# Ground Water Remedial Investigation Bedrock Characterization

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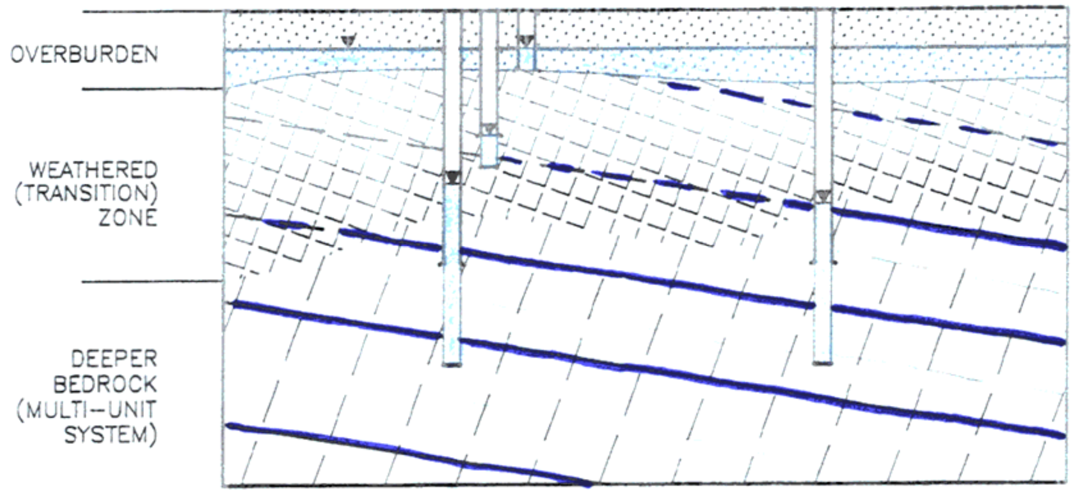
# WHAT'S INCLUDED IN THE BEDROCK TECHNICAL GUIDANCE?

CONCEPTUAL GW FLOW MODELS FOR BEDROCK SITES ⟷ BEDROCK CHARACTERIZATION TOOLS

- POROUS MEDIUM
- DISCRETE FRACTURE →
- HYBRID MODELS →

<u>FLOW-SENSITIVE</u> CHARACTERIZATION TOOLS ARE NEEDED.

## GENERIC CONCEPTUAL MODEL FOR THE NEWARK BASIN & SEDIMENTARY BEDROCK SITES




LMAS MODEL WITH WEATHERED ZONE & SATURATED OVERBURDEN (Michalski, 1990)

- Few dipping bedding fractures with larger apertures act as discrete aquifers (high T, low S) and preferential flow pathways.
- Such aquifer units occur at uneven intervals and tend to lose their aquifer properties updip and downdip of their prime extent areas.

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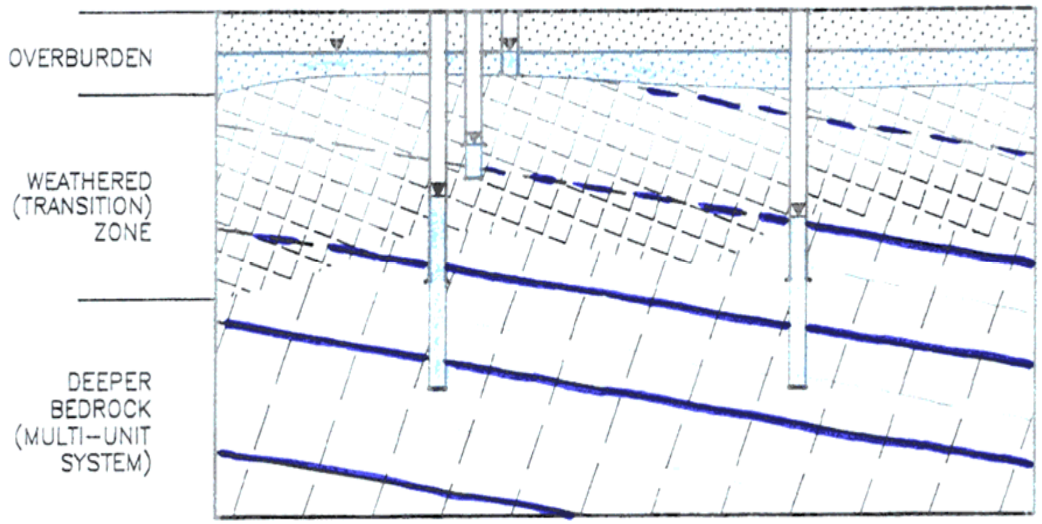
# FOR THE NEWARK BASIN & SEDIMENTARY BEDROCK SITES




- The gw flow is bedding-parallel, with prevailing flow direction along the strike of bedding;
- Sub-vertical joints provide pathways for leakage between the bedding fractures. Note: Thick aquitard units have complex structure and flow;.

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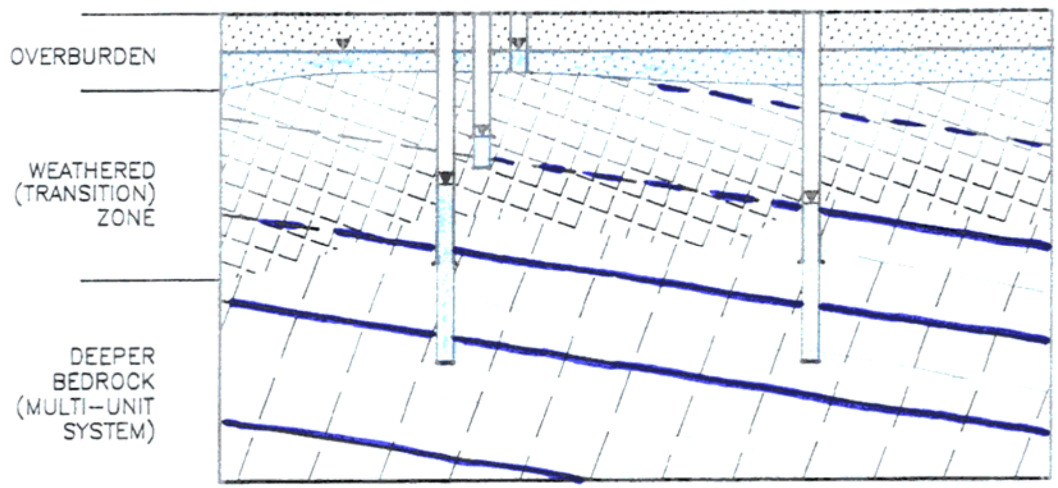


- The weathered bedrock zone typically exhibit higher porosity/storage (S) but reduced permeability (K). Up-dip extensions of the bedding fractures into the weathered zone connect this zone and the overburden (if present) with the multiunit bedrock;

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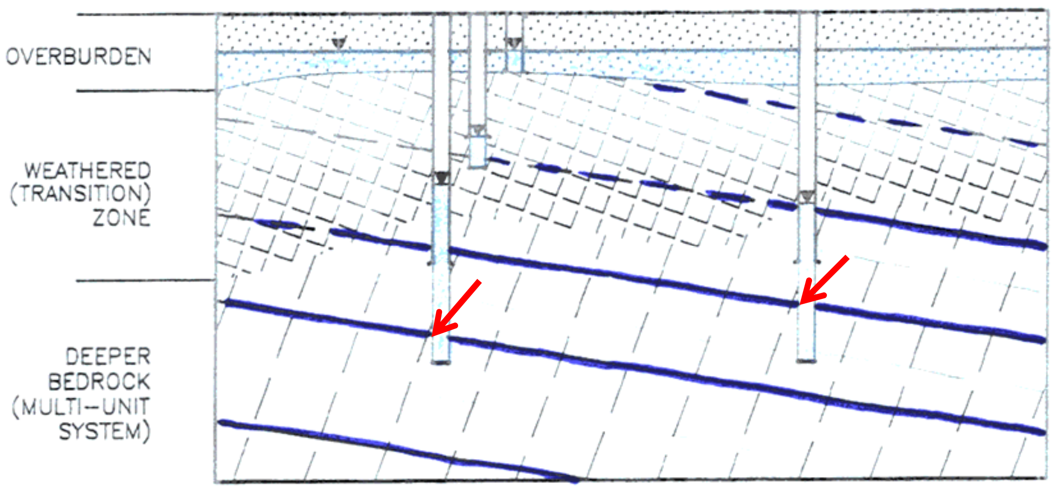



THE TWO DEEPER WELLS, COMPLETED TO THE SAME DEPTH, ARE OPEN TO DIFFERENT DIPPING AQUIFER UNITS. INCORRECT GW FLOW DIRECTION IS OBTAINED FROM WATER LEVELS TAKEN IN SUCH WELLS.

*ONLY WELLS COMPLETED INTO THE SAME AQUIFER UNIT SHOULD BE USED TO DETERMINE HORIZONTAL GW FLOW DIRECTION.*

# Characterization Needs

## FOR A LEAKY, MULTIUNIT BEDROCK

1. **Identify** major transmissive bedding fractures (aquifer units) and the intervening aquitards.

2. For each aquifer unit of interest, **determine**:

   - Hydraulic heads (water levels, vertical and horizontal gradients);
   - Contaminant concentrations (delineation), and
   - Hydraulic parameters T and -if needed - S.

3. **Assess** flow disturbance caused by nearby supply wells and open-hole segments of existing monitoring wells.

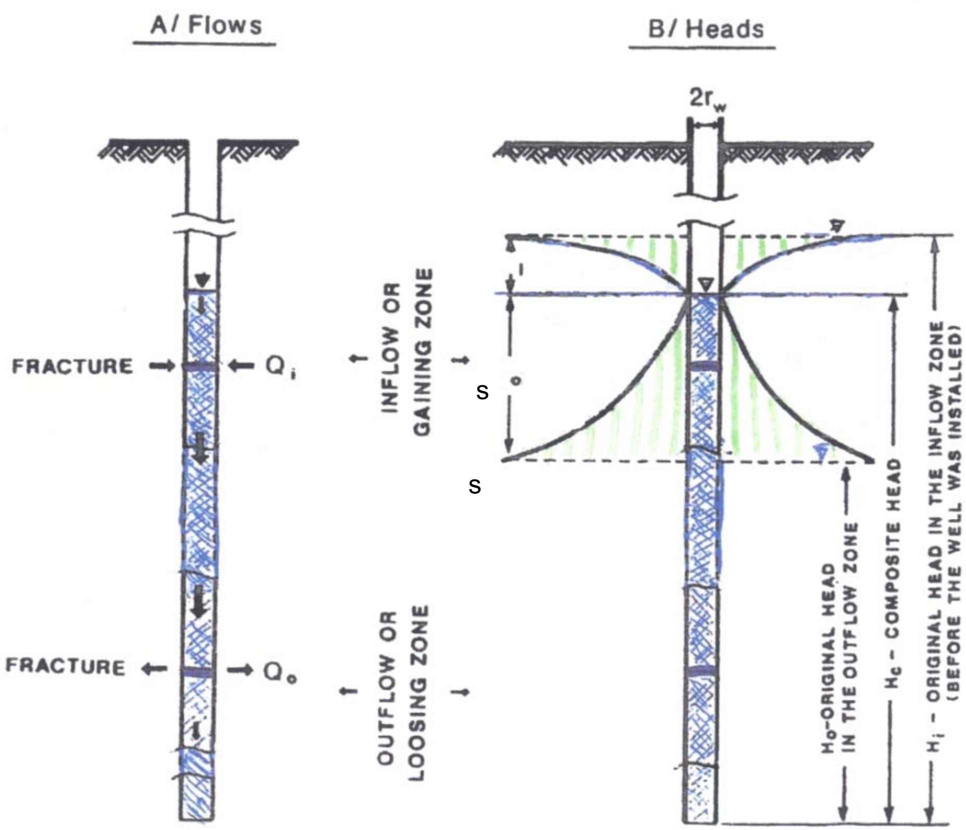
# HOW TO IDENTIFY TRANSMISSIVE BEDROCK FRACTURES?

- ✓ OUT OF HUNDREDS OF FRACTURES OBSERVED IN CORES OR OUTCROPS – <u>VERY FEW ARE HYDRAULICALLY ACTIVE</u>, SO VISUAL METHODS WILL NOT SUFFICE.

- ✓ INSTALLATION OF <u>TEMPORARY TEST HOLES (TTH)</u> WITH LONG OPEN HOLES CREATES HYDRAULIC SHORT-CIRCUITING OF TRANSMISSIVE FRACTURES. IT REVEALS LOCATIONS OF SUCH FRACTURES AND OFFERS THE MOST RELIABLE MEANS OF THEIR IDENTIFICATION AND CHARACTERIZATION.

# HYDRAULICS OF VERTICAL CROSS-FLOWS WITHIN A LONG OPEN HOLE

Consider two transmissive bedding fractures are cross-connected by drilling a long open hole.




*SOURCE:*
*MICHALSKI & KLEPP, 1990*

$s_i$ - DRAWDOWN IN THE INFLOW ZONE

$s_o$ - IMPRESSION IN THE OUTFLOW ZONE

$$Q_{IN} = Q_{OUT}$$

$$s_i = H_i - H_c$$

$$s_o = H_o - H_c$$

$$Q_i = \frac{2\pi T_i s_i}{\ln\left(\frac{R}{r_w}\right)} \qquad Q_o = \frac{2\pi T_o s_o}{\ln\left(\frac{R}{r_w}\right)}$$

$$\boxed{H_c = \frac{H_i T_i + H_o T_o}{T_i + T_o}}$$

$$\frac{s_i}{s_o} = \frac{T_o}{T_i}$$

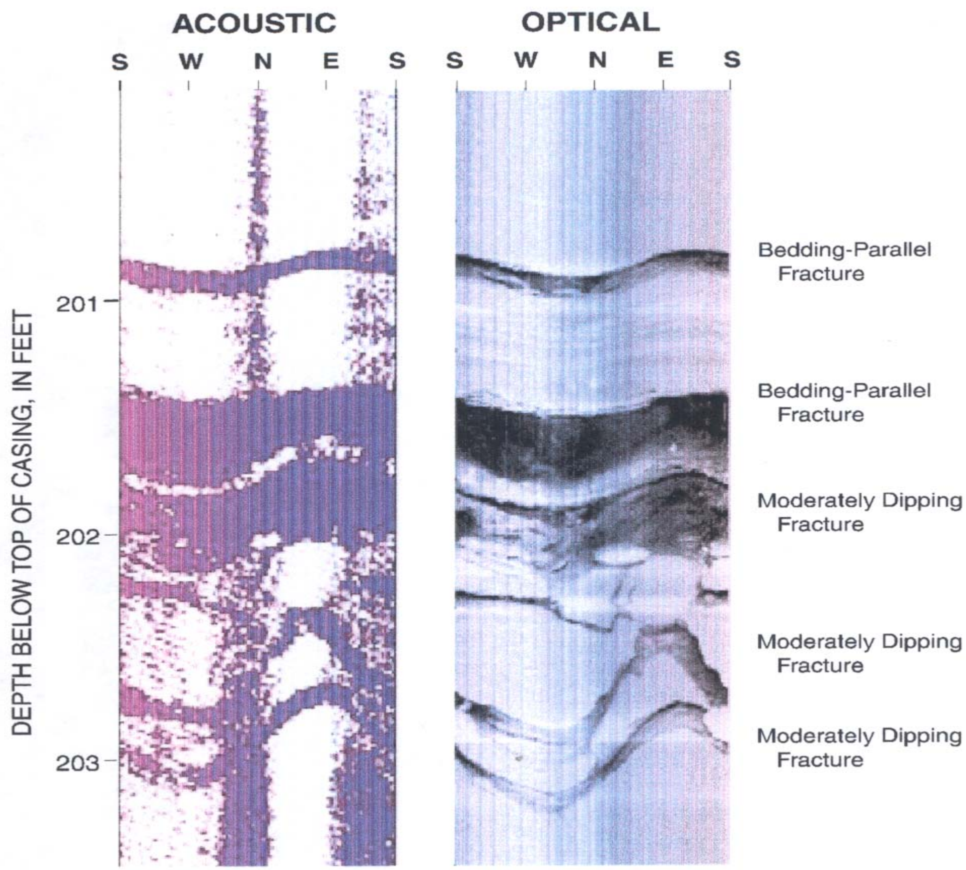
# TESTING MENU FOR TTHs

- BOREHOLE GEOPHYSICS
- VERTICAL FLOW MEASUREMENTS
- DEPTH-DISCRETE SAMPLING
- PACKER TESTING

Best results in conjunction with air-rotary drilling of TTHs (observation of dust suppression depth, water producing fractures, logging of cuttings, penetration rate, etc.)

Wet drilling methods –use of foreign water - may impact the testing results.

# BOREHOLE GEOPHYSICS: BOREHOLE IMAGING

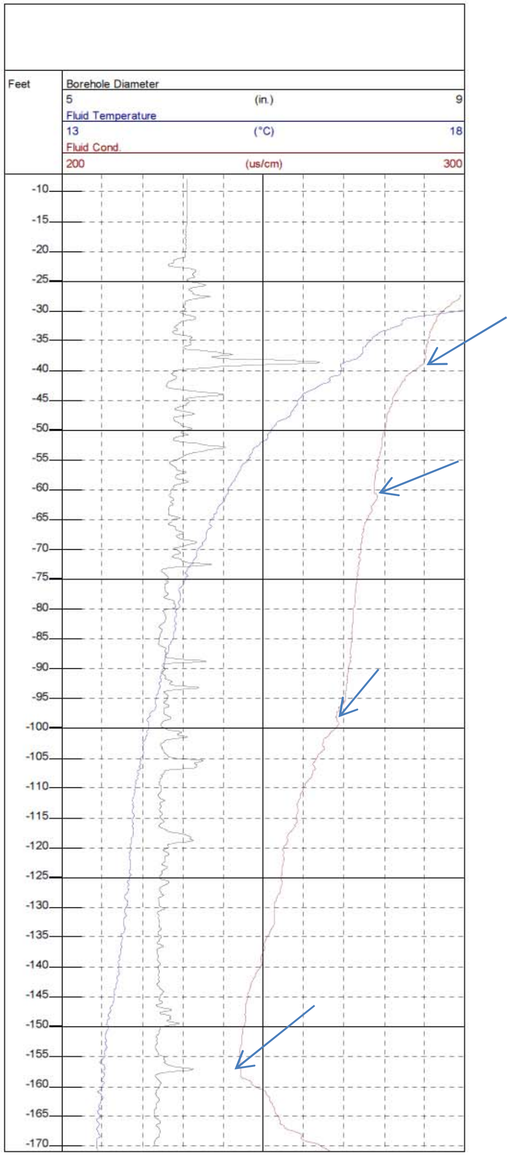



SOURCE: WILLIAMS, 2002; Fig 6

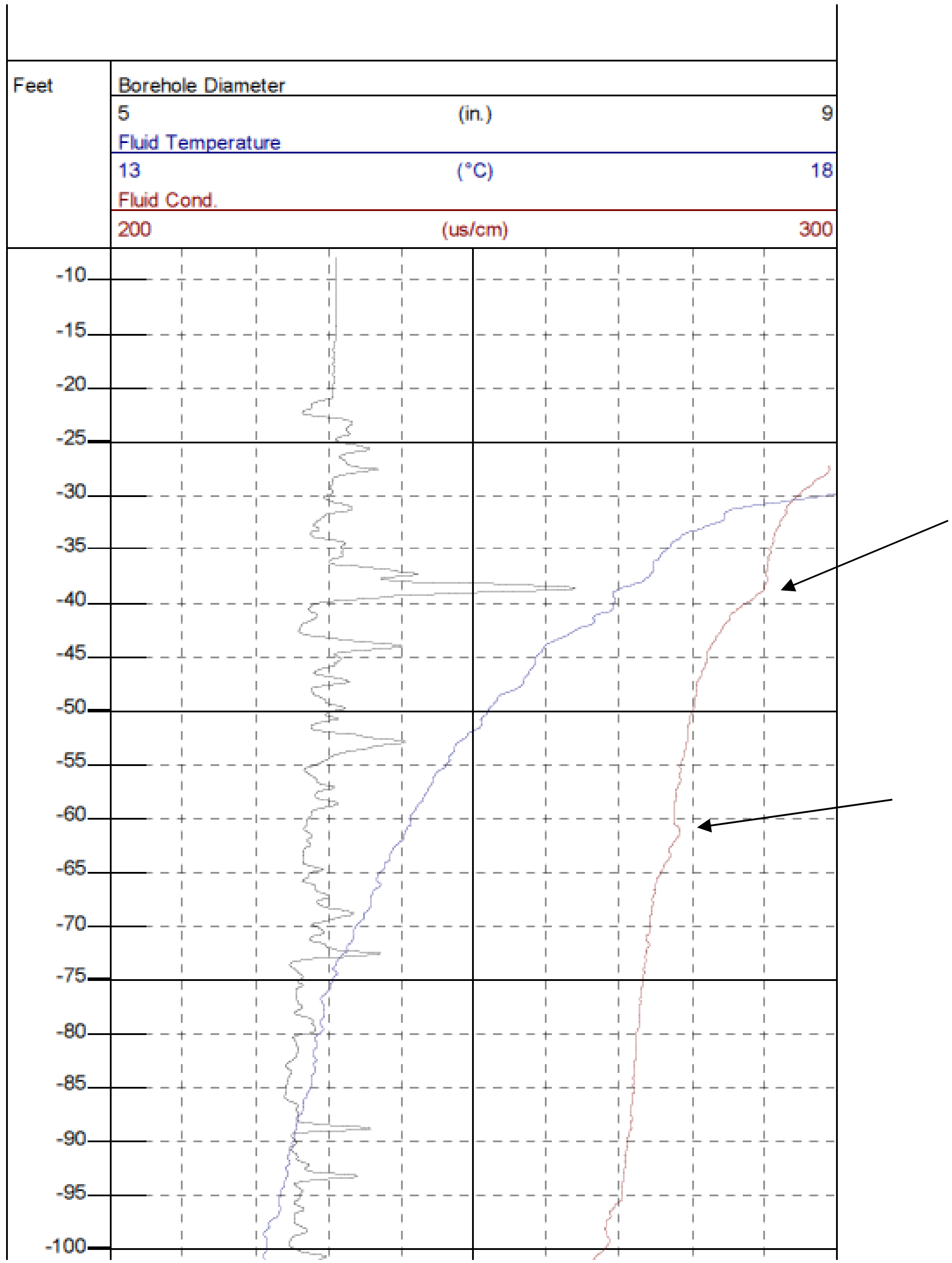
**Figure 6.** Acoustic- and optical-televiewer images of the flow zone near 201 feet in borehole RD-35B, Rocketdyne Santa Susana Field Laboratory, Ventura County, California.

- SUBSTITUTE FOR CORING
- FRACTURE ORIENTATION
- AID IN CORELATION

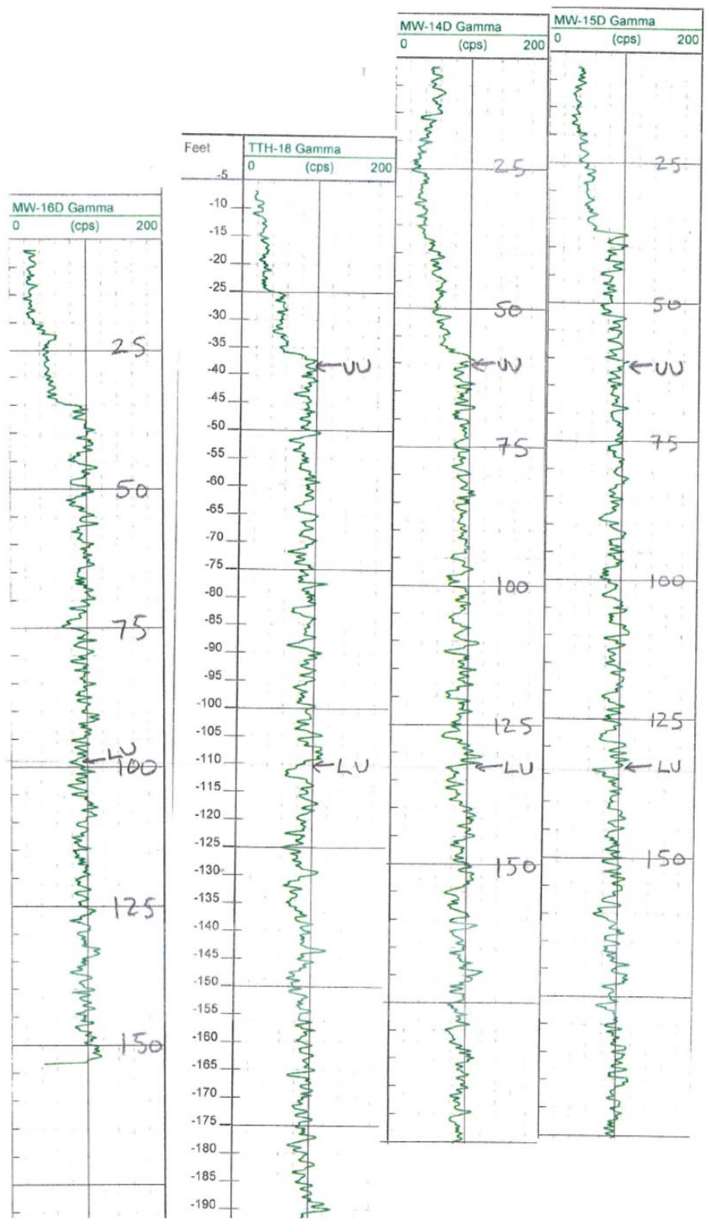
# BOREHOLE GEOPHYSICS: FLUID EC, T & CALIPER LOGS




- ❖ Indentations on fluid EC and T logs point to possible locations of hydraulically active fractures.
- ❖ Enlarged hole diameter on the caliper logs identifies weak or fractured strata. Relevant for flowmeter data and the placement of packers.


Feet
Borehole Diameter
5
(in.)
9
Fluid Temperature
13
(°C)
18
Fluid Cond.
200
(us/cm)
300
-10
-15
-20
-25
-30
-35
-40
-45
-50
-55
-60
-65
-70
-75
-80
-85
-90
-95
-100

# BOREHOLE GEOPHYSICS: GAMMA LOG




USEFUL FOR STRATIGRAPHIC CORRELATIONS BETWEEN TTHs AND STRIKE & DIP DETERMINATION

STANDARD LOGGING SUIT ALSO INCLUDE SP AND RESISTIVITY LOGS.

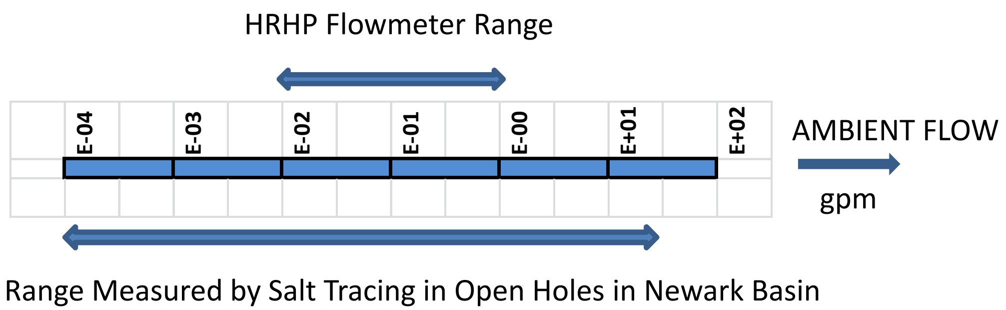
# VERTICAL FLOW MEASUREMENTS
## *Critical Characterization Aspect*

**FLOWMETERS**

Need to use a high-resolution heat-pulse(HRHP) flowmeter with a flow diverter (shroud) to achieve the claimed lower measurement range of 0.02 gpm.  Some commercial flowmeters measure flows >0.4 gpm, and would not detect vertical flows in the majority of open holes.

**SALT TRACING**

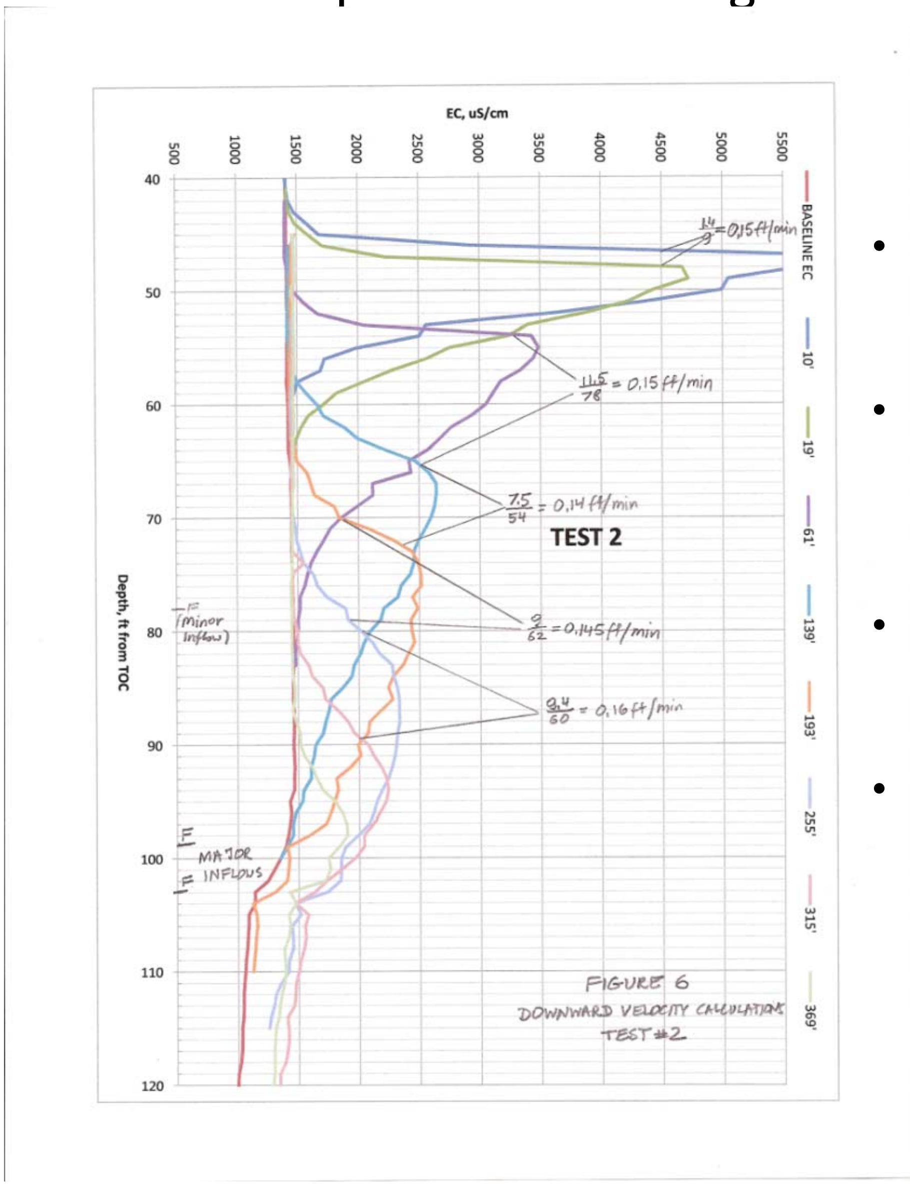
Described in APPENDIX B




FLOWMETERS MEASURE INSTANT FLOW AT DISCRETE LOCATIONS WITHIN AN OPEN HOLE WHILE SALT TRACING PROVIDES  CONTINUOS FLOW  MEASUREMENTS OVER LONGER TIMES.

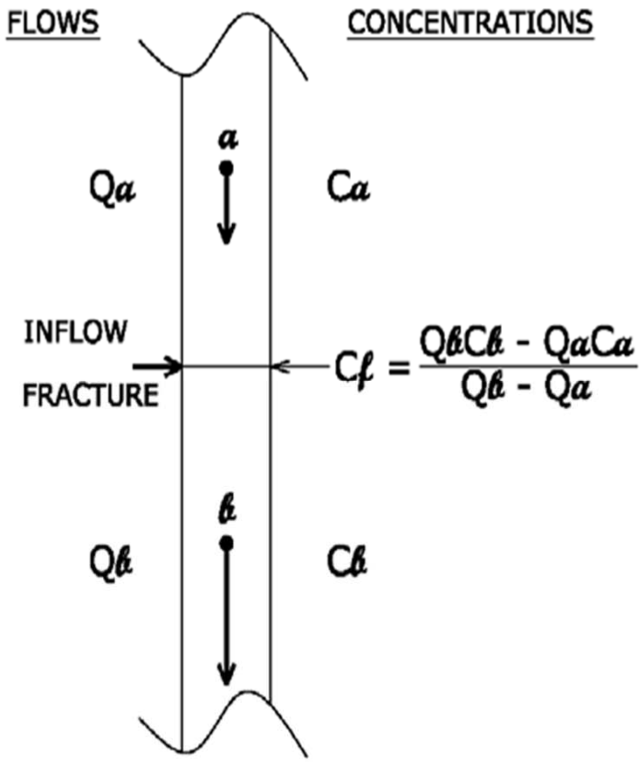
# VERTICAL FLOW MEASUREMENT VIA SALT TRACING

## Example of Salt Tracing Test Record and Interpretation




- Salt tracer solution was injected at 47 ft, and its first image was obtained with a downhole EC probe 10 min later (dark blue shape ).
- A series of subsequent tracer images at various elapsed times shown reveals a downward tracer migration, and two major fracture inflows ~ 100 ft.
- Plotting the series of tracer images on one graph helps in tracer velocity calculations (shown in pencil).
- Flow = Velocity x Unit cross-sectional storage

# DEPTH-DISCRETE SAMPLING




1. COLLECT GRAB GW SAMPLES IN THE TTH ABOVE AND BELOW EACH INFLOW FRACTURE – NOT AT THE FRACTURE (MIXING ZONE);
2. CALCULATE CONTAMINANT CONCENTRATION IN EACH FRACTURE, BASED ON MEASURED FLOWS AND CONCENTRATIONS IN THE GRAB SAMPLES ABOVE AND BELOW.

Discussed in APPENDIX C

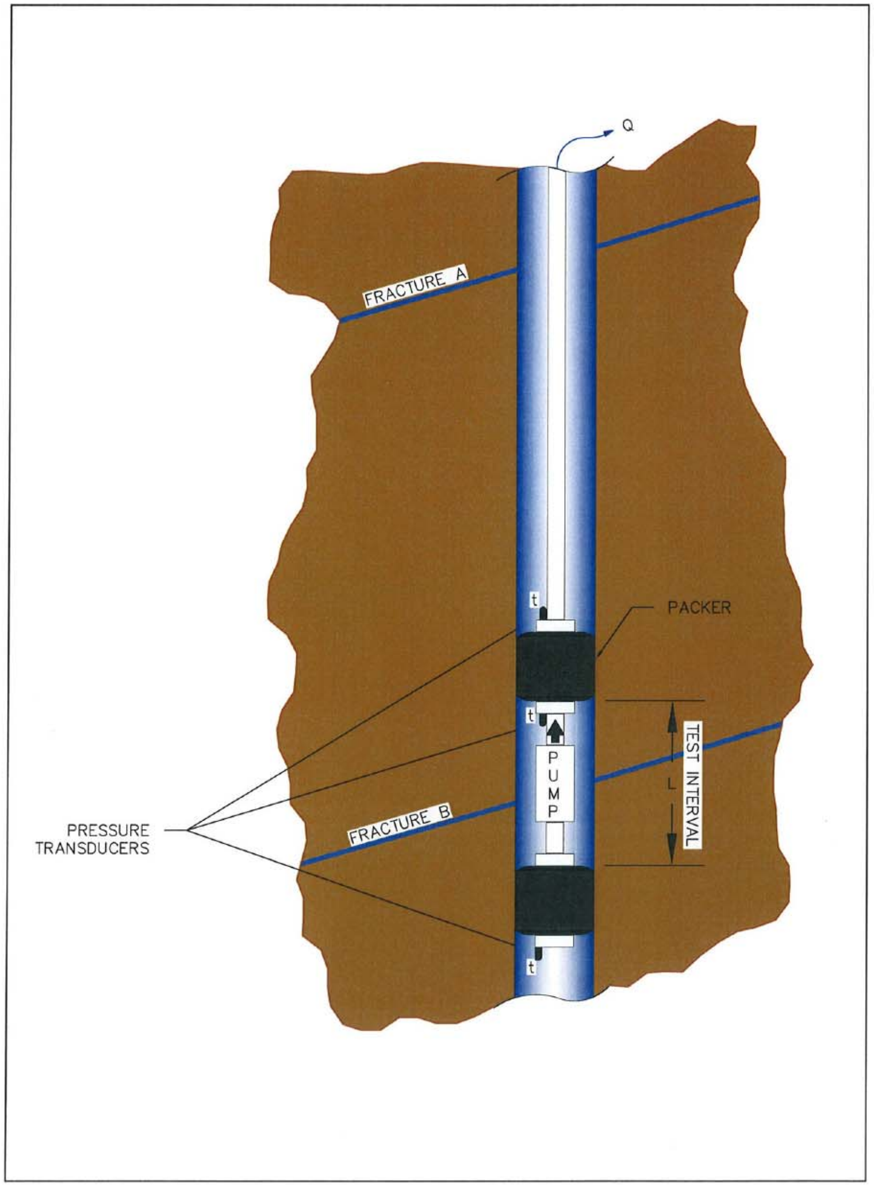
*POWERFULL SCREENING TOOL TO QUICKLY ASSES VERTICAL CONTAMINANT DISTRIBUTION, IDENTIFY THE MOST CONTAMINATED FRACTURE AND CROSS-FLOW IMPACTS ON EXIT FRACTURE(S).*

# EXAMPLE OF MEASURED AMBIENT FLOWS AND DEPTH-DISCRETE SAMPLING RESULTS.

ALSO SHOWN IS COMPARISON OF THE CALCULATED CONCENTRATIONS WITH SUBSEQUENT PACKER SAMPLING ANALYTICAL RESULTS

| AMBIENT FLOW gpm | Borehole | SAMPLE NO. and Depth | CONTAMINANT CONCENTRTIONS CT | CF | PCE | TCE | 1,1DCE | |
|---|---|---|---|---|---|---|---|---|
| | BOC @ 22.4 | | | | | | | |
| | 40' fracture | | | | | | | |
| | 47' fracture | | | | | | | |
| 0.20 | | | | | | | | |
| | 62' fracture | PACKER 57'-67' | 25 | 2.3 | 0.38J | 3.4 | 0.35J | |
| 0.18 | | **GW-04 70'** | **160** | **14** | **ND(10)** | **14** | **ND(10)** | |
| | 94' fracture | PACKER 90'-100' | 163 | 15.9 | 1.2J | 8.9 | 1.3J | **UNIT B** |
| | | *Calculated Conc.* | *182* | *16* | | *15* | | |
| 0.027 | | **GW-03 110'** | **38** | **3.2** | **1.3** | **11** | **1.1** | |
| | 120' fracture | PACKER 115'-125' | 19 | 2 | 2 | 17 | 1.4 | **UNIT C** |
| | | *Calculated Conc.* | *55* | *4* | *2* | *13* | | |
| 0.01 | | **GW-02 140'** | **9.8** | **1.1** | **0.55J** | **6.9** | **ND(1)** | |
| | 158' Fracture | PACKER 153'-163' | *NS* | *NS* | *NS* | *NS* | *NS* | |
| | | **GW-01 165'** | **10** | **1.2** | **0.39J** | **6.2** | **ND(1)** | |

# PACKER TESTING



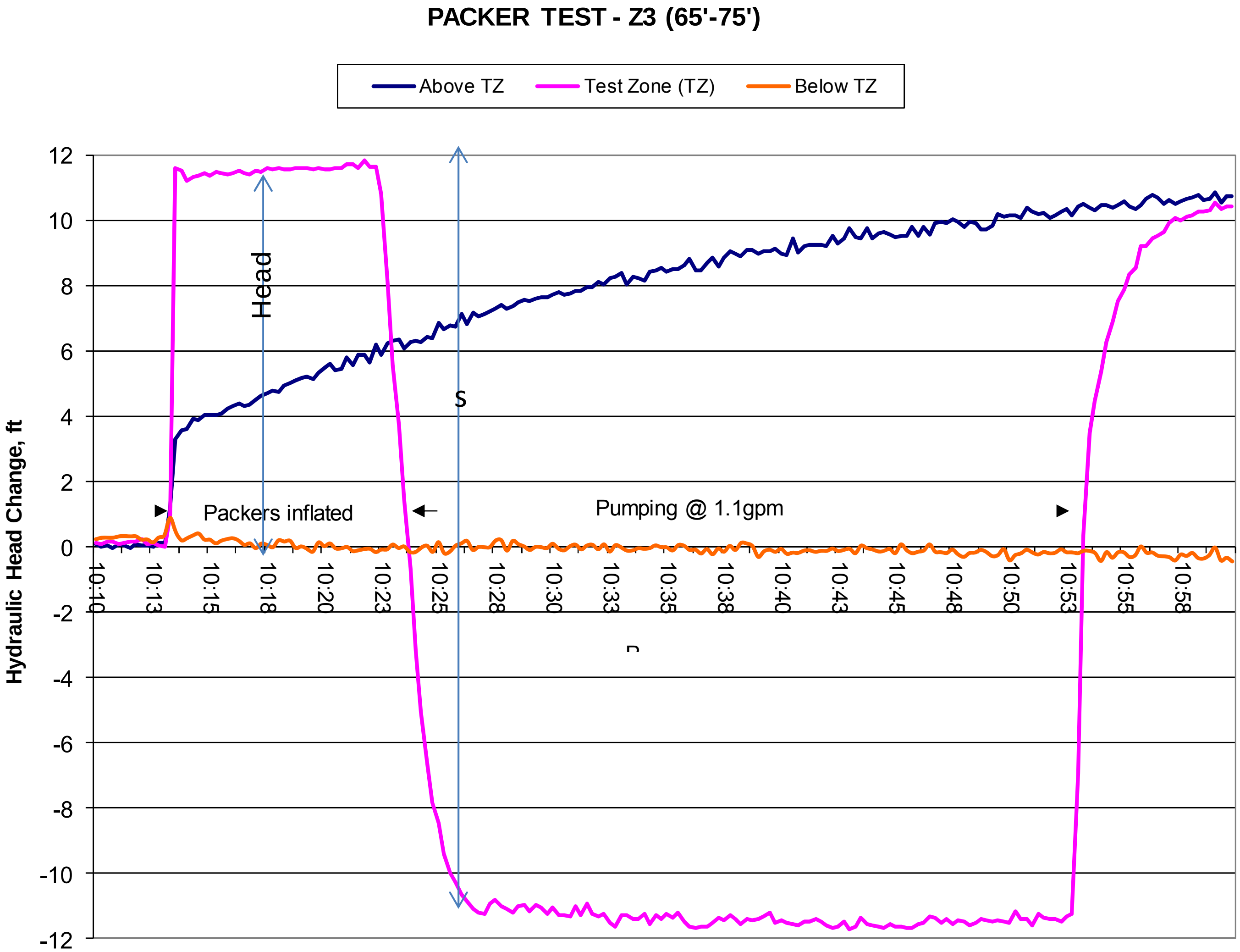

**CAPABILITIES**:

- PACKER SAMPLING
- VERTICAL HEAD PROFILING
- TRANSMISSIVITY DETERMINATION
- LEAKAGE ASSESSMENT
- PUMPING TESTS WITH EXISTING WELLS USED AS OBSERVATION WELLS

*UTILIZE ALL CHARACTERIZATION CAPABILITIES - NOT ONLY ROUTINE PACKER SAMPLING.*

Packer tests discussed in APPENDIX D.

# PACKER TESTING RECORD EXAMPLE
# FOR A TEST ZONE STRADDLING A MINOR BEDDING FRACTURE

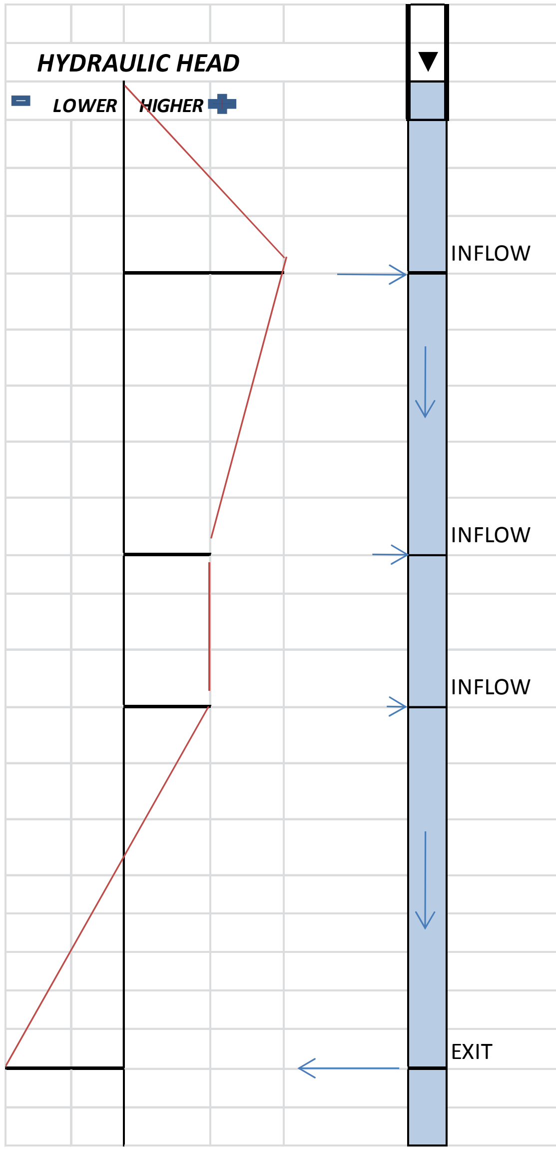



$$T = \frac{Q\ln\left(L/r\right)}{2\pi s}$$

T – Transmissivity
Q – Pumping Rate
s - Drawdown
L – Test Interval Length
r – Hole Radius

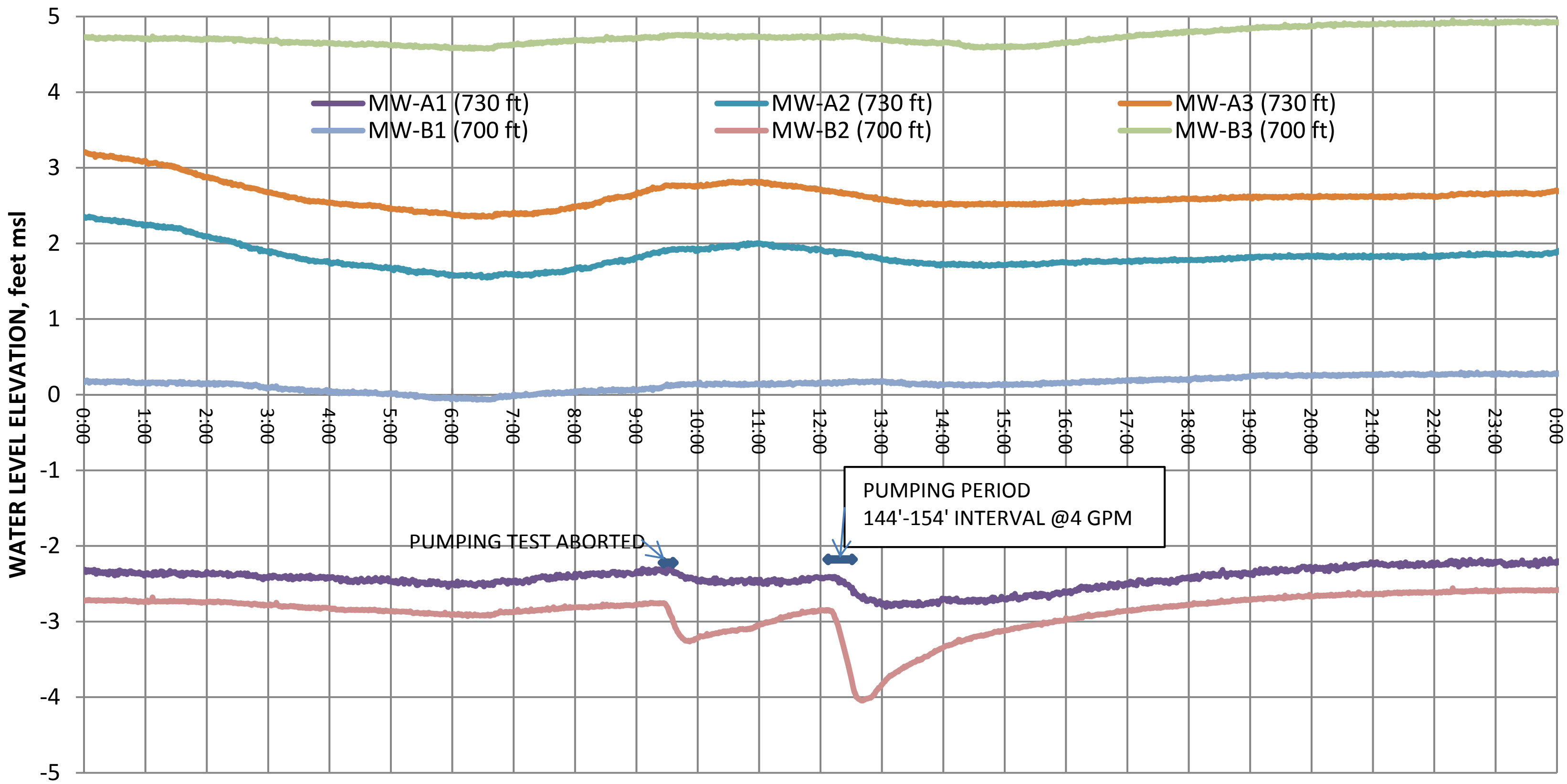
**PACKER TESTING**

**VERTICAL HEAD PROFILE**
FROM PACKER TESTS
CONDUCTED IN A TTH

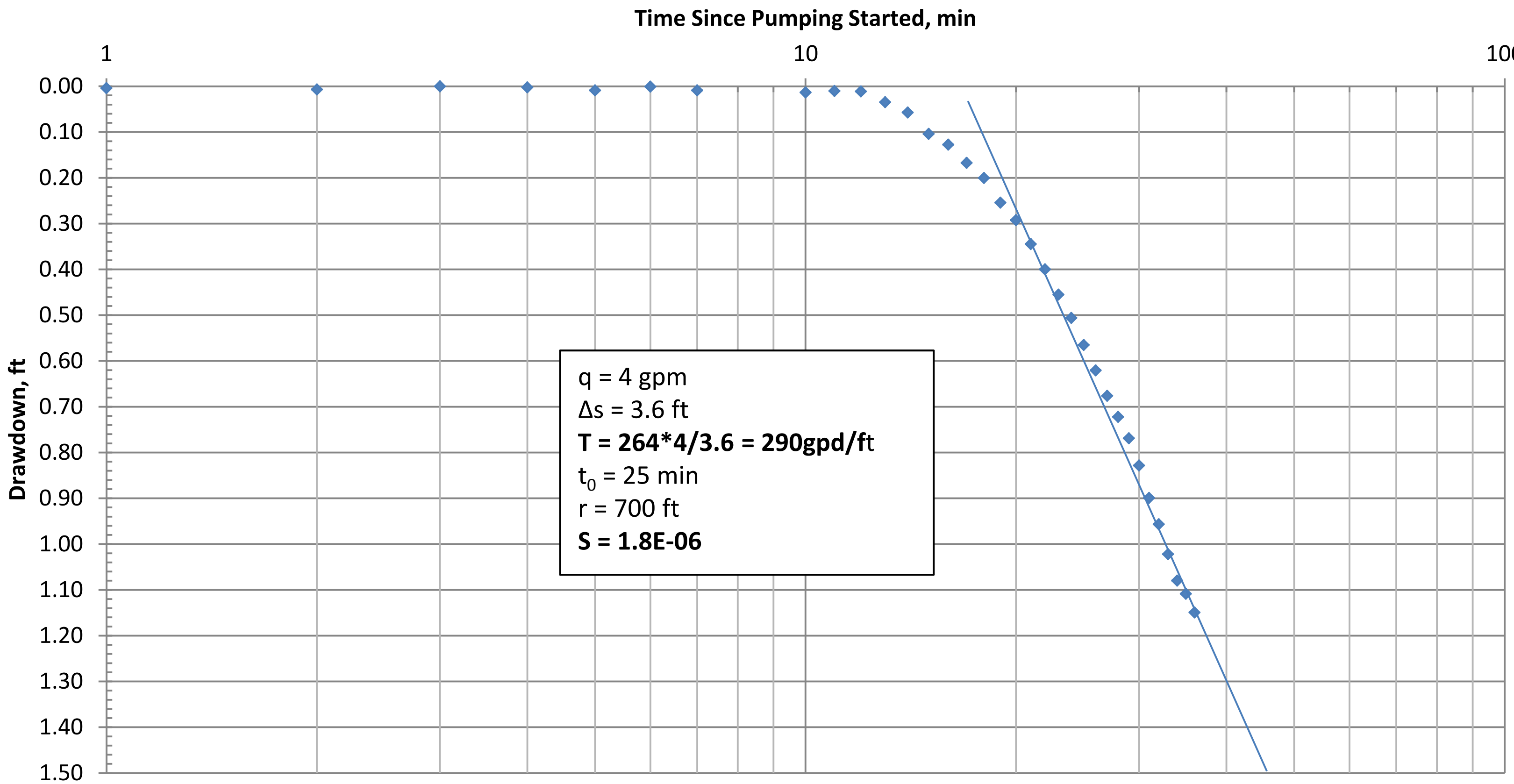


# USE OF PACKER TESTING FOR INTERWELL PUMPING TESTS

RESPONSE OF OBSERVATION WELLS IN CLUSTERS "A" (730 ft away) & "B" (700 ft away) DURING A 24-HOUR PERIOD THAT INCLUDED PUMPING OF PACKER-ISOLATED BEDDING FRACTURE @ 149 ft IN A TTH



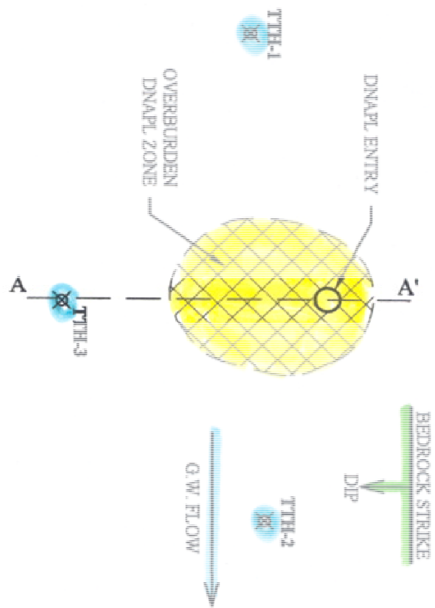
# PACKER TESTING – INTERWELL PUMPING TESTS
# RESPONSE OF OBS. WELL MW-B2 TO PACKER TEST PUMPING ANALYZED ON DRAWDOWN v.LOG OF TIME GRAPH

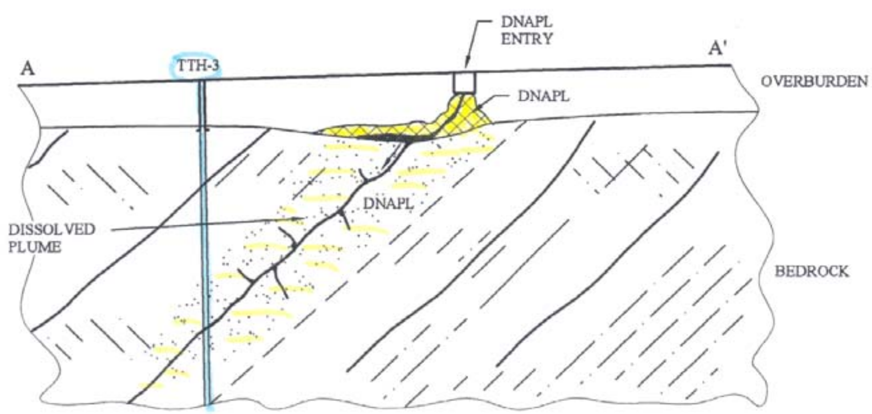



*THIS VERIFIES THE CONTINUITY OF THE 149 FT FRACTURE AND THE OBS WELL AND ALLOWS FOR CALCULATION OF AQUIFER PARAMETERS FOR THIS FRACTURE (AQUIFER UNIT).*

# PLACEMENT OF TTHs

## RELATIVE TO BEDROCK STRUCTURE AND SOURCE AREA AT NEW CONTAMINATED SITES




*MINIUM OF THREE TEST HOLES NEEDED FOR AN INITIAL INVESTIGATION CONDUCTED IN OUTSIDE-IN FASHION:*

**1**ST TTH IS PLACED UPGRADIENT OF THE SOURCE

**2**ND TTH IS DOWNGRADIENT AND ALONG STRIKE

**3**RD TTH, DOWN-DIP OF THE SOURCE, IS DRILLED TO A GREATER DEPTH THAN TTH-1 AND 2; SEE THE CROSS-SECTION.

# CONVERTING TTHs TO SHORT-SCREEN MWs

At the completion of the testing program, convert TTHs to MWs. Monitoring targets may include:

- Exit units/fractures
- Most contaminated
- Most transmissive

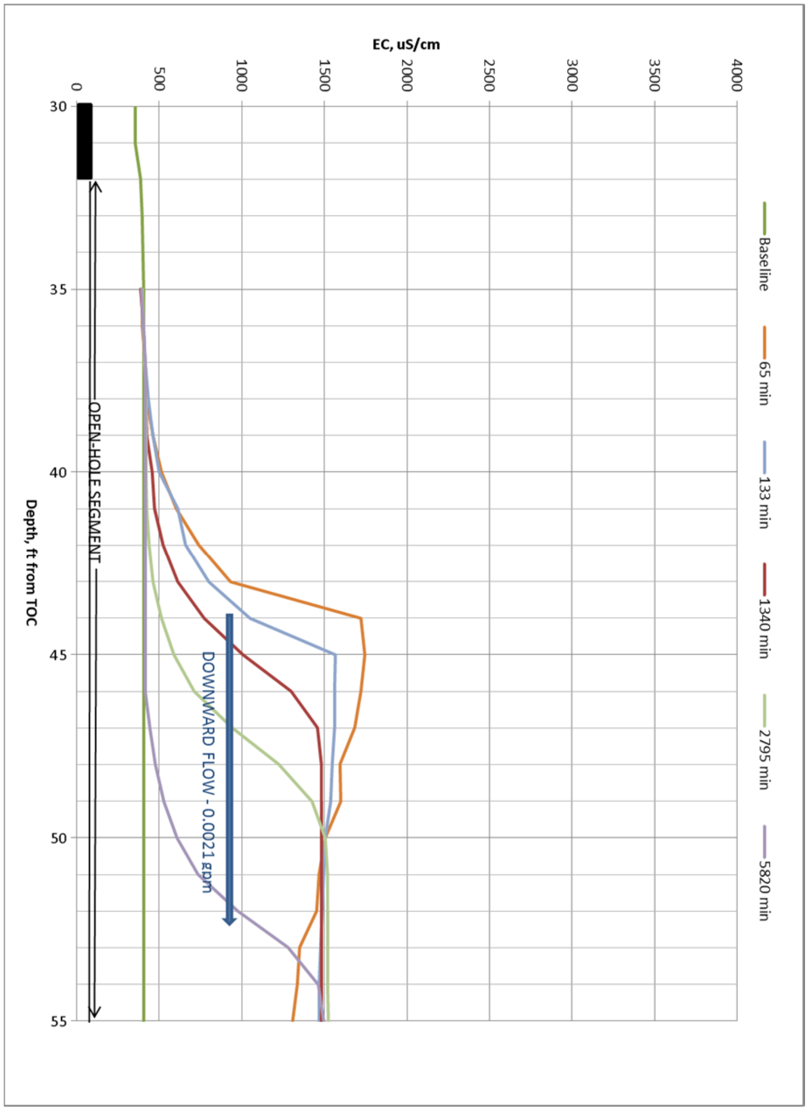
Once the bedrock hydrogeology is adequately characterized, installation of additional wells can be based on projections of monitoring targets. The projections require reliable determination of site-specific dip and strike.

# RE-EVALUATION OF CONTAMINATED SITES WITH EXISTING MONITORING WELLS

Needed for sites with excessive open-hole segments and sites with generic flow models that *de facto* ignore bedrock structure, including sites with horizontal slicing of dipping bedrock into the “shallow”, “intermediate”, and “deep” aquifers. Steps to re-evaluate such sites:

- Conduct supplemental testing in existing wells (borehole geophysics, or at least EC-T logging, salt tracing and depth-discrete sampling, if appropriate). Determine dip and strike of bedding.
- Prepare a cross-section projecting onto it open/screened well intervals and locations of identified conductive fractures (initial site hydrogeologic model).
- Identify data gaps, needs for additional wells and correcting well construction in problem wells.
- When adding new wells, consider at least one TTH with a comprehensive testing program.
- Demonstrate the continuity of aquifer units and the validity of the site model by observed responses to short-term pumping/hydraulic stresses.

# PREFERENCE FOR SHORT OPEN-HOLE SEGMENTS/WELL SCREENS LESS THAN 25 FT ALLOWED




- ✓ A short (10-15 ft) open-hole or screen should only straddle aquifer units. Avoid screen placement in vertical gradient zones, as exemplified by a MW on the left.

- ✓ V. slow downward flow was measured via salt tracing in this 23-ft long open hole in weathered bedrock:

  0.0021gpm=3gpd=90gal/quarter

GW quality in this well was controlled by clean inflow (ND) from the upper well portion. Low-flow sampling was unable to detect contamination present in the receiving zone at the bottom.