EFFECTS OF TEST SCALE ON HYDRAULIC MEASUREMENTS IN A CRYSTALLINE ROCK SETTING

Kent Novakowski
& Laura Elmhirst

Dept. of Civil Engineering, Queen's University
Kingston, Ontario, Canada

Introduction

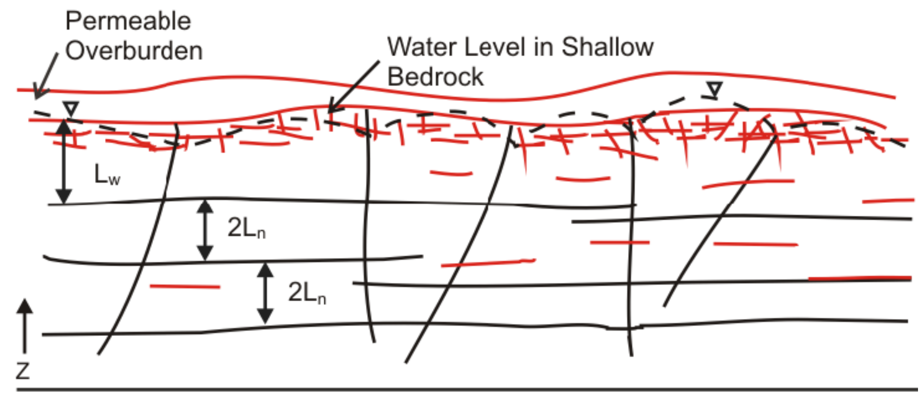
- Effect of scale is a long-standing issue with hydraulic tests conducted in many hydrogeological media.
- In fractured rock, typically assumed that bulk estimates of transmissivity increase with increasing scale.
- Opposite observed with effective porosity and storativity.
- No information however in the literature on scale effects with specific yield or vertical hydraulic conductivity.

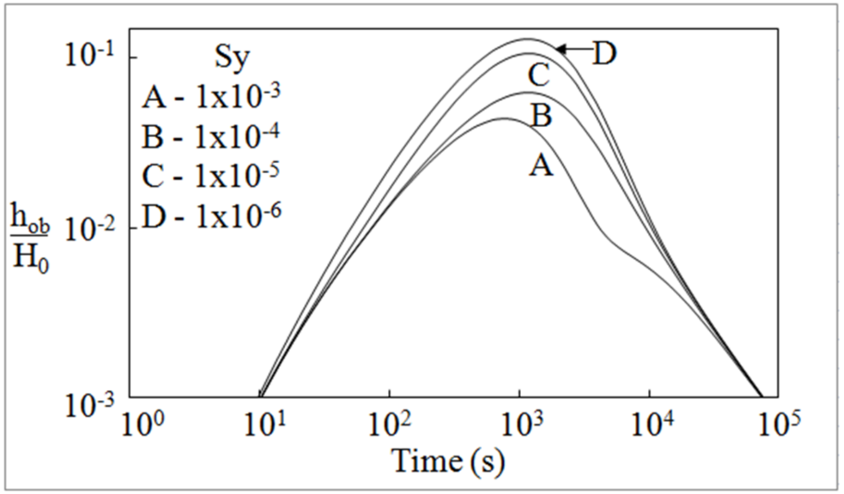
Objectives

- Develop a new analytical model for pulse interference testing that includes discrete fractures.
- Compare the results of pulse interference tests to local-scale constant head tests and larger-scale pumping tests.
- Conduct this study in three-well array in a crystalline rock environment.
- Are scale artefacts a result of inappropriate analytical methods?
- Can scale effects be attributed to preferential pathways in these settings?

Pulse Interference Test (PIT) Model

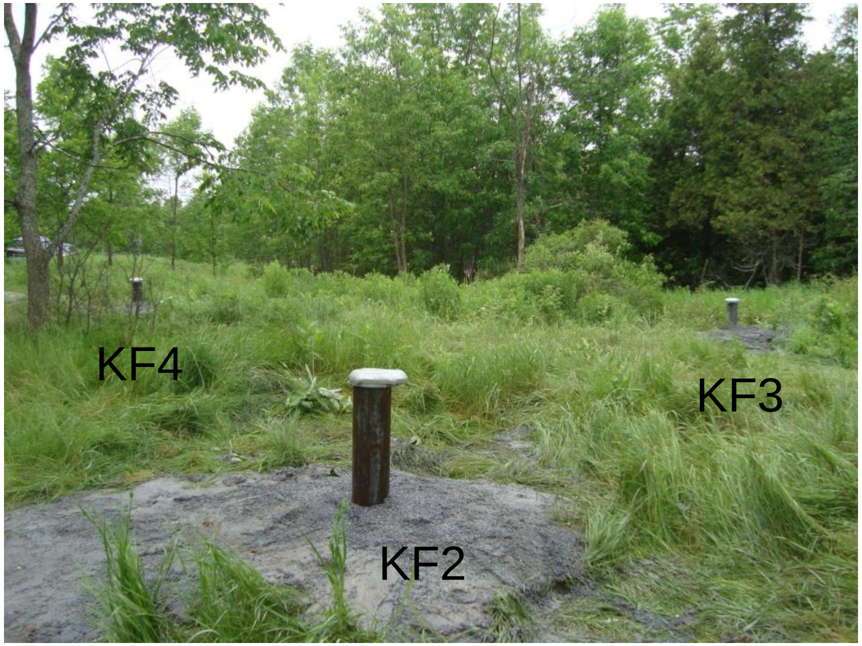
- Discrete fractures accommodated in the horizontal direction.
- K'_v, S'_s, and S_y for vertical properties.
- Wellbore storage in both source and observation wells.
- Open-hole conditions.





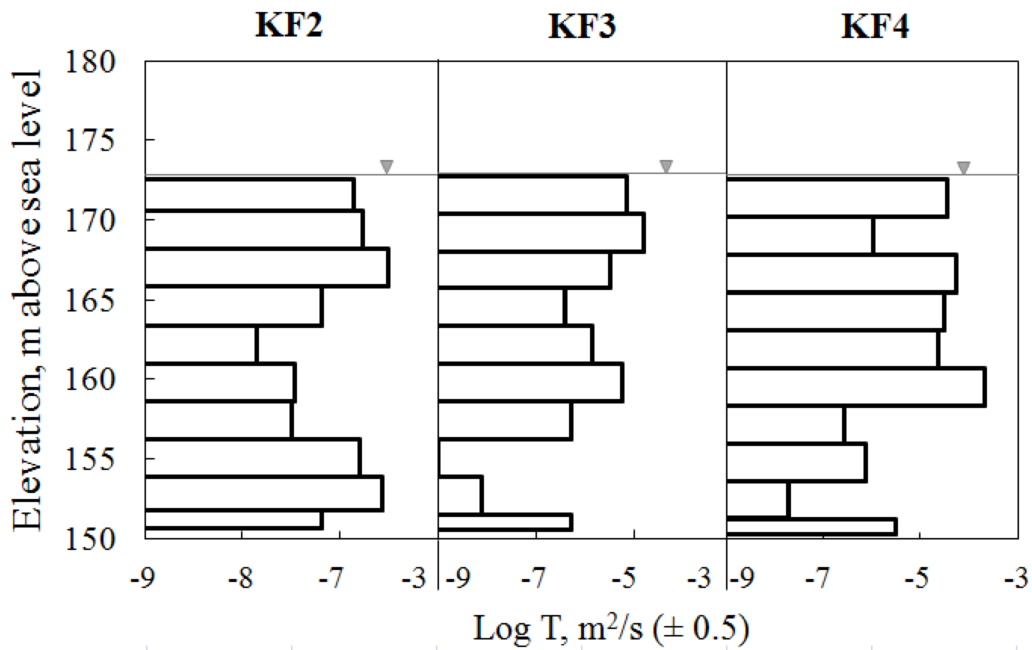
Field Investigation

- Three wells (25 m deep) separated by 10 m in an unconfined gneiss with less than 0.5 m overburden cover.
- Results compared from four hydraulic testing methods:
  - 30 constant head tests
  - 18 slug tests
  - 16 pulse interference tests
  - four 48-hr pumping tests



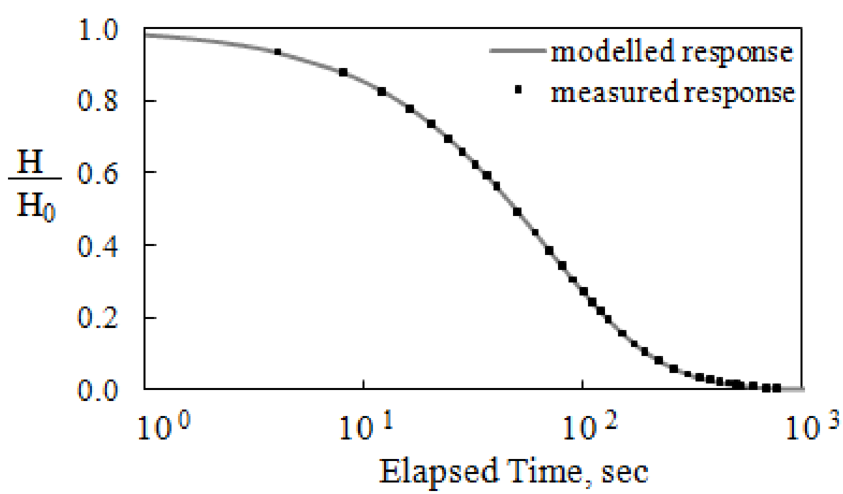
Constant Head Tests

- Testing done contiguously with depth using a packer spacing of 2.4 m. Thiem equation used to analyse each test.
- Cumulative T was estimated by summing the intervals, the cubic law used to estimate fracture aperture, and aperture used to estimate total porosity and thus S_y.

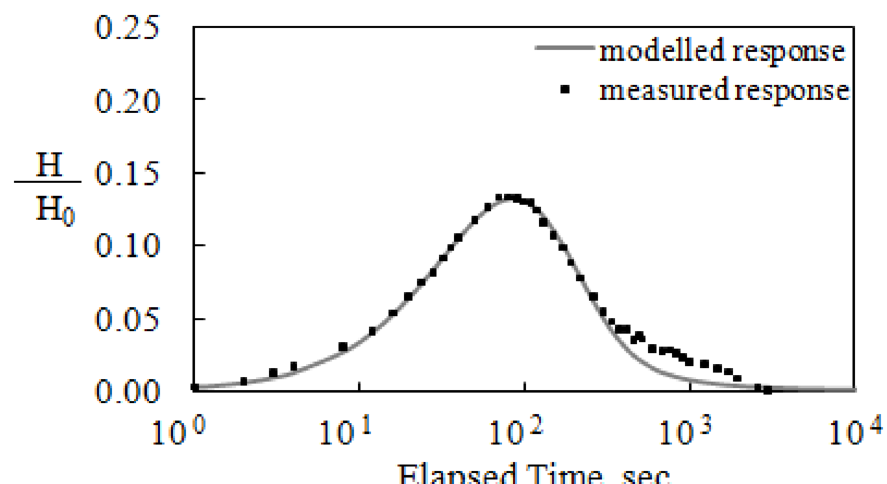


Slug and Pulse Interference Tests

- Poor model fit to late time PIT response.
- Heterogeneity unaccounted for in model prevents unique determination of S'_s at field site.
- T, K'_v, S_y, S are uniquely determined when S'_s is fixed at a low value (10^{-6} m^{-1}) typical of fractured rock.



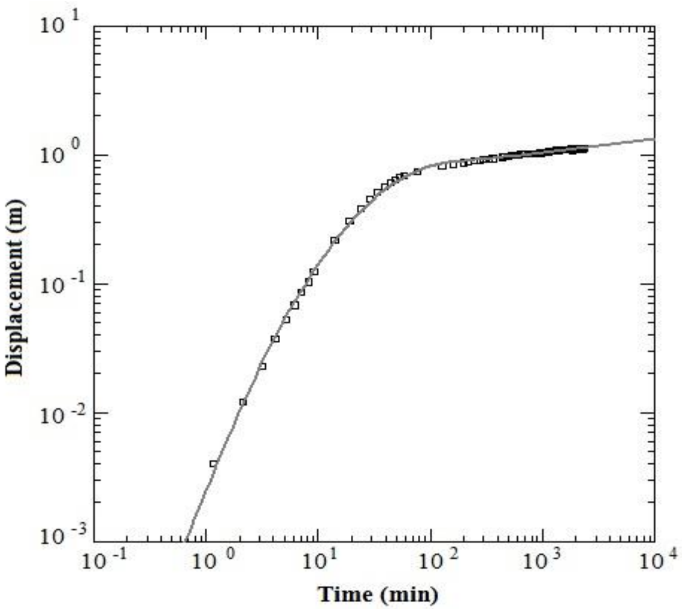
Slug test response



Interference test response

Long-Term Pumping Tests

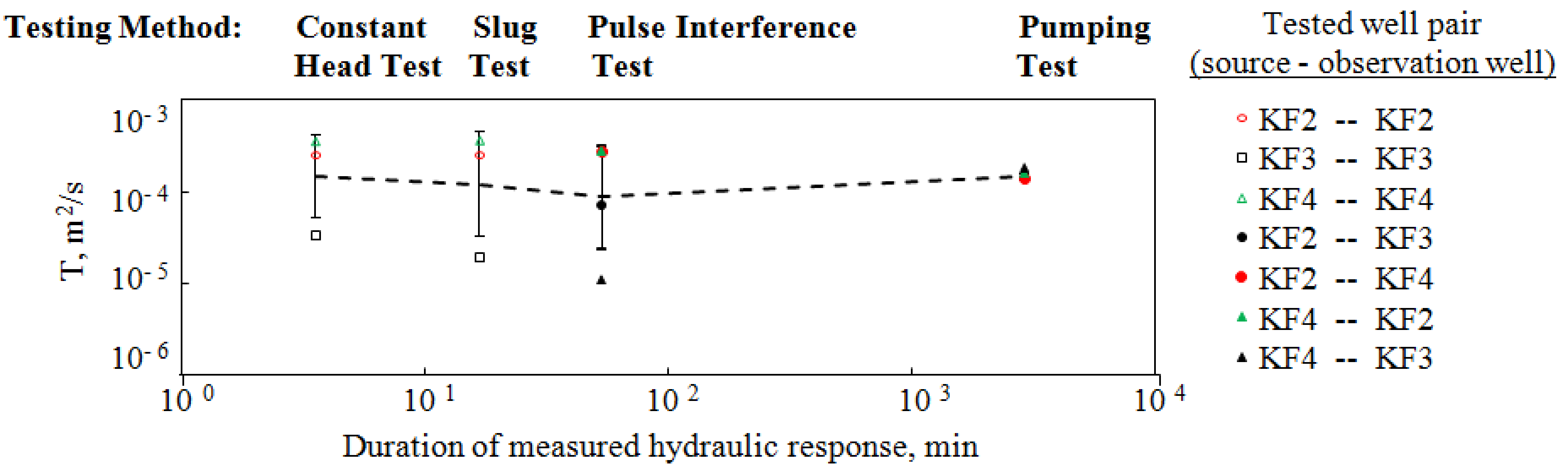
- 48-hour pumping tests performed on KF2 and KF4 with drawdown measured in KF2, KF3 and KF4
- Hydraulic responses analyzed using Moench (1997) solution
  - Includes wellbore storage and skin effects
  - Enables S_y estimates



Drawdown and fitted Moench (1997) type curve for observation well response

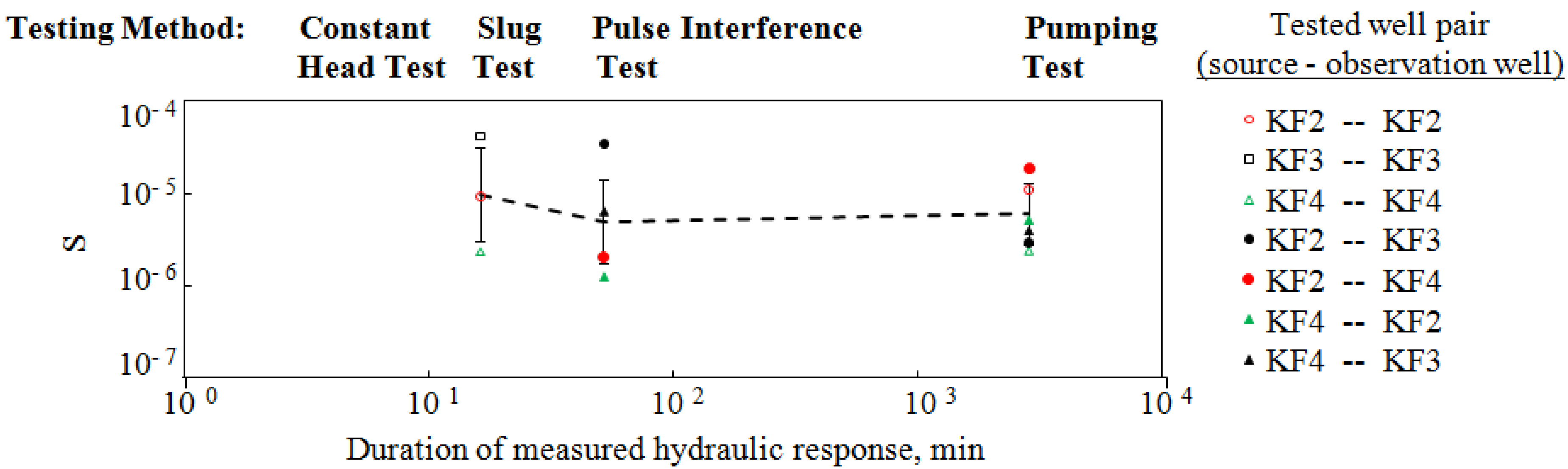
Results

- Scale inferred from duration of hydraulic response.
- Geometric mean T values insensitive to measurement scale.
- Completion of multiple PITs on several well pairs may be an alternative to long-term pumping tests in large-scale T estimation.



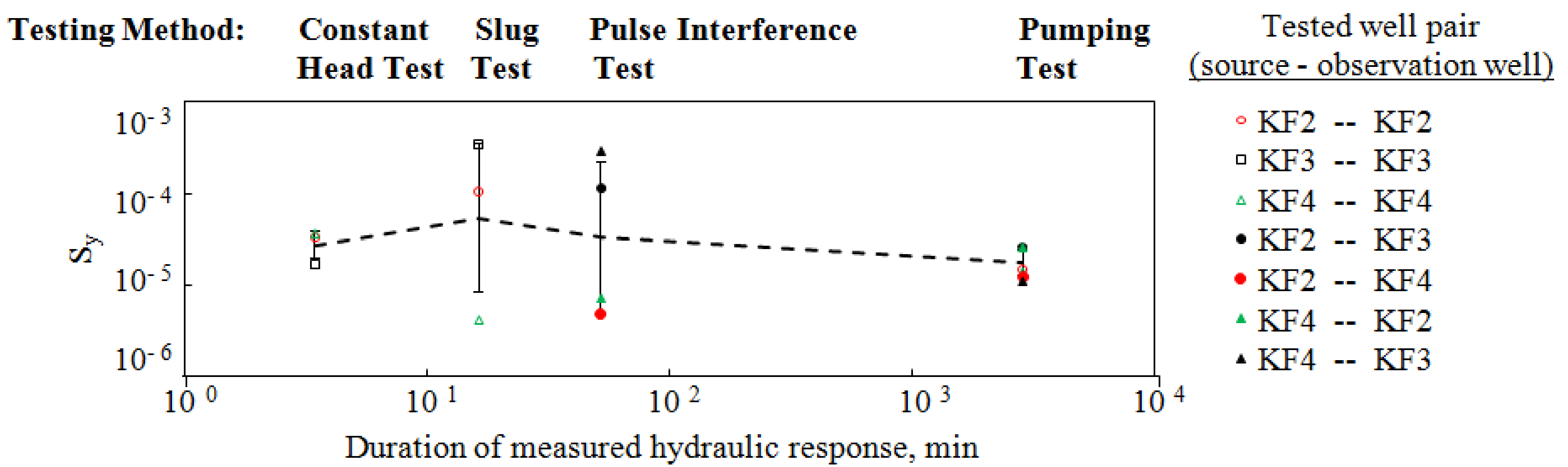
Storativity

- Geometric mean S similar at all test scales
- Half order of magnitude standard deviation present at all test scales
- Local-scale tests on: - high T wells underestimate S
  - low T wells overestimate S



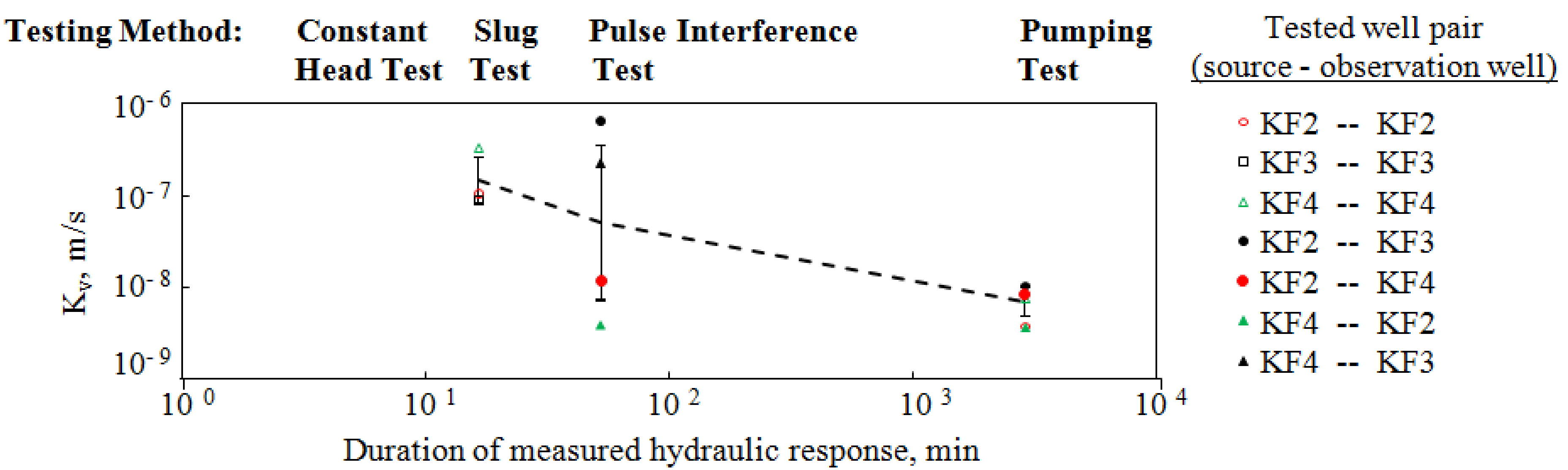
Specific Yield

- Geometric mean S_y from PITs similar to pumping tests.
- Approximately one order of magnitude standard deviation for PITs.
- PITs on high T wells underestimate S_y and on low T wells overestimate S_y.



Vertical K

- Geometric mean K'_v decreases by approximately 1.5 orders of magnitude from slug test to pumping test.
- Pulse interference tests on high T wells approximate pumping test estimates of K'_v.



Conclusions

- Despite non-uniqueness concerns, pulse interference tests can provide reasonable estimates of the hydraulic parameters.
- Negligible effects in T and S between scales.
- Geometric mean S_y over all scales is very similar. More heterogeneity however observed with slug and pulse interference test analysis.
- Agreement for K'_v estimates not as good.
- Little evidence of the influence of preference pathways in these data.
- The K'_v effect may be a function of the analytical method.

Initial Boundary Value Problem

- Governing equation for each horizontal fracture:

$$\frac{\partial^2 h}{\partial r^2} + \frac{1}{r}\frac{\partial h}{\partial r} - q = \frac{S}{T}\frac{\partial h}{\partial t} \qquad r \geq r_w$$

- Exchange between the horizontal fracture and the vertical domain:

$$q = -\frac{K'}{T}\frac{\partial h_m}{\partial z}\bigg|_{z=0} = 0\,; \qquad 0 \leq z \leq L_w$$

- The source condition:

$$K_v \frac{\partial h_m}{\partial z}\bigg|_{z=L_w} = -\,\alpha_1 S_y \int_0^t \frac{\partial h_m(r,L_w,t)}{\partial \tau} \exp\{-\alpha_1(t-\tau)\}\,\partial\tau$$