Hydraulic and Water-Quality Characterization of Fractured-Rock Aquifers Using Borehole Geophysics

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Flow in Open Borehole

Runkel and others (2003)
Ambient Flow

Edwards carbonate-rock aquifer, Texas
Ambient Flow

Edwards carbonate-rock aquifer, Texas
Ambient Fluid Log and FW/SW Interface

Edwards carbonate-rock aquifer, Texas
Pumped Fluid Logs

Edwards carbonate-rock aquifer, Texas
Pumped Fluid Logs and FW/SW Interface

Edwards carbonate-rock aquifer, Texas

Fresh Water

Saline Water
Flow and Fluid Logging under Ambient and Pumped Conditions

Deep borehole in TCE source area, cased to 155 ft

Flow zones at 201 and 312 feet

Downward ambient flow

Pumped flow:
- 80% 201 feet
- 20% 312 feet

Cretaceous sandstone aquifer, southern California
Bedding fractures

Intermediate angle fractures

High angle fractures

Bedding fracture
Flowmeter Detects Most Transmissive Flow Zones

<table>
<thead>
<tr>
<th>Depth</th>
<th>CAL (INCH)</th>
<th>PMP1</th>
<th>PMP FLOW</th>
<th>PACKER T</th>
</tr>
</thead>
<tbody>
<tr>
<td>1:680</td>
<td>2</td>
<td>17.53</td>
<td>-6</td>
<td>0.001 FT2/D</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>18.5</td>
<td>GAL/Min</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>AMB FLOW</td>
<td>1000 FM MODEL T</td>
</tr>
<tr>
<td></td>
<td></td>
<td>17.53</td>
<td>18.5</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>AMB FLOW</td>
<td>1000</td>
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</table>
CORE ANALYSIS
MATRIX DIFFUSION

High TCE in the matrix near the 201-foot zone

No TCE in the matrix near the 312-foot zone
CROSS CONTAMINATION

TCE point samples
CROSS CONTAMINATION

TCE Monitoring

Sterling (1999)
Central New York
7-mile VOC plume in Silurian-Devonian carbonate-rock aquifer
Surface-water drainage divide

Union Springs wells
1988 – Detected DCE
1999 – 6.2 ug/L DCE

RCRA site
1990s – TCE in shallow bedrock
2000 – Vacuum extraction
Phosphate clasts
Bentonite
Shaley dolomite
Gypsiferous

Stratigraphy

Corehole 181

Characteristic gamma signature in Silurian-Devonian carbonate rocks
Borehole-Wall Images

BERTIE FLOW ZONE
Flowmeter Log Analysis

Flow, in gal/min

ONONDAGA FLOW ZONES

BERTIE FLOW ZONE
RONDOUT FLOW ZONE
BERTIE FLOW ZONE
ONONDAGA FLOW ZONES
RONDOU FLOW ZONE
BERTIE FLOW ZONE
Discrete Zone Heads in Well 181

Head, in Feet
560  670

ONONDAGA FLOW ZONES

UPPER MANLIUS CONFINING UNIT

RONDOUT FLOW ZONE

BERTIE FLOW ZONE
Stratigraphy and Discrete Zone Heads

ELEVATION, IN FEET

218 219 181 185 186 205

HEAD, IN FEET

450 560 670

0 1000 FT
Recharge and Head Response

Well 183 - Bertie zone

Well 204 - Rondout zone
Discrete Zone Heads in Well 222

ONONDAGA FLOW ZONES

UPPER MANLIUS CONFINING UNIT

RONDOUT FLOW ZONE

BERTIE FLOW ZONE
# Advances in Flow Log Analysis

## FLOW-B INPUT AND PLOTS

### Required Input:

- **Well Name:** Temple Terrace PW
- **Hawea Tank:**
  - Elevation of Measuring Point (FT): 50
  - Number of Fractures: 2
  - Well Diameter (IN): 12
  - Drawdown (FT): 23
  - Step Factor [:]: 1
  - Total Transmissivity (FT²/day): 1000
  - Depth to Ambient Water Level (FT): 57.16
  - Depth at bottom of Plot (FT): 170
  - Depth at top of Plot (FT): 110

<table>
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</thead>
<tbody>
<tr>
<td>2</td>
<td>153.500</td>
<td>6.000</td>
<td>270.000</td>
<td>6.000</td>
<td>0.230</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>131.500</td>
<td>-6.400</td>
<td>167.000</td>
<td>20.000</td>
<td>0.000</td>
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### Simulated Output from FWARP (DO NOT CHANGE)

- **SSE [GPM²]:** 11.77813
- **MSE Error [GPM]:** 2.428533508
- **Ambient WL [FT]:** -7.16
- **Pumped WL [FT]:** -3.35

### Fractures Table:

<table>
<thead>
<tr>
<th>Fractures</th>
<th>Depth [FT]</th>
<th>Ambient Flow above Zone T</th>
<th>Pumped Flow above Zone T</th>
<th>Water Level [FT]</th>
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</thead>
<tbody>
<tr>
<td>2</td>
<td>153.500</td>
<td>0.000</td>
<td>267.563</td>
<td>56.949</td>
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<tr>
<td>1</td>
<td>131.500</td>
<td>-6.378</td>
<td>189.416</td>
<td>57.229</td>
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</table>
Flow Logging and QW Point Sampling in Production Wells

Floridan carbonate-rock aquifer
Specific Ion logging

Crystalline-rock aquifer, southeastern New York
FRACTURE GEOMETRY, TRANSMISSIVITY, AND STORAGE

Graph 1: Flow, in gallons per minute, as a function of elapsed time, in minutes, for different values of transmissivity (T) and storativity (S).

Graph 2: Flow, in gallons per minute, as a function of elapsed time, in minutes, for different values of transmissivity (T).

- For Graph 1:
  - S = 10^-5
  - T = 200
  - T = 100
  - T = 50

- For Graph 2:
  - T = 100 ft^2/d
  - 0.5 x 10^-5
  - 10^-5
  - 5 x 10^-6
EXPLANATION

L-19  Lockatong lithostratigraphic unit
S-12  Stockton lithostratigraphic unit

Mesozoic clastic-rock aquifer, Newark Basin
CROSS-HOLE FLOW TEST IN MUDSTONE

EXPLANATION

- Extraction well
- Corehole

0 300 FT
North
### Geophysical Log and Hydraulic Analysis

**Corehole in Mesozoic mudstone, Newark Basin**

<table>
<thead>
<tr>
<th>Depth, in feet</th>
<th>Flow, in gal/min</th>
<th>Trans, in m²/s</th>
<th>Head, in ft</th>
</tr>
</thead>
<tbody>
<tr>
<td>40</td>
<td>-0.3 0 0.3</td>
<td>10⁻⁹ 10⁻⁴</td>
<td>87 97</td>
</tr>
<tr>
<td>80</td>
<td>5 ft²/d</td>
<td></td>
<td></td>
</tr>
<tr>
<td>120</td>
<td>1 ft²/d</td>
<td></td>
<td></td>
</tr>
<tr>
<td>160</td>
<td>80 ft²/d</td>
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</tbody>
</table>

**Notes:**
- The corehole is located in Mesozoic mudstone in the Newark Basin.
- The table shows the flow rates, transmissivities, and heads at different depths.
- The graph on the left illustrates the gamma, FWS, OVT, and ATV readings along the corehole.
WATER-LEVEL RESPONSE

- Pumped 9.2 gal/min
- Depth to water level, in feet: 68BR < 0.05 FT, 15BR 7 FT
- Pump off for 30 Minutes
- Pump off
TRANSIENT FLOW RESPONSE IN COREHOLE 68BR

BETWEEN SHALLOW AND INTERMEDIATE FLOW ZONES
SUMMARY

• Borehole geophysics provides critical hydraulic and water quality information for fractured-rock investigations

• Borehole-wall images and other logs help define the lithologic, stratigraphic, and structural framework

• Borehole-flow logs under ambient and stressed conditions are used to estimate zone transmissivity and head

• Cross-borehole, transient flow tests are used to evaluate the hydraulic connectivity of the zones

• Borehole-fluid logs and point samples provide insights into zone water quality and cross-contamination

• Newly developed specific-ion tools for logging dissolved oxygen, chloride, and nitrate