Analysis and Evaluation of Aquifer Pumping Test Data
What Can We Learn and What is Relevant?

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Overview

1. Basics of Pumping Wells
2. Types of Pumping Tests
3. Test Procedures
4. Data Analysis
5. Summary
Basics of a Pumping Well

- Ground Surface
- Static Water Level
- Aquifer Loss
- Well Loss
- Pumping Water Level
- Cone of Depression
- Discharge
Cone of Depression

Pumping Depression (1 Well)
Specific Capacity

Specific Capacity (gpm/ft) = Discharge Rate / Drawdown
Specific Capacity

- Specific capacity (Q/s) defines the relationship between drawdown in the well and its discharge rate.
  - gallons per minute per foot (gpm/foot) of drawdown
- Often used as a metric of well performance
- Varies with both time and flow rate.
- Lower specific capacities will result in deeper pumping water levels, resulting in higher energy costs to pump.

**Example Calculation**

\[
Q = 1,793 \text{ gpm} \\
\text{Static water level} = 114.07 \text{ feet} \\
\text{Pumping water level} = 160.3 \text{ feet} \\
\frac{Q}{s} = \frac{1,793 \text{ gpm}}{(160.3 \text{ ft} - 114.07 \text{ ft})} = 39 \text{ gpm/ft}
\]
Well Efficiency

Well Efficiency (%) = Aquifer Loss / Total Drawdown

Diagram showing Ground Surface, Static Water Level, Discharge Rate (gpm), Aquifer Loss, Well Loss, Drawdown (ft), and Aquifer.
Well Interference

- Ground Surface
- Static Water Level
- Aquifer
- Discharge
- Cone of Depression
- Interference
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Typical Pumping Tests

- Step Drawdown
- Constant Rate Drawdown
- Recovery
- Distance Drawdown
Step Drawdown Test

- Testing the well at multiple flow rates for a constant time period (one to three hours)
- Normalize to set time (e.g., 24 hrs)
- Use to Calculate well efficiency
  - Well efficiency relates to the ratio between the theoretical drawdown of the aquifer to the actual drawdown inside the well structure
- Can be used as a baseline from which to assess clogging of the well intake structure
Step Drawdown Test

Test Date: October 19, 2015
Static Water Level = 147.3 ft bgs
\( \Delta s = \text{Projected Incremental Drawdown} \)

- \( Q_1 = 1,000 \text{ gpm} \)
- \( \Delta s_1 = 24.3 \text{ ft} \)

- \( Q_2 = 1,471 \text{ gpm} \)
- \( \Delta s_2 = 11.0 \text{ ft} \)

- \( Q_3 = 1,936 \text{ gpm} \)
- \( \Delta s_3 = 11.2 \text{ ft} \)
Step Drawdown Test

City Of Roseville Well W-77
(9/25/2006)

Transducer Data

1242 GPM Test
Q/s = 40 GPM/FT

1800 GPM Test
Q/s = 41 GPM/FT

2392 GPM Test
Q/s = 40 GPM/FT

SWL = 113.8 FT

Elapsed Time (Minutes)
Constant Rate Drawdown Test

- Testing the well at a constant rate for an extended period of time
- Typically 12 to 24 hours in duration
- Used to calculate aquifer parameters such as transmissivity
- Often performed following installation of a new well to determine pumping dynamics for design of the permanent pump
  - Short- and Long-term drawdown estimates
  - Pump setting
Constant Rate Drawdown Test

Important to Keep Discharge Rate Constant to Determine Accurate Transmissivity

Transmissivity \((T) = \frac{264Q}{\Delta s}\)

Test Date: October 20, 2015
Static Water Level = 148.2 ft bgs
Average Pumping Rate \((Q) = 1,855\) gpm
\(\Delta s = \text{Drawdown over 1 log cycle}\)
Recovery Test

Transmissivity ($T$) = $264Q/\Delta s$

Good Quality Data Unaffected by Variations in Pump Operation, etc.
Distance Drawdown Test

Radius of Influence \( (r_0) \)

Plot Data for Specific Time \((t)\)
- in this case 1,040 min

Transmissivity \( (T) = \frac{528Q}{\Delta s} \)

Storativity \( (S) = \frac{Tt}{r_0^2} \)

\( Q = 14.8 \text{ gpm} \)
\( r_0 = 398 \text{ ft} \)
\( t = 1,040 \text{ min} = 0.72 \text{ day} \)
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Test Procedures

- Considerations:
  - Operation of nearby wells which may affect water levels
  - Discharge during time of drought
  - Aquifer boundaries (faults, recharge sources, etc.)
- Well must be fully developed prior to performing pumping tests
- Water levels must be recovered from any prior pumping (i.e., well development)
- Typical Test Equipment
  - Test Pump and motor
  - Water level sounder
  - Totalizing flowmeter
  - Rossum Sand Tester
Well Development

Progression of Well Development Process

- Undeveloped (negative slope)
- Developed (positive slope)

Specific Drawdown (ft/gpm) vs. Discharge Rate (gpm)

Days:
- Day 1
- Day 2
- Day 3
- Day 4
- Day 5
- Day 6
Test Procedures

- Measured During Testing
  - Static groundwater level
  - Pumping water levels
  - Instantaneous pumping rate
  - Totalizer reading
  - Spinner Survey

<table>
<thead>
<tr>
<th>Elapsed Time (minutes)</th>
<th>Measurement Interval (minutes)</th>
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<tbody>
<tr>
<td>0 – 10</td>
<td>2</td>
</tr>
<tr>
<td>10 – 30</td>
<td>5</td>
</tr>
<tr>
<td>30 – 60</td>
<td>10</td>
</tr>
<tr>
<td>60 – 120</td>
<td>15</td>
</tr>
<tr>
<td>&gt; 120</td>
<td>30</td>
</tr>
</tbody>
</table>
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Step Drawdown Test

<table>
<thead>
<tr>
<th>Step</th>
<th>Q [gpm]</th>
<th>Δs [ft]</th>
<th>s [ft]</th>
<th>(s/Q) [ft/gpm]</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>1,367</td>
<td>53.41</td>
<td>54.4</td>
<td>0.040</td>
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<tr>
<td>2</td>
<td>1,785</td>
<td>53.40</td>
<td>107.8</td>
<td>0.060</td>
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<td>3</td>
<td>2,207</td>
<td>36.75</td>
<td>144.6</td>
<td>0.066</td>
</tr>
</tbody>
</table>

Incremental Drawdown (Δs) (t = 1,440 min)

Q₁ = 1,367 gpm
Q₂ = 1,785 gpm
Q₃ = 2,207 gpm
Specific Drawdown

Formation Loss Coefficient (y-intercept)
\[ B = 0.0164 \text{ ft/gpm} \]

Well Loss Coefficient (slope of line)
\[ C = 0.000005083 \text{ ft/gpm}^2 \]
Well Efficiency Analysis Chart

Well Efficiency (%) = Formation Loss / Drawdown in Well

where:
- $s_w$ = drawdown in well (ft)
- $Q$ = pumping rate (gpm)
- $B$ = formation loss coefficient (ft/gpm)
- $C$ = well loss coefficient (ft/gpm$^2$)
- $BQ$ = formation loss (ft)
- $CQ^2$ = well loss (ft)
- $E$ = well efficiency (%)
Aquifer Transmissivity

- The rate of flow in gallons per minute through a vertical section of aquifer 1-ft wide, extending the full thickness of the aquifer, under a hydraulic gradient of 1.
- Or more simply, the transmission capability of an entire thickness of aquifer
- Can be determined from:
  - Constant rate pumping test
  - Distance drawdown test
  - Recovery test
- Estimated from specific capacity
Jacob’s Equation:
\[ T = \frac{264 \times Q}{\Delta s} \]

where:
- \( Q \) = pumping rate, gpm
- \( \Delta s \) = drawdown over 1 log cycle

\[ T = \frac{(264)(1,855 \text{ gpm})}{3.1 \text{ ft}} \]

\( T \approx 160,000 \text{ gpm/ft} \)
Aquifer Storativity

- The amount of water released or added to storage through a vertical column of aquifer having a unit cross-sectional area, due to a unit decline or increase in average hydraulic head.
- In unconfined aquifers this represents the drainable volume of water and is equivalent to specific yield.
- Can help to determine if your aquifer is confined or unconfined.
- Can be determined from:
  - Distance drawdown test
  - Observation well time-drawdown data
Aquifer Storativity

Transmissivity ($T$) = $\frac{528Q}{\Delta s}$

Storativity ($S$) = $\frac{Tt}{r_0^2}$

Radius of Influence ($r_0$)

Plot Data for Specific Time ($t$) - in this case 1,040 min

$Q = 14.8$ gpm
$r_0 = 398$ ft
$t = 1,040$ min = 0.72 day
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What Can I Learn?

- Short- and long-term pumping dynamics
- Aquifer parameters
  - Transmissivity
  - Storativity
- Well interference
- Well efficiency
- Flow profile
Pump Design

- Determine the most efficient and appropriate design pumping rate for any well
- Estimate short- and long-term drawdown from which to design the permanent well pump
  - Total Dynamic Head (TDH)
  - Pump intake setting
- Estimate well interference
- Estimate sand production and need for pump-to-waste
- Establish baseline well efficiency to be used as metric for future well rehabilitation efforts
Why Do I Care About Transmissivity and Storativity?

- Siting of wells in productive aquifers
- Can be used to estimate magnitude of water level interference at given time and distance from a pumping well
  - Anticipate interference when siting new wells
  - Assess minimum well spacing in a well field
- Calculate anticipated flow rates before installing a well
- Useful in development of groundwater models
Well Efficiency Monitoring

Well Efficiency has declined from 78% to 25% in 6 years (at 3,000 gpm)

Aquifer Loss is Unchanged

Well Loss has increased due to clogging of well intake structure

February 2009

June 2015
Flow Profile

- Spinner (flowmeter) survey
  - Measures depth-specific flow contribution
  - Useful for addressing future flow and WQ issues
Summary

- Aquifer pumping tests provide invaluable data that can be used for a wide variety of needs.
- You may not know when you will need this information.
- It is recommended that controlled pumping tests be conducted following any new well installation, or following a well rehabilitation event.
- Step tests should be conducted periodically to assess well efficiency trends and to assist with determination of when to rehabilitate.
Questions?

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