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Outline

• Need for 3D Wellbore Characterization
• Summary of approaches and difficulties to characterize flow in fractured rock
• Describe our dissolved oxygen alteration method (DOAM)
• Show results for Connecticut studies
Understanding Flow of Water in Fractured Rock

Important for:

• Water supply assessments
• Water source
• Recharge rates/sustainability
• Locating sources of contamination
• Remediating contaminated water
Difficulties in Characterizing Fracture Flow

- Fracture systems are complex
- Apply open hole characterization approaches
  - Water Levels are K and h weighted averages
  - Pumping test results high K fracture weighted
  - Water quality is average of waters from different fractures
Issues in characterizing contamination using tap samples or low flow sampling
Difficulties in Characterizing Fracture Flow

- Fracture systems are complex
- Apply open hole characterization approaches
  - Water Levels are K and h weighted averages
  - Pumping test results high K Fracture weighted
  - Water quality is average of waters from different fractures
- Detailed Characterization costly
  - USGS tool box
  - Flute
Tool Box Approach

(1) Logging
(2) Develop and interpret logs to locate fractures
(3) Conduct flow meter logging to determine water contributing fractures
(4) Conduct straddle packer testing
Flute Liner Characterization

- Locate Fractures
- Determine transmissivity
- Determine contamination
- Determine hydraulic head
- But costly
The Constraints on Detailed Characterization!

- Takes days to conduct work on one well
- Equipment not readily available
- Equipment experimental
Tracer Testing

A Tracer Dilution Method for Fracture Characterization in Bedrock Wells
by Richard J. Brainerd and Gary A. Robbins

- Tracer testing Issues
  - Safety concerns constrain use or amounts to use
  - Requires expensive detectors and sampling systems
  - Technical issues— injection, uniform mixing
Dissolved Oxygen Alteration Method

• Alter the dissolved oxygen (DO) concentrations in a well and profile DO periodically as DO returns to background over time
• Without pumping to decipher ambient flow
• Single well pumping to determine contributing fractures
• Multiple wells (pumping well and aerated well) to determine fracture interconnectivity)
Inject compressed air into well using a porous polypropylene bubbler connected to a hose and pressure gauge.
Profile

Monitor change in DO concentrations using a YSI Sonde or INW DO Sensor
DOAM Uses

- Find water contributing fractures
- Determine how water is flowing in wellbore (Identify active zone)
- Determine which fractures are contaminated and at what level by sampling in active zone
- Use to optimize locations of passive samplers in wellbore.
- Map out fracture flow field by determining which fractures transmit water between wells
Benefits over Traditional Geophysical and Tracer Methods

• Cost- and time-effective
• Benign tracer
• Easily detectable
• No change in well water level (head) → no impact on flow conditions
• Low public or regulatory concern
• No need for tracer mass recovery (DO diminishes by abiotic and biotic means)
Ideal Detection of Single Fracture

After aeration DO increases with depth (solubility of DO increases with Pressure)
Ideal Detection of Multiple Fractures
Hebron Gneiss

Well Construction:
• SIMA 1
  • 0-6.1m fill/till
  • 9.3 m of casing
  • 9.3 - 94.5 m (310 ft)
• SIMA 2
  • 0-6.4 m fill/till
  • 9.3 m of casing
  • 9.3 - 94.5 m (310 ft)
Ambient Flow Test

Sima 1

Compressed Air

Dissolved Oxygen (mg/l)

Depth (m)

- Background
- Aerated
- 5.5-6.7 hours
- 8.4-9.4 hours
- 24.9-25.5 hours

Sima 2

Compressed Air

Dissolved Oxygen (mg/l)

Depth (m)

- Background
- Aerated
- 5.6-6.8 hours
- 9.7-10.6 hours
- 28.8-29.4 hours

Chelbica and Robbins (2013)
Slug Tests

Compressed Air

Displaced Oxygen (mg/l)

Depth (m)

Flow

In

Out

Up

Down

Displacement - 12.0 meters

Sima 1

Displacement - 9.3 meters

Sima 2

Chelbica and Robbins (2013)
Interconnected Fractures

- Pumping tests indicate wells are hydraulically connected.
- Previous work suggests connection in upper 30 m
Recent Bedrock Applications

Identification of transmissive fractures connecting bedrock wells

- Crystalline bedrock test wells
  - Beach Hall- UCONN
  - UCONN Farm
  - USGS Branch of Geophysics
Ideal Identification of Connecting Fracture in Well Where Vertical Borehole flow is Low
Ideal Identification of Connecting Fracture in Well Where Vertical Borehole Flow is Substantial
Under ambient flow conditions, water flows in at 16.5 m, then down. Once pumping begins in Sima 2, water flows straight through.
Sima 2

(a) Sima 2 DO (mg/L) Profiles

(b) Drawdown with Time

(c) Change in Rate of DO Decrease
UCONN Farm

3 pumping wells and 4 monitoring wells

Pumping tests indicate all wells are hydraulically connected

DO tests on MW-2 (600 ft/182 m deep)
UCONN Farm

MW2 Ambient Dissolved Oxygen (mg/L)

- Aerated
- 5.5 hours
- 25.25 hours

Depth (m)

MW2 Single Well Pumping Dissolved Oxygen (mg/L)

- Aerated
- Pumped

Depth (m)
Other Recent Advanced Applications

- Flow characterization in screened monitoring wells
- Measuring vertical flow rate in wellbores
- Aiding in the discrete sampling of individual fractures
Conclusions

The DOAM provides a low-cost alternative to traditional methods of borehole flow characterization.

Aid in interpretation of averaged sampling results in consideration of three-dimensional factors that influence flow.
Have A Site? Will Travel.

Questions?