Bedrock Dewatering for Construction of Marmet and Soo Lock Projects

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US Army Corps of Engineers

BUILDING STRONG®

BEDROCK DEWATERING FOR CONSTRUCTION

OUTLINE

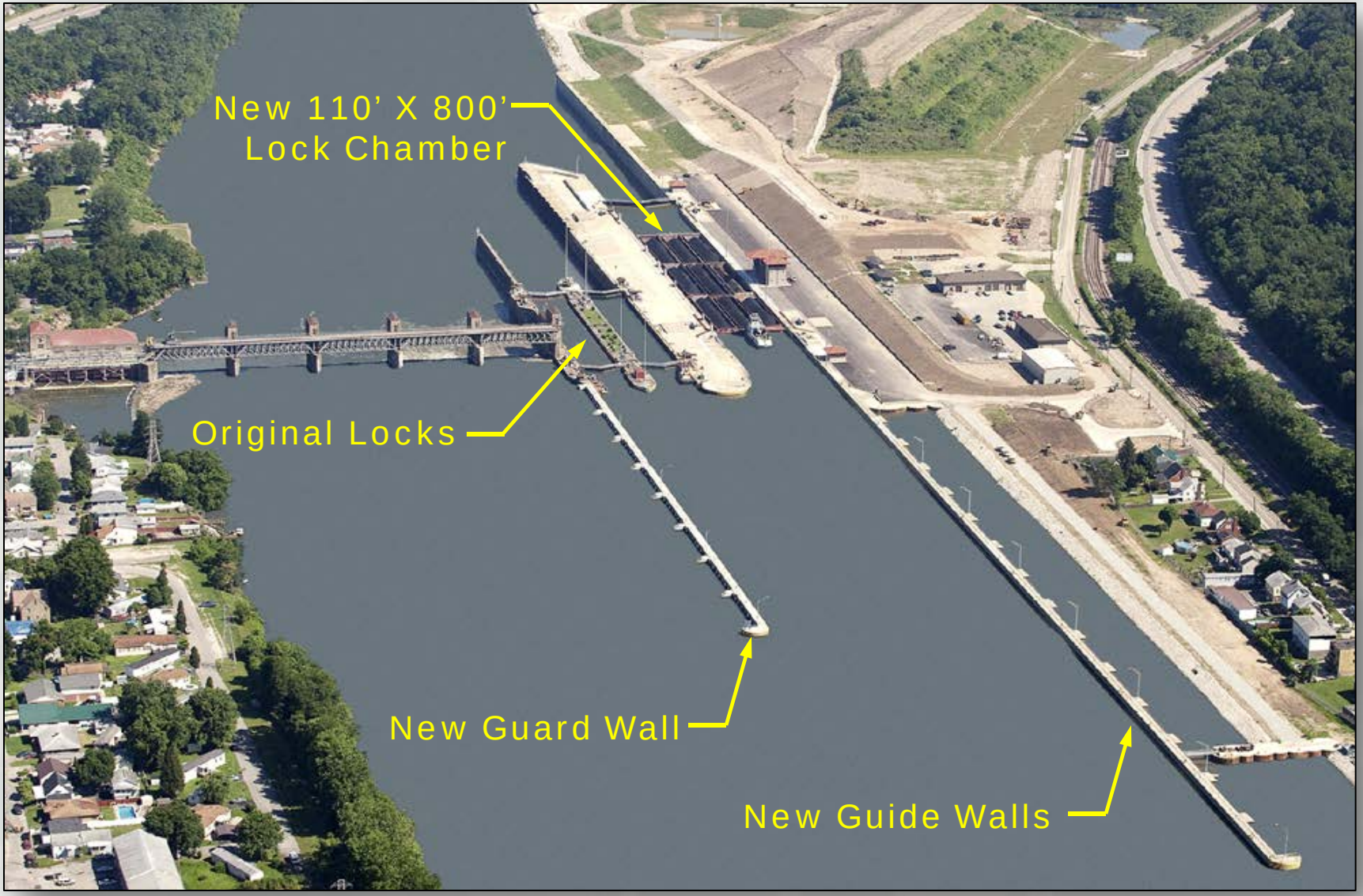
1. Marmet Lock Replacement Project (construction)
   - Project Description
   - Site Geology
   - Permeability and Groundwater Inflow
   - Dewatering Provisions

2. Soo Lock Replacement Project (design)
   - Project Description
   - Site Geology
   - Permeability and Predicted Groundwater Inflow
   - Impact to Design

MARMET LOCK - PROJECT DESCRIPTION

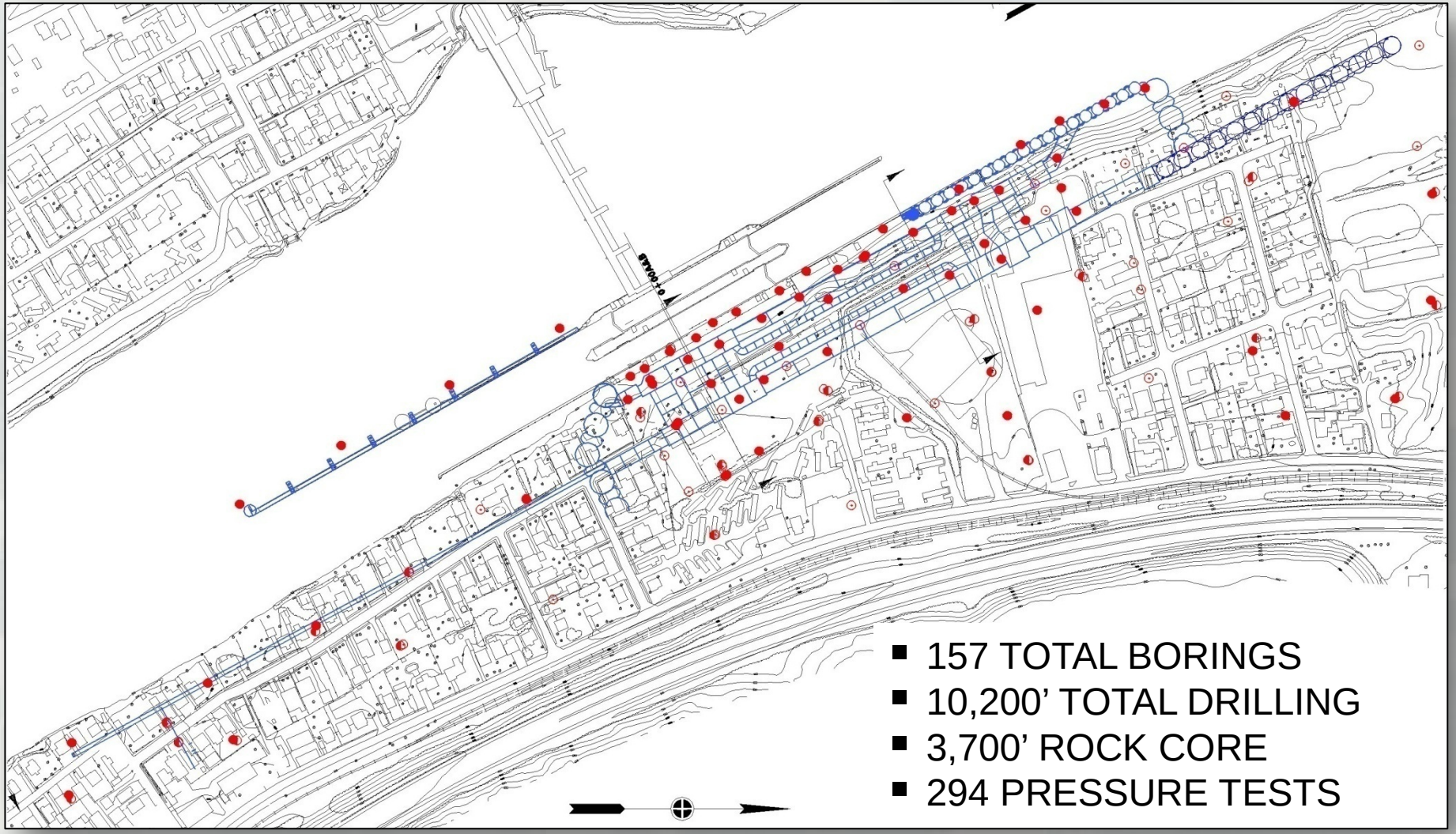
- Located on Kanawha River, near Charleston, West Virginia.
- Permits economic river transportation of coal, aggregate and chemicals.
- Construction of the new replacement lock was completed in 2009

Aerial View – Original Locks



Aerial View – New Replacement Lock

MARMET LOCK - SITE GEOLOGY



Subsurface Exploration – Boring Location Plan

General Geology

- Soil thickness 40 to 60 feet
- Relatively flat top of rock surface at elev. 552 ± 3’
- Sedimentary rock of the Pennsylvanian-aged Kanawha Formation
  Sandstone member (23 to 43 feet thick)
  Shale member (19 to 33 feet thick)
- Low angled bedding with 0°-10° dip to the Northwest
- Slightly fractured with occasional high angled joints (70°-90°)

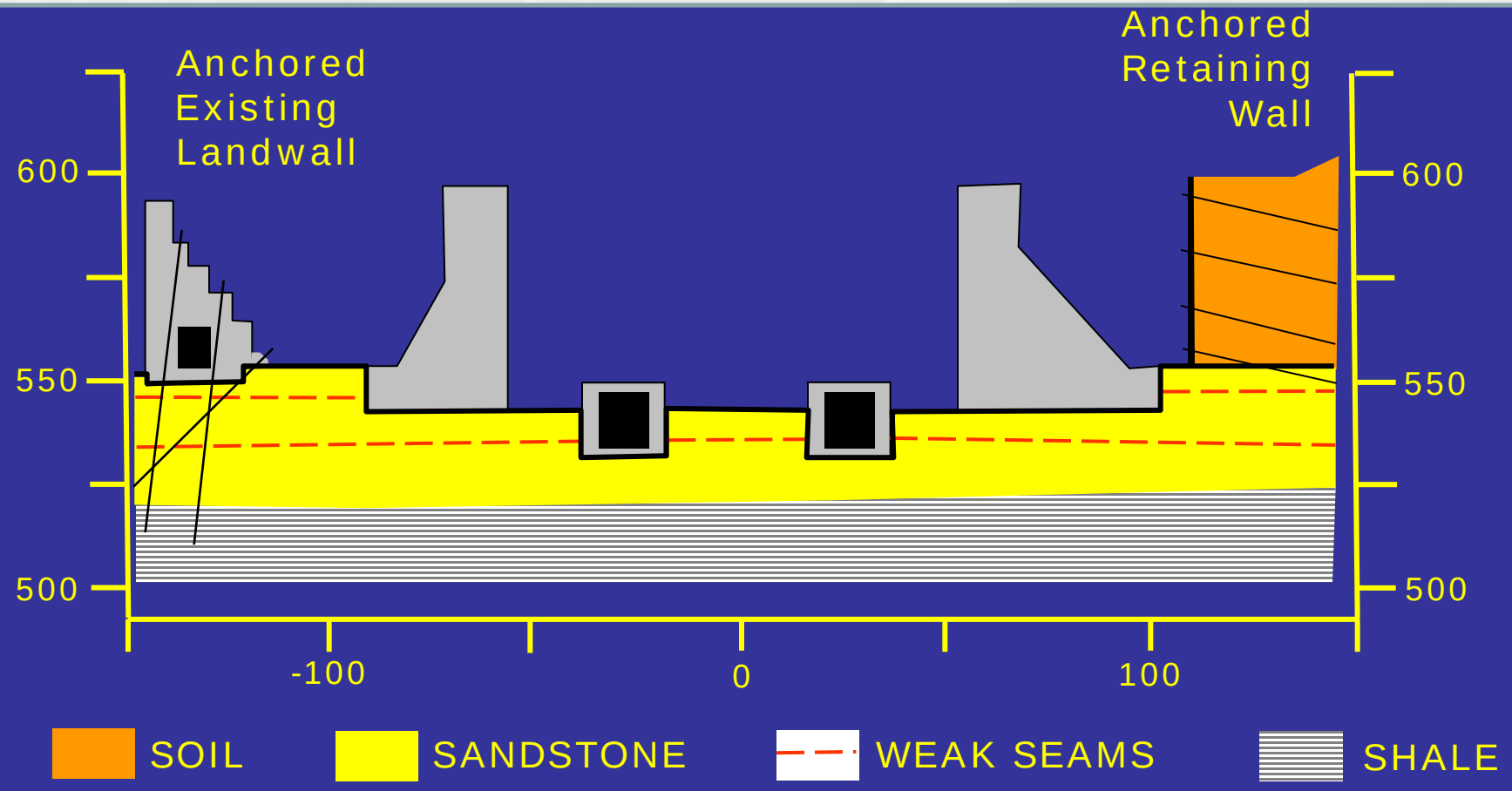
Bedrock Units - Sandstone Member

- Light gray
- Moderately hard to hard
- Medium to fine grained
- Average unconfined compressive strength 8,442 psi
- Foundation for lock walls
- Occasional thin coal seam or zone of carbonaceous stringers

Bedrock Units - Shale Member

- Gray to dark gray
- Moderately hard to soft
- Silty
- Average unconfined compressive strength 6,678 psi

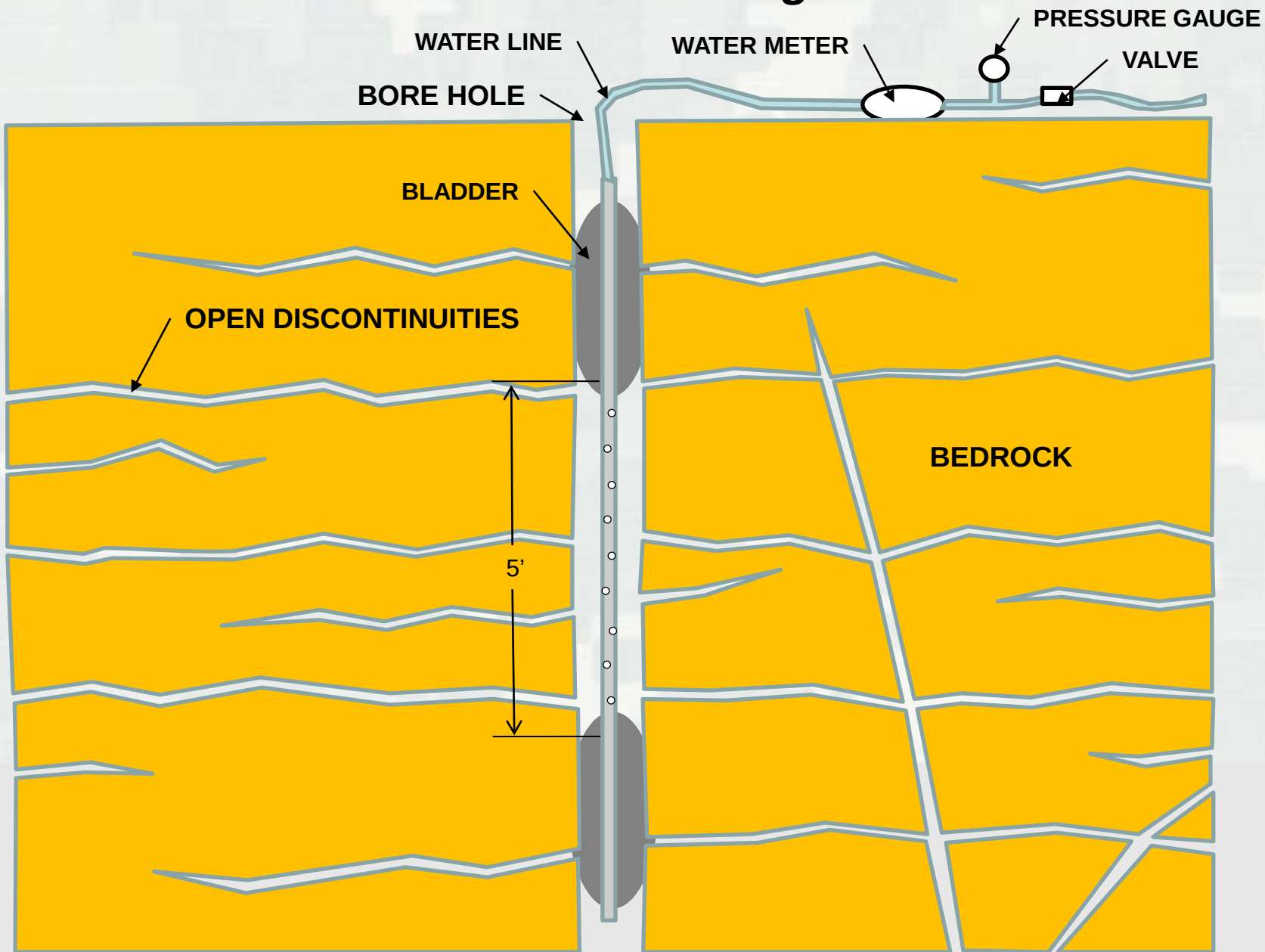
Geologic Cross Section - During Construction



Geologic Cross Section – Chamber Monoliths

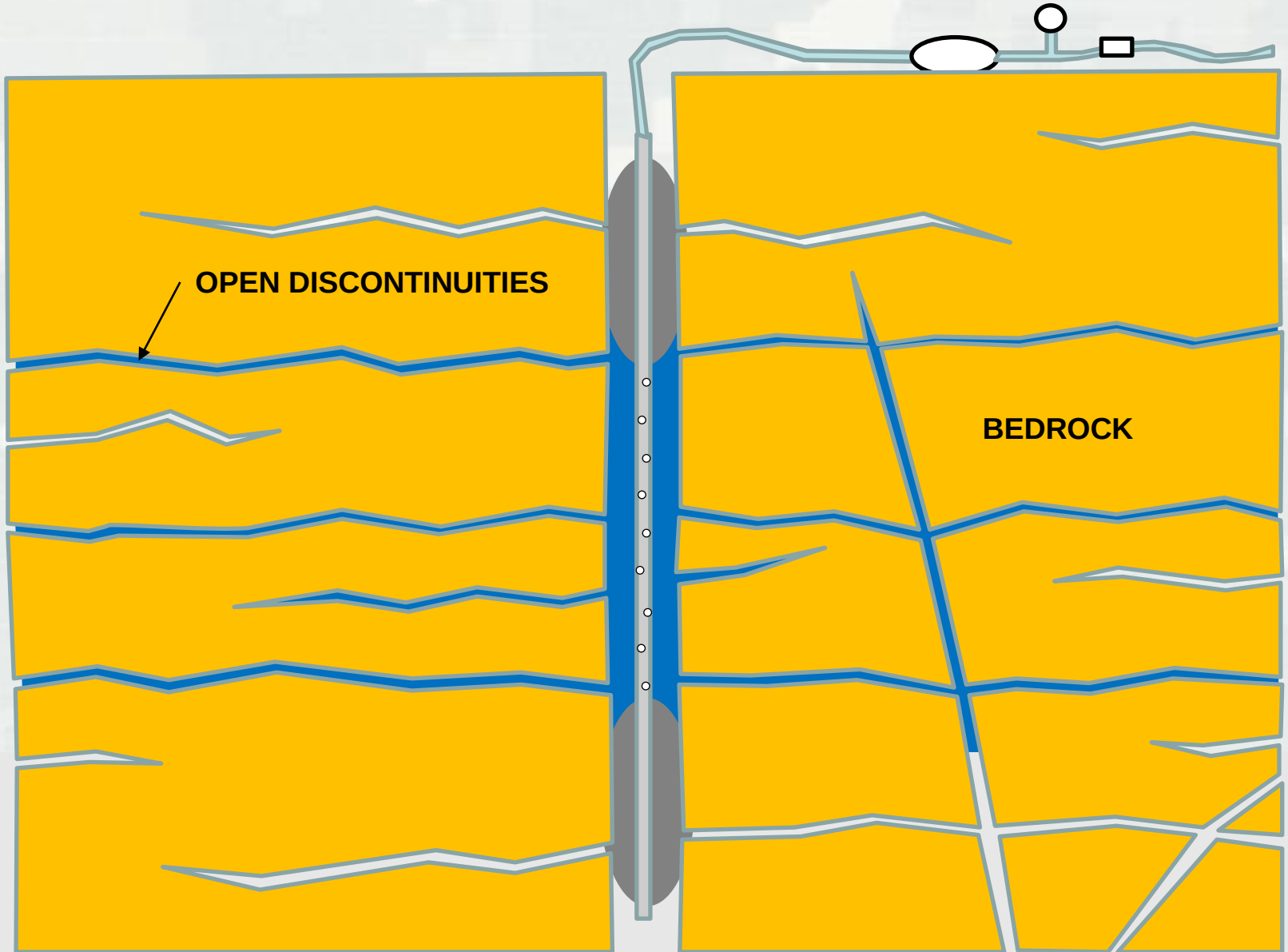
MARMET LOCK – BEDROCK PERMEABILITY

Pressure Testing



Pressure Testing

- **Measure water flow while maintaining predetermined pressure, typically recorded in gal/min, CFM.**
- **Values are often converted to Lugeons**



Hydraulic Conductivity

- 294 individual pressure tests in 36 holes located within cofferdam.

- Convert pressure testing results to Hydraulic Conductivity value K using equation from USBR:

  $$K = Q/2\pi LH \ \log_e(L/r)$$

  (Q=flow, L=length tested, H=pressure, r=hole radius)

- Convert pressure test data to Lugeon then convert to Hydraulic Conductivity K:

  $$K = Lu \times 10^{-7}$$

  (1 Lugeon equals one liter per minute per meter hole at a pressure of 10 bars)

Hydraulic Conductivity – Groundwater Inflow

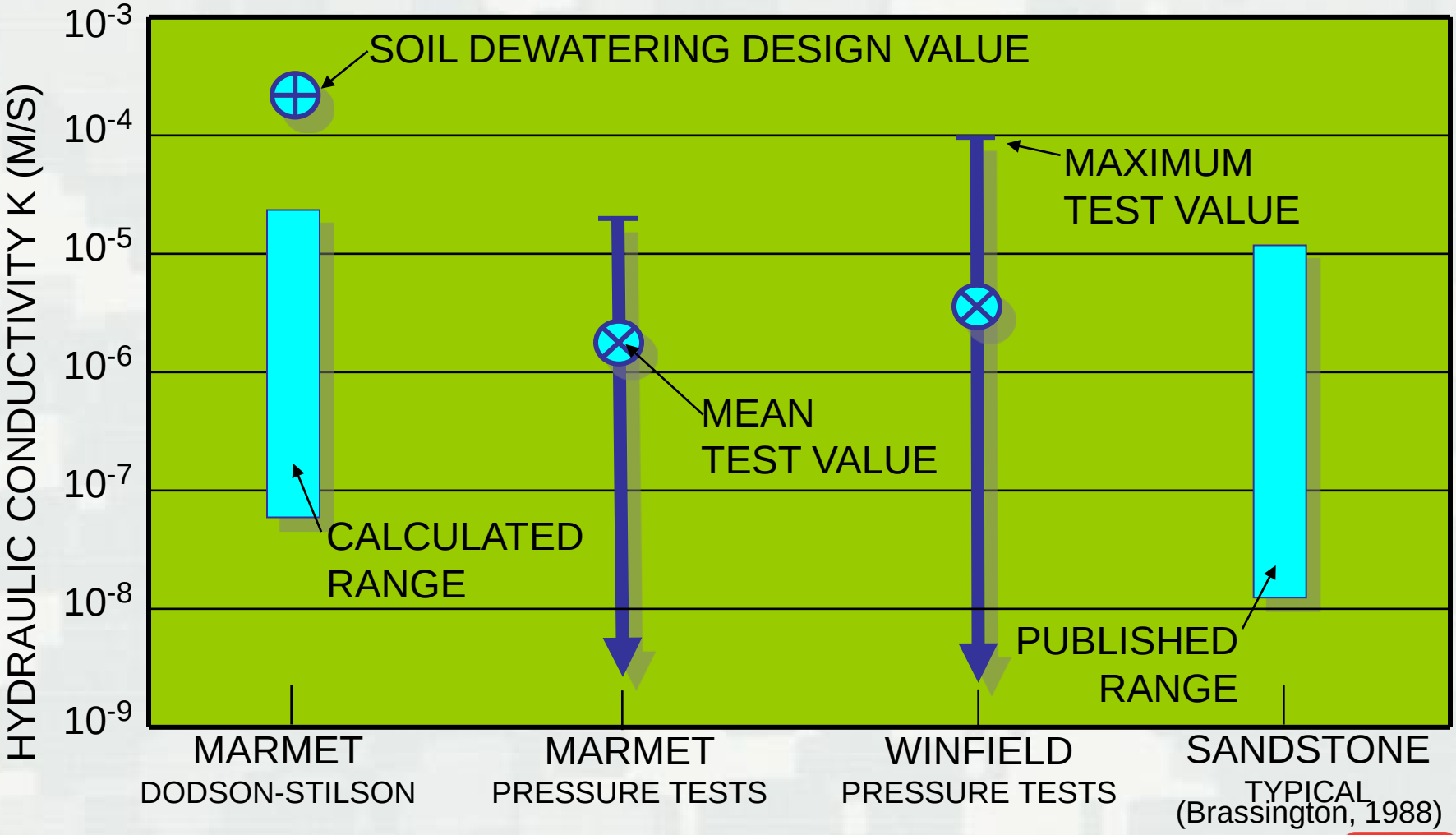
- **Average** permeability or **Hydraulic Conductivity** (K) value from pressure testing results at **Marmet is 1.69X10^{-6} m/s (5.54x10^{-6} ft/s),** which is **typical for sandstone**.

- Average Hydraulic Conductivity **values in bedrock increased when overlying soil was removed** during construction at both Marmet and Winfield projects.

- Hydraulic Conductivity, along with known hydraulic gradient and excavated surface area can be utilized to **help develop preliminary estimate of groundwater inflow** during construction (using Darcy's law).

- **Calculated inflow** from average K value is **520 gal/min** and upper bound inflow value is 7,000 gal/min.

Permeability Comparison – Logarithmic Scale



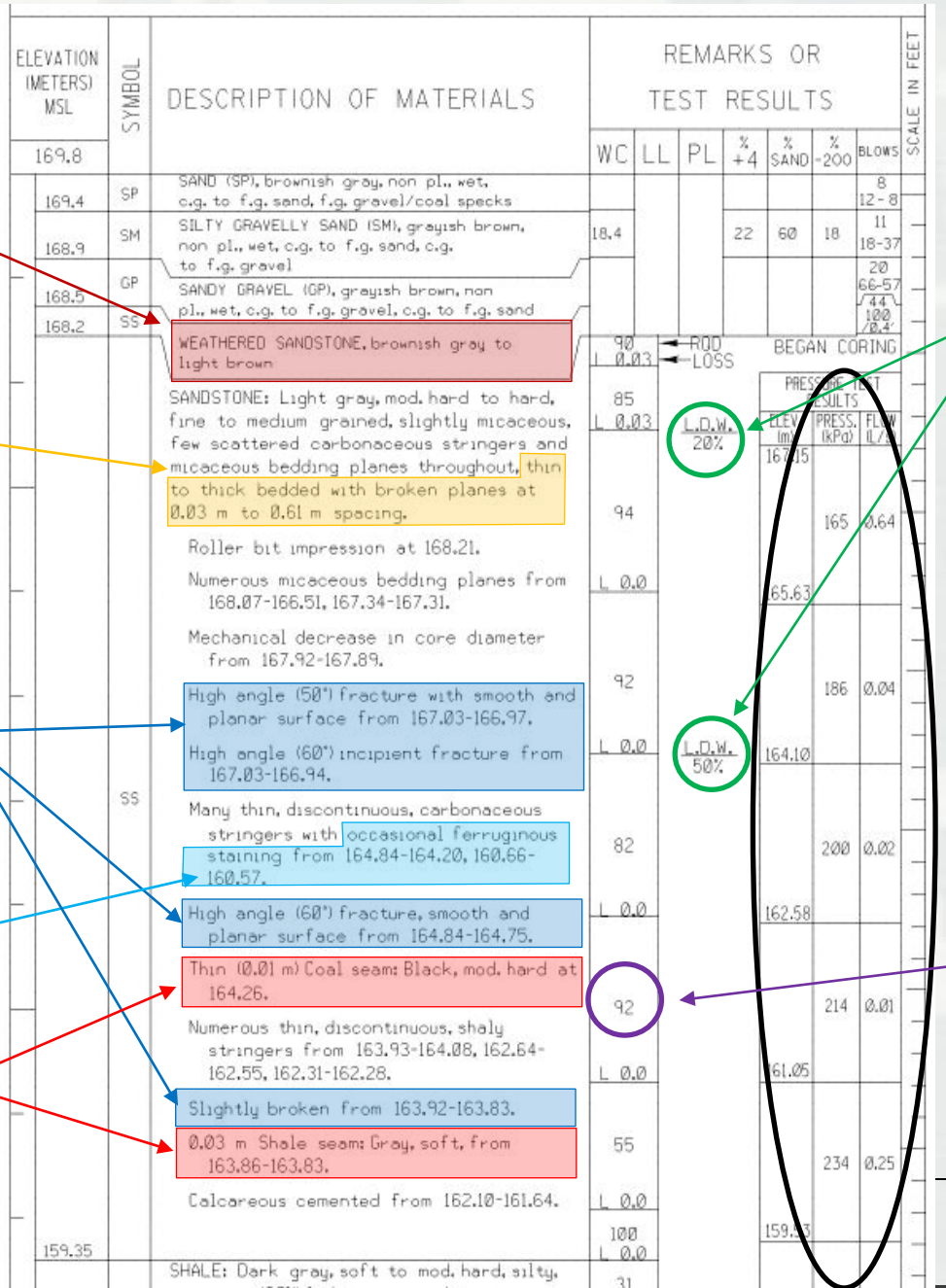
MARMET LOCK – DEWATERING PROVISIONS

- Accurately portray bedrock conditions in contract documents, alerting the contractor to potential dewatering concerns and work effort.
  - Graphic Logs of Borings
  - Geologic Sections
  - Geologic Mapping
  - Geotechnical Baseline Report

- Address in the specifications groundwater concerns during construction and provide appropriate bid items for compensation.
  - Dewatering
  - Grout Curtains
  - Concrete Placement
  - Anchor Installation

Graphic Logs of Borings – Indicators of Permeability

- QUANTIFY DESCRIPTIVE TERMS IN LEGEND
- INCLUDE DOWN-HOLE CAMERA IMAGES IF AVAILABLE



TOP OF ROCK AND DEPTH OF WEATHERING

BEDDING PLANE SPACING

FRACTURES

IRON STAINING

SEAMS

DRILL WATER LOSS

PRESSURE TEST DATA

RQD

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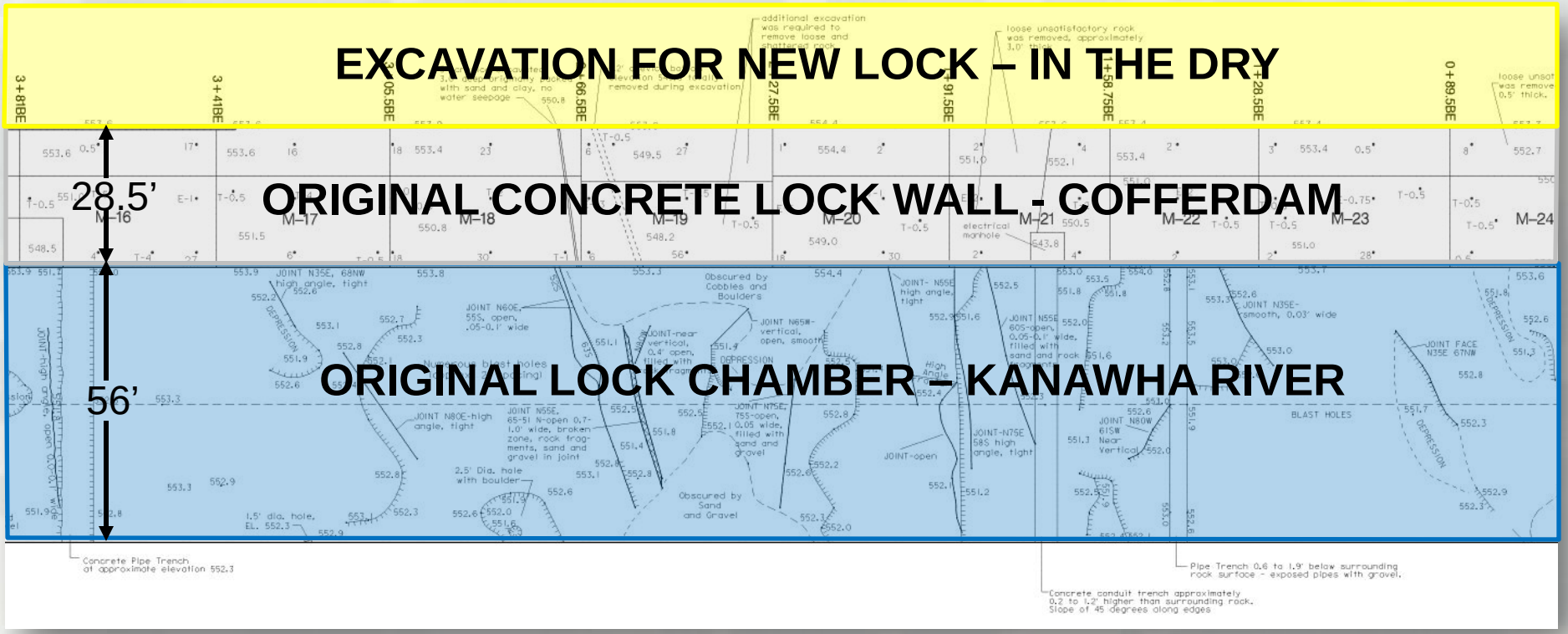
Existing Foundation Maps – Indicators of Permeability

- Fracture orientation, spacing, length and aperture
- Foundation grout takes
- Records of groundwater seepage and control methods



Original Lock Chamber and Lock Wall

Existing Foundation Maps – Indicators of Permeability

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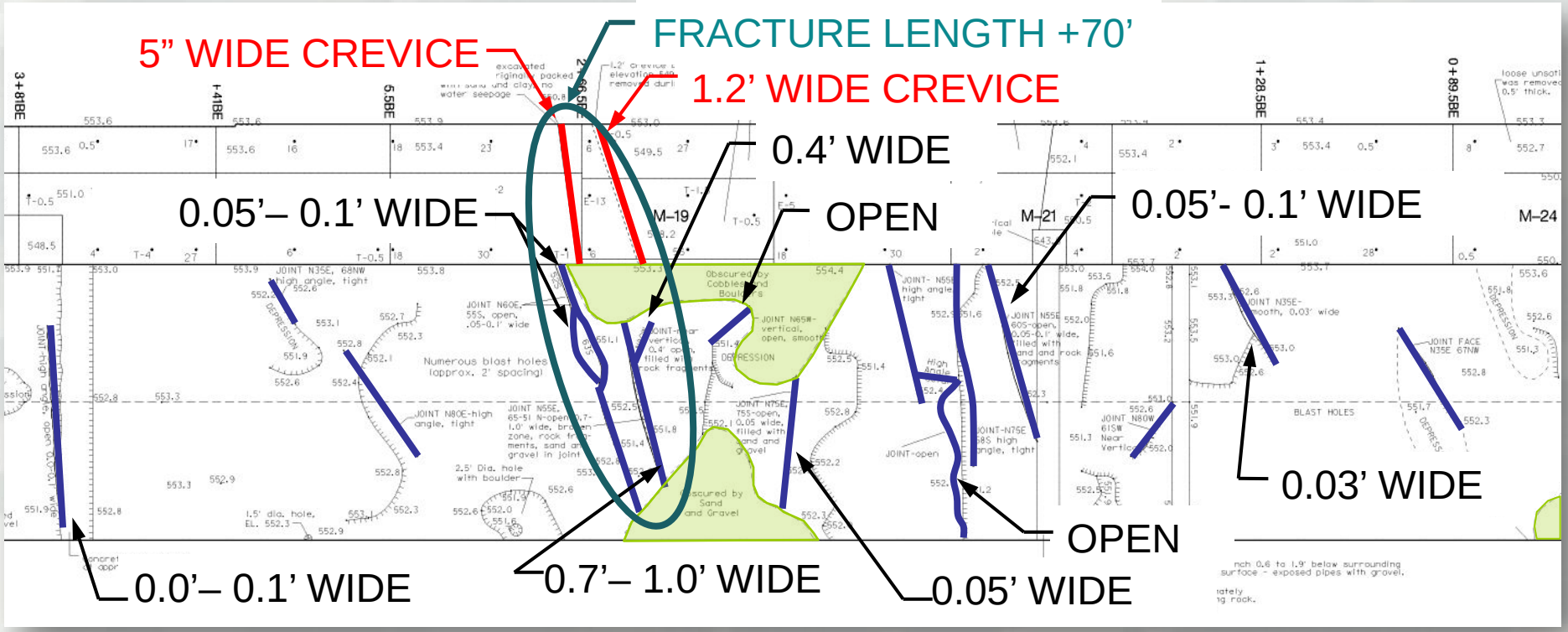


Original Lock Chamber and Lock Wall

Groundwater Flow Through Fractures

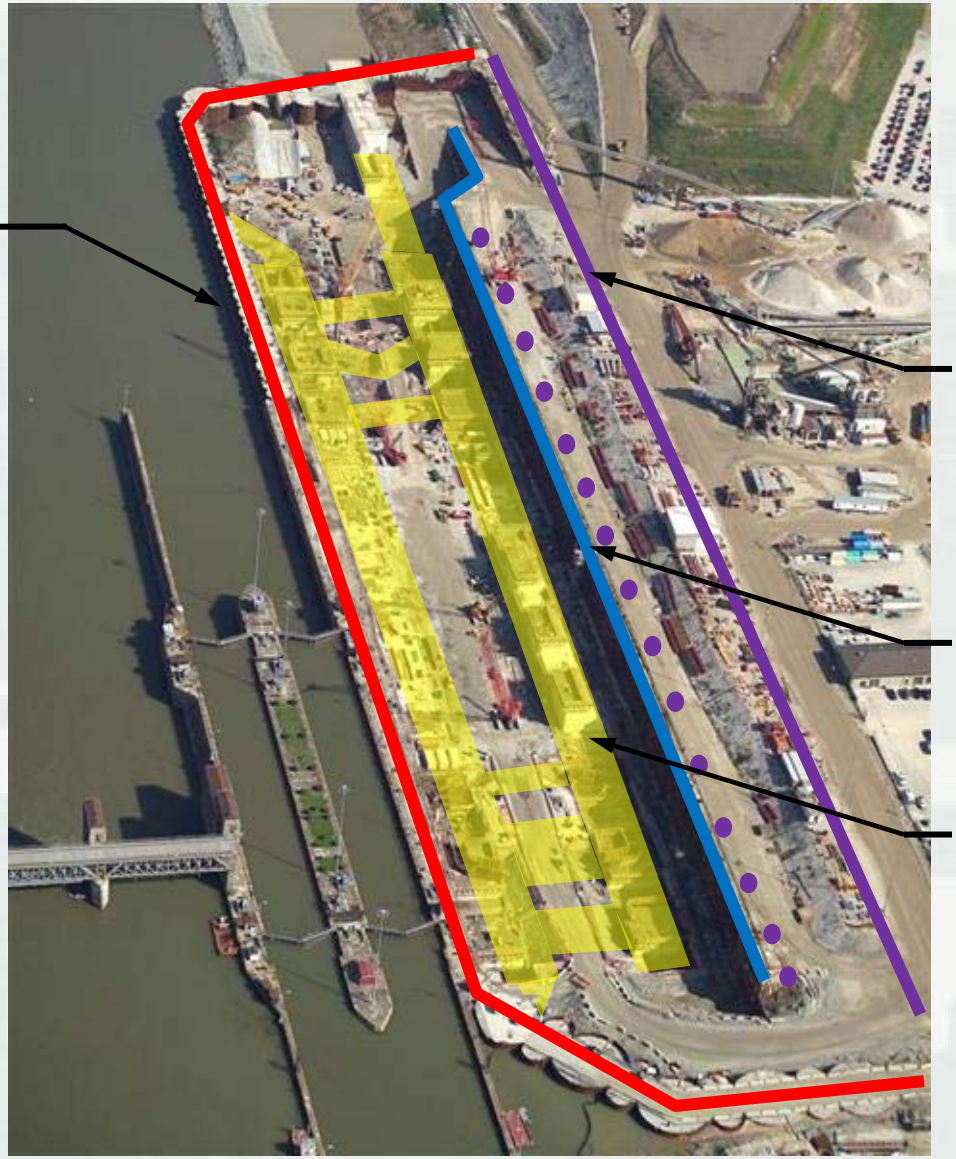
Fractures are the primary mechanism for bedrock groundwater inflow into an excavation.

Groundwater flow can be estimated through individual bedrock fractures utilizing the following equation (maximum value – does not take into consideration joint roughness, shape, infilling, laminar flow etc.):

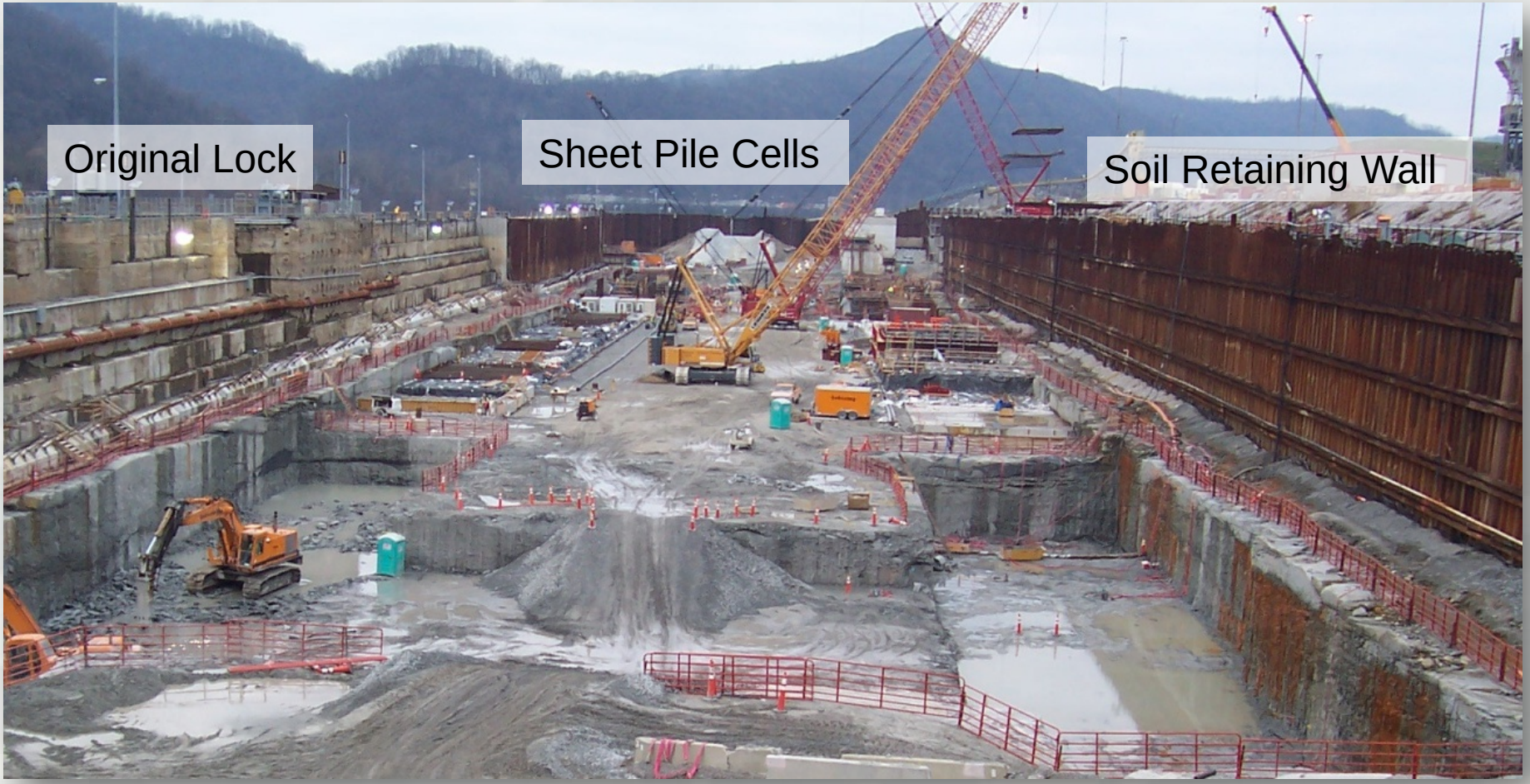
$$q = \gamma_w / 12\mu_w \; e^3 \; i$$

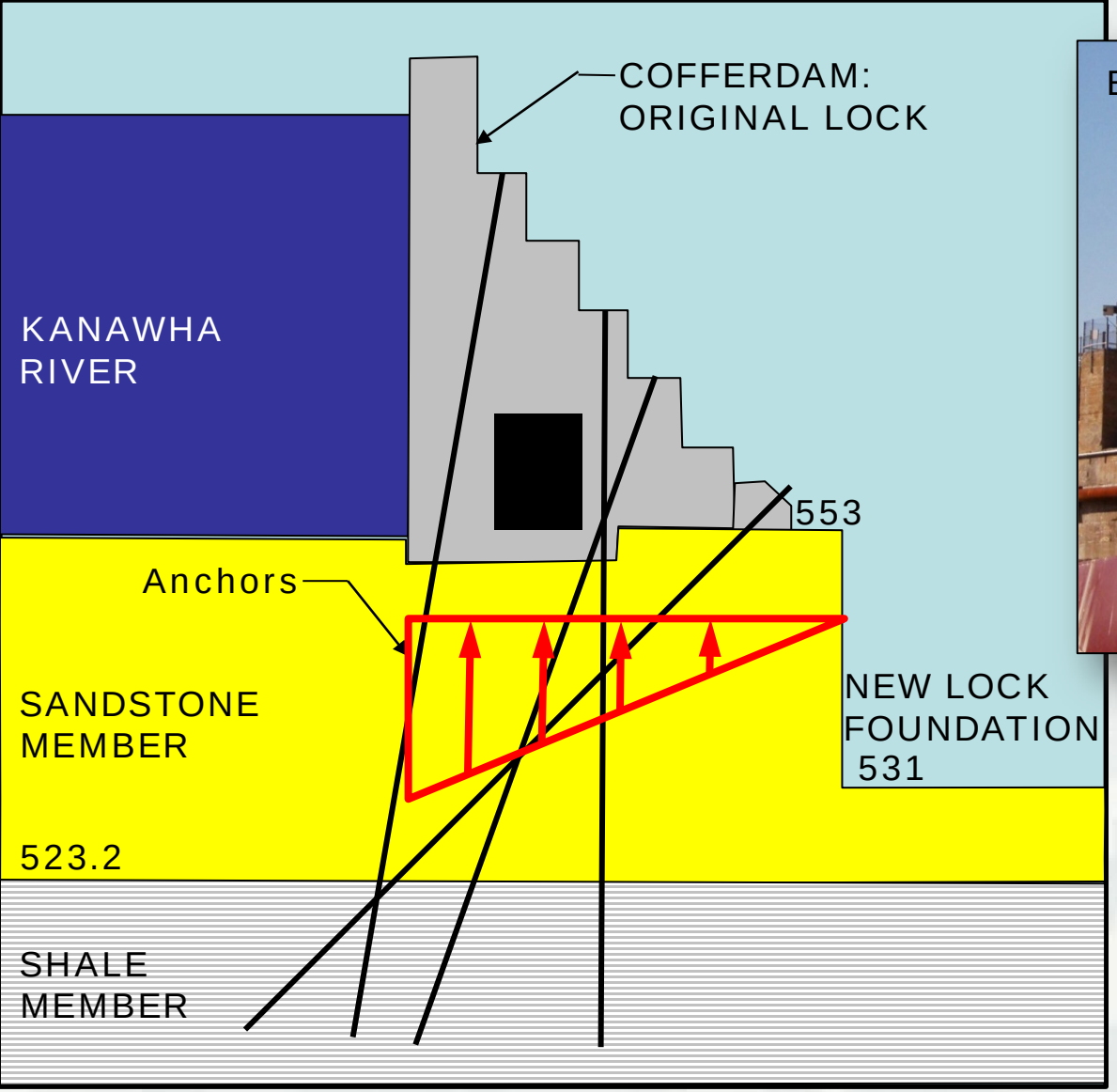
(q=flow, γ_w=unit weight of water, μ_w=dynamic viscosity of water, e=fracture aperture, i=hydraulic gradient)

Cofferdam – Construction of New Lock – Aerial View



Cofferdam – Construction of New Lock – Rock Excavation





Hydraulic gradient ranges from 0.13 to 1.2

Uplift pressures measured using piezometers during construction – found to be as anticipated or less.

Cofferdam – Hydraulic Gradient & Uplift

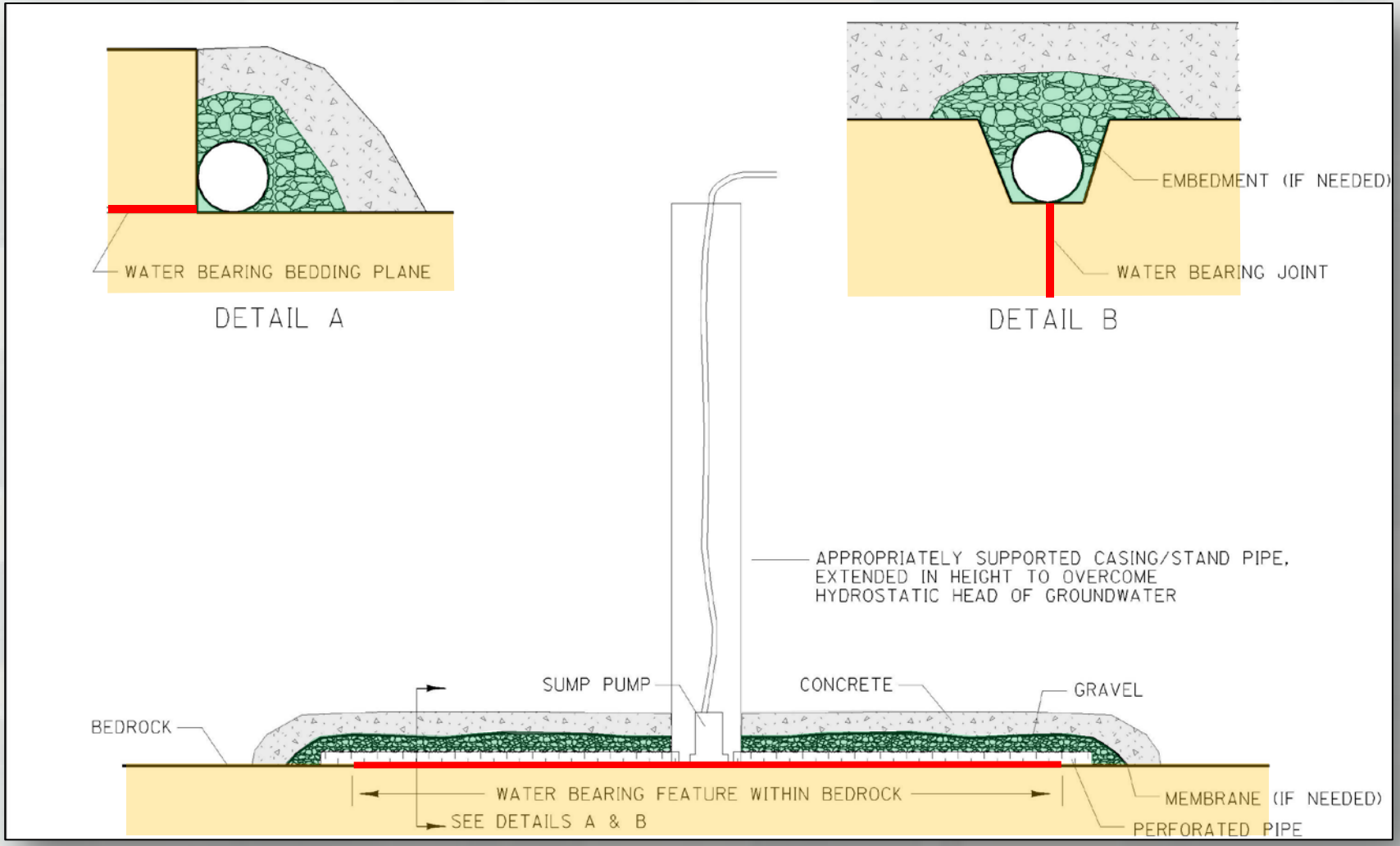
Specifications – Dewatering Bedrock Groundwater

- "The **Dewatering Systems shall be designed and operated so as to allow construction** of the lock chamber **to be accomplished essentially in the dry**, as well as to facilitate construction of all other project features."
- "The Contractor's Dewatering System shall be designed in order to control groundwater, surface water, and incidental water**, including seepage through the rock foundation**…
- "…and then **sumping the remaining groundwater and any other seepage into the bottom of the excavation**."
- "…dewatering facilities and **supplemental dewatering facilities** that may be required to control any seepage from excavated slopes or into the bottom of the excavation..."
- "Supplemental measures may include the installation of **wellpoints, inverted filters, french drains, relief wells drilled into either soil or rock, and appropriate pumps, piping, and appurtenances as necessary**…"

Control Groundwater Seepage – Concrete Placement

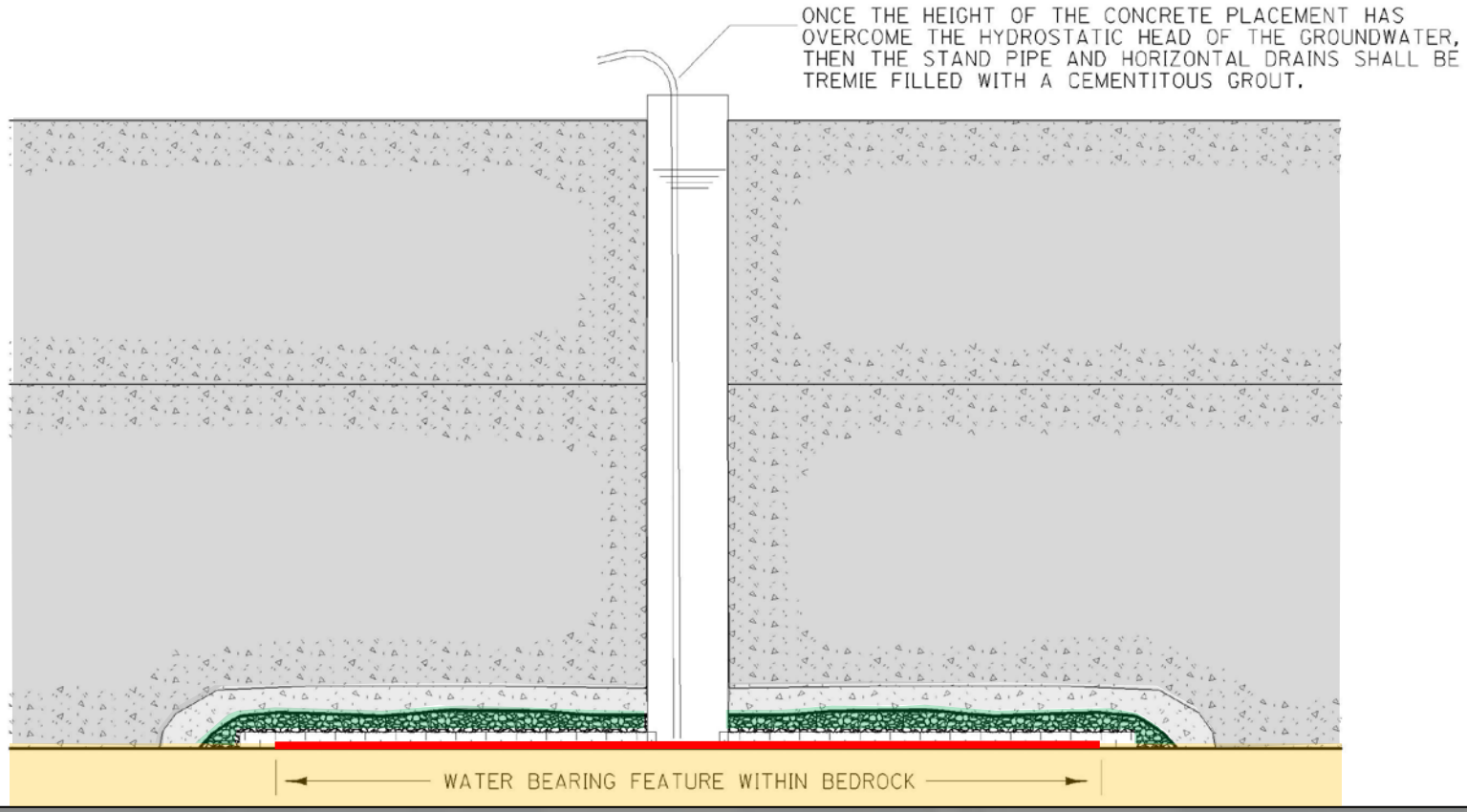
"**Rock surfaces upon which concrete is to be placed shall be clean and free from** oil, **standing or running water**, ice, mud, drummy rock, coatings, debris, and loose, semi-detached, overhanging, or unsound fragments."

Control Groundwater Seepage – Foundation Treatment



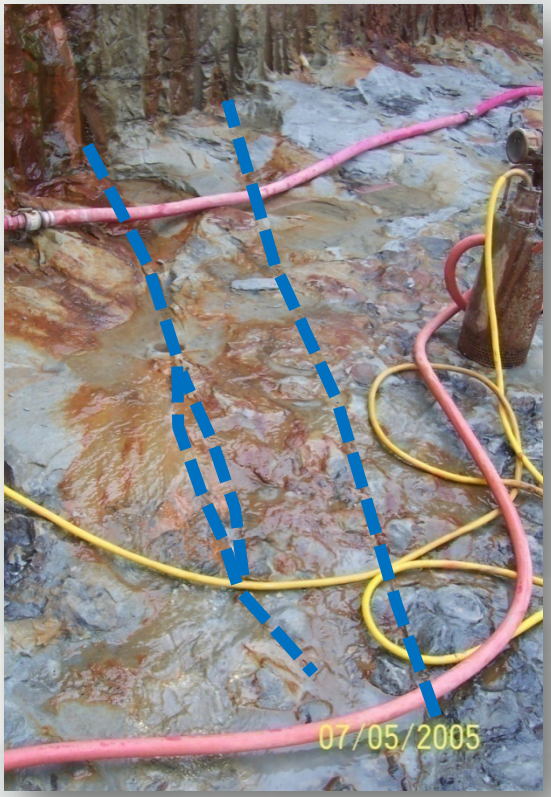
Profile – Prior to Concrete Lift Placement

Control Groundwater Seepage – Foundation Treatment



Profile – After Concrete Lift Placement

Control Groundwater Seepage - Foundation



Isolate Groundwater Seepage from Mass Concrete Placement

Dewater and Control Groundwater Seepage

Primary Discharge Pump

Control of Seepage - Sidewalls

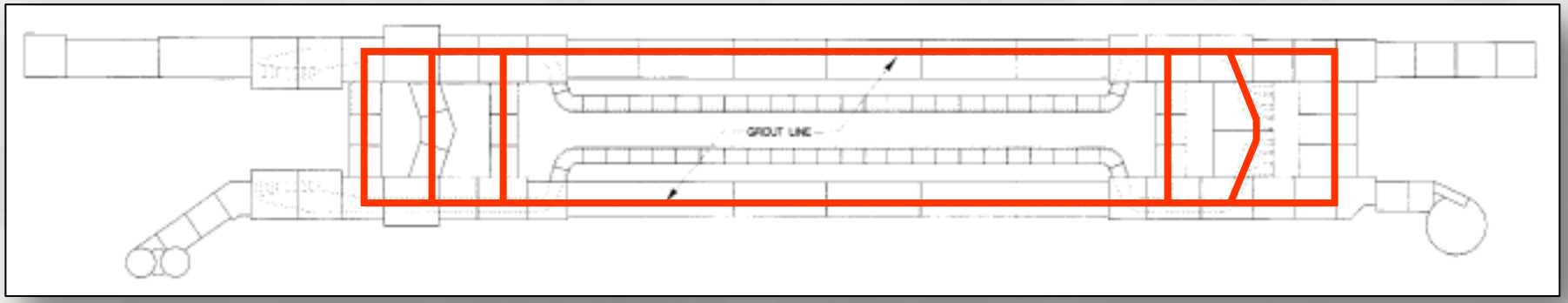
Sand Bags & Sump Pump

Provisions in Specifications Concerning Artesian Pressure

Control Artesian Pressures:

- Grouting for Foundation Anchor Installation
- Foundation Drilling and Grouting

Foundation Drilling and Grouting



- Grout Curtain Inhibits Groundwater Flow Into Lock Chamber
- Grout Curtain Extends to Elevation 510
- 10’ Spacing Between Primary Secondary Holes
- Optional Tertiary and Higher Order Holes

Top of Rock Surface

Know Location of Top of Rock Surface:

- Sheet Pile Driven to Rock – Cofferdam & Retaining Wall
- Seepage Cutoff Wall Through Soil – Key into Rock

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   - Impact to Design

SOO LOCKS – PROJECT DESCRIPTION

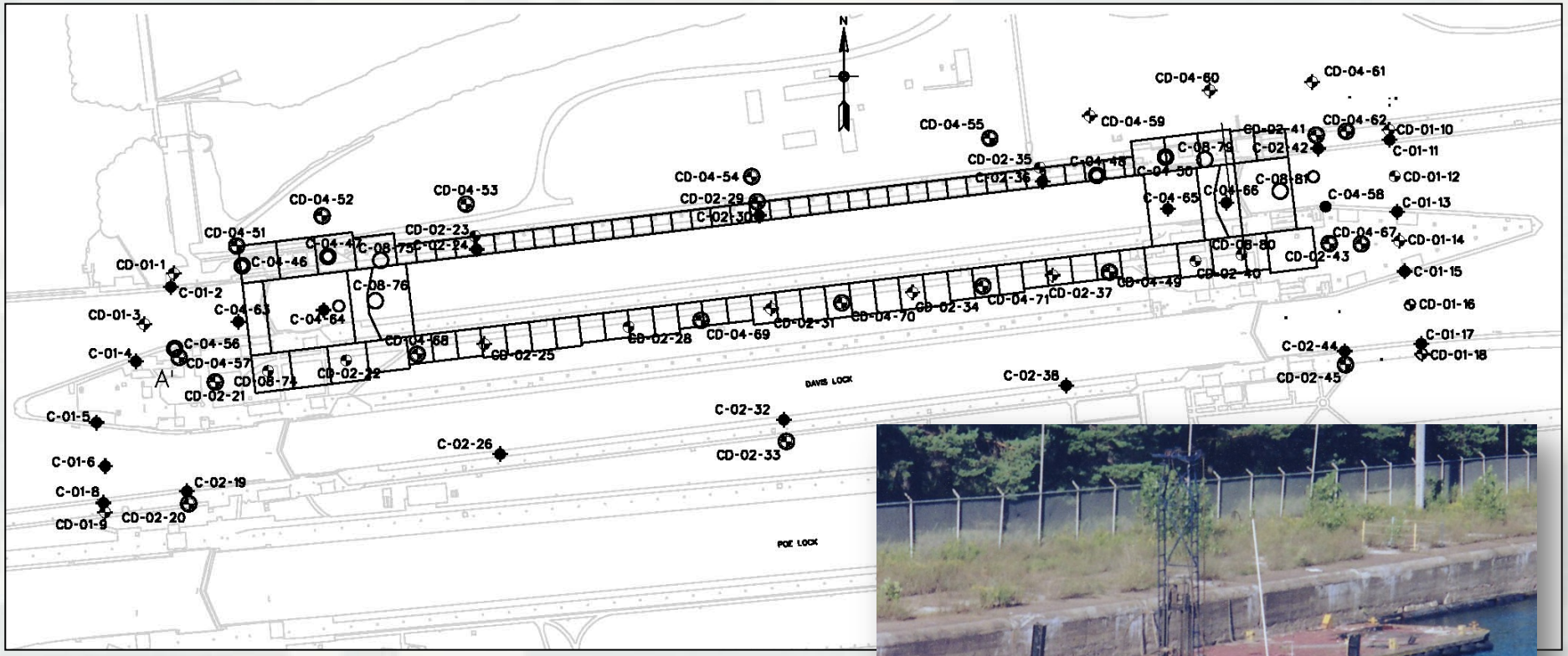
- **Located in Michigan's Upper Peninsula at Sault Ste. Marie and near Canadian boarder.**
- **All shipping in/out of Lake Superior travels through Soo Locks**
- **New lock is in plans and specifications phase. Partial cofferdam has been constructed and approach channel deepened.**

Aerial View of Project - Taken From Upstream

Aerial View of Locks

Aerial View of Locks – Proposed New Lock

SOO LOCKS – SITE GEOLOGY

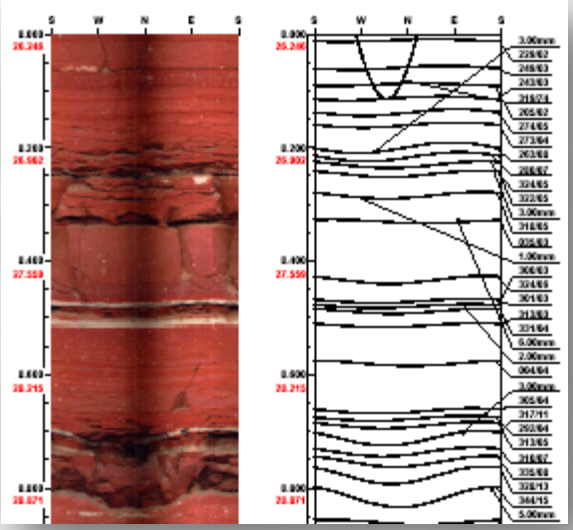


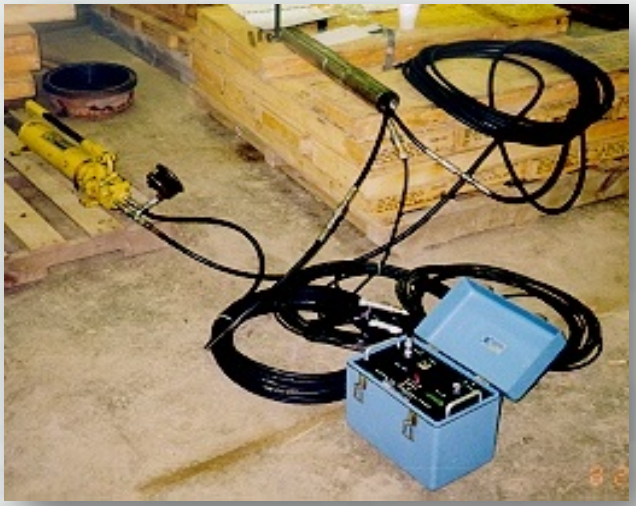
- 76 Borings
- 6,036 Total Feet of Exploratory Drilling
- 4,139 Feet of Coring
- 24 Piezometers

Subsurface Exploration – Boring Location Plan

Subsurface Exploration – Down Hole Testing

496 Pressure Tests





21 Borehole Jack Tests

1,000’ of Down-the-Hole Camera Images

General Geology

- Soil and rock fill – 0 to 35 feet thick
- Natural top of rock dips downstream (1%) – altered by past excavations
- Jacobsville Sandstone Formation (Cambrian Age) - interbedded sandstones
  - Hard Sandstone Member
  - Moderately Hard Sandstone Member
  - Shaly & Weathered Sandstone Members
- Thin, continuous seams of clay, claystone and shale within sandstone.
- Bedding plane dip in a westerly direction at a 3 percent slope.

Bedrock Units – Hard Sandstone

<u>HARD SANDSTONE MEMBER</u> is typically light gray, light red or light purple with few light gray reduction spots, hard to very hard, fine to medium grained, occasionally cross bedded and medium to thick bedded.

12,400 psi Average Unconfined Compressive Strength

Increased number of high-angled joints

Bedrock Units – Moderately Hard Sandstone

<u>MODERATELY HARD SANDSTONE MEMBER</u> is typically red with few to numerous light gray reduction spots, moderately hard, fine to medium grained and thin to medium bedded.

9,900 psi Average Unconfined Compressive Strength

The predominant member sampled.

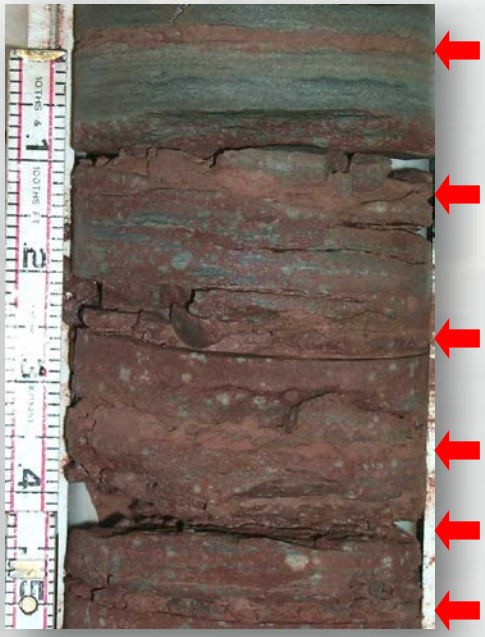
Bedrock Units – Weathered and Shaly Sandstone

<u>WEATHERED SANDSTONE MEMBER</u> is typically red with numerous light gray reduction spots, moderately hard, fine to medium grained, moderately weathered and thin bedded.

<u>SHALY SANDSTONE MEMBER</u> is typically red to dark red with light gray reduction spots, soft to moderately hard, fine grained and thin bedded

Increased number of weak / clay seams within these two members.

Bedrock Units – Weak Seams



<u>WEAK / CLAY SEAMS</u> are typically thin (ranging from 0.4-foot to 0.02-foot thick), laterally continuous and have a scattered vertical distribution (1-foot to 7-foot vertical spacing). These weak seams consist of:

- Clay Seams
- Clay Coated Bedding Planes
- Zones of Severely Broken Rock
- Claystone or claystone interlaminated with clay seams

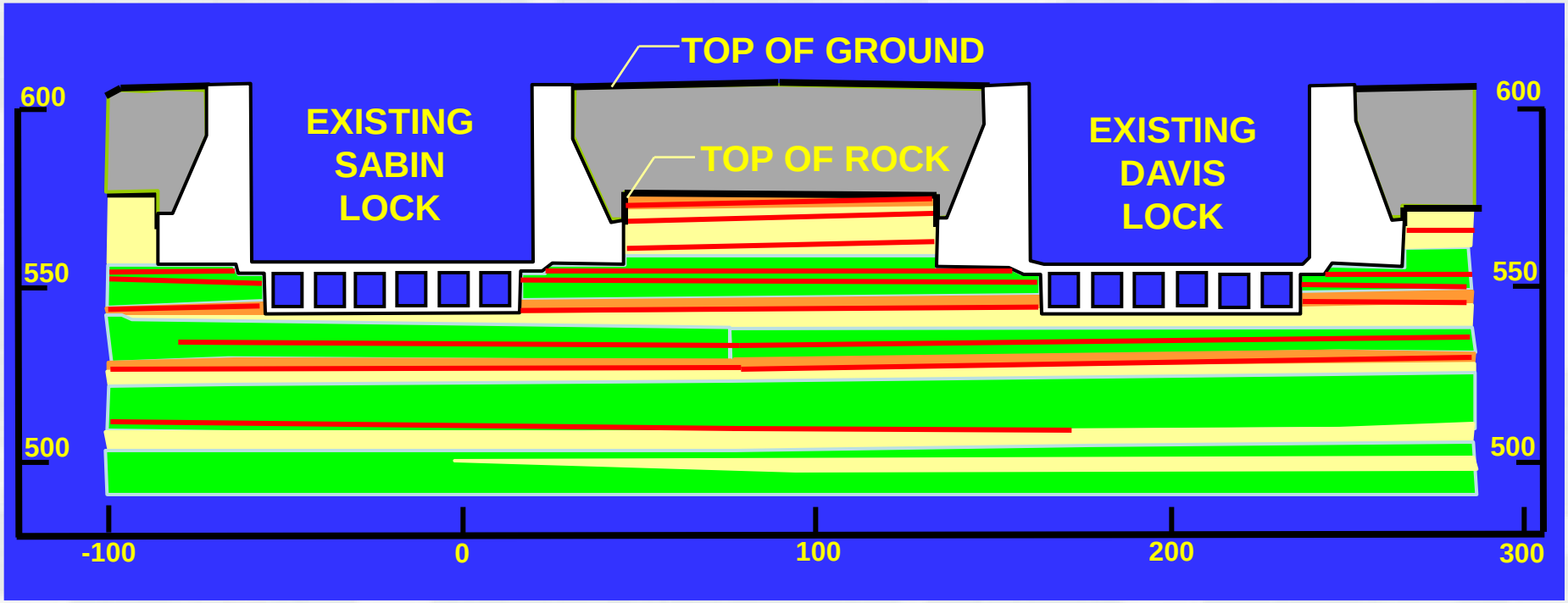
Bedrock Fractures

The predominant joint set orientation has been measured to have a dominant direction of N 70° E, and a secondary direction of N 30° E.

Joints are typically high-angled (70° to vertical) with a smooth and planar surface, occasionally displaying some discoloration of the bedrock, and aperture ranging from tight to open with occasional clay coating or filling.

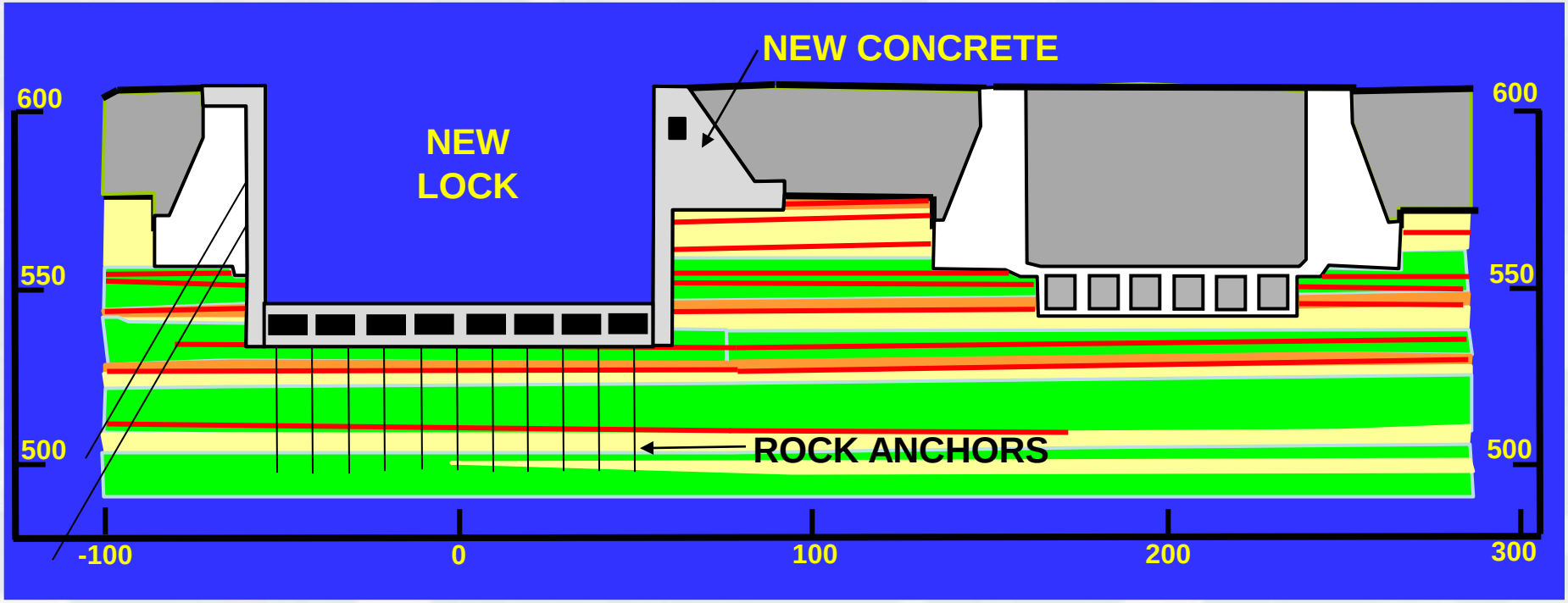
Few faults were noted during construction of Poe Lock. These were high angled with limited vertical extent.

Geologic Cross Section – Existing Lock Chambers



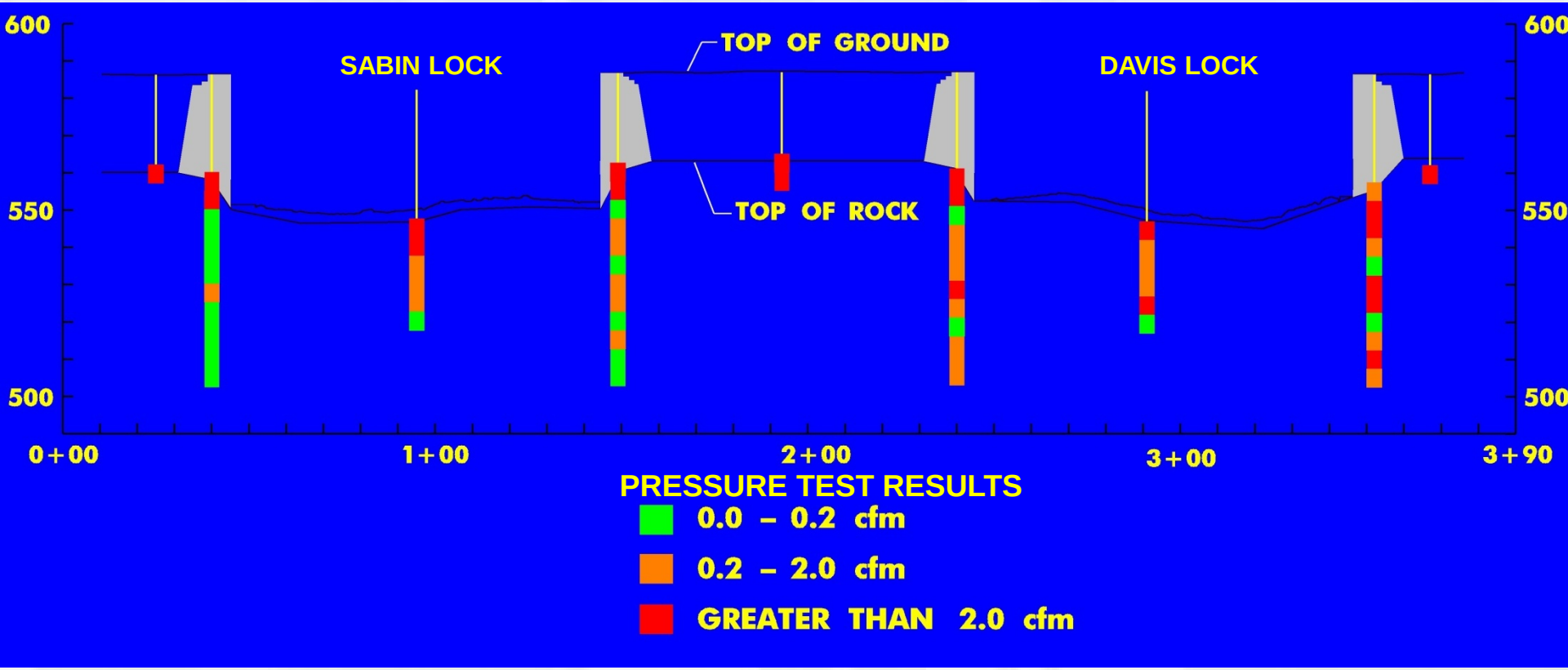
- Soil and Rock Fill
- Moderately Hard Sandstone Member
- Hard Sandstone Member
- Weathered and Shaly Sandstone Members
- Continuous Weak/Clay Seams

Geologic Cross Section – New Lock Chamber

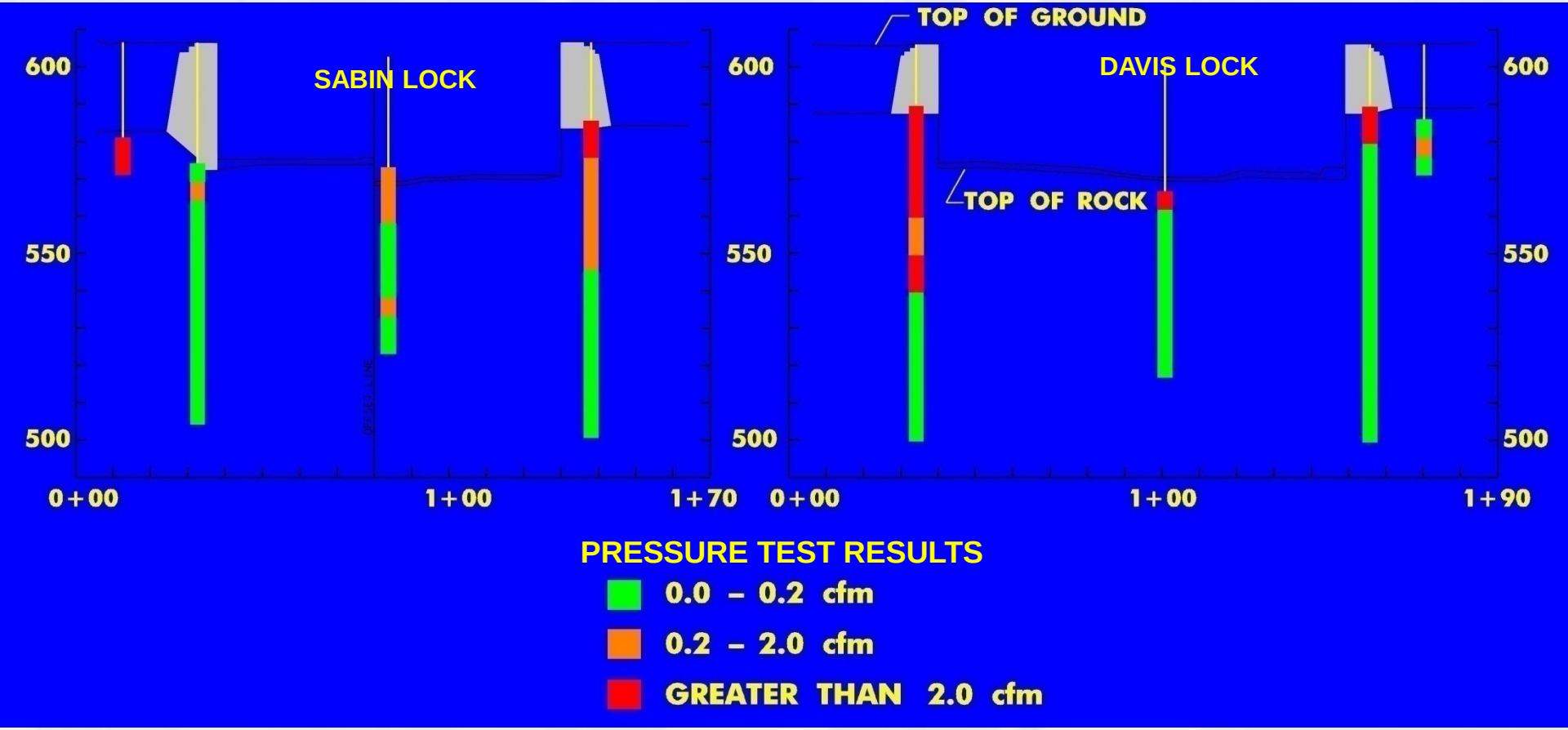


- Soil and Rock Fill
- Moderately Hard Sandstone Member
- Hard Sandstone Member
- Weathered and Shaly Sandstone Members
- Continuous Weak/Clay Seams

SOO LOCKS – PERMEABILITY



Cross Section – Pressure Testing – Downstream Cofferdam

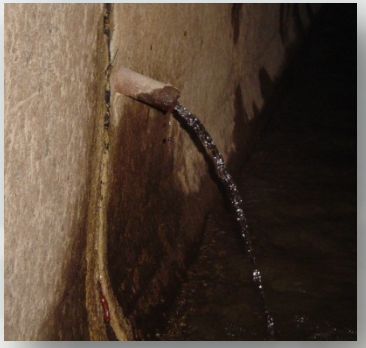


Cross Section – Pressure Testing – Upstream Cofferdam

Hydraulic Conductivity – Groundwater Inflow

- Hydraulic Conductivity or Permeability of the bedrock is determined from pressure test results.
- **Average bedrock permeability** at the Soo Lock Replacement Project located between top of rock surface and the excavated chamber elevation (533.6) **is 5.4 x10^{-3} ft/min**.
- **Magnitude greater than Marmet L&D** (3.3x10^{-4} ft/min) or Winfield L&D (6.9 x10^{-4} ft/min).
- **Individual pressure tests** resulted in localized permeability of 1.3x10^{-1} ft/min (comparable to clean sand) and flow rates up to **9.3 cfm (70 gal/min)** within a 5-foot increment.
- **Estimated** groundwater inflow through bedrock ranged from **1,480 to 2,625 gpm**.

Seepage Through Bedrock During Dewatering



Groundwater Inflow During Construction

- Study performed in 2010 by Dr. Frank Schwartz, Ohio State University.
- Preliminary study with limited scope.
- Developed groundwater model using FTWORK, a finite-difference modeling package.

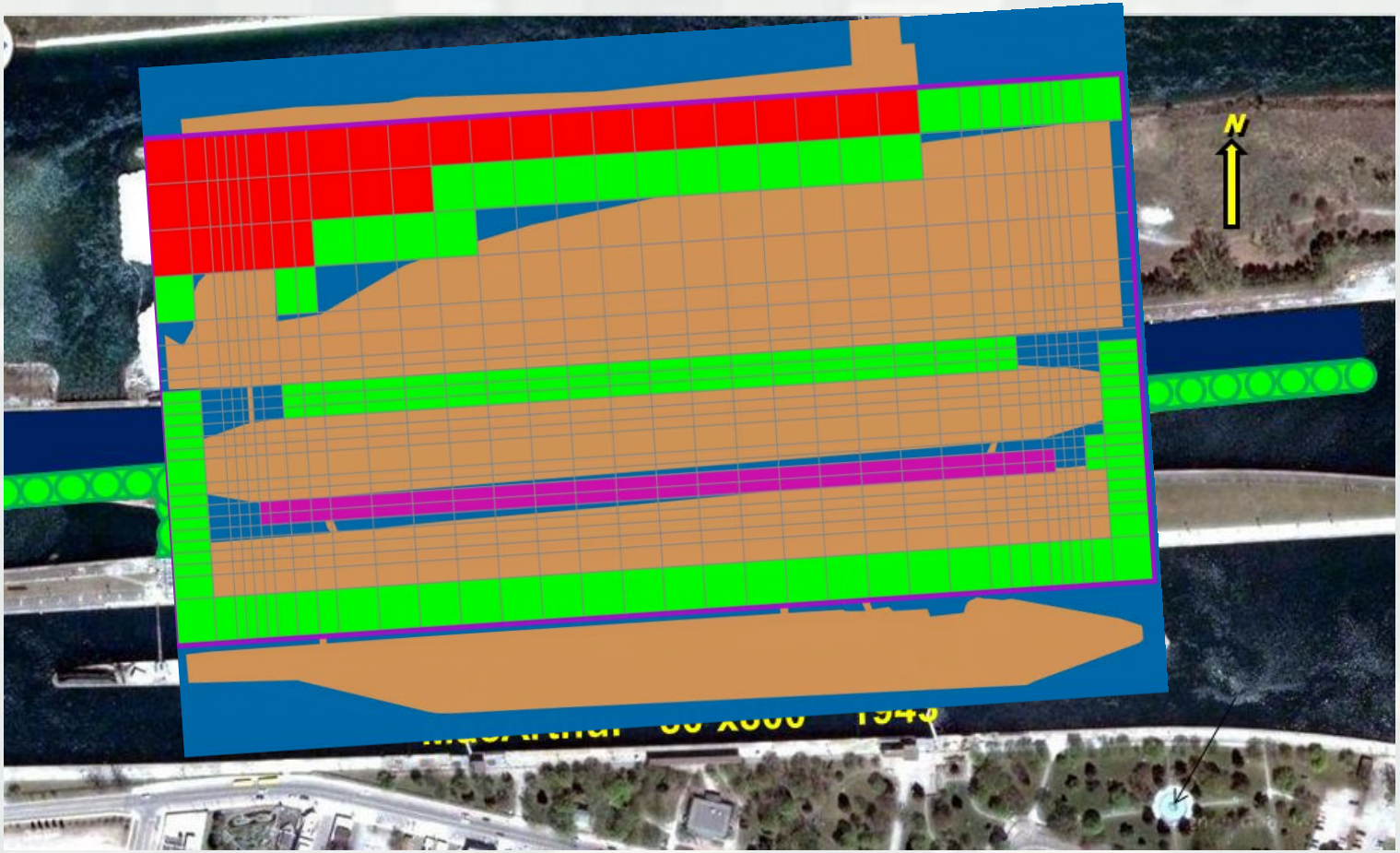
Table 1: Summary of dewatering requirements for Trials #1 to #5.

Trial #	K_B *(ft/s)*	Inflow (gpm) Davis Lock	Replacement Lock	Total: DL+RL
1	$6x10^{-5}$	0	1480	1480
2	$6x10^{-5}$	560	1290	1850
3	$6x10^{-5}$	630	940	1570
4	$8x10^{-5}$	660	1690	2350
5	$9x10^{-5}$	735	1890	2625

K_B: Hydraulic Conductivity Background
DL + RL: Davis Lock plus Replacement Lock

Summary: Trial 1 dewater new lock excavation only, Trial 2 dewatered new lock and Davis Locks. Trial 3: same as 2 with conservative grout curtain, Trails 4&5: same as 3 with varying K values.

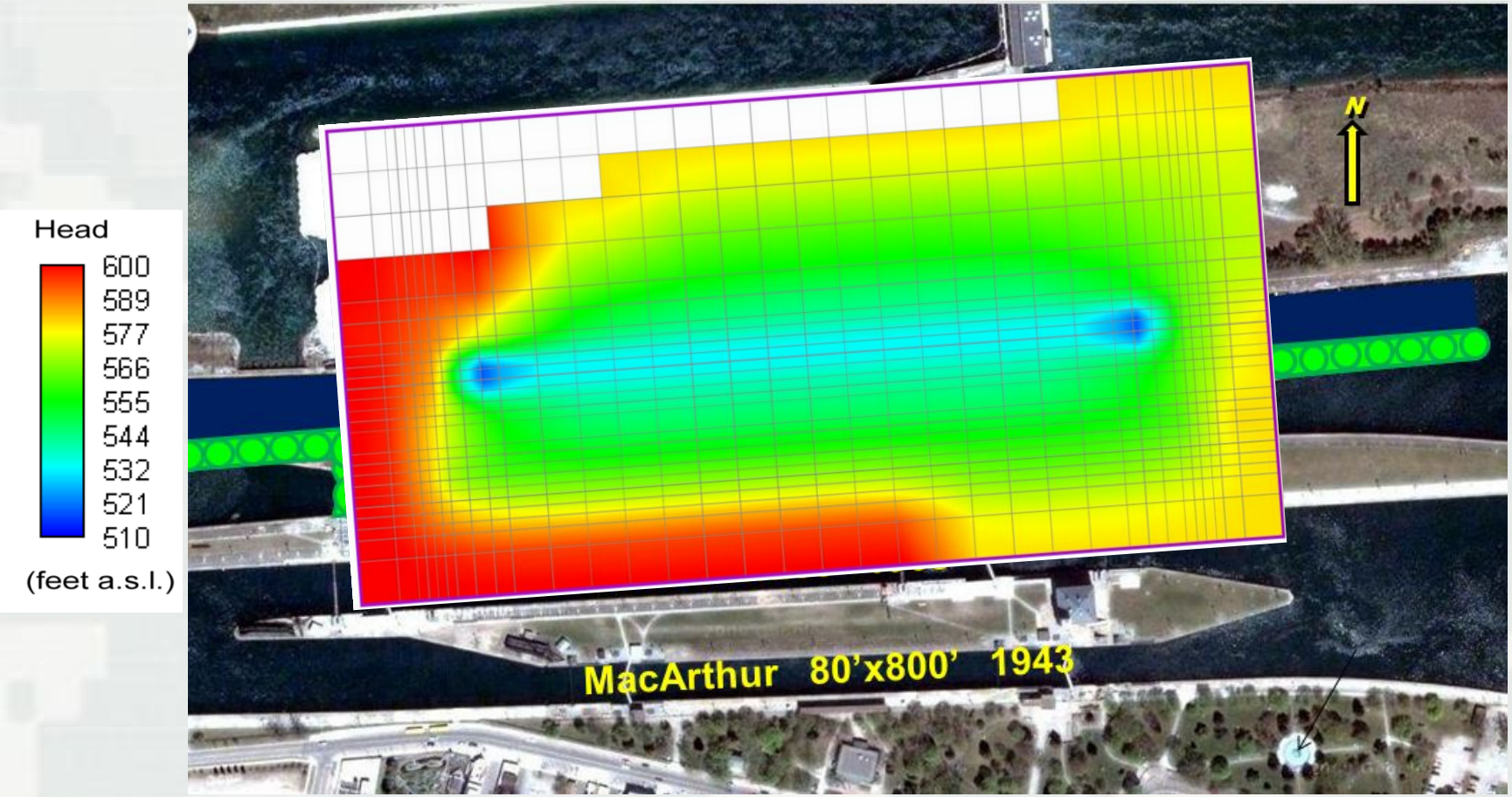
Groundwater Model



Map of Model Grid in Relation to the Lock Structure

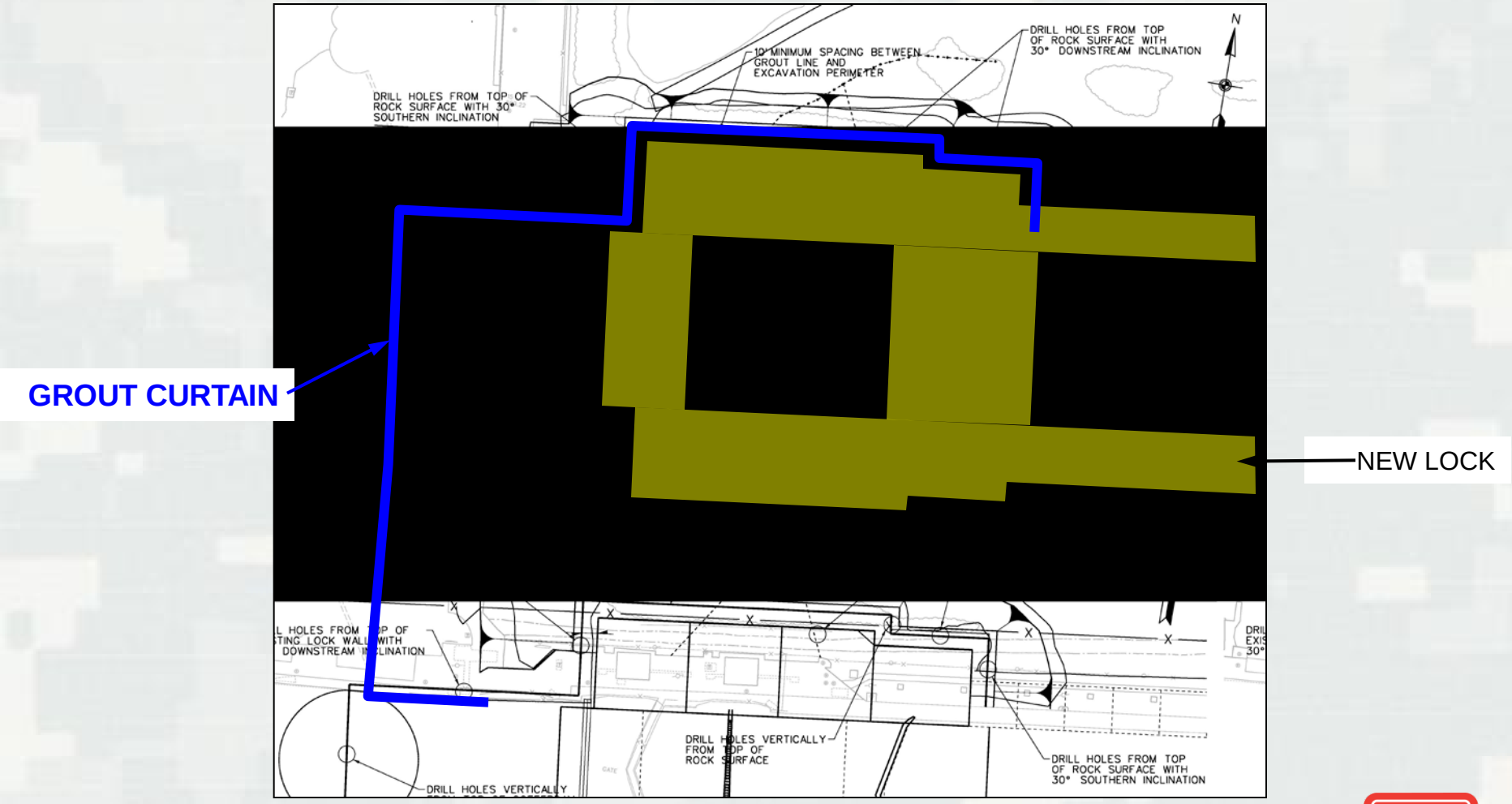
- Simulation domain
- Inactive cells
- Constant head
- General head

Groundwater Model



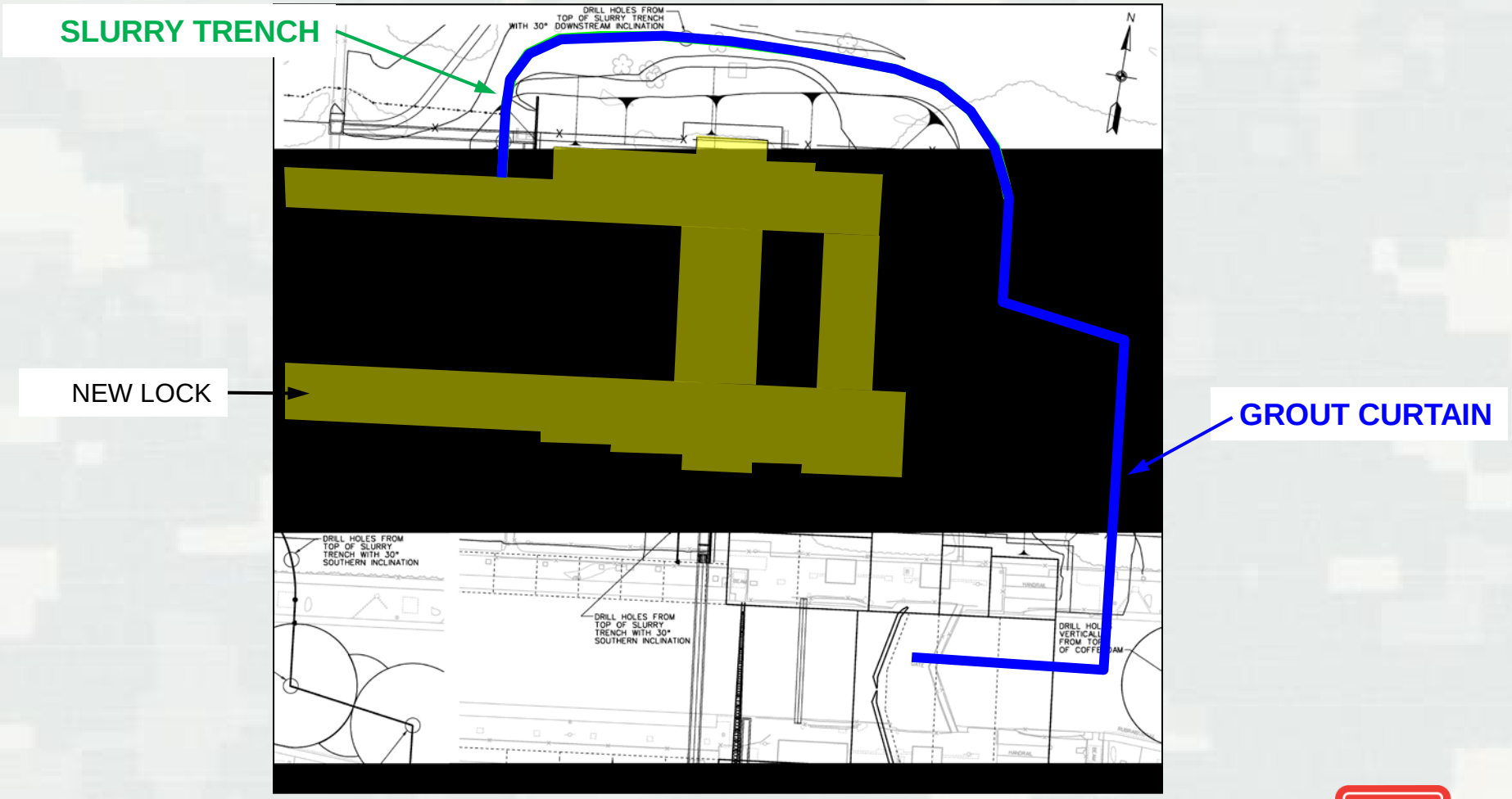
Distribution of Hydraulic Head

Grout Curtain for Dewatering Purposes - Upstream



Plan View – Upstream Monoliths

Grout Curtain and Slurry Trench for Dewatering Purposes Downstream

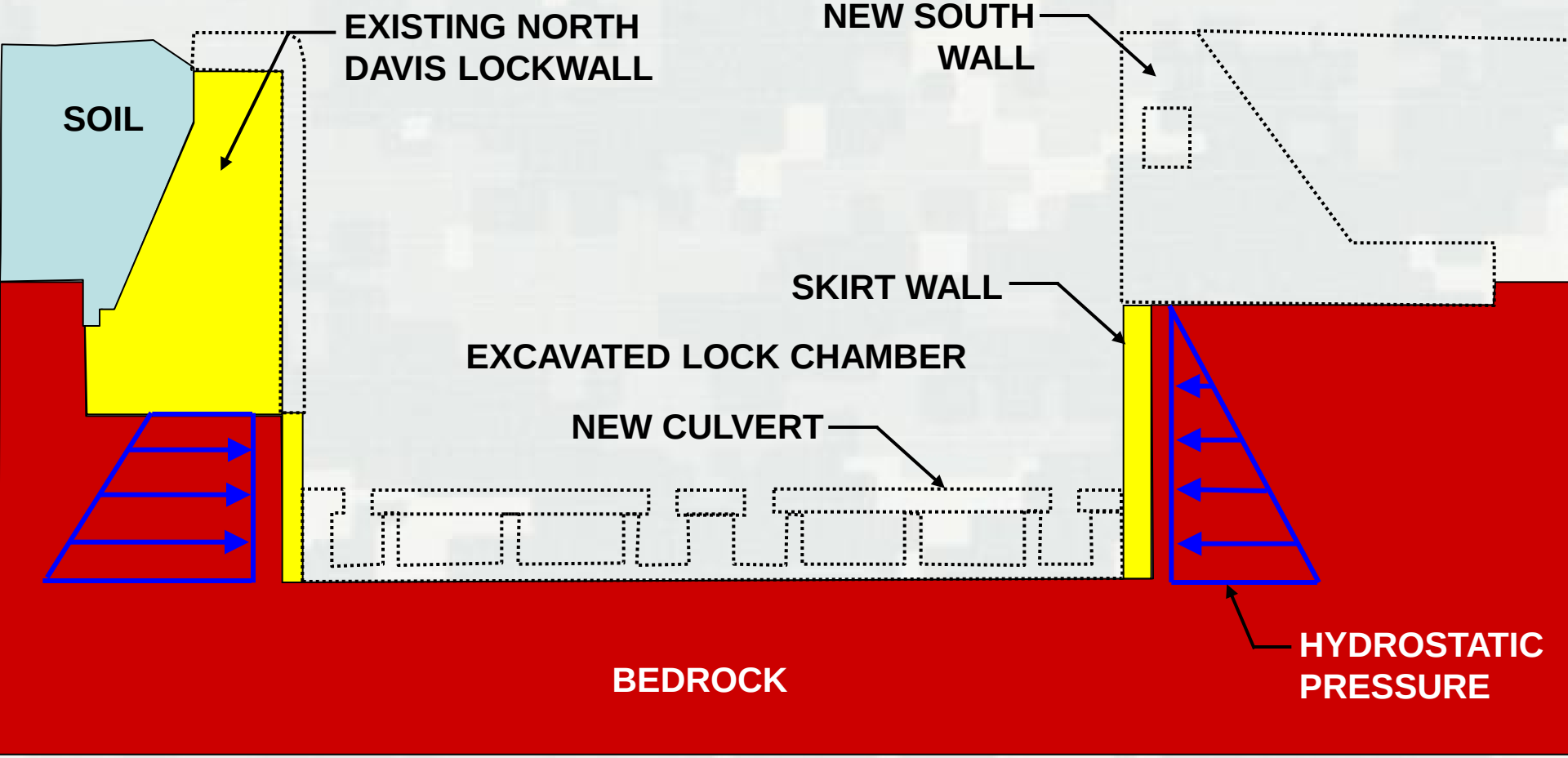


Plan View – Downstream Monoliths

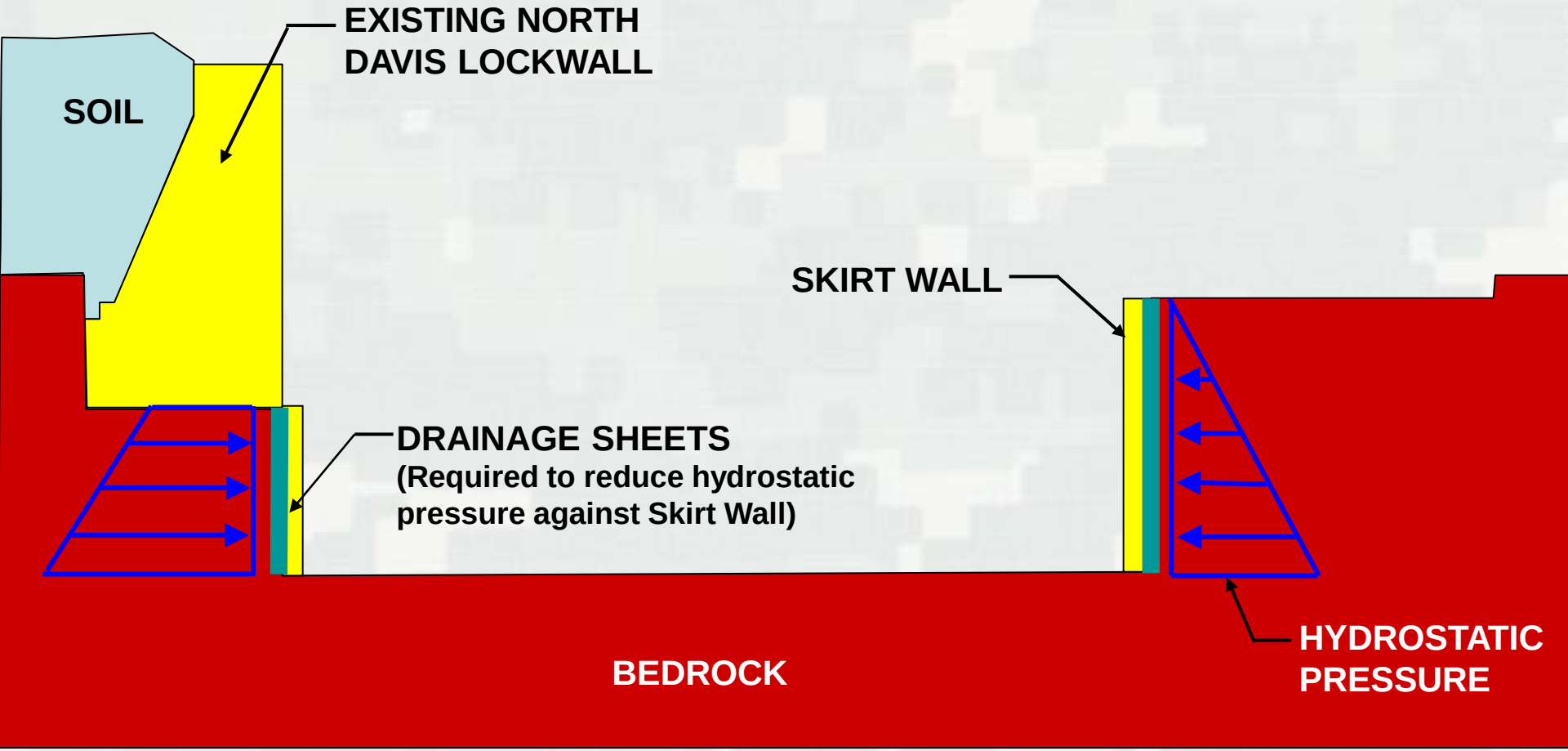
Grout Curtain Details

[redacted]

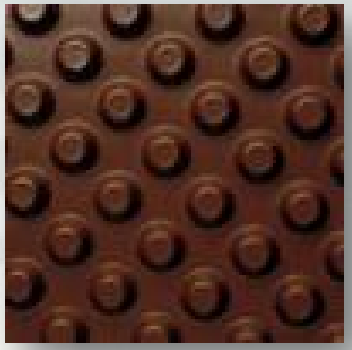
Groundwater Flow Into Excavation – Lock Chamber



Groundwater Flow Into Excavation – Drainage Sheets



Groundwater Flow Into Excavation – Drainage Sheet Details



Questions & Discussion

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