Why Transmissivity Values from Specific Capacity Tests Appear Unreliable

Rich Soule
Justin Blum
Steve Robertson
Wellhead Protection in Minnesota

• State Wellhead Protection Rule specifies the use of groundwater flow models to determine wellhead protection areas.

• Transmissivity is typically the most sensitive and uncertain parameter in these models.

• There are over 900 community water supply systems covered by the Rule.

• There are six of us to do the work.
Sauk Centre

Drinking Water Supply Management Area (DWSMA) MN-00251
10 year Time of Travel

- Public Water Supply Well
- Emergency Management Zone
- Wellhead Protection Area (WHPA)
- Groundwater Capture Zone
- DWSMA
- DWSMA Vulnerability Boundary

H = High Vulnerability
M = Moderate Vulnerability
L = Low Vulnerability

0.4 0 0.4 Miles

Approved December 11, 2002
Transmissivity Information

Pumping Tests
Observation Wells
Multiple Analysis
Preferred T Values

Specific Capacity Tests
Driller Data
Location Checked
Obvious errors removed.
Estimating $T$ from a Specific Capacity Test

$$s = \frac{Q}{4\pi T} \left[ \ln \frac{2.25 \ T \ t}{r_w^2 \ S} \right]$$

Cooper and Jacob, 1946

- **Measured**
  - $Q$ = discharge
  - $s$ = drawdown
  - $t$ = time since start
  - $r_w$ = radius of well

- **Assume**
  - $S$ = Specific Storage

- **Calculate**
  - $T$ = Transmissivity

- **Iterate**
  $$T = \frac{Q}{4\pi s} \left[ \ln \frac{2.25 \ T \ t}{r_w^2 \ S} \right]$$
## Test Differences

<table>
<thead>
<tr>
<th>Test Type</th>
<th>Water Levels</th>
<th>Observed Wells</th>
<th>Analysis Methods</th>
<th>Duration</th>
<th>Discharge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pumping</td>
<td>Very Many</td>
<td>Several</td>
<td>Too Many</td>
<td>Days</td>
<td>High</td>
</tr>
<tr>
<td>Specific Capacity</td>
<td>Two</td>
<td>One</td>
<td>Few</td>
<td>Hours</td>
<td>Low</td>
</tr>
</tbody>
</table>
# Information Available from Test

<table>
<thead>
<tr>
<th>Test Type</th>
<th>T</th>
<th>S</th>
<th>Bounds</th>
<th>Leakage</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pumping</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>489</td>
</tr>
<tr>
<td>Specific Capacity</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td>127,834</td>
</tr>
</tbody>
</table>
What’s the Difference?

Frequency Distributions of $T$ Estimates

Lognormal Distribution
But Not the Same Populations
Direct Comparison of Methods-Same Wells

Scattered
$R^2=0.25$
But
Unbiased
Pumping Tests – Different Analysis Methods

Scattered

$R^2 = .20$

But

also

Unbiased
Conventional Wisdom

**Specific Capacity**
- Measurement Bias.
- Limited Data
- Limited Analysis
- Just wrong.

**Pumping Test**
- No Measurement Bias.
- Lots of Data
- Unlimited Analysis
- Always right.

LOCATION  LOCATION  LOCATION
Population Bias

• Pumping tests are done in wells located and designed for high production.

• Specific capacity tests are done in domestic wells located randomly and designed to meet a minimum demand.
Population Bias: Spatial Variation

Within 6 km variability is due to small scale effects or measurement error.

Beyond 6 km more than half of the variability is due to location.
Confirming the Location Bias

- Find all specific capacity tests within 2 km of the pumping tests.
- Determine the average values for these tests.
- Check for bias.
- Correlation should improve with the number of specific capacity tests.
Check for Bias

Scattered But Unbiased

Correlation improves with N
Sources of Specific Capacity Bias:

- Measurement Error
- Partial Penetration
- Aquifer Heterogeneity
- Casing Storage
- Well Efficiency

Would be unbiased
**Measurement Bias: Partial Penetration**

- 114,452 Quaternary Wells
- 75% have unknown H
- Average known H = 25 ft.

\[
T = \frac{Q}{4 \pi S} \left[ \ln \left( \frac{2.25 \left( \frac{T}{t} \right)}{r_w} \right) + 2S_p \right]
\]

\[
s_p = \frac{1 - (L/H)}{(L/H)} \left( \ln \left( \frac{H}{r_w} \right) - G(L/H) \right)
\]

Brons and Marting (1961)  
Where

\[
G(L/H) = 2.948 - 7.363(L/H) + 11.447(L/H)^2 - 4.675(L/H)^3
\]

Bradbury and Rothschild (1985)

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**Maybe but Low Q…..**
Measurement Bias: Isotropic Aquifer

If the Aquifer is Isotropic K is constant for different screen lengths
### Interesting Like the Chinese Curse

A Statistical Model

<table>
<thead>
<tr>
<th>Screen Length</th>
<th>T (ft²/day)</th>
<th>K (ft/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 ft.</td>
<td>1370</td>
<td>137</td>
</tr>
<tr>
<td>15 ft.</td>
<td>6606</td>
<td>440</td>
</tr>
<tr>
<td>20 ft.</td>
<td>9600</td>
<td>480</td>
</tr>
</tbody>
</table>
Heterogeneous Aquifer: Interesting Zone

May be an Important Measurement Bias
Casing Storage Effects?

\[ t_c = \frac{0.6 (d_c^2 - d_p^2)}{Q / s} \]

- \( d_c \) = casing diameter (in)
- \( d_p \) = riser diameter (in)
- \( Q \) in gpm, \( s \) in feet

\[ E = \frac{T_2}{4T_1} \quad \text{Schafer (1978)} \]

Probably not. Wells might be fairly efficient too......
Conclusions

• Pumping tests are essential to evaluate aquifer hydraulics in the vicinity of the well. However, the selection of the well location often ensures that it is not representative of the aquifer.

• Specific capacity tests generally provide unbiased estimates of transmissivity. However, they are often highly variable and may require many tests to provide a good estimate of transmissivity.
Meak K of Specific Capacity within 2 Km v. Pumping Test K
N < 5

![Graph showing the relationship between Mean K (ft/day) Specific Capacity Test and K (ft/day) Pumping Test. The graph includes a scatter plot with data points and trend lines.](image-url)
Meak K of Specific Capacity within 2 Km v. Pumping Test K

$10 > N > 5$

K (ft/day) Pumping Test

Mean K (ft/day) Specific Capacity Tests

K (ft/day) Pumping Test
Meak K of Specific Capacity within 2 Km v. Pumping Test K
20>N>10
Meak K of Specific Capacity within 2 Km v. Pumping Test K
N>20