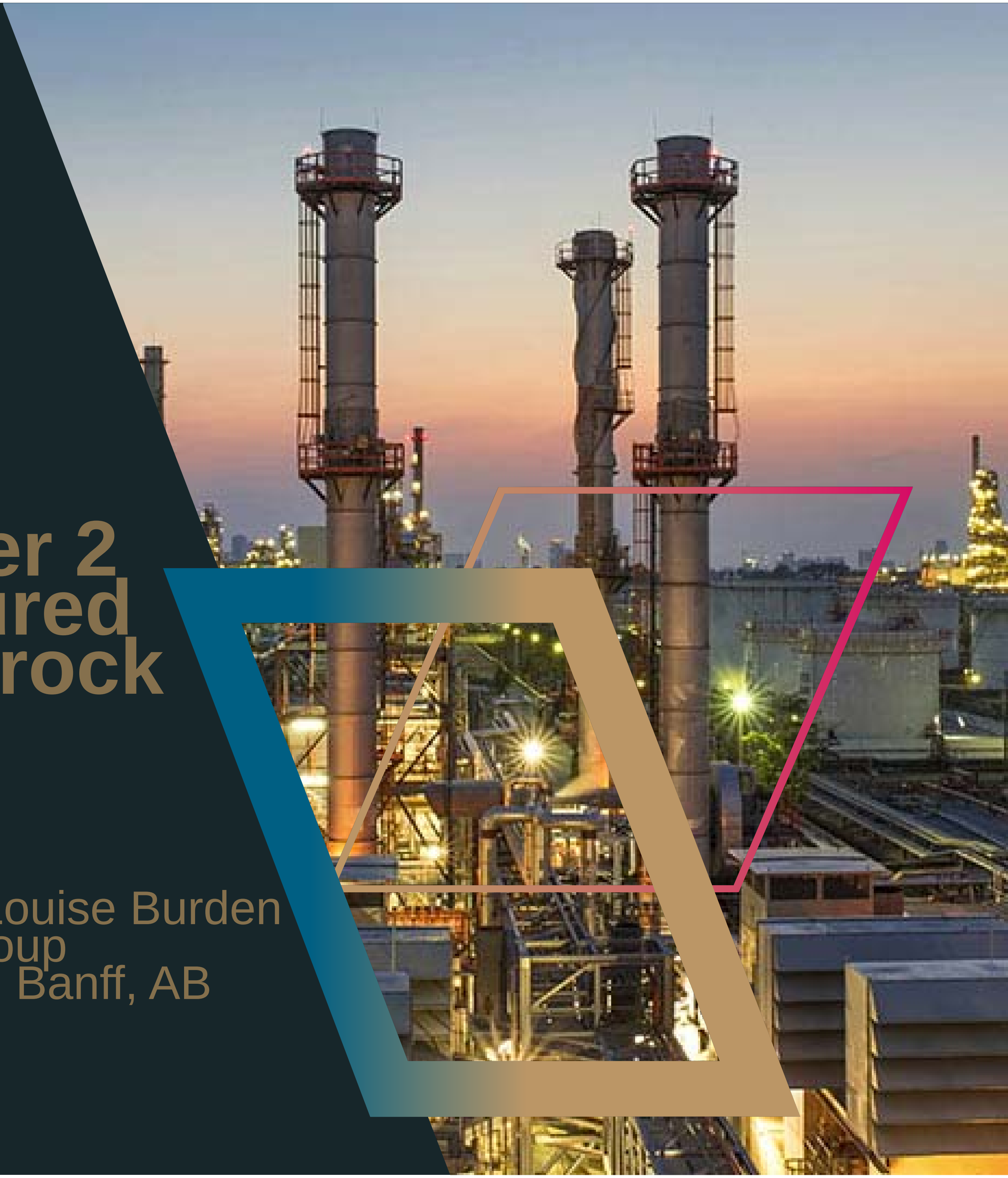
# Assessing the Tier 2 Trigger for Fractured Sedimentary Bedrock Sites



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# INTRODUCTION

- **High level look at assessing the Tier 2 trigger**
  - What the regulatory guidelines say
  - Assessing fractured sedimentary bedrock groundwater flow systems
  - Tier 1 and 2 scenarios and approaches
  - Wrap-up thoughts

- **Intent is to promote discussion among proponents, consultants, regulators and other stakeholders**

# What the Alberta Environment and CCME Guidelines Say

# Alberta Tier 1 & 2 Guidelines (ESRD 2014a,b)

- Guidelines developed for unconsolidated soil … presence of bedrock may require Tier 2 re-evaluation

- Tier 1 may be applied if bedrock likely to behave conservatively as coarse or fine soil … look at expected contaminant mobility and not the rock texture e.g. fine-grained (weathered) fractured shale may behave as coarse-textured soil

# Tier 1 and 2 cont'd

- Tier 2 re-evaluation required where flow paths not similar to (aggregated) soil medium, fracture length > ~2 cm (??), non-Darcy flow
- These conditions outside scope of Tier 1 calculations and site-specific risk assessment or exposure control required (other options exist as shown at end of presentation)
- Relatively little discussion of how to assess these conditions, resulting in confusion … typical responses range from ignoring the trigger to panic and undertaking irrelevant work

# Tier 1 Calculations

Soil Remediation Guidelines for Groundwater Pathways

- Soil guidelines based on organic contaminant fate and transport used by CCME (2006) protocol i.e. Domenico & Robbins (1985) contaminant transport analytical equation
- Inorganics should be assessed by groundwater sampling

$$DF4 = \frac{2}{\exp(A) \times [erf(C) - erf(D)]}$$

$$A = \frac{x}{2D_x}\left\{1 - \left(1 + \frac{4L_s D_x}{v}\right)^{1/2}\right\}$$

$$C = \frac{y + Y/2}{2(D_y x)^{1/2}}$$

$$D = \frac{y - Y/2}{2(D_y x)^{1/2}}$$

$$L_s = \frac{0.6931}{t_{1/2s}} \times \exp(-0.07d)$$

$$v = \frac{V}{\theta_t R_s}$$

ESRD (2014a)

# CCME (2006) Tier 1 Protocol Assumptions include:

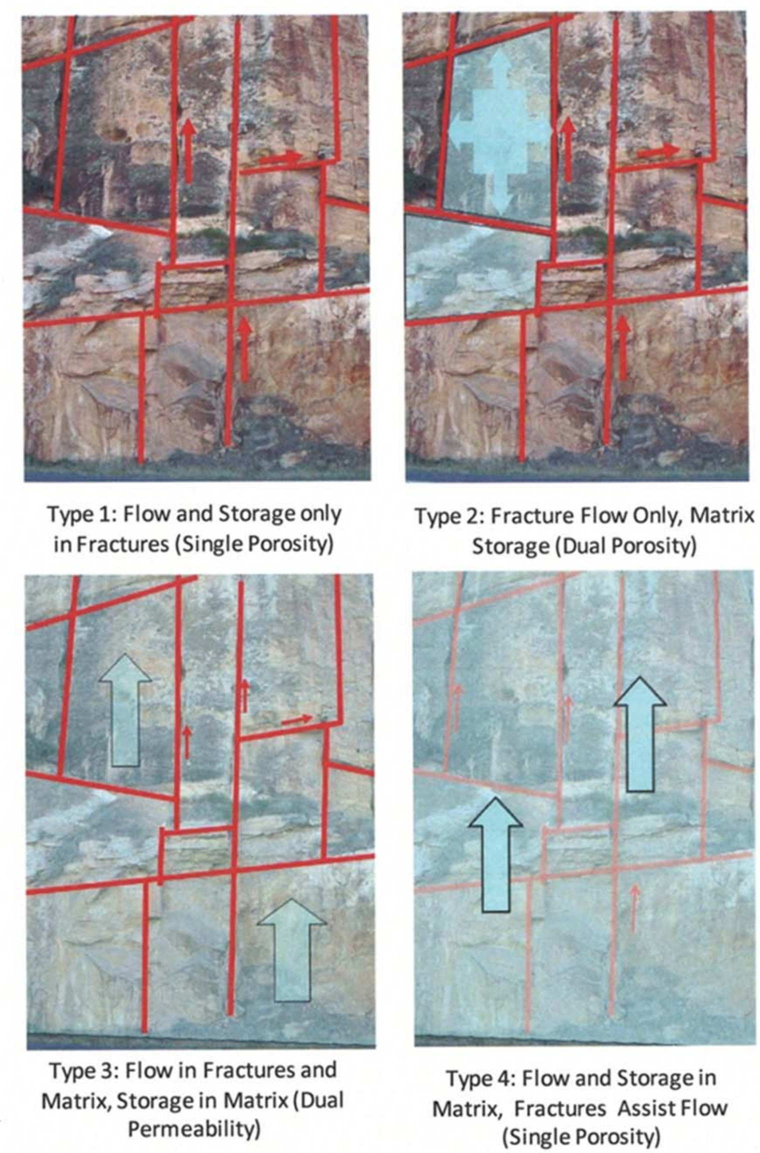
- Soil/porous medium is physically and chemically homogeneous – same value of properties (e.g. K) at all locations
- Medium is isotropic - same value of properties in all directions
- Medium is fully saturated and continuous – all points in a flow system connected with each other
- Violations of these assumptions indicate the presence of fracture flow to varying degrees … **fracture flow is the trigger, not fractured rock!**

# Assessing Fractured Bedrock Flow Systems

# Types of Fracture Flow Systems

- Type 1. Flow and storage only in fractures (single porosity)
- Type 2. Flow only in fractures,, some storage in matrix
- Type 3. Flow in fractures and matrix, storage in matrix (dual porosity)
- Type 4. Flow and storage in matrix, fractures assist flow (single porosity)

Classification System Based on Continuity and Degree of Saturation (Nelson 2001 as adapted by Golder 2010)



Type 1: Flow and Storage only in Fractures (Single Porosity)

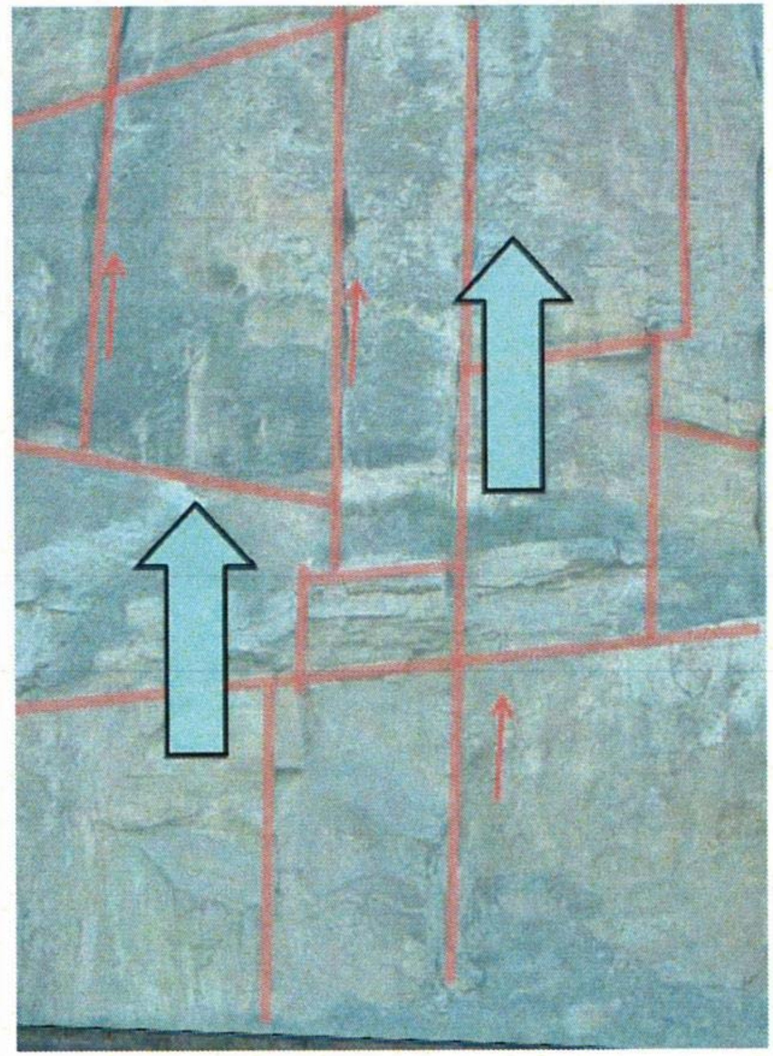
Type 2: Fracture Flow Only, Matrix Storage (Dual Porosity)

Type 3: Flow in Fractures and Matrix, Storage in Matrix (Dual Permeability)

Type 4: Flow and Storage in Matrix, Fractures Assist Flow (Single Porosity)

# Type 4 Flow Systems

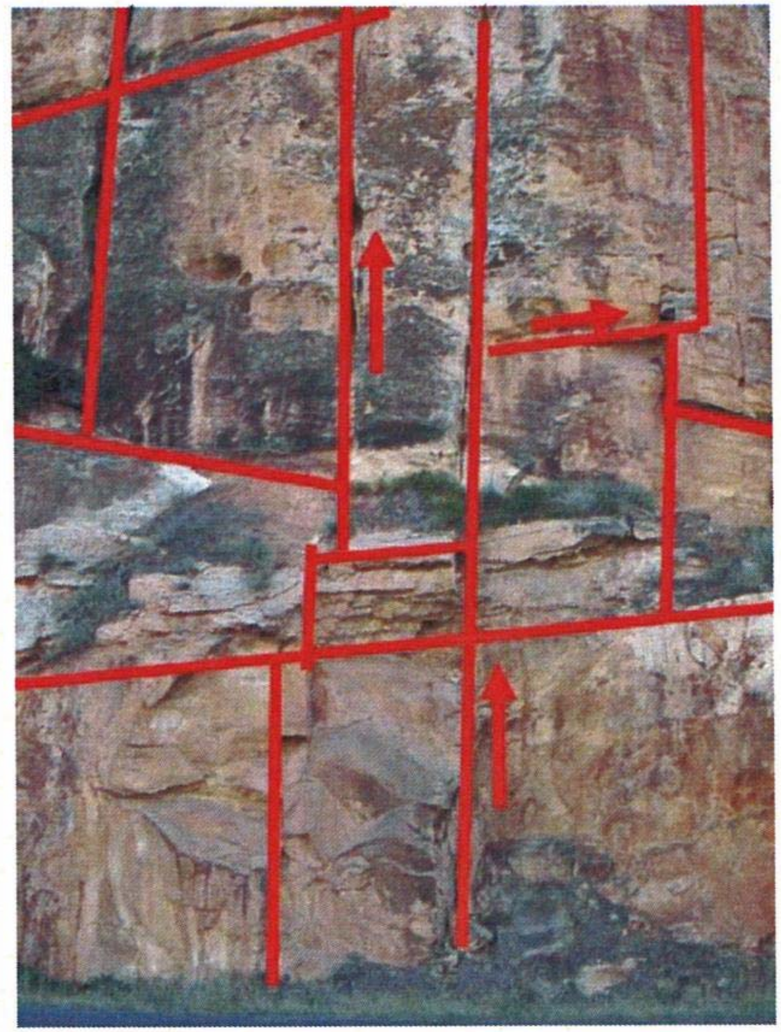
- Strong candidates for consideration as equivalent porous medium flow



Type 4: Flow and Storage in Matrix, Fractures Assist Flow (Single Porosity)

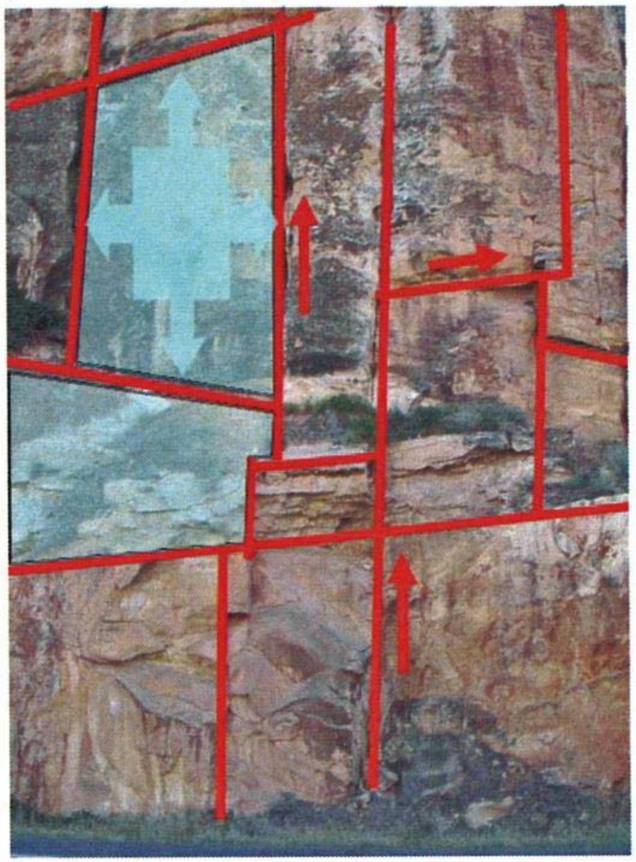
# Type 1 Flow Systems

- Strong candidates for consideration as fracture flow
- No point analysing rock samples as soil

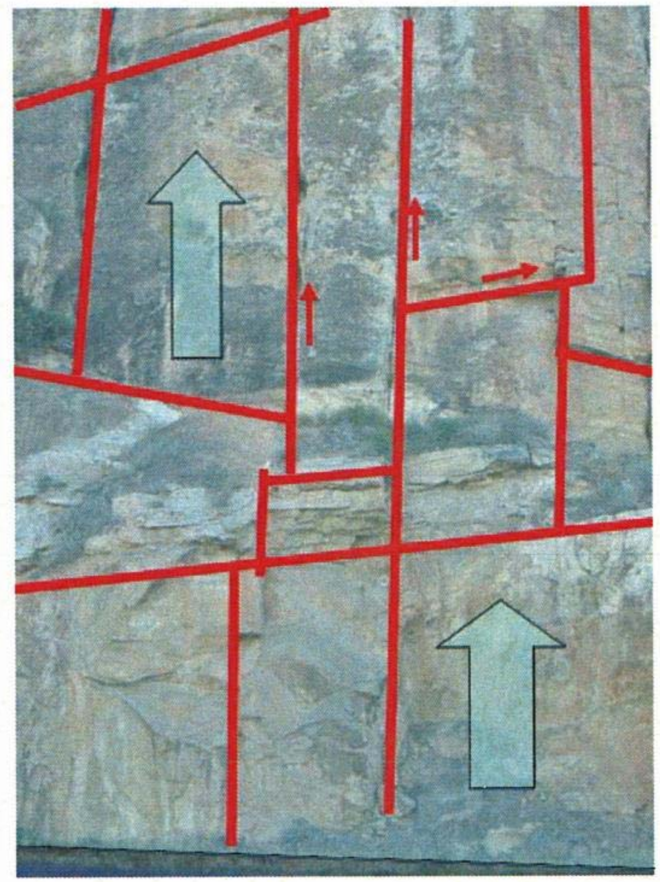


Type 1: Flow and Storage only in Fractures (Single Porosity)

# Types 2 & 3 Flow Systems



Type 2: Fracture Flow Only, Matrix Storage (Dual Porosity)



Type 3: Flow in Fractures and Matrix, Storage in Matrix (Dual Permeability)

- Candidates for consideration as either type of flow

## Some Characteristics of Equivalent Porous Media Flow

- High degree of weathering of relatively homogenous lithology
- Relatively uniform K values
- Relatively high fracture density and fractures well connected
- Groundwater contaminant plumes behave as expected in a porous medium
- Sites large enough for definition of a Representative Elementary Volume that can be treated as an Equivalent Porous Medium

# Some Characteristics of Fracture Flow Systems

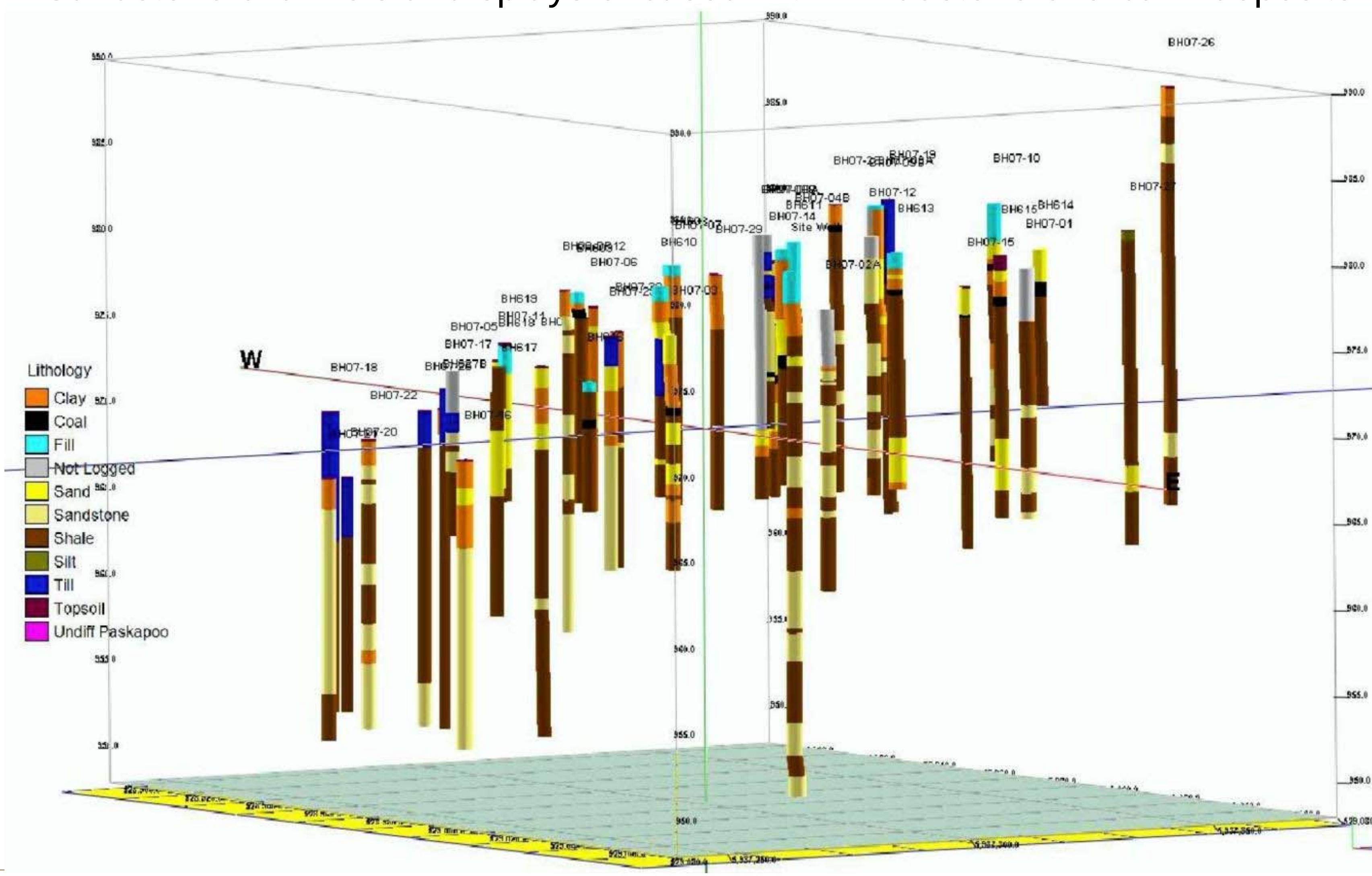
- Sudden and significant loss of water circulation during drilling
- Highly heterogenous lithology
- Rock cores indicate water transport through fractures with no or less transport through competent rock matrix e.g. oxidation haloes, dry matrix
- Wide range and rapid changes in groundwater levels in monitoring wells (requires use of short-screened intervals and pressure transducers)

# Characteristics of Fracture Flow Systems cont'd

- High vertical downwards hydraulic gradients
- Range of hydraulic conductivity values over a few to several orders of magnitude, lower lab permeameter test results than field test results
- Anisotropic pumping or injection test results, uninterpretable pumping test results
- Lateral spreading of contamination in unanticipated or unusual directions
- Rapid transport of conservative solutes such as chloride

# 3-Dimensional Visualization of Heterogenous Lithology

Sandstone channels and splays encased within mudstone overbank deposits

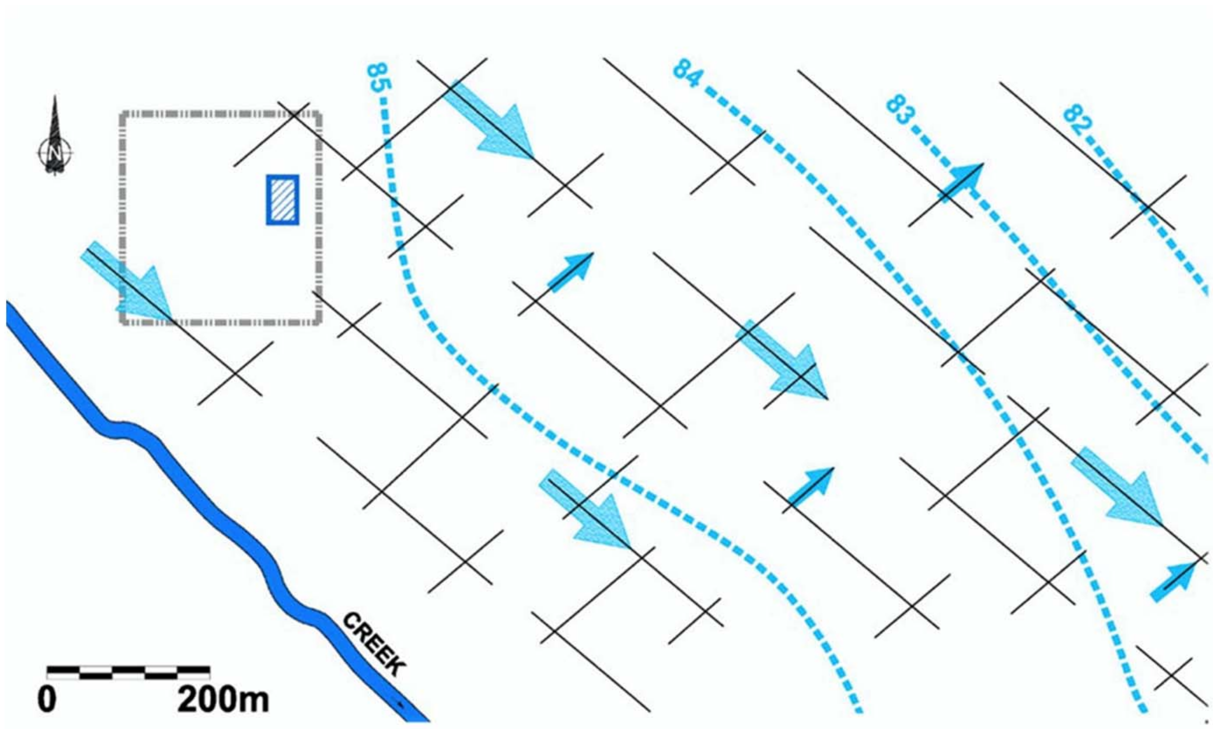


# One Clue that Fractures are Connected

Fracture in sandstone with oxidation halo

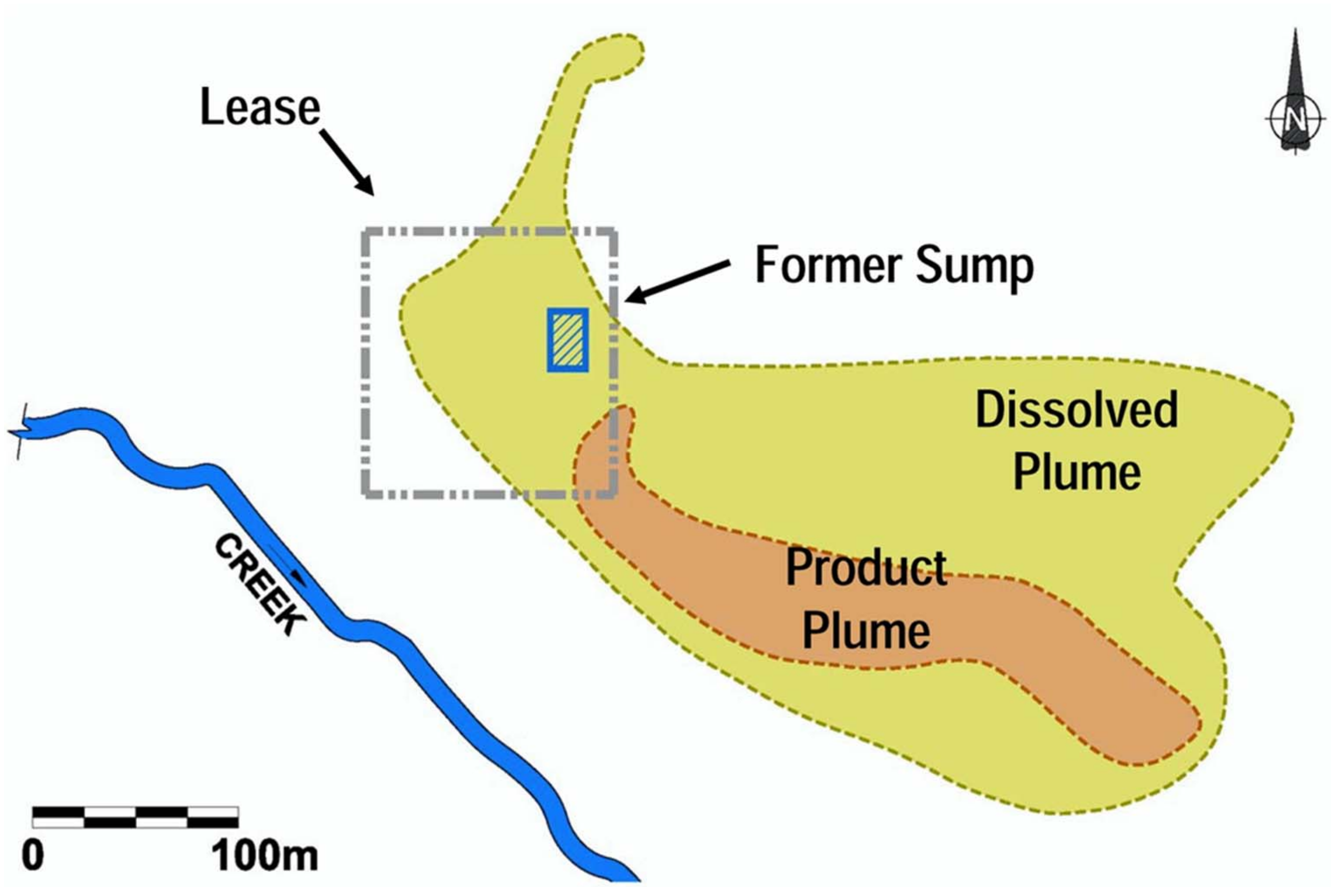
## Example of Anisotropic Fracture Control

Upstream gas well site. Diesel invert mud impacts. Lateral hydraulic gradient in fractured sandstone to northeast, predominant groundwater flow component to southeast.



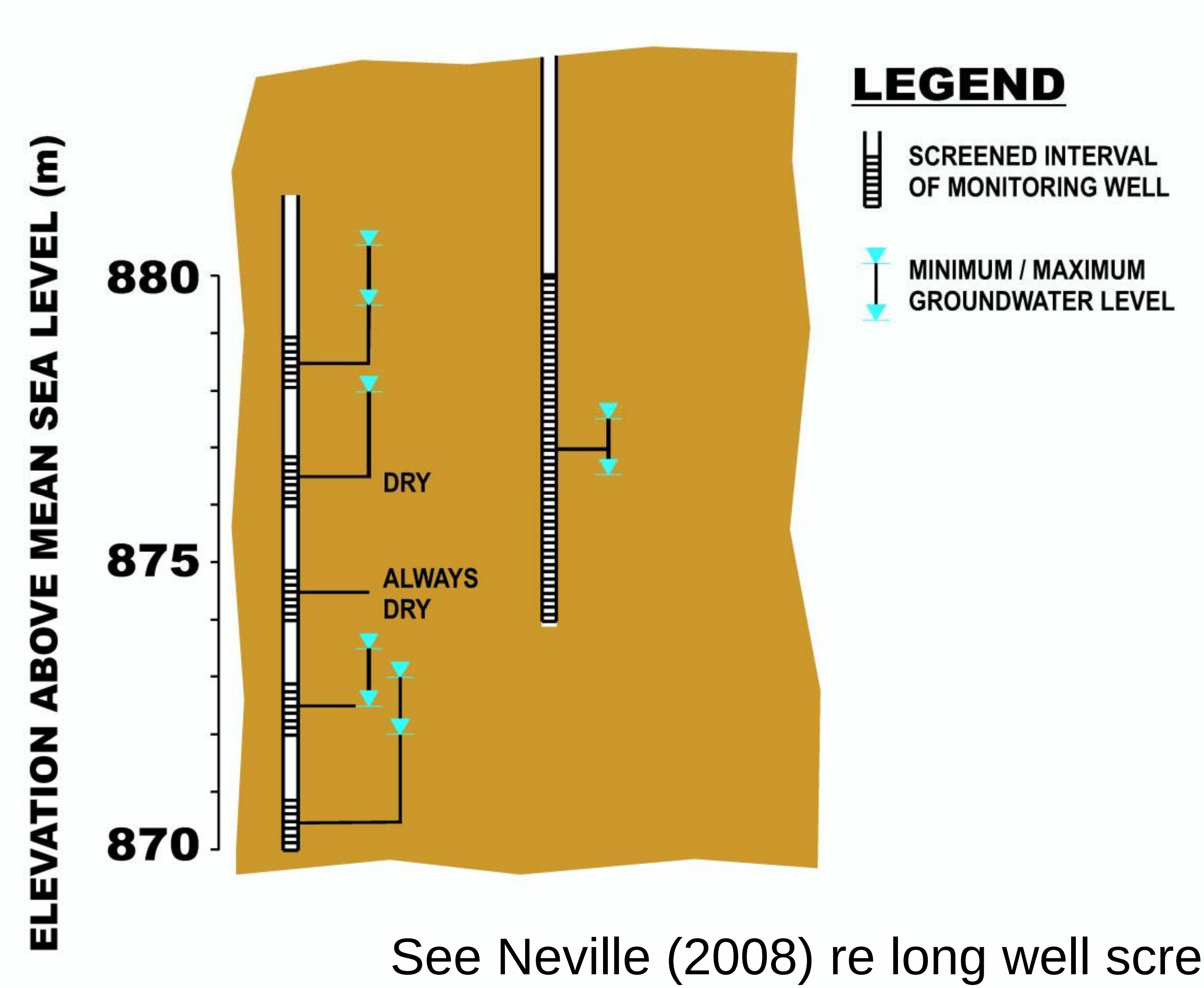

Thomson & Humphries (2007)

# Effect of Connected Fracture Anisotropy on LNAPL and Dissolved Phase Plumes




Thomson & Humphries (2007)

# Example of what multi-level monitoring wells with short well screens can show




Type 3 system "perched" over Type 1 system that overlies fully saturated Type 3 or 4 system

See Neville (2008) re long well screens/ open intervals

## Summary of Investigation Methods

- Observations noted earlier in presentation
- Installation of conventional monitoring wells at different depths with no more than ~1.5 m long well screens
- Installation of multilevel sampling wells (several types available)
- Surficial geophysical investigations – looking at depth to bedrock under the site, and other structural features that could influence groundwater flow
- Bedrock coring to visually confirm the presence of fractured bedrock; looking for oxidation halos, evidence of impacts within fractures, etc.
- Downhole geophysics looking at fractures and fracture sets with depth, assessing flow within the borehole
- Pumping and packer tests
- Transmissivity profiling using FLUTe liners
- Tracer testing

# Tier 1 & 2 Scenarios and Approaches

# Scenarios and Approaches

- Flow in fractured bedrock behaves conservatively as coarse- or fine-grained soil (stay in Tier 1) …
- Flow in fracture-dominated system clearly do not meet porous media fate and transport assumptions … kicked out of Tier 1
- Not clear what conditions apply

# Approaches when Tier 1 Cannot be Applied

- Quantitative modeling typically not simple or practical … environmental risk must be very high to justify data collection

- Set Dilution Factor 4 = 1 (i.e. adopt compliance point guideline)

- Exposure Control
  - May be impractical to remediate based on e.g. excavation constraints, fracture connectivity, matrix diffusion

# Tier 1 Cannot be Applied cont'd

- Exposure Control cont'd
  - Requires a stable plume and a good conceptual site model based on adequate field investigations
  - Can be time consuming and expensive

- Site-Specific Risk Assessment … it may be possible to obtain closure by careful consideration of contaminant and exposure pathways and e.g. whether parameter concentrations are stable

# Approaches When not Clear What Applies

- Take a closer look at the data
- Analyse applicable contaminant and exposure pathways from perspective of environmental risk … overlying soil can be assessed differently from underlying rock
- Go back to the site with higher levels of investigation
- Take ESRD’s 2-cm fracture “length” guideline with a grain of salt
- Discuss the site on a case-by-case basis with the regulator … they may accept a “reasonable” fit with Tier 1 requirements

# A Final Suggestion

- When faced with fractured rock conditions
  - Don't ignore them
  - Don't freak out
  - Instead, hunker down and try to figure out what you've got and how to deal with it

**THANK YOU!**

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# References & Additional Resources

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