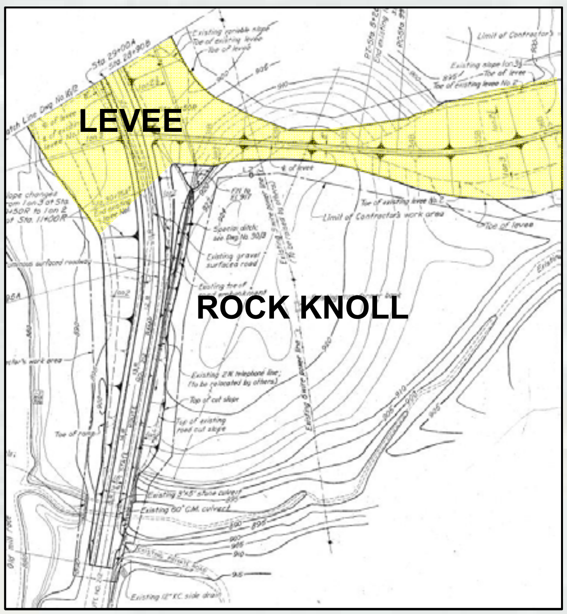
1. Diversion Dam
2. Rock Knoll Reach (Levee)

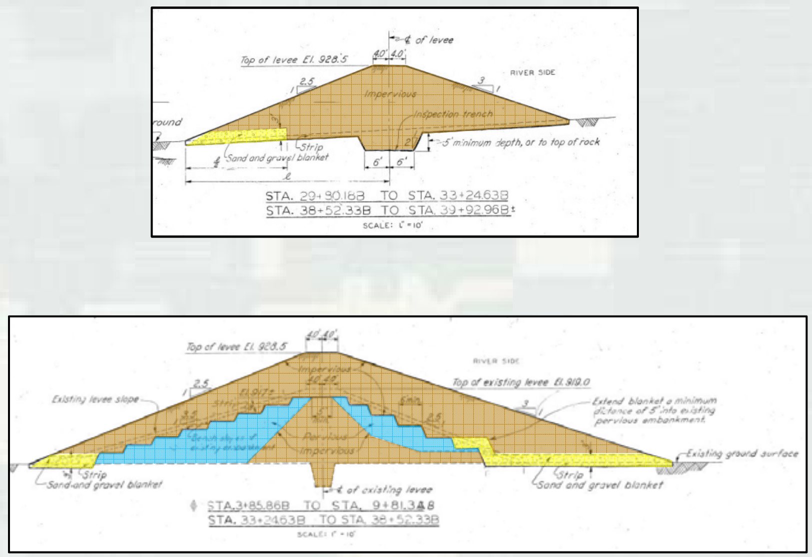
ROCK KNOLL REACH – ZOAR LEVEE



AERIAL VIEW

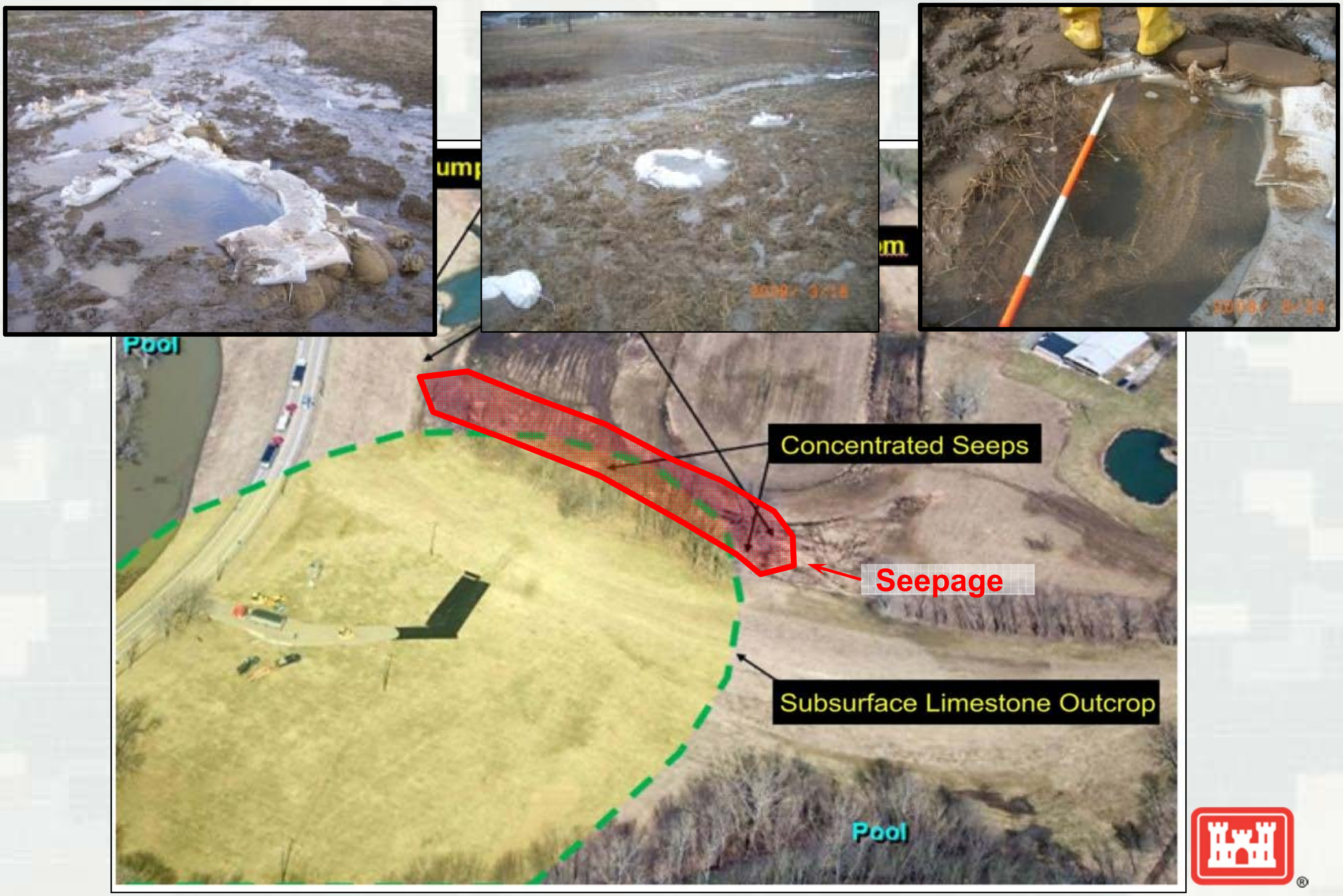
- Levee Embankment Founded on Glacial Outwash (sands & gravel) and Glacial Lake Deposits (clays & silts)
- Top of Rock 5'- 25' Below Levee Foundation.
- 5' - 20' Levee Height
- Approx 500' Length (sta 30+00 – 35+00)



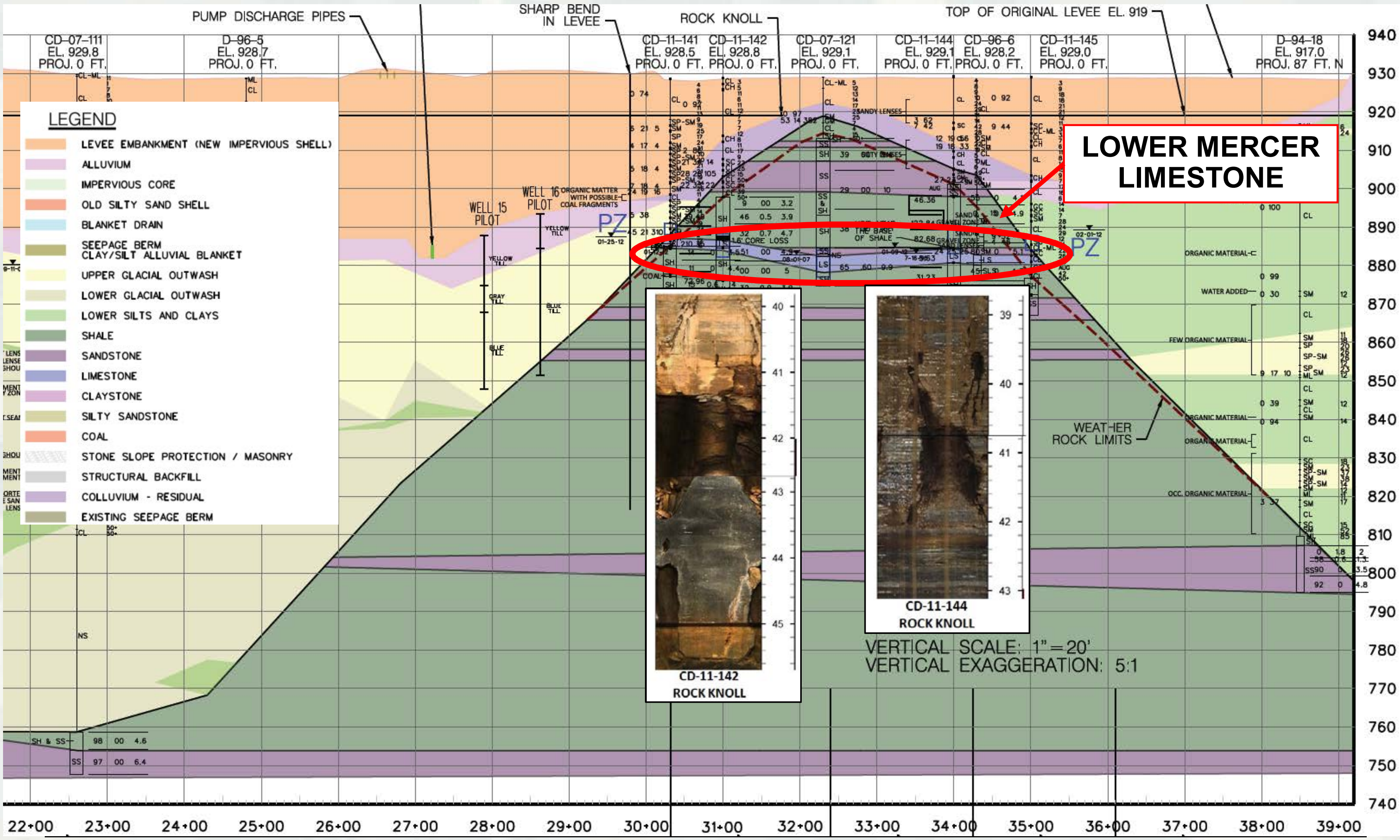


CROSS SECTIONS

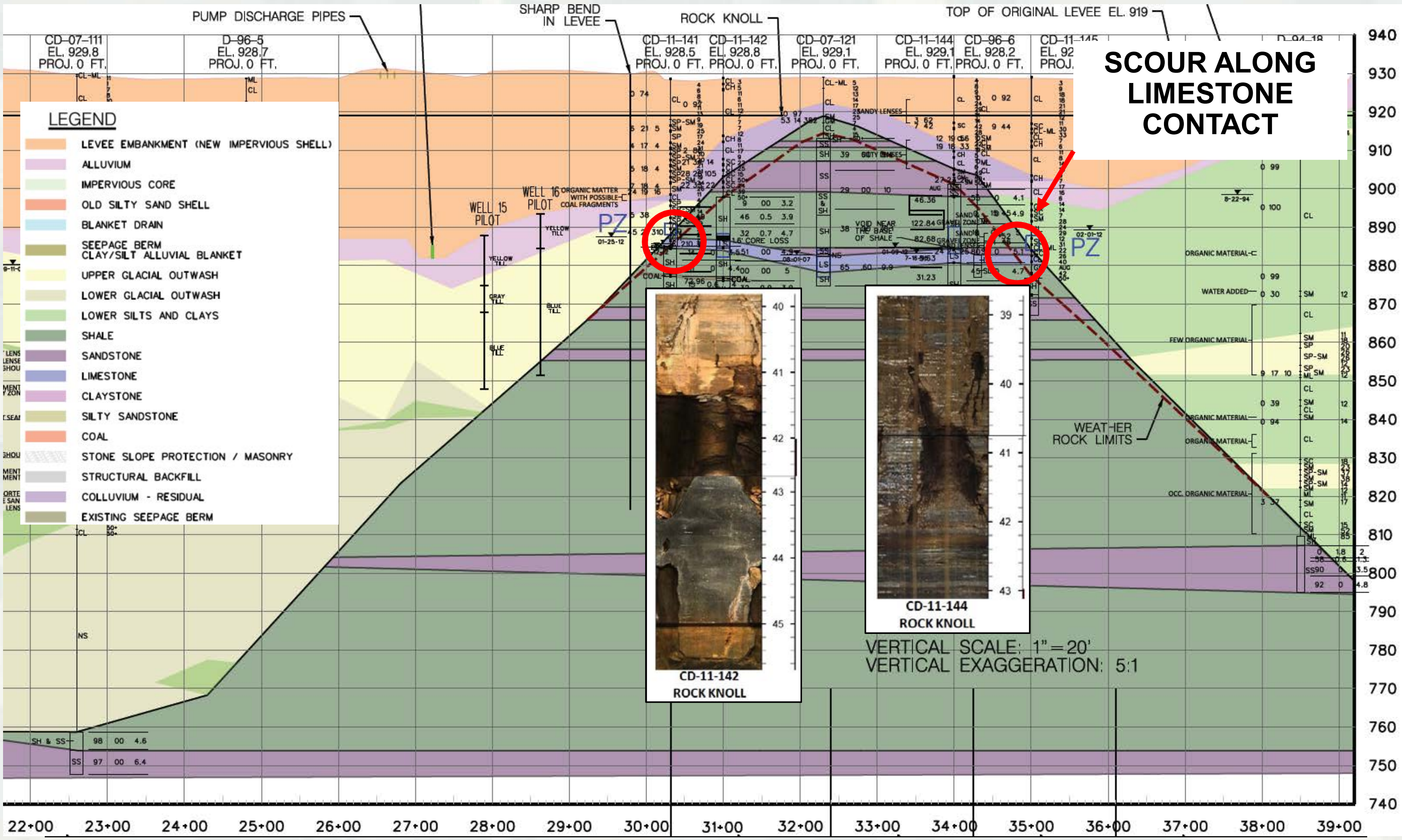
ROCK KNOLL REACH - SEEPAGE



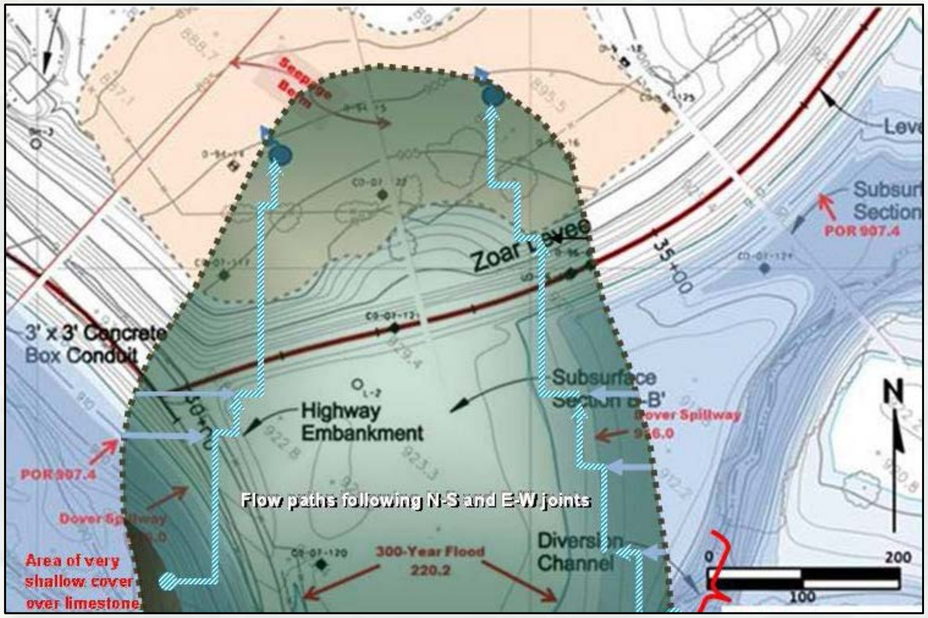
ROCK KNOLL REACH – GEOLOGIC PROFILE



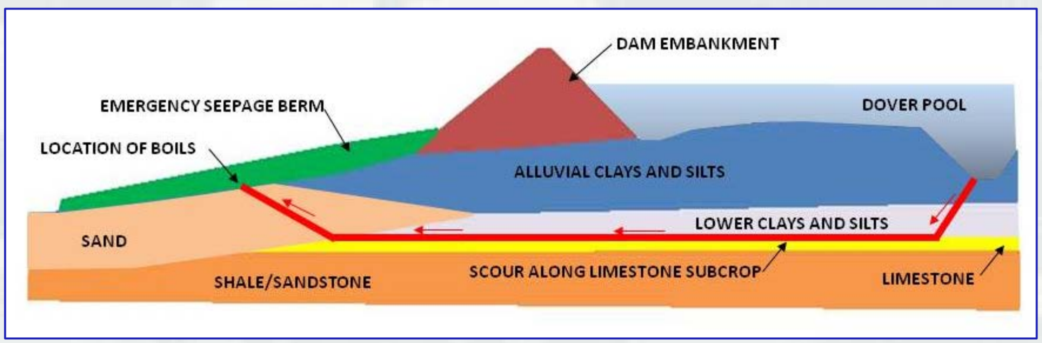
ROCK KNOLL REACH – FAILURE MODE



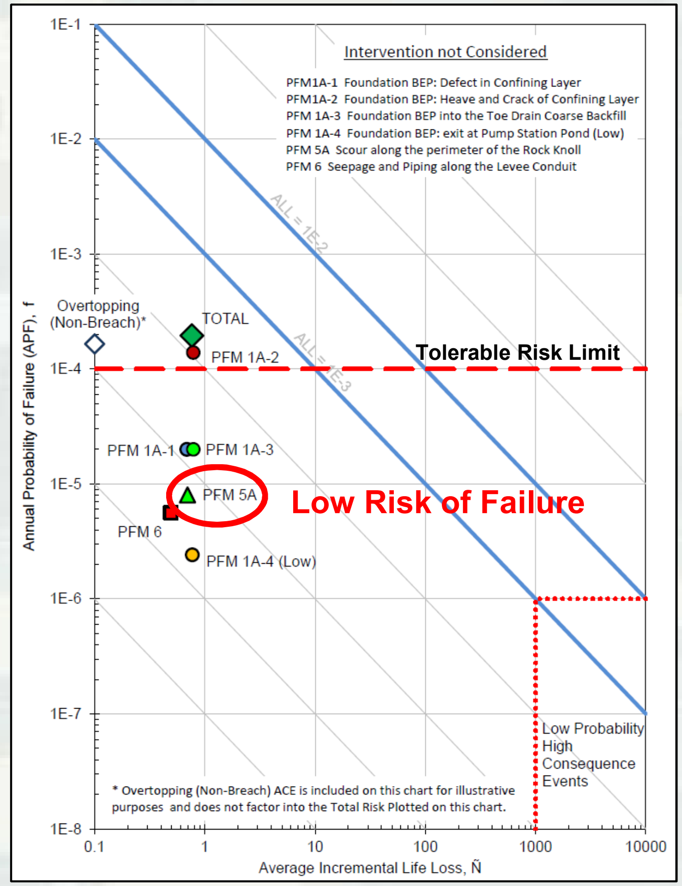
ROCK KNOLL REACH – RISK ASSESSMENT



PLAN VIEW

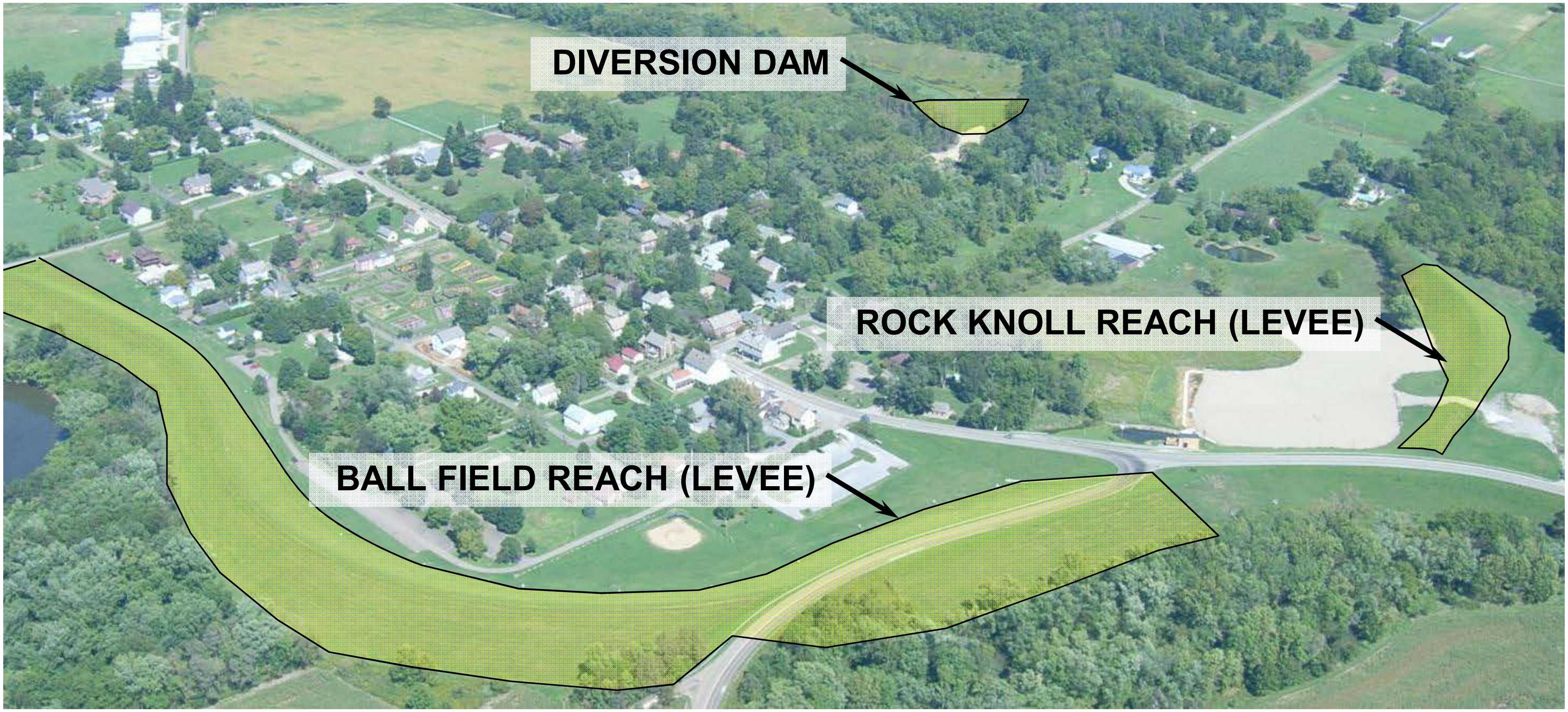


CROSS SECTION



RISK ASSESSMENT (fn chart)

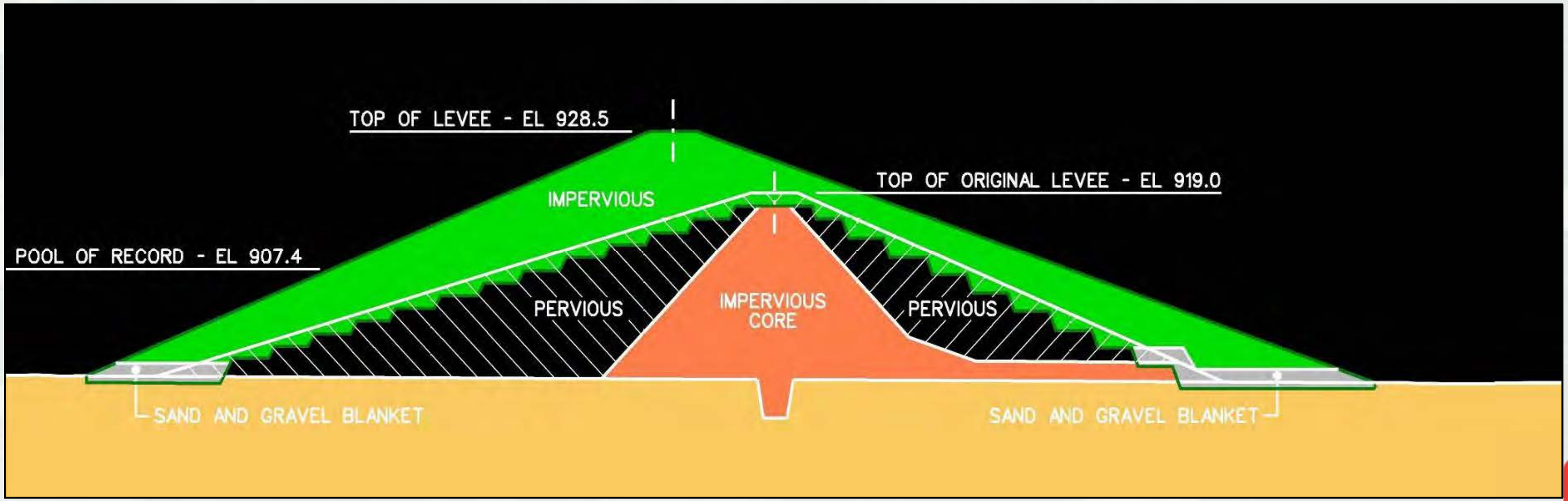
ZOAR LEVEE – THREE AREAS OF CONCERN



1. **Diversion Dam**
2. **Rock Knoll Reach (Levee)**
3. **Ball Field Reach (Levee)**

BALL FIELD REACH – ZOAR LEVEE

- Levee Embankment Founded on Glacial Outwash (sands & gravel)
- 38’ Levee Height (varies)
- Approx 2,500’ Length (ball field reach of levee)



CROSS SECTION

BALL FIELD REACH - SEEPAGE

2005

2008

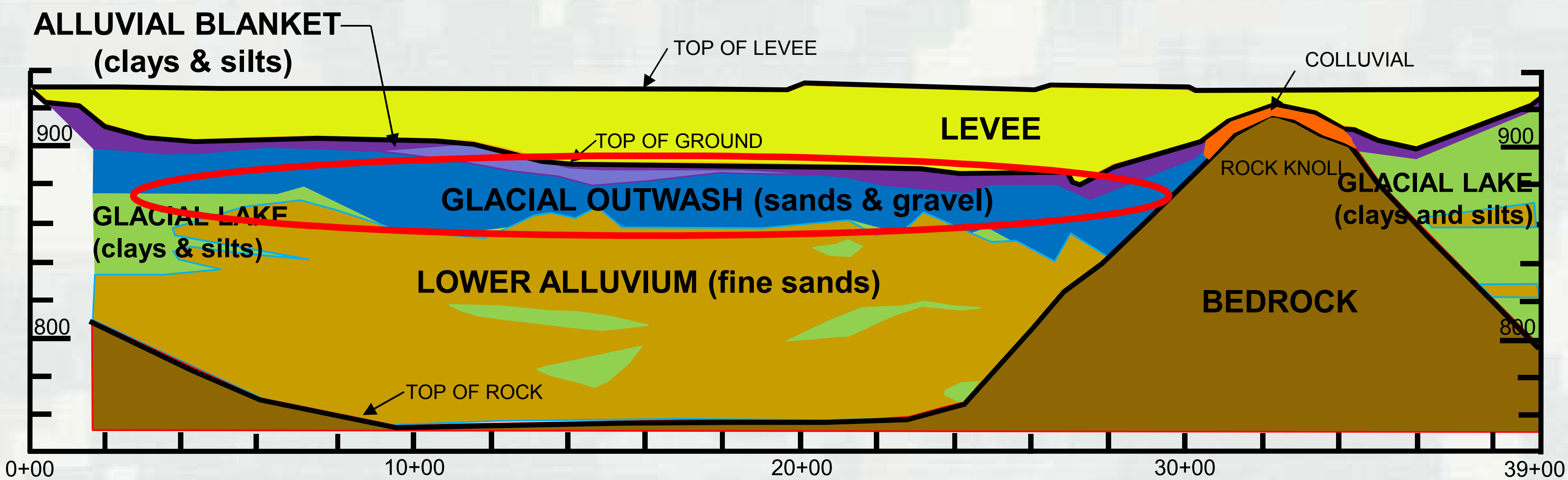






Seepage within Ball Field Reach of Levee

ZOAR LEVEE – GEOLOGIC PROFILE



LEVEE: Original levee constructed in 1937 with crest raised in 1951 to elevation 928.5.

ALLUVIAL BLANKET: Fine grained clays and silt, recent

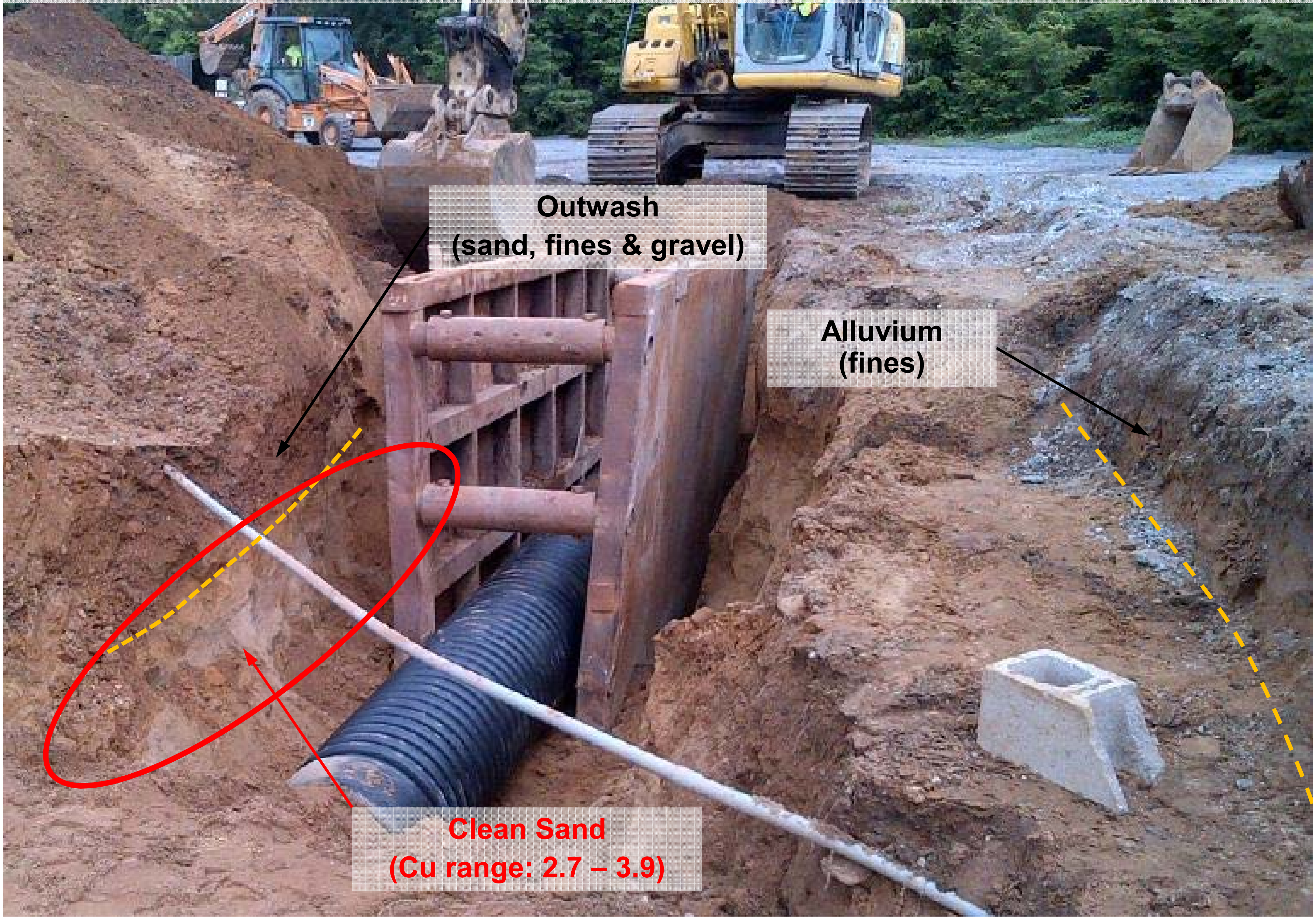
GLACIAL OUTWASH: Sands and gravels, glacial outwash, Wisconsin ice advance

GLACIAL LAKE - CLAYS AND SILTS: Clays and silts, glacial lake deposits, partially eroded and replaced by overlying Upper Glacial Outwash, Wisconsin ice advance

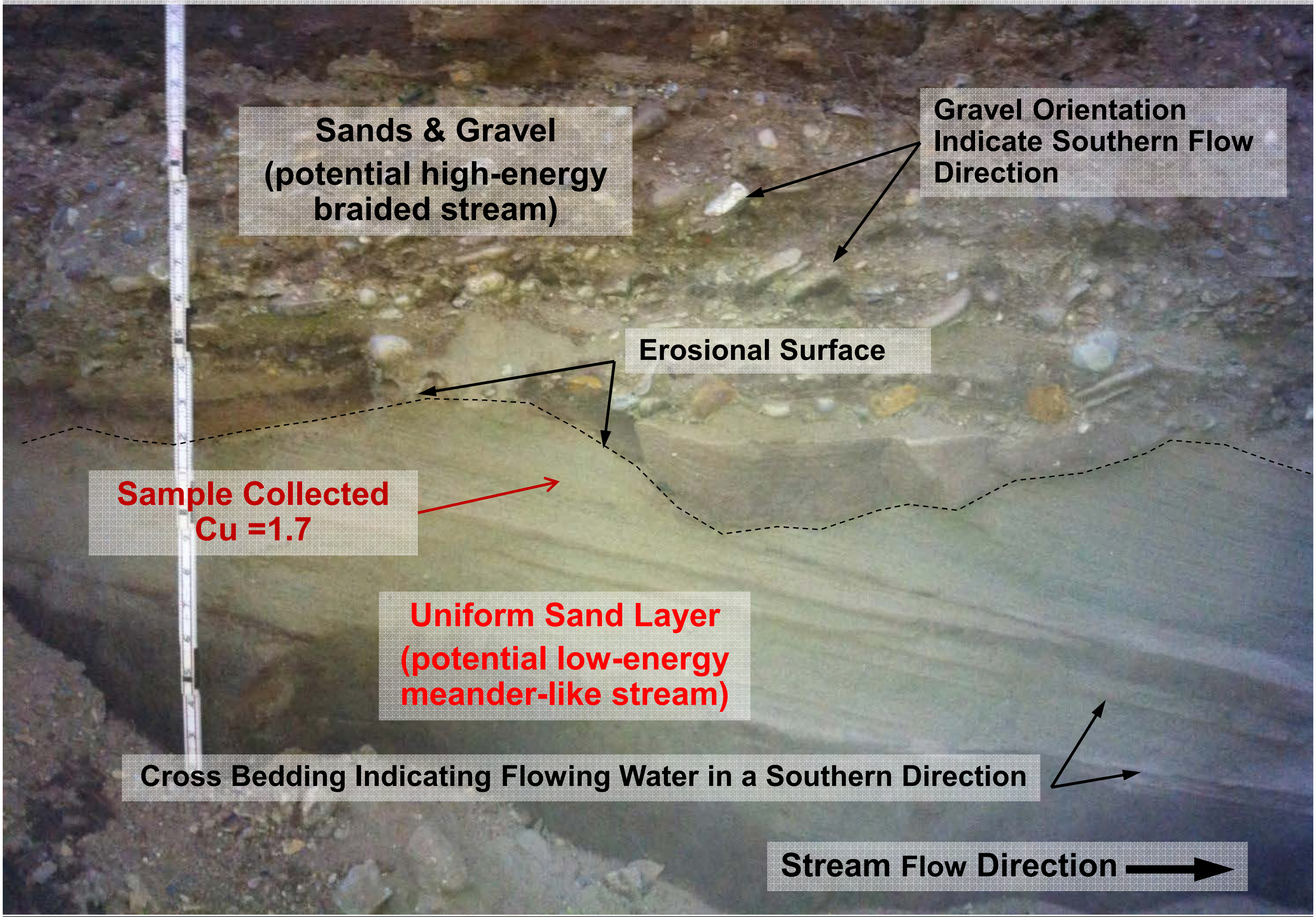
LOWER ALLUVIUM: Sand and silty sand with lenses of clays and silts, alluvial and possible isolated glacial lake deposits.

BEDROCK: Relatively flat lying sedimentary rock of the Pennsylvanian-aged Pottsville Group

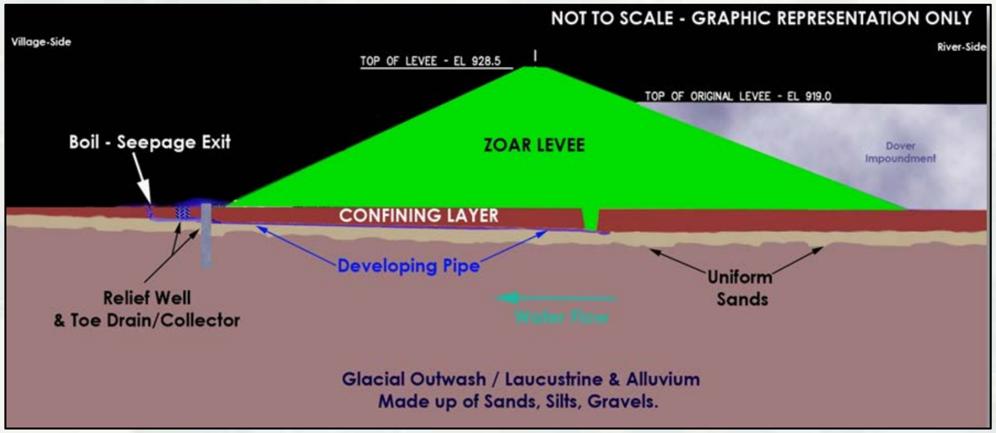
ZOAR – STORM DRAIN TRENCH



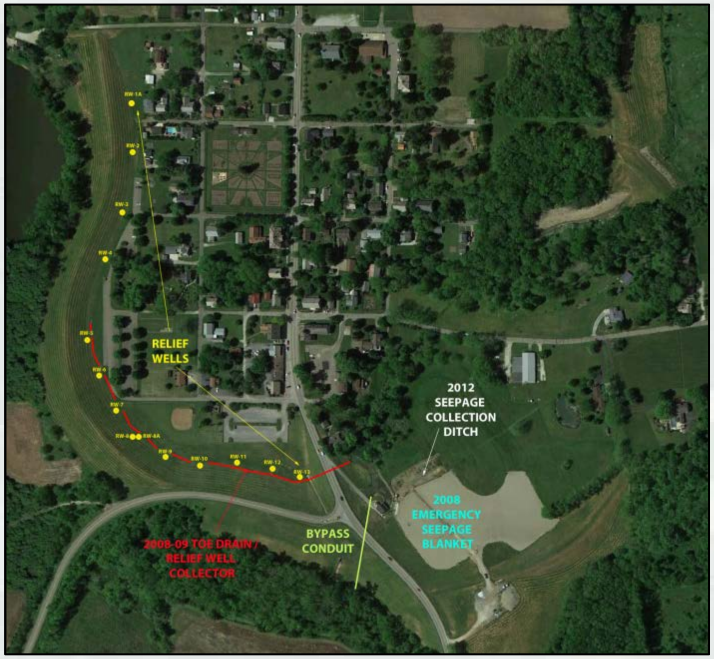
ZOAR – BIMELER HOUSE FOUNDATION



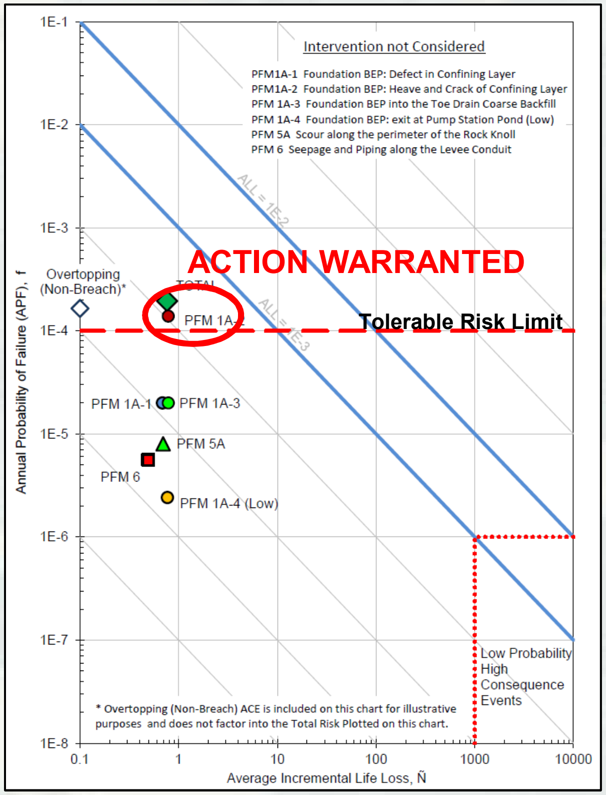
BALL FIELD REACH – RISK ASSESSMENT



CROSS SECTION

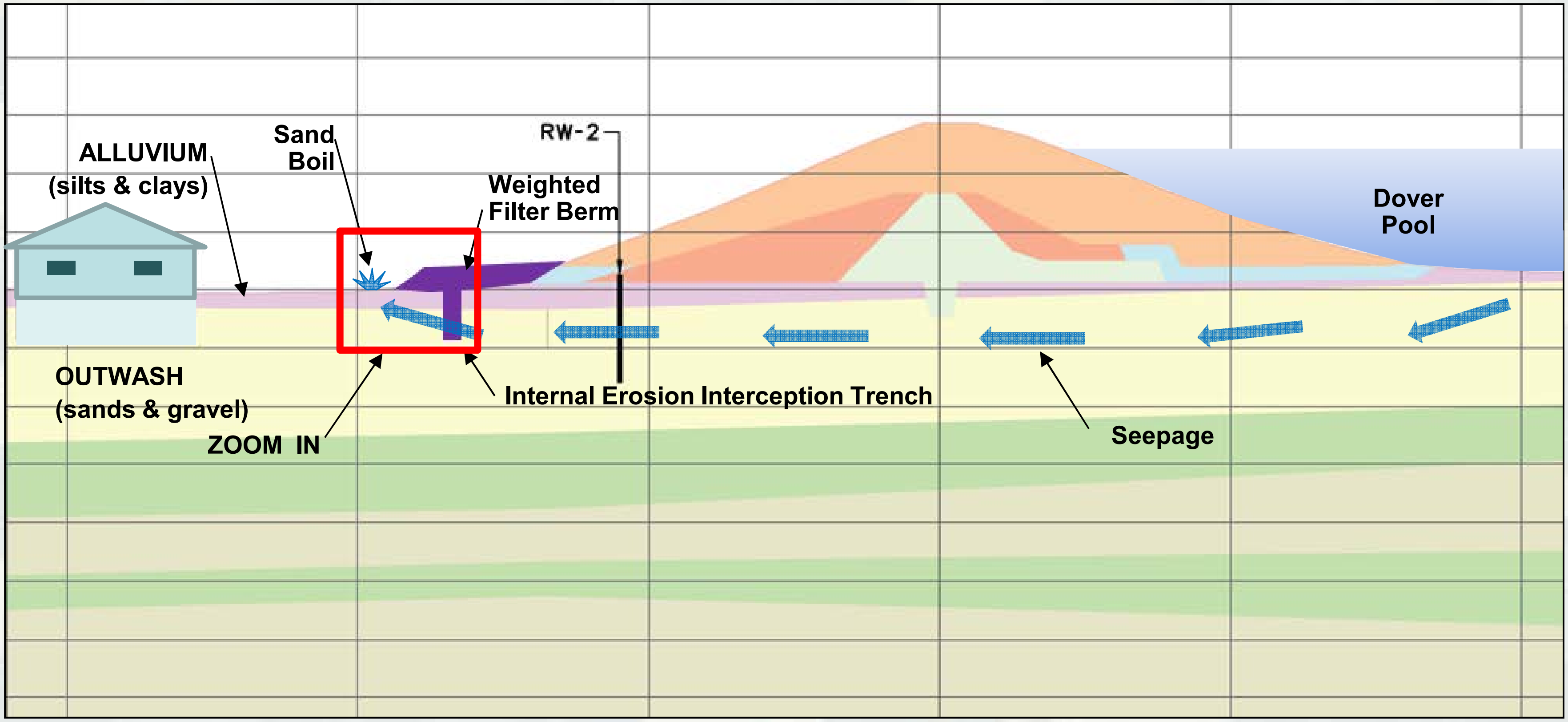


EXISTING REMEDIAL MEASURES



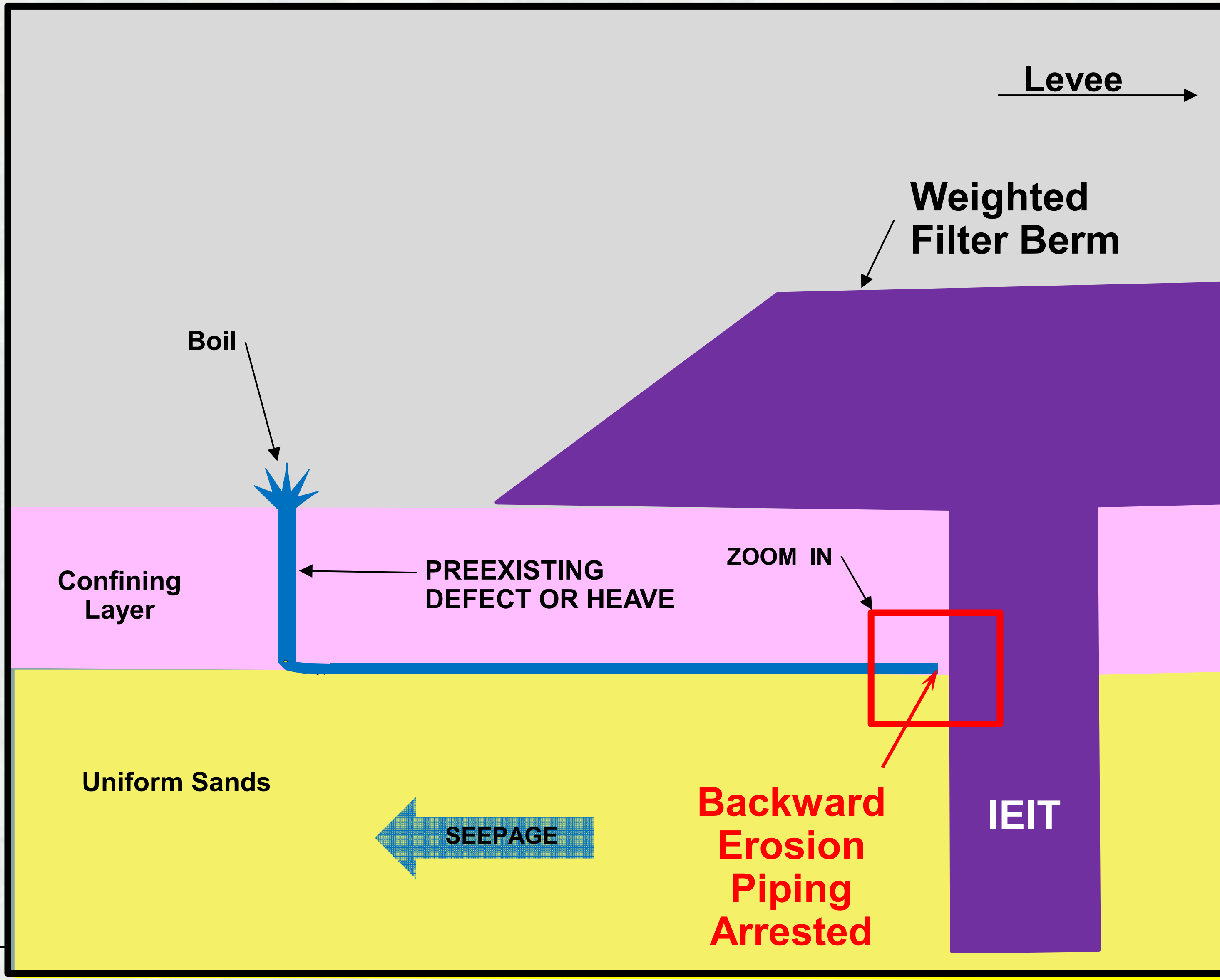
RISK ASSESSMENT
(fn chart)

BALL FIELD REACH
TENTATIVE SELECTED ALTERNATIVE

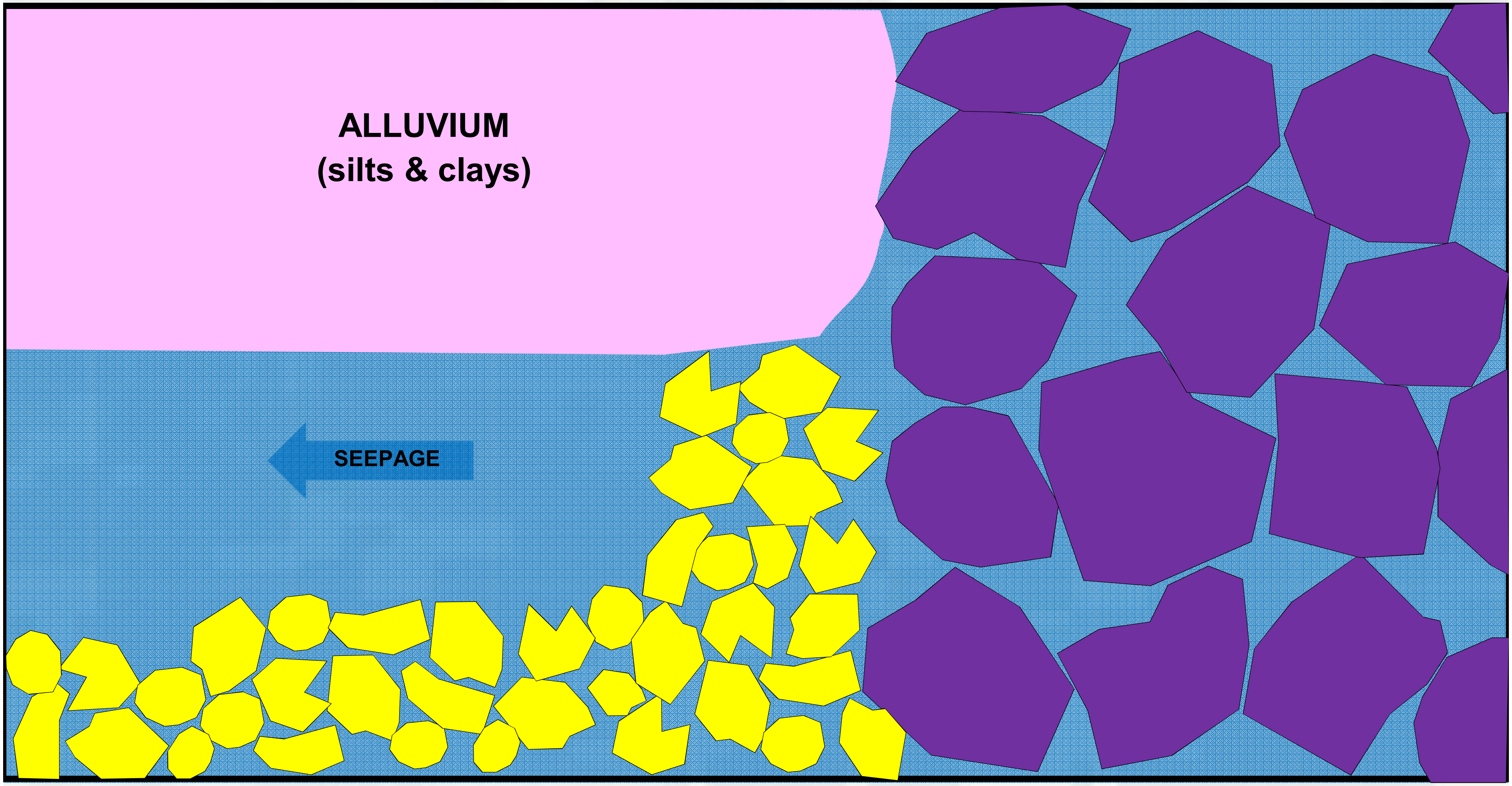


Internal Erosion Interception Trench (IEIT)

BACKWARD EROSION PIPING - FOUNDATION



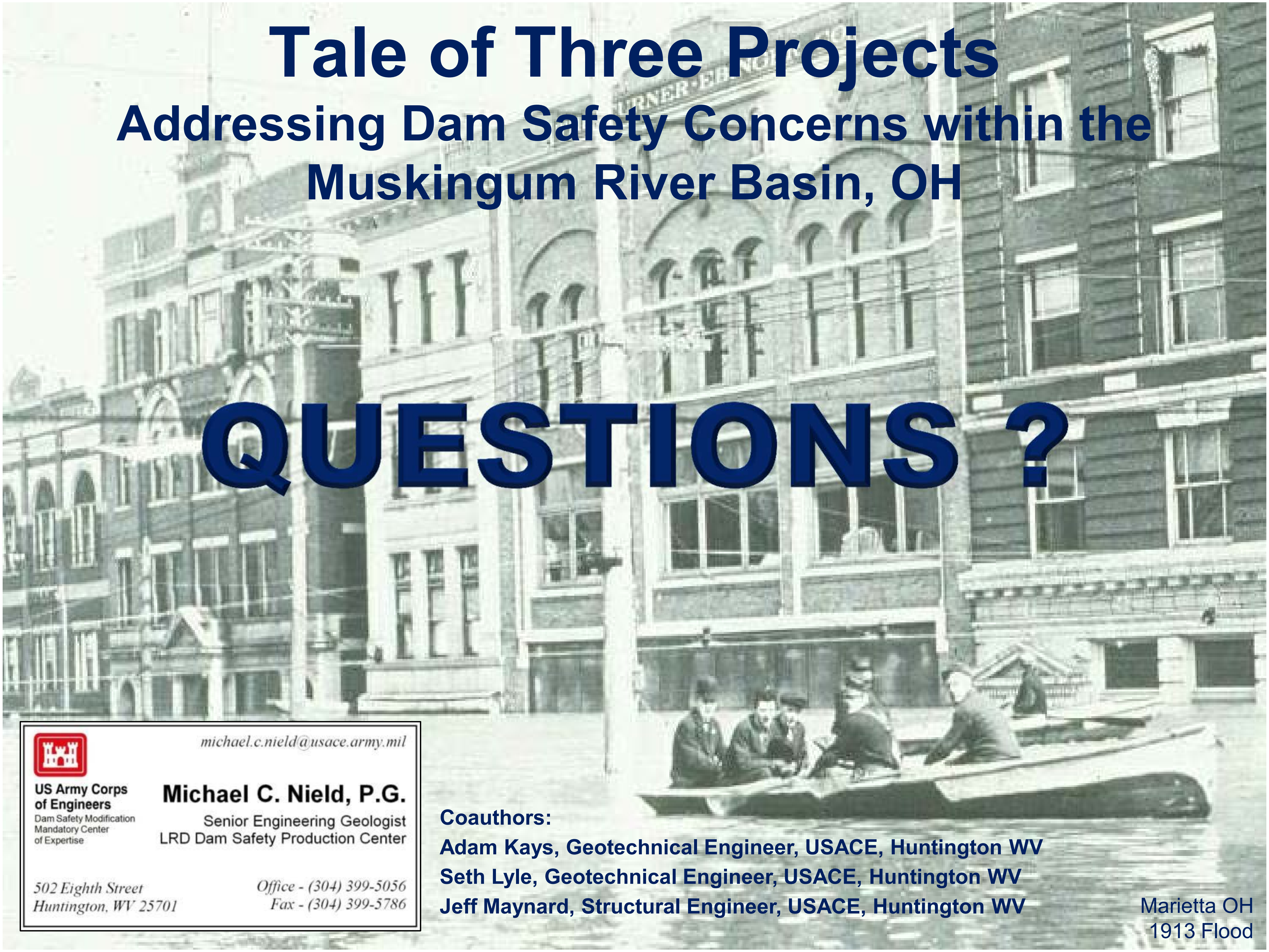
INTERNAL EROSION INTERCEPTION TRENCH (IEIT)



OUTWASH
(sands & gravel)

Tale of Three Projects

Addressing Dam Safety Concerns within the Muskingum River Basin, OH



QUESTIONS ?

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Marietta OH
1913 Flood

GROUT RECORDS – UPSTREAM LINE