CONTAMINATED SITES INVESTIGATIONS IN FRACTURED BEDROCK SETTINGS - INFORMATION AND EXAMPLES OF WHEN AND HOW TO INVESTIGATE THEM

CSAP Fall Professional Development Workshop

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OUTLINE

- Introduction
- Regulatory Requirements
- Important Considerations
- Components of Bedrock Investigations
- Techniques
- Data Analysis
- Use of Conceptual Site Models
- Summary and Conclusions

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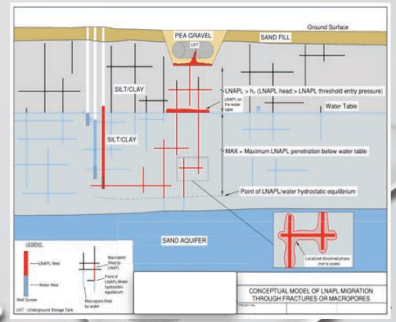
INTRODUCTION

Why investigate bedrock?

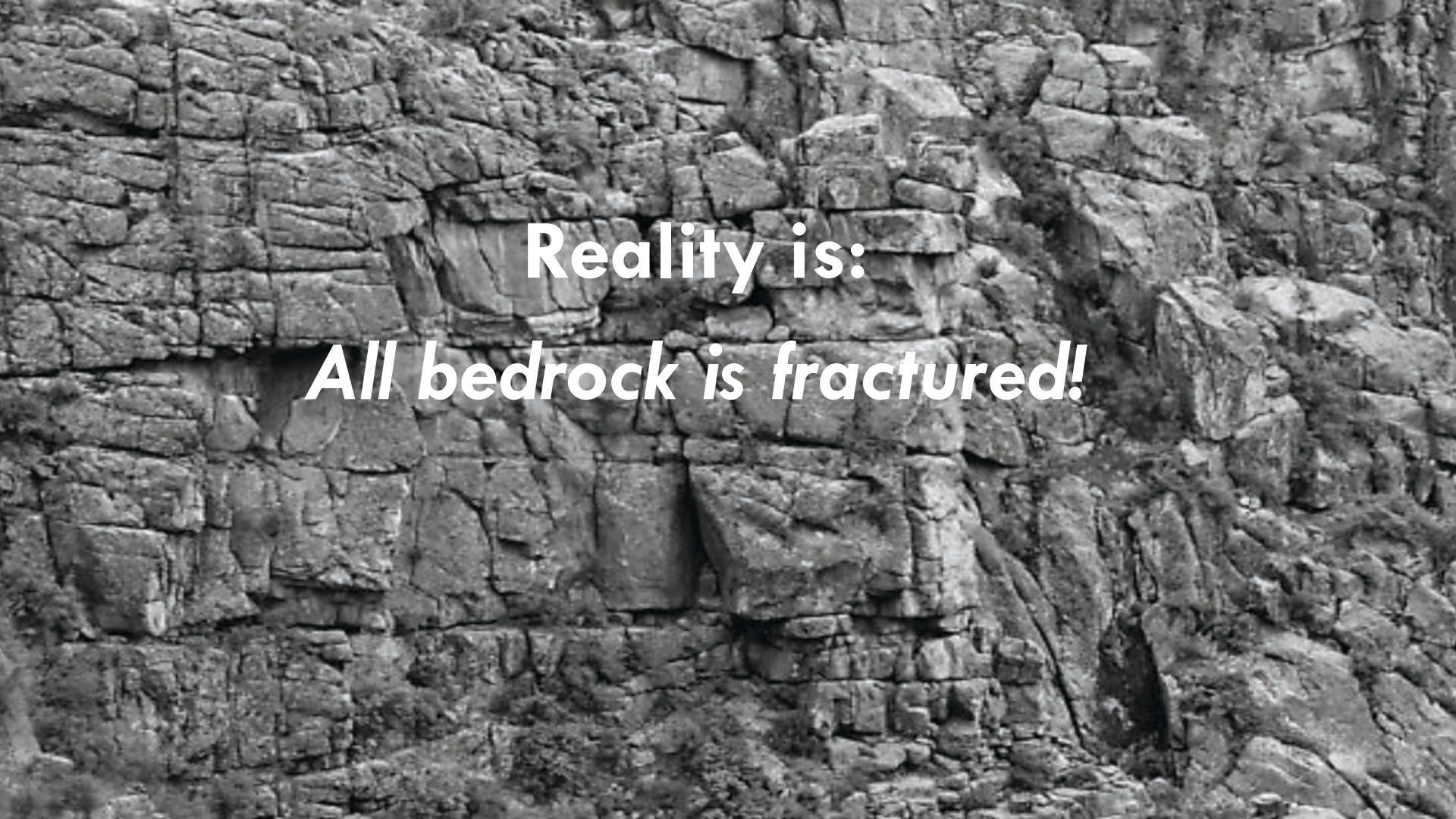
- Regulatory requirements
- Many potable water supply wells are constructed in bedrock
- Flow/transport through bedrock can act as a significant pathway to sensitive receptors
- Groundwater flow and contaminant transport behave differently in bedrock



INTRODUCTION (CONT'D)

Some common misconceptions about bedrock:

- Bedrock is an an impermeable barrier
- Groundwater does not flow in bedrock
- Contaminants do not migrate in bedrock
- Bedrock is not fractured


Reality is:
All bedrock is fractured!

INTRODUCTION (CONT'D)

Several conceptual models for fractured flow:

1. Dual porosity

2. Single fracture

3. Equivalent porous media

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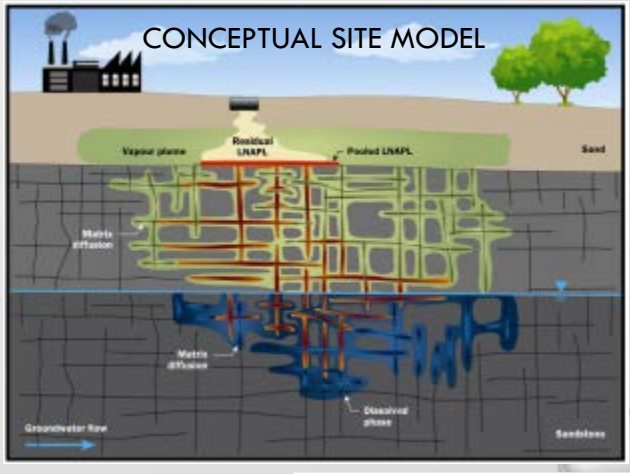
REGULATORY REQUIREMENTS

When are Bedrock Investigations Required?

- Regulatory requirements:
  - Ensure that groundwater at a site is suitable for current and future uses and is of adequate quality to protect adjacent water uses
  - If contamination is identified or suspected, site investigations of all relevant media for each PCOC are required
  - Define the nature and extent of contamination to provide information necessary for conducting a risk assessment and/or develop a remediation plan



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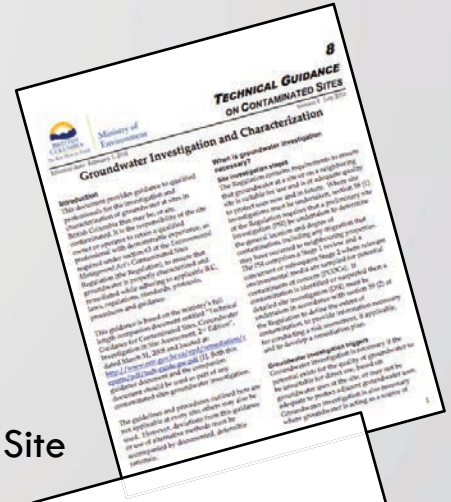
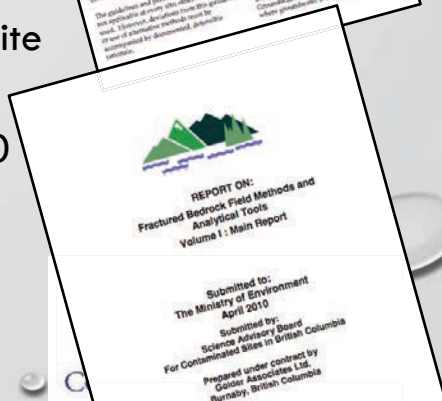
REGULATORY REQUIREMENTS

How to Investigate Bedrock

- No "specific" ministry guidance on bedrock investigations
  - Protocol 21, Water Use Determination
  - Technical Guidance 6, Assessment of Hydraulic Properties for Water Use Determinations
  - Technical Guidance 8, Groundwater Investigation and Characterization
  - Technical Guidance for Contaminated Sites. Groundwater Investigation in Site Assessment, Golder, June 2010
  - Fractured Bedrock Field Methods & Analytical Tools, SABCS, October 2010
- Advice of a qualified professional should be obtained to plan and conduct a bedrock aquifer investigation

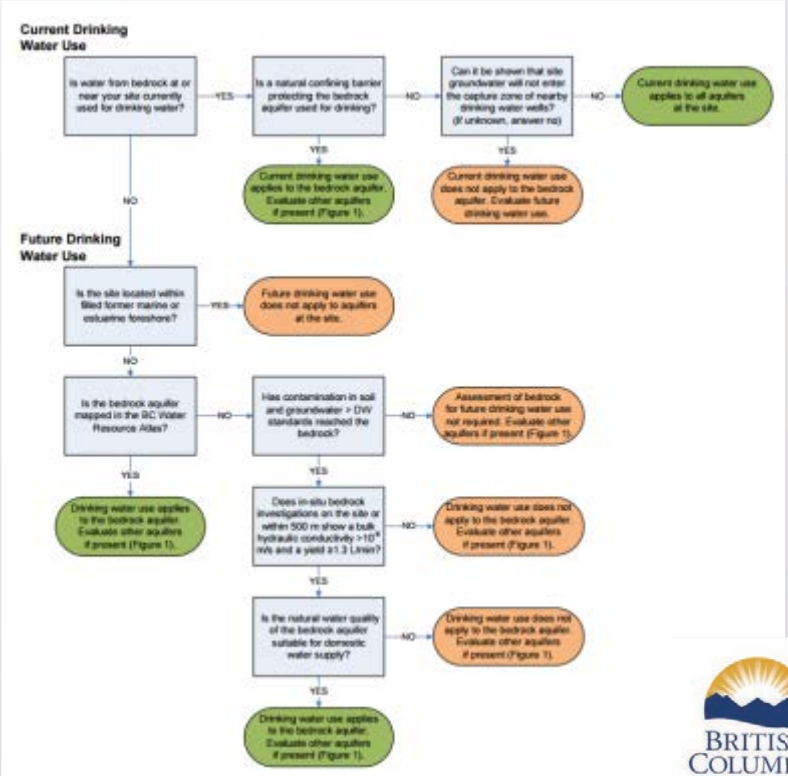




PROTOCOL 21

Water Use Determinations

- Bedrock
  - Drinking water use



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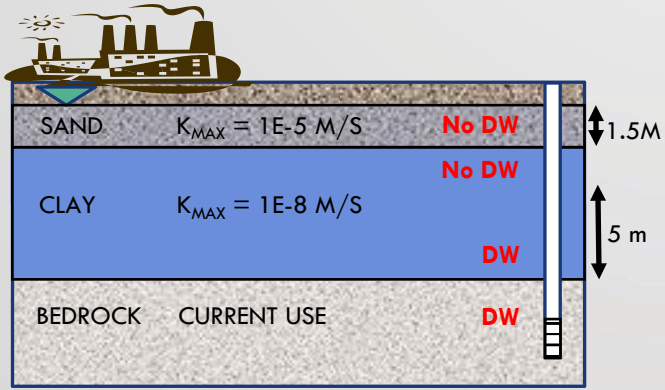
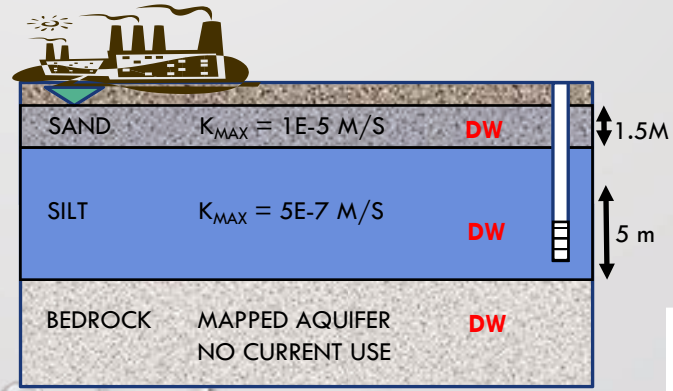
PROTOCOL 21

Drinking Water Use Determinations in Bedrock

- DW automatically applies to bedrock units when:
  - Current use within 500 m
  - Aquifer mapped in the BC Water Resource Atlas

Natural Confining Barrier





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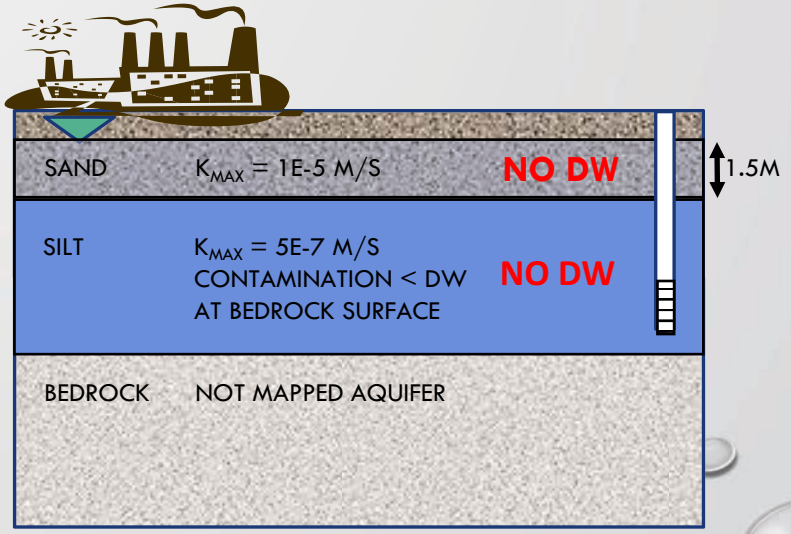
PROTOCOL 21

Future Drinking Water Use Evaluation in Bedrock

- Bedrock investigations required when:
  - Contamination in soil and groundwater
    > DW standards extends to the bedrock surface



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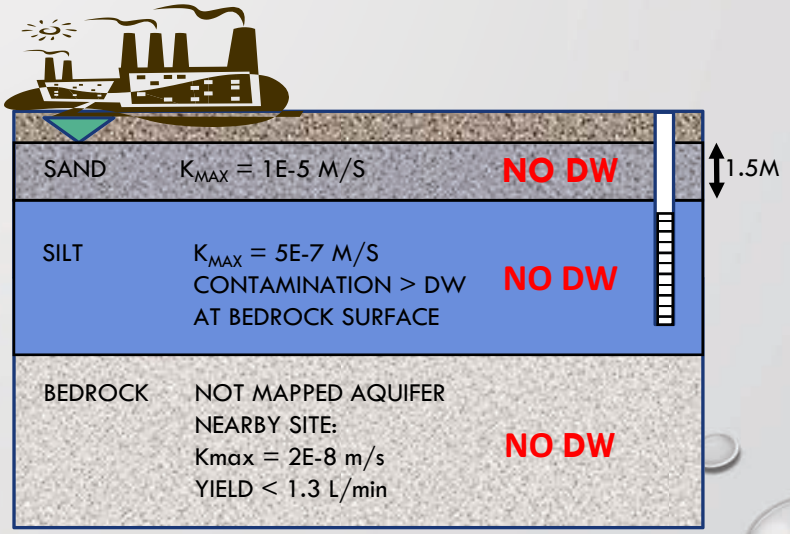
Future Drinking Water Use Evaluation in Bedrock

- Bedrock investigations must include:
  - Hydraulic conductivity
    - $K_{geomean}$ if ≥ 6 wells
    - K_{max} if ≤ 5 wells
  - Yield (sustain pumping at 1.3 L/min)
- Utilize nearby data:
  - TG6: Bedrock data within 500 m
  - Imap: Borehole Map



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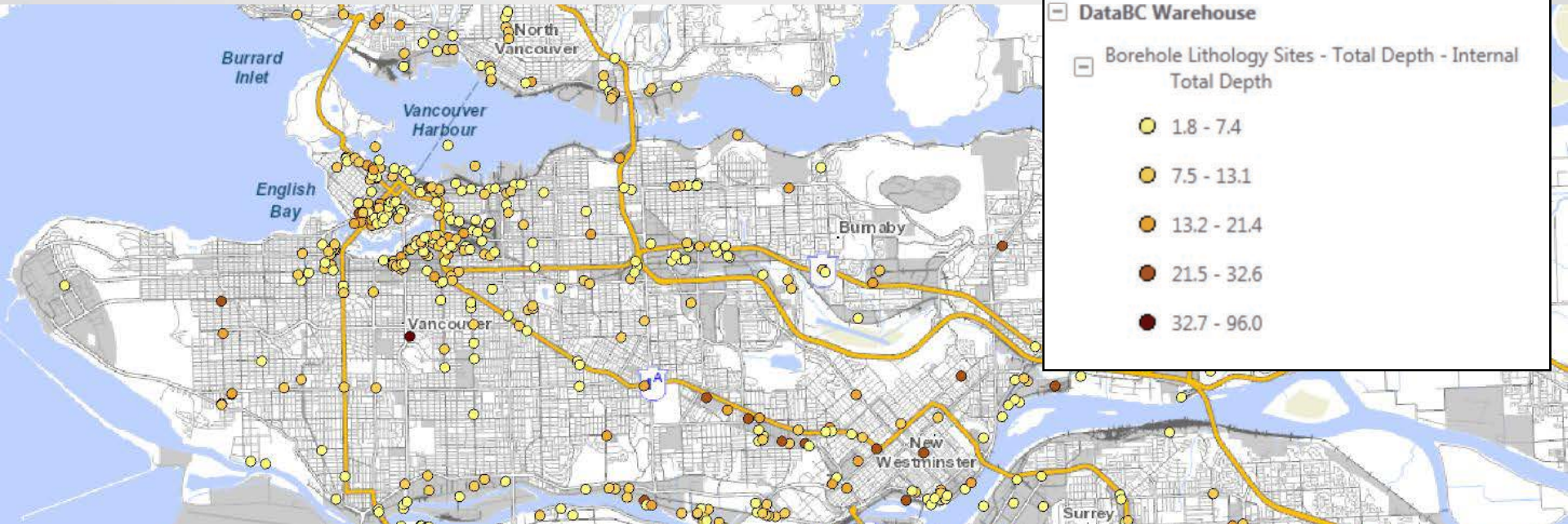
MOE Borehole Mapping Project

- >900 contaminated sites borehole logs in BC



PROTOCOL 21

Natural Confining Barriers

- P21 definition: NCB's are unconsolidated geological units
- Bedrock as a natural confining barrier
  - Where bedrock investigations indicate that part of the bedrock unit operates as a natural confining barrier protecting the deeper more permeable bedrock unit, a site-specific director's determination of water use can be obtained
    - Detailed bedrock investigation
    - Contaminant free
- Preapproval to not delineate
  - Not practicable / feasible to delineate

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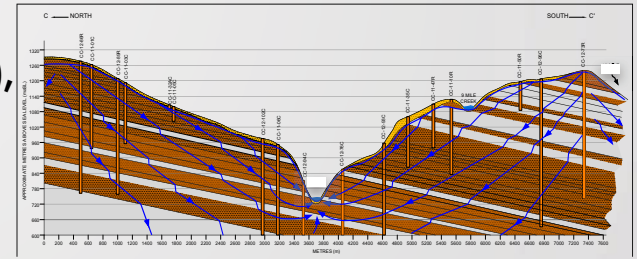
SOME IMPORTANT CONSIDERATIONS

- Requires greater evaluation of the geology and hydrogeology e.g. lithology, porosity, structure (fracturing), hydraulic properties, flow
- May require specialized drilling and well installation methods
- Greater training and management of field staff
- Staff with specialized expertise in geology and hydrogeology
- If planned well can be completed relatively economically



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COMPONENTS OF BEDROCK INVESTIGATIONS

Main Components:

1. Geology and hydrogeology data collection
2. Data analysis
3. CSM development
4. Additional investigation (if required)
5. CSM refinement

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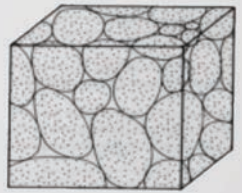
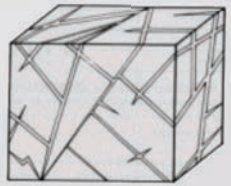
BEDROCK INVESTIGATION GOALS

- Define the geology (lithology and structure)
- Identification of flow features (primary and secondary porosity – e.g. fractures)
  - If possible, determine which fractures are flowing
  - Screen over the flowing fractures (if discrete fracture flow model)



Pores in unconsolidated Sedimentary Deposits e.g. Sand



Joints in Hard Rock e.g. Granite, Quartzite

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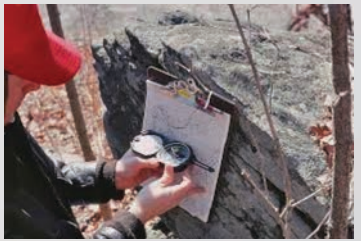
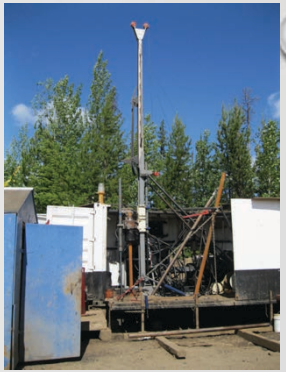
TECHNIQUES

- Desktop research (review regional geology maps)
- Map the surface geology at outcrops:
  - Lithology and structure (fracture identification, fracture density, orientation - strike/dip)
- Collect rock samples for lithology



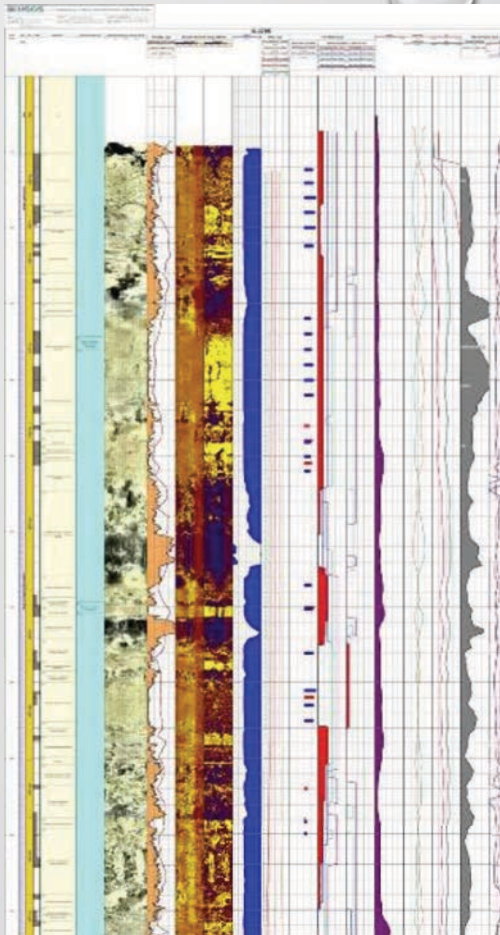
TECHNIQUES (CONT'D)

- Bedrock drilling methods:
  - ODEX, Air Rotary, Sonic – all provide an "open" borehole
  - Diamond drilling provides open borehole and rock core
- Core drilling good option if not performing borehole geophysics to find fractures



TECHNIQUES (CONT'D)

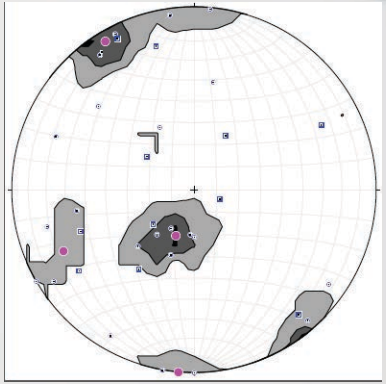
- Borehole geophysics:
  - Temperature, resistivity, caliper logs
  - Acoustic and optical televiewer
  - Flow meter
- Good option on "open" boreholes to identify fractures



TECHNIQUES (CONT'D)

- Monitoring well installation:
  - Slotted PVC, Flute Sampler, Solinst Packers/Waterloo Multilevel Sampling, CMT, Westbay Multilevel Systems
- Hydraulic testing:
  - Slug tests / packer tests / pumping tests
- Lateral and vertical hydraulic head distributions i.e. flow determination
- Groundwater chemistry sampling
- Tracer studies

DATA ANALYSIS



- Determine lithology and porosity
- Define structural geology (e.g. number of fracture sets/orientations, etc.)
- Geophysical data - which fractures are flowing, directions and rates
- Hydraulic data - fracture transmissivity/conductivity / connectivity – gradients and flow directions, probable fracture model type

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CONCEPTUAL MODEL DEVELOPMENT

- Geologic model
- Physical hydrogeology
  - Hydrostratigraphy, flow boundaries, flow directions, hydraulic conductivities, hydraulic gradients and velocities/fluxes, recharge/discharge areas
- Contaminant hydrogeology
  - Source area(s), source properties (physical and chemical), release mechanisms, transport mechanisms

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BEFORE INVESTIGATION

UST

????

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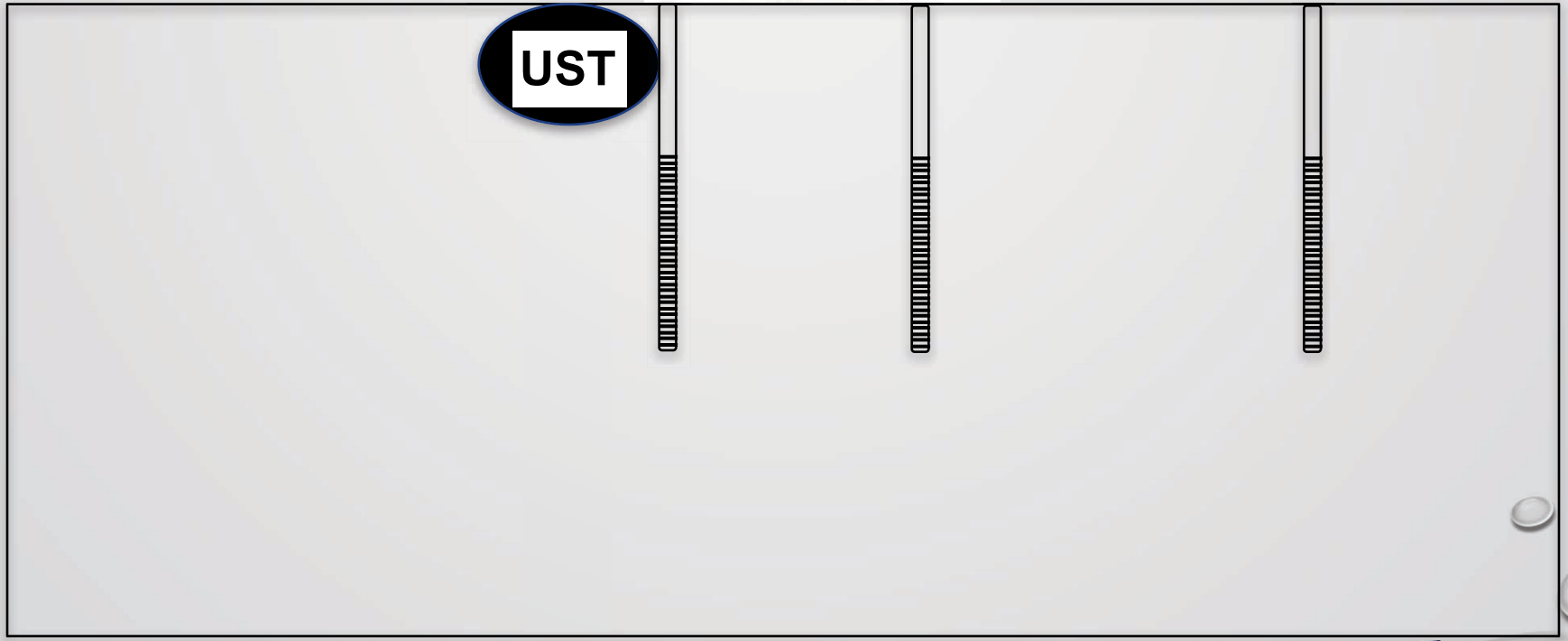
INITIAL INVESTIGATION



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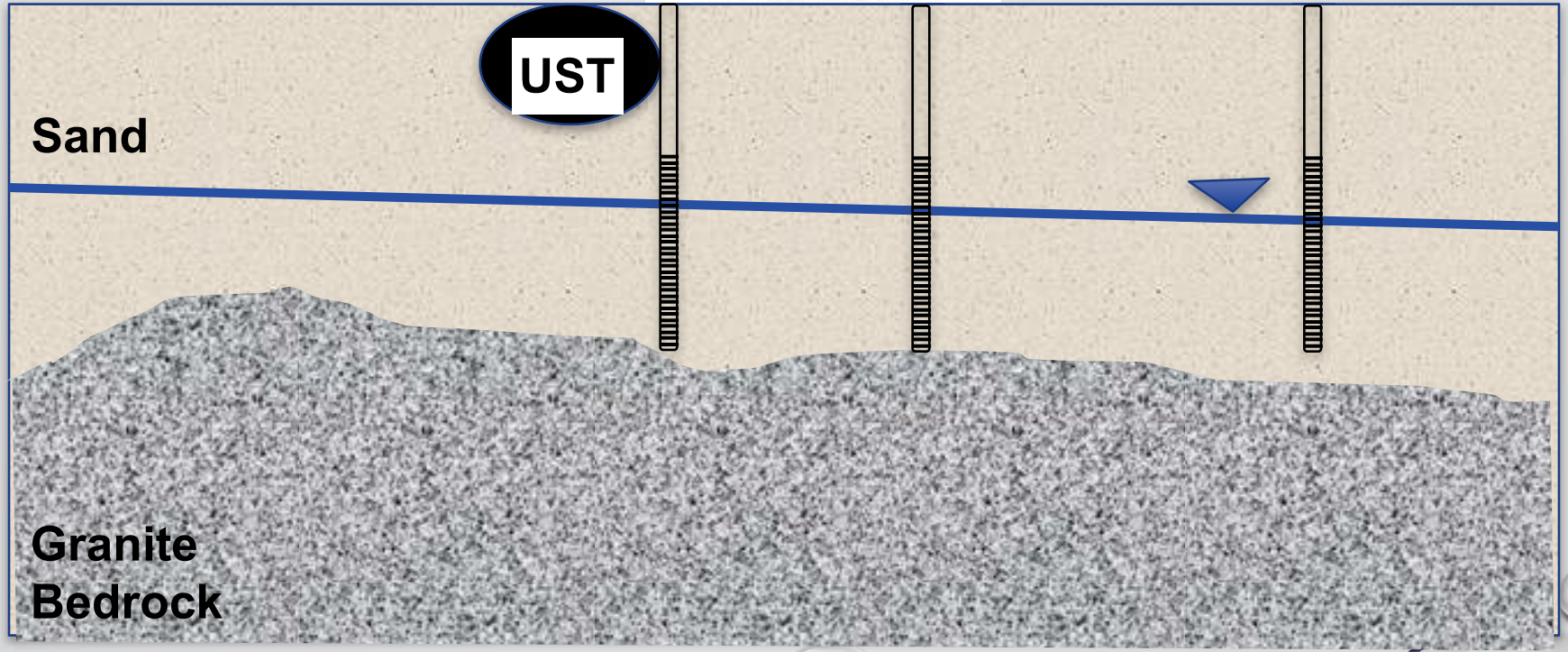
GEOLOGY AND GROUNDWATER INFO.



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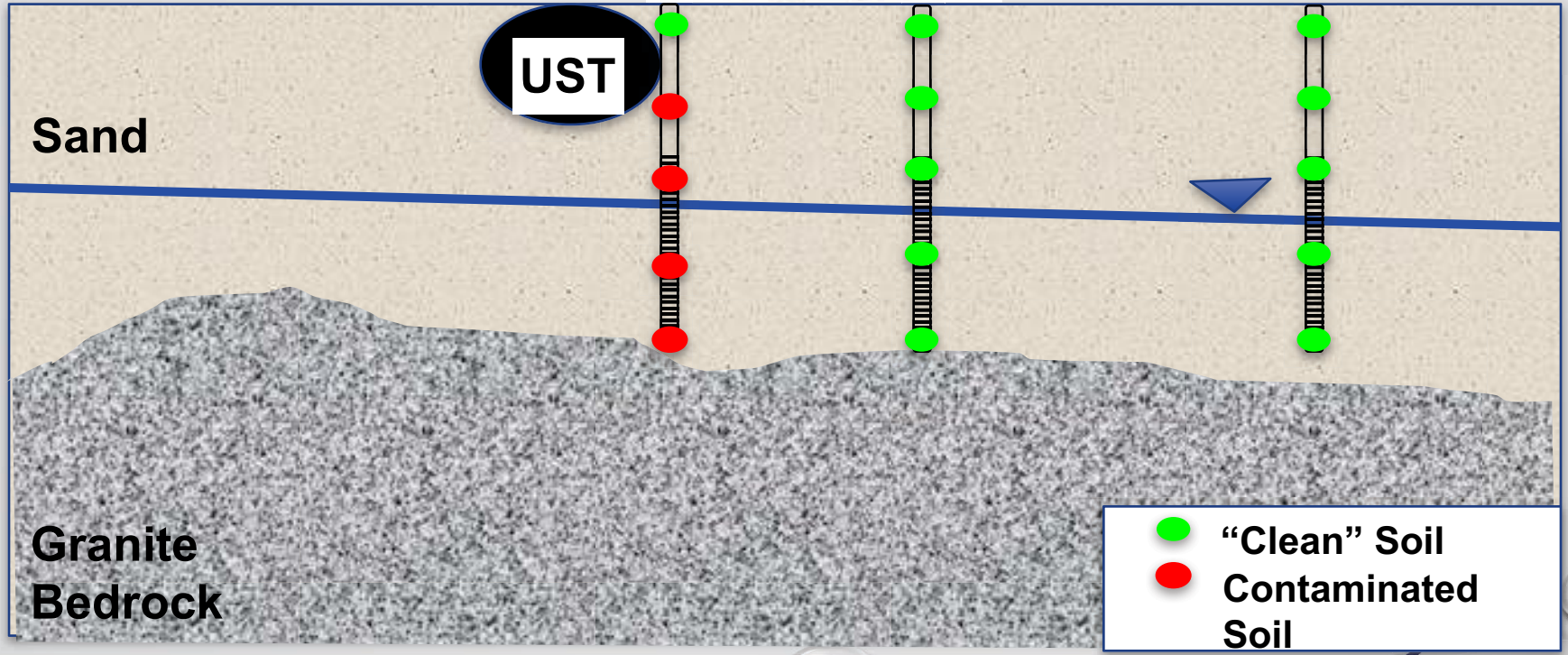
INITIAL SOIL DATA



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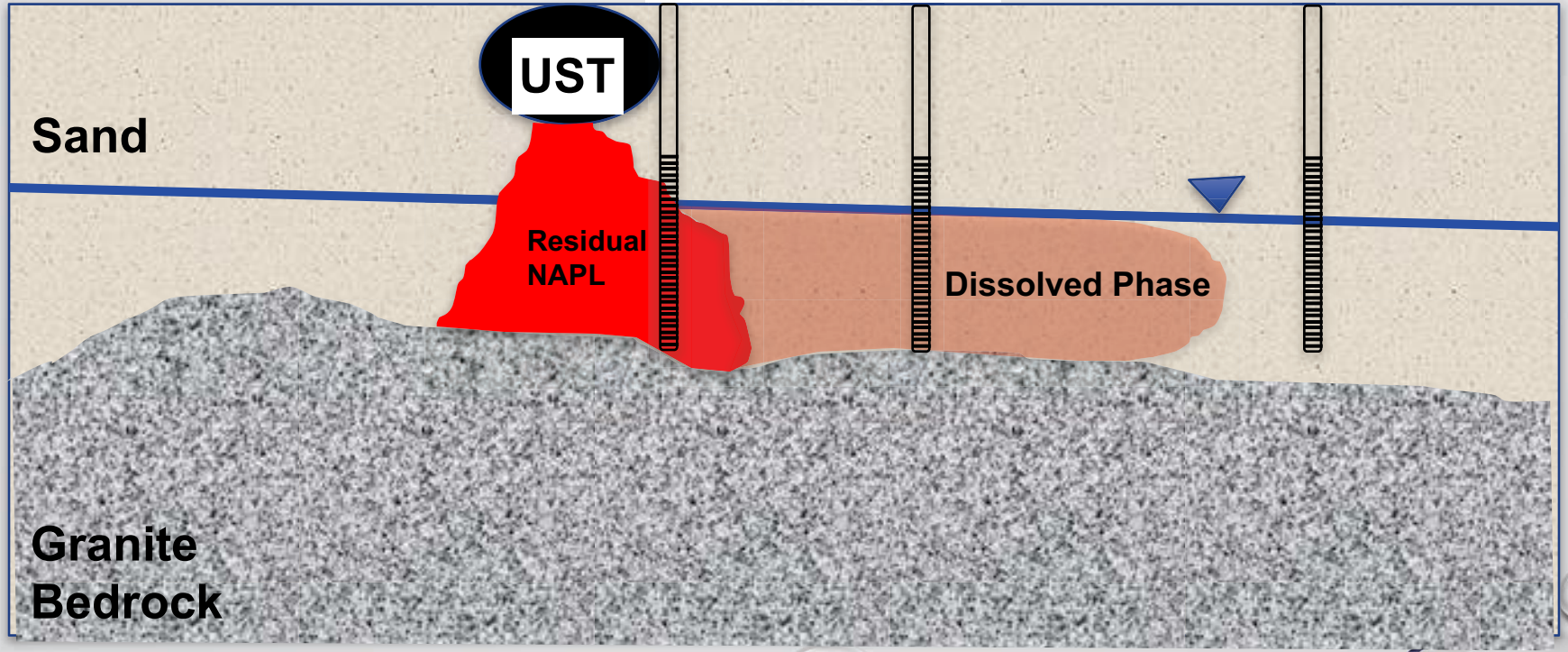
INITIAL GROUNDWATER CHEMISTRY DATA



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INITIAL CSM

Recharge Boundary

UST

Sand

Sand Aquifer

Residual NAPL

Dissolved Phase

FLOW PATHLINES

No Flow Boundary

Granite Bedrock

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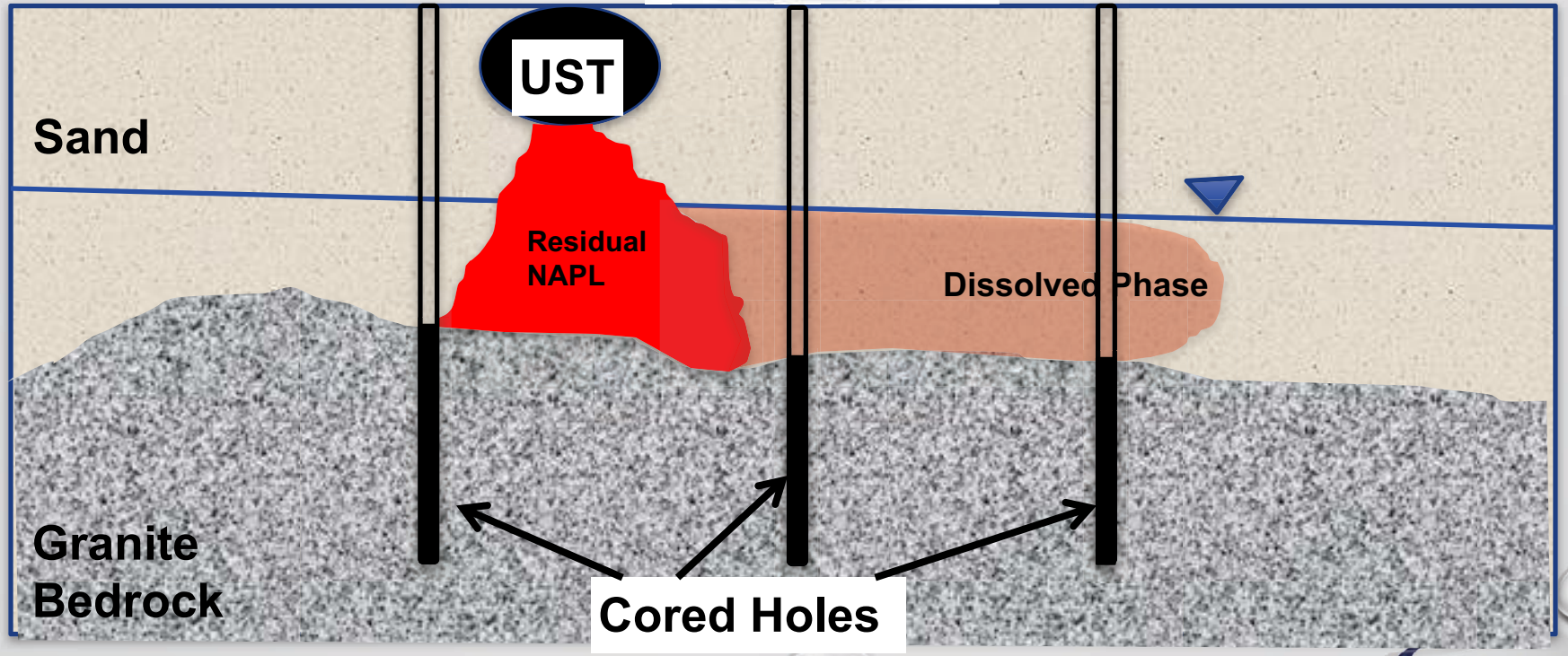
BEDROCK INVESTIGATION



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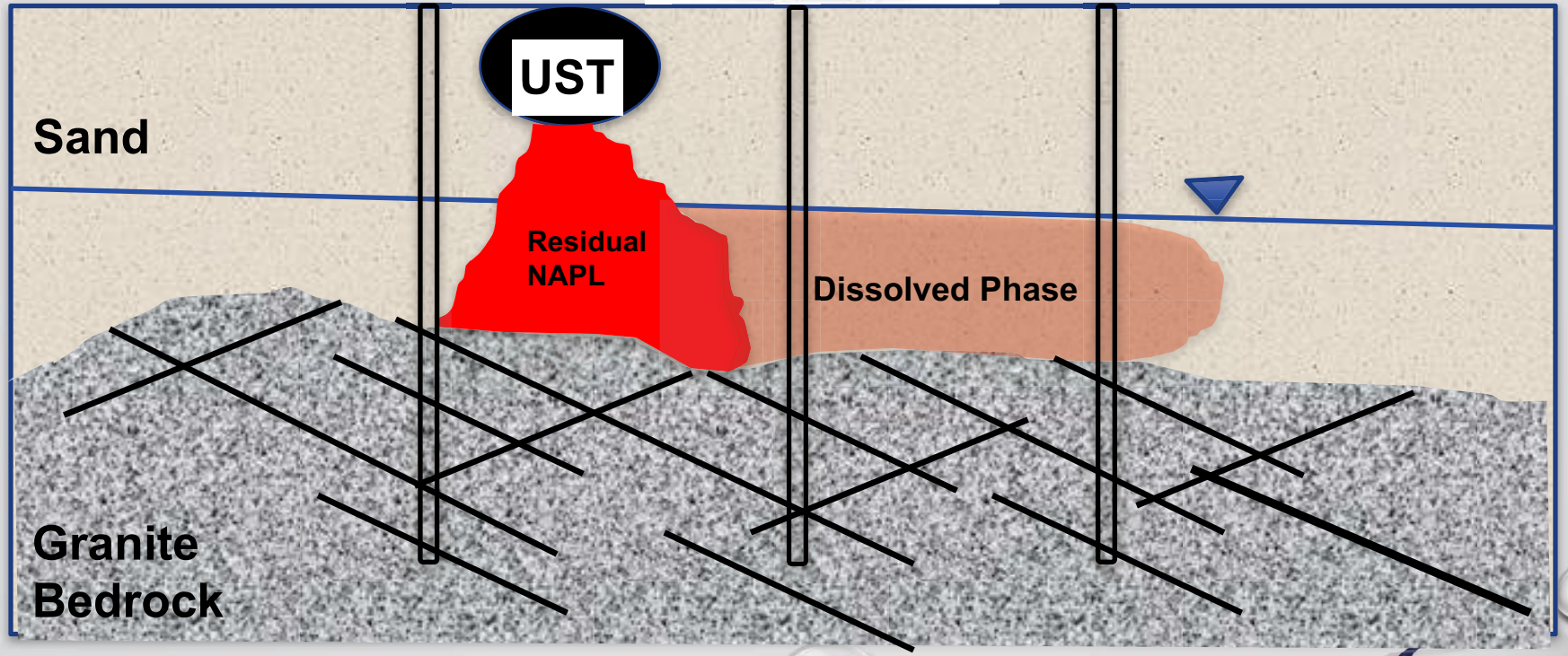
GEOLOGY DATA GATHERED



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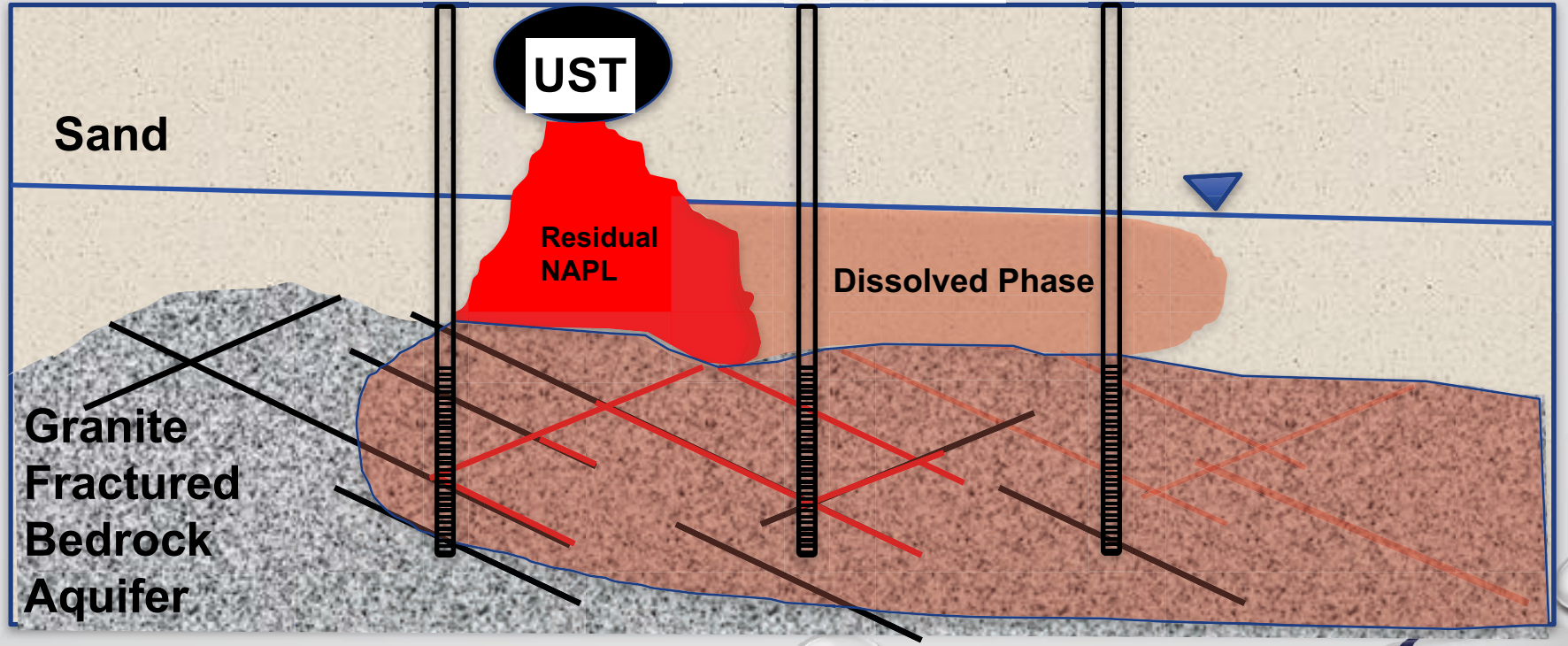
GROUNDWATER CHEMISTRY COLLECTED



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REFINED CSM

Recharge Boundary

UST

Sand

Sand Aquifer

Residual NAPL

Dissolved Phase

FLOW PATHLINES

Granite Fractured Bedrock Aquifer

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EXAMPLE CSMS

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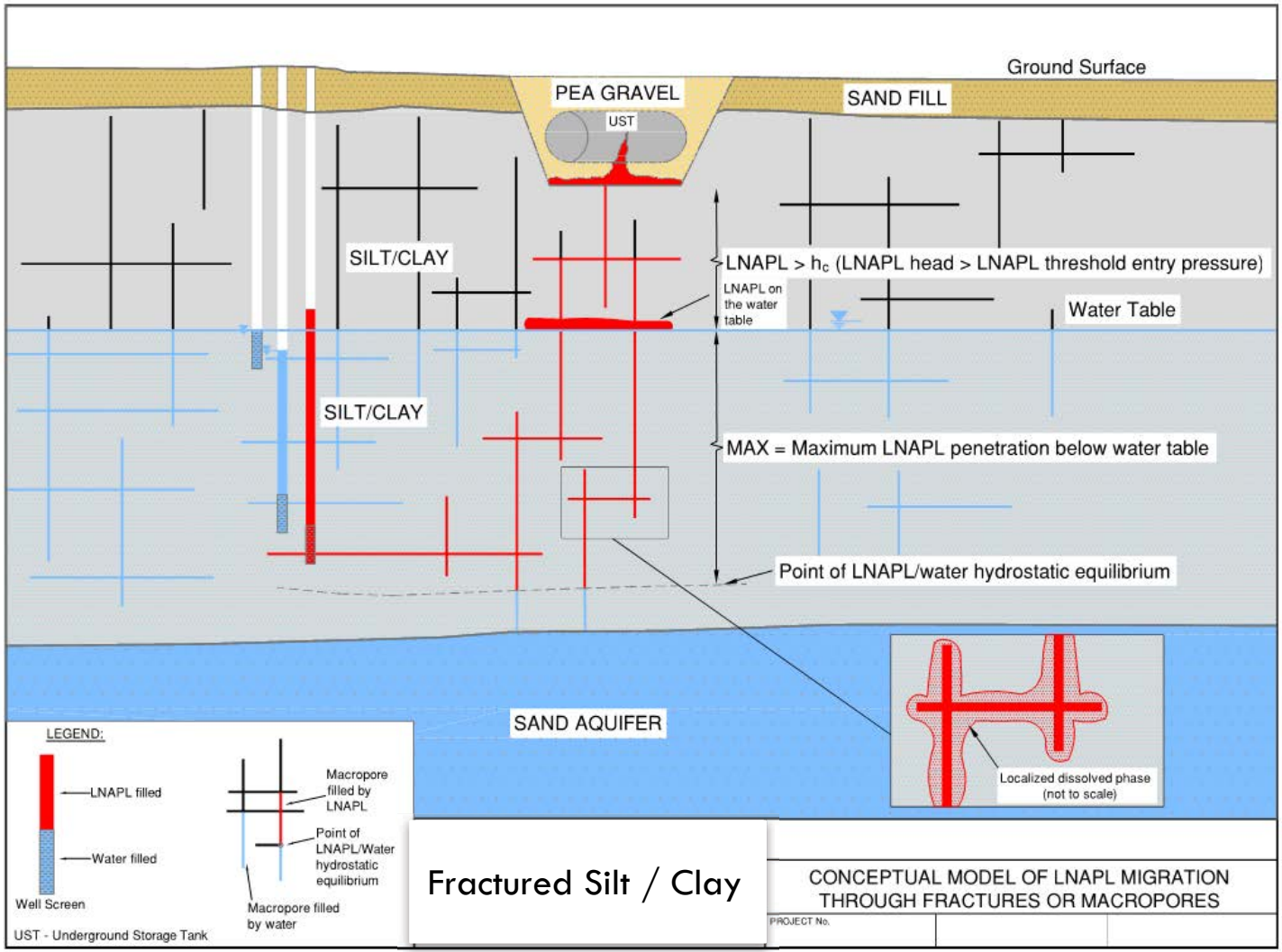

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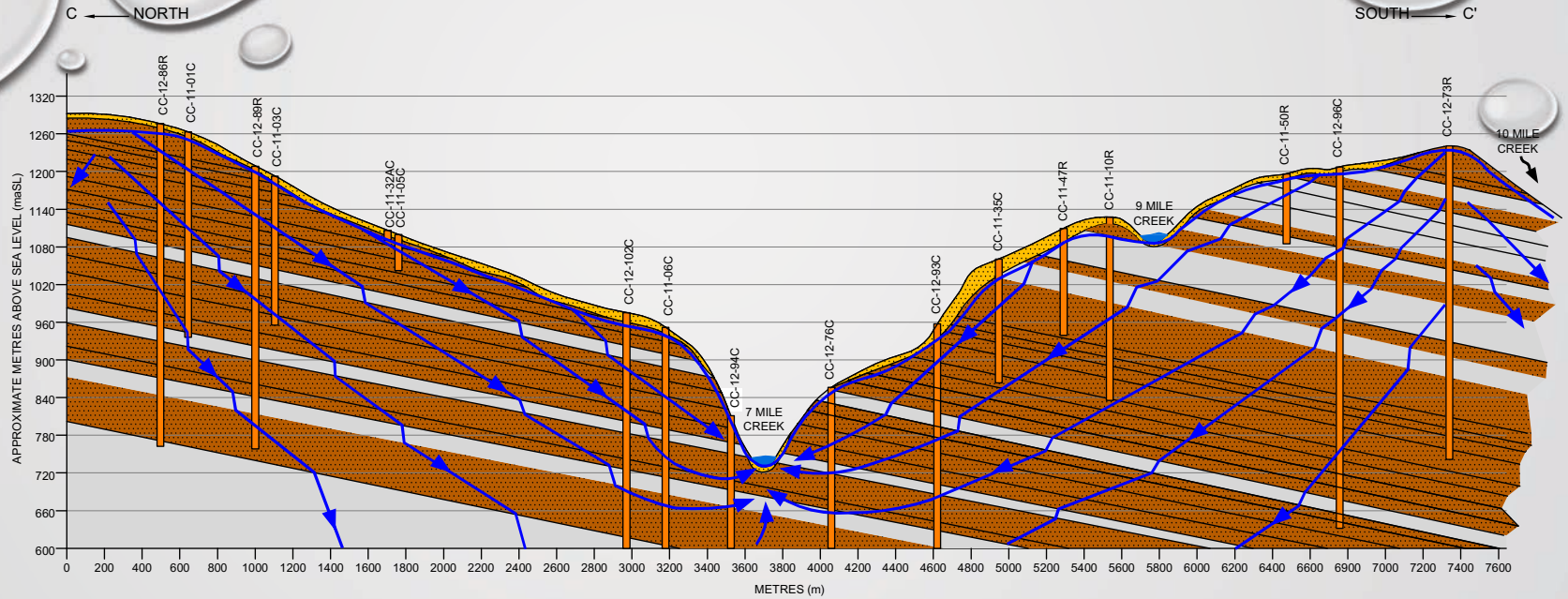
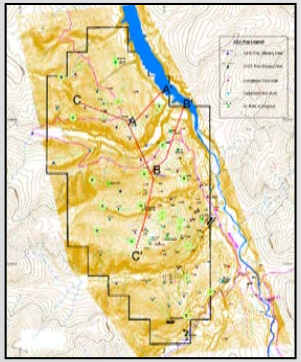


KEY PLAN SHOWING SECTION LINE LOCATIONS



STRATIGRAPHY

- OVERBURDEN SOILS
- SANDSTONE WITH VARIABLE SILTSTONE INTERBEDS
- SILTSTONE WITH VARIABLE MUDSTONE INTERBEDS
- MUDSTONE

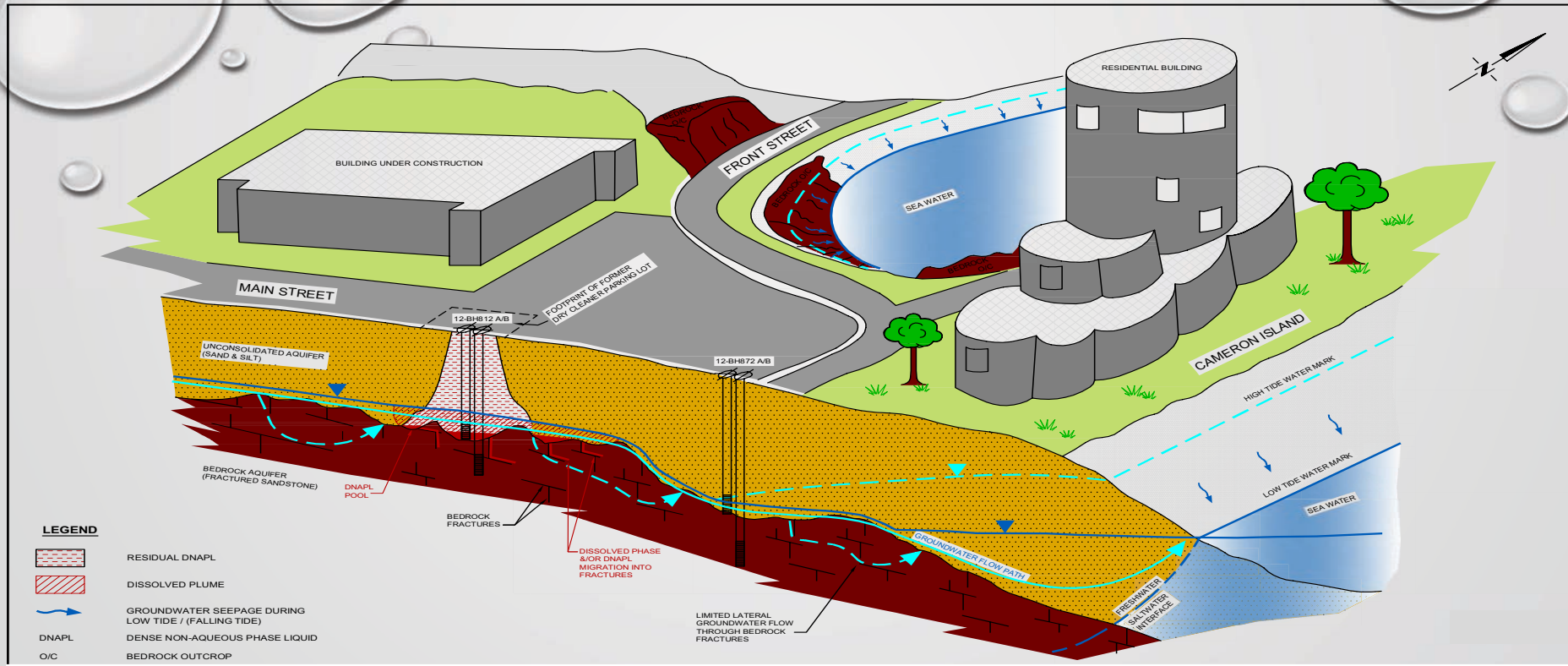
LEGEND

- INFERRED SOIL STRATIGRAPHIC CONTACT
- WATER TABLE (DASHED INFERRED)
- INFERRED GROUNDWATER PATH LINES
- GROUNDWATER ELEVATION (METRES ABOVE SEA LEVEL) MEASURED OCTOBER, 2012

NOTES:

1. TOPOGRAPHIC ELEVATIONS, GEOLOGIC CONTACTS, AND HYDROGEOLOGIC INFORMATION EXTRAPOLATED FROM TOPOGRAPHIC MAPS, OBSERVATIONS RECORDED ON BORING LOGS AND FIELD MEASUREMENTS RECORDED.

Fractured / Stratified Rock at a Mine Site



Unconsolidated Soil and Bedrock Contaminated Site Adjacent to Marine Environment

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SUMMARY AND CONCLUSIONS

- Several circumstances when bedrock should be investigated
- Investigations can be done relatively economically
- Requires thorough evaluation of geology and hydrogeology
- Flow and transport in bedrock often behaves very differently
- Development of CSMs can assist in establishing the flow and contaminant transport regime and remedial planning
- Can be a significant pathway to a receptor

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THANK YOU!
QUESTIONS?

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