How good are results from small scale injection tests?

A comparison of results from two testing methods in deep bedrock at a Canadian arctic site.

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Presented at Mine Water Solutions in Extreme Environments 2015 by InfoMine. The full papers and the full Proceedings volume are available for purchase at InfoMine’s eStore - [https://estore.infomine.com/](https://estore.infomine.com/).
Introduction

- Hydrogeologists never have a perfect understanding of hydraulic conductivity, at least not at the beginning of a project.

- Traditionally greenfields projects utilize small scale test methodologies (i.e. packer testing).

- However, can we effectively assess aquifer uncertainties using only these small scale methods?

- Large-scale testing methods at the artic mine site were utilized in an order to assess this uncertainty and gain a better understanding of the distribution and magnitude of hydraulic conductivity (K).
Regional Setting / Logistical Challenges

- Study site located within Nunavut along Arctic Ocean
- Extremely cold climate
- Deposits located beneath regional lakes
  - Majority of testing conducted during winter months
- Saline water conditions

Mayer (2011)
Regional Geology

- North-south striking Hope Bay volcanic belt
  - Within northeastern Slave Structural Province

- Greenstone-hosted quartz-carbonate vein deposit
  - Dominated by:
    - Pillowed Mg-rich tholeiitic basalt
    - Basaltic andesite
    - Fe-rich tholeiites
  - Interlayed with:
    - Intermediate felsic volcanic rocks
    - Sedimentary rocks

Modified from Sherlock and Sandeman (2003)
Local Geology: Doris Deposit

- Succession of mafic meta-volcanics
  - Groundwater flow is predominantly fracture controlled

- Geology is locally folded within a doubly plunging upright anticline

- Increased fracturing observed near hinge zone
  - Zone is also associated with increased quartz veining

- Cross-cut by localized diabase intrusions
  - Dykes are more competent than surrounding meta-volcanics

Mayer (2011)
Conceptual Model

Underground Mine

Fault

Shallow lake

Isolated talik

Deep lake

Continuous permafrost zone

Deep unfrozen regional aquifer system

Antiformal quartz veins

Regional groundwater flow driven by lake elevations

Talik connected to deeper aquifer system

Dyke

Synformal quartz veins

Modified from Mayer et al. (2014)
Hydrogeological Testing

- **Phase One:**
  - Packer testing (56 short test)
    - 10 to 30 mins
    - Isolated, small-scale injection tests
  - Thermal monitoring
  - Deep Westbay multi-level wells

- **Phase Two:**
  - Long term injection test
    - 14 hours
    - Packer-isolated injection zone
    - Monitored from Westbay multi-level well

Arctic Testing Method Comparison

Mayer (2011)
Phase One

Small-Scale Packer Isolation Tests
Small Scale Testing (Isolated Packers)

**Arctic Testing Method Comparison**

- **Geometric Mean**: $3 \times 10^{-8}$ m/s
- **Arithmetic Mean**: $4 \times 10^{-7}$ m/s
Geotechnical Comparisons

Mayer et al. (2014)
Multivariate Statistics

Mayer et al. (2014)
Phase Two

Long-Term Injection Test
Large Scale Injection Test

Injection Well

Westbay Well

Quartz veining and alteration in meta-volcanics

Diabase Sill

0 200 400 600

5000 4800 4600

Diabase Dike

Doris Lake
Quartz Vein
Alteration Zone
Diabase
Injection Well

![Graph showing the relationship between delta hydraulic head and time, with labels indicating 'Well Bore and Variable Flow Rate Effects' and 'Constant Head or Spherical Flow Period'.]
Westbay Well Observations

Arctic Testing Method Comparison

Composite Plot

Δ Hydraulic Head (m)

Time / r² (s m⁻²)

Zone 12: 26.5 mbgs
Zone 11: 41.0 mbgs
Zone 10: 77.3 mbgs
Zone 9: 120.5 mbgs
Zone 8: 161.4 mbgs
Zone 7: 198.2 mbgs
Zone 6: 233.4 mbgs
Zone 5: 278.9 mbgs
Zone 4: 326.8 mbgs
Zone 3: 377.3 mbgs
Zone 2: 446.3 mbgs
Zone 1: 490.0 mbgs
Central Aquifer

Arctic Testing Method Comparison

Zone 5

Zone 6

Zone 7

Zone 8

Test Data

Derivative
Upper Aquifer

Arctic Testing Method Comparison
Comparison of Small vs. Large Scale Tests

<table>
<thead>
<tr>
<th>Small Scale</th>
<th>Large Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geometric</td>
<td>3e-6 m/s</td>
</tr>
<tr>
<td>Arithmetic</td>
<td>3e-6 m/s</td>
</tr>
</tbody>
</table>

3e-8 m/s 4e-7 m/s

Comparison is not without its challenges:

- Large scale testing indicates an two orders of magnitude larger K than suggested by packer testing average
- This is consistent with published literature which suggest fractured systems are disproportionally controlled by highest K features

What does this all mean?
Conclusions/Final Thoughts

How often are we getting “blinded” by our methods?
• Under-estimation of large-scale behaviour using small-scale tests

Analytical models and even numerical models require some sort of average K value for the zones or domains being assessed
• Is this even appropriate for fracture rock hydrogeology?
• How can we utilize traditional analysis method if an appropriate REV does not exist?

In theory, all the test data is good but:
• We need to understand limitations,
• Interpret with regard to lithology and structure,
• Assess reasonable worst case scenarios considering these factors.

We’ll never be “right” but we can get better at managing “wrong”