Hydraulic Conductivity of Minnesota Confined Glacial Aquifers

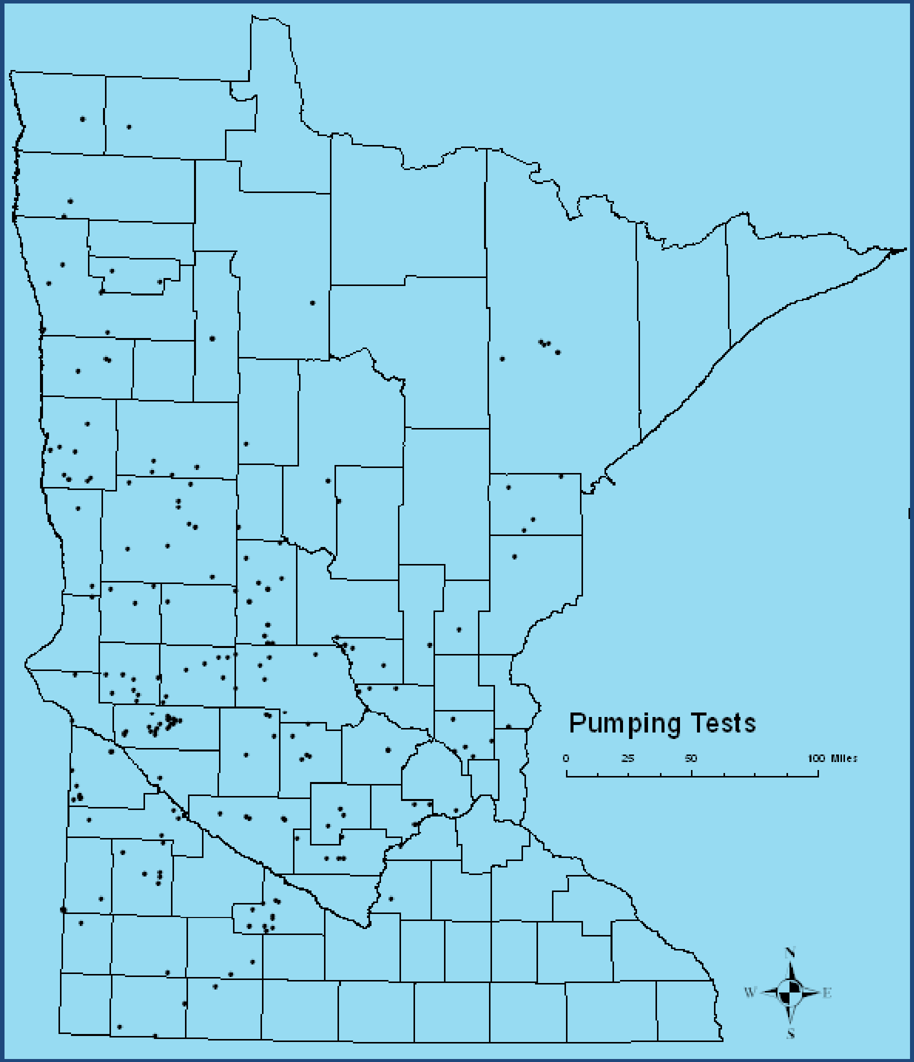
R. G. Soule
Minnesota Department of Health
R. J. Barnes
University of Minnesota

Overview

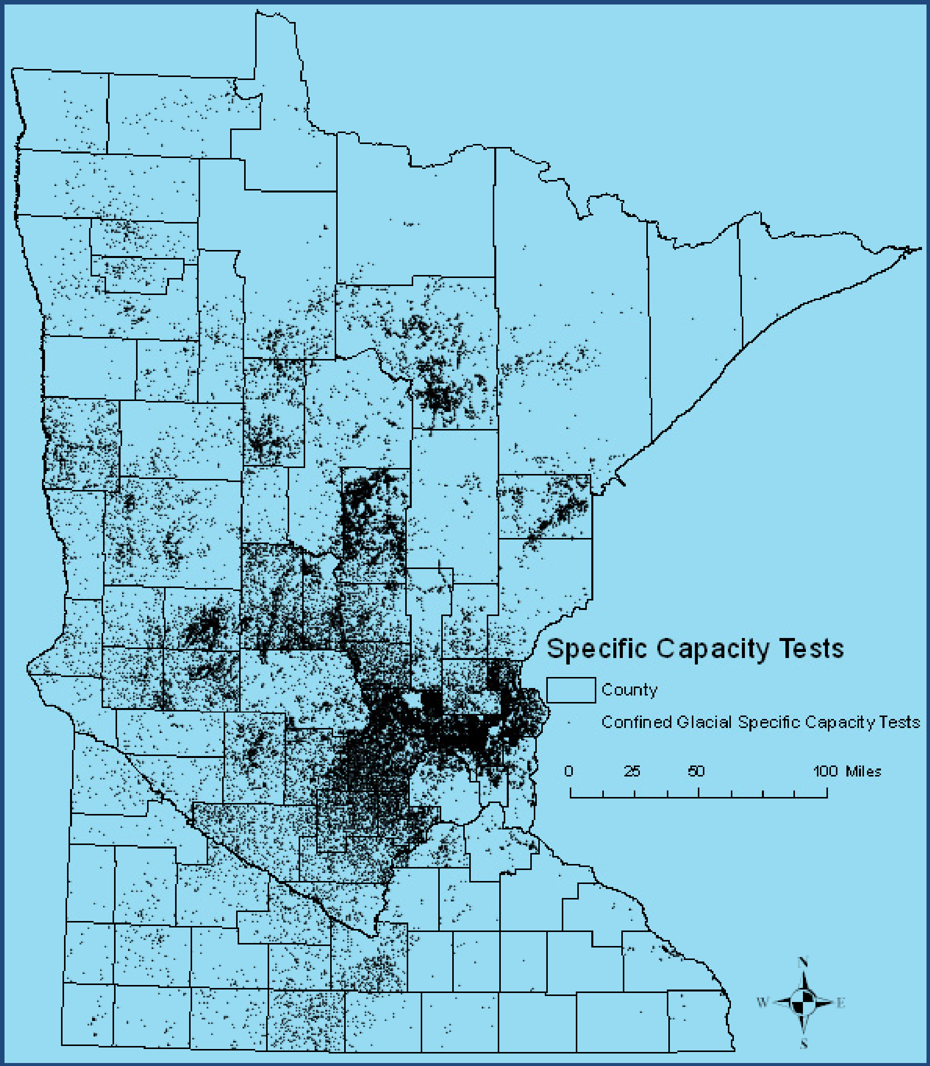
- Well by well comparison of pumping test and specific capacity test estimates of hydraulic conductivity (K).
- Explore the additional information afforded by using specific capacity test K values.
- Consider the limitations of these tests.

Pumping and Specific Capacity Tests

"Gold Standard" N = 239



N = 70,773



Pumping and Specific Capacity Test Pairs

- Must have the same unique well number*,
- Must have verified location*,
- Must be sufficient well construction and geologic information*,
- Must be analyzed in a similar fashion.

*County Well Index (CWI) Minnesota Geological Survey

Estimating Specific Capacity Test Transmissivity

- Cooper-Jacob with partial penetration*:

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

where

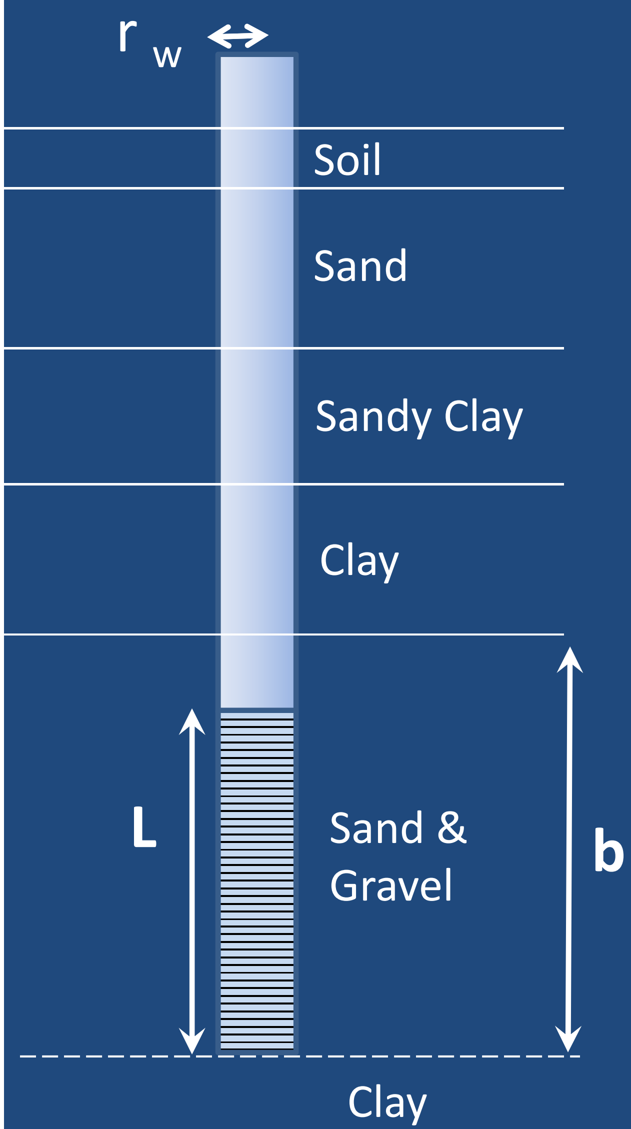
$$s_p = \frac{1 - L/b}{L/b}\left[ln\left(\frac{b}{r_w}\right) - G\left(\frac{L}{b}\right)\right]$$

And the function G is:

$$G\left(\frac{L}{b}\right) = 2.98 - 7.363\,\frac{L}{b} + 11.447\left(\frac{L}{b}\right)^2 - 4.675\left(\frac{L}{b}\right)^3$$

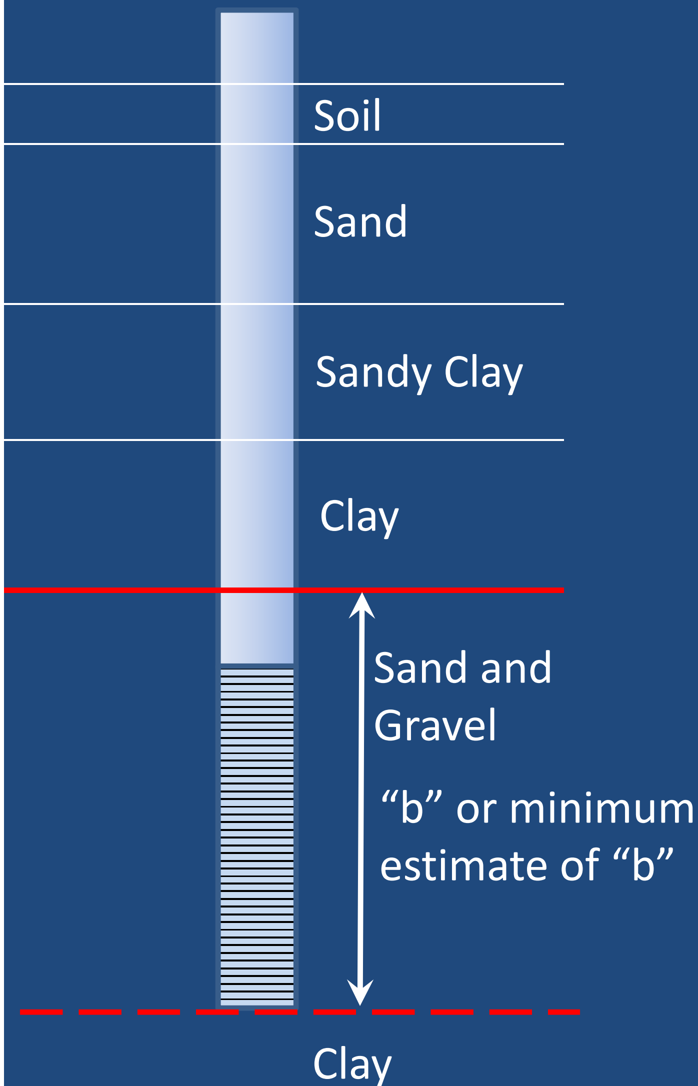
*Bradbury and Rothschild (1985)

Required Well Information



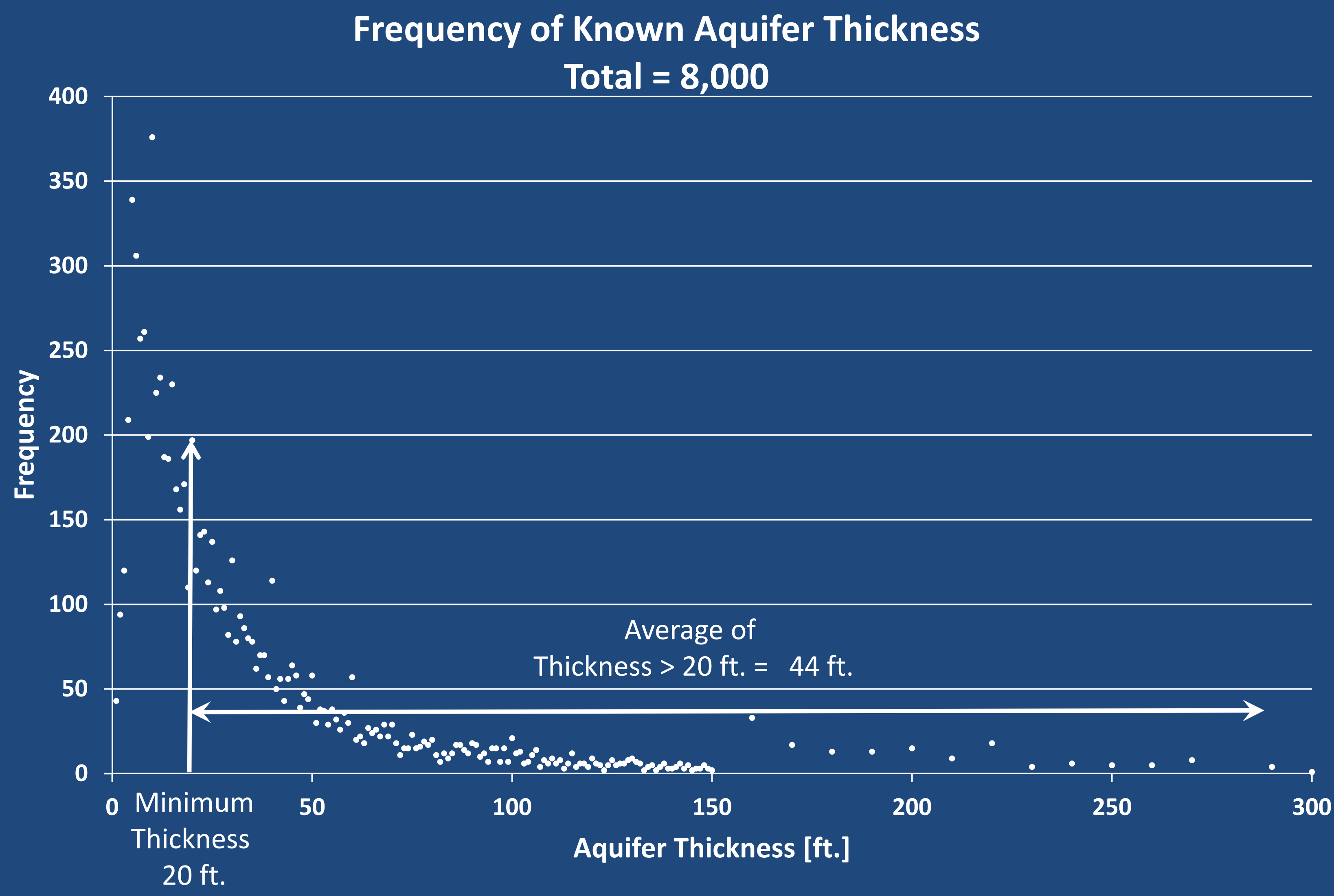
- Screened interval (L)
- Radius (r_w)
- Aquifer thickness (b)

Aquifer Thickness Problem



- Many wells do not have lower confining layer information.
- Option 1: Use the observed “minimum” thickness.
- Option 2: Estimate from the known thicknesses.

Estimating Aquifer Thickness



Tests Requirements

Pumping Tests

- Sources: Federal (USGS), State (MDH, DNR & MPCA), consultants, well drillers and publications.
- Analysts chosen Transmissivity.
- Cooper-Jacob or Theis methods.

Specific Capacity

- Source: CWI
- Pumping rate (Q)
- Duration (t)
- Drawdown (s)

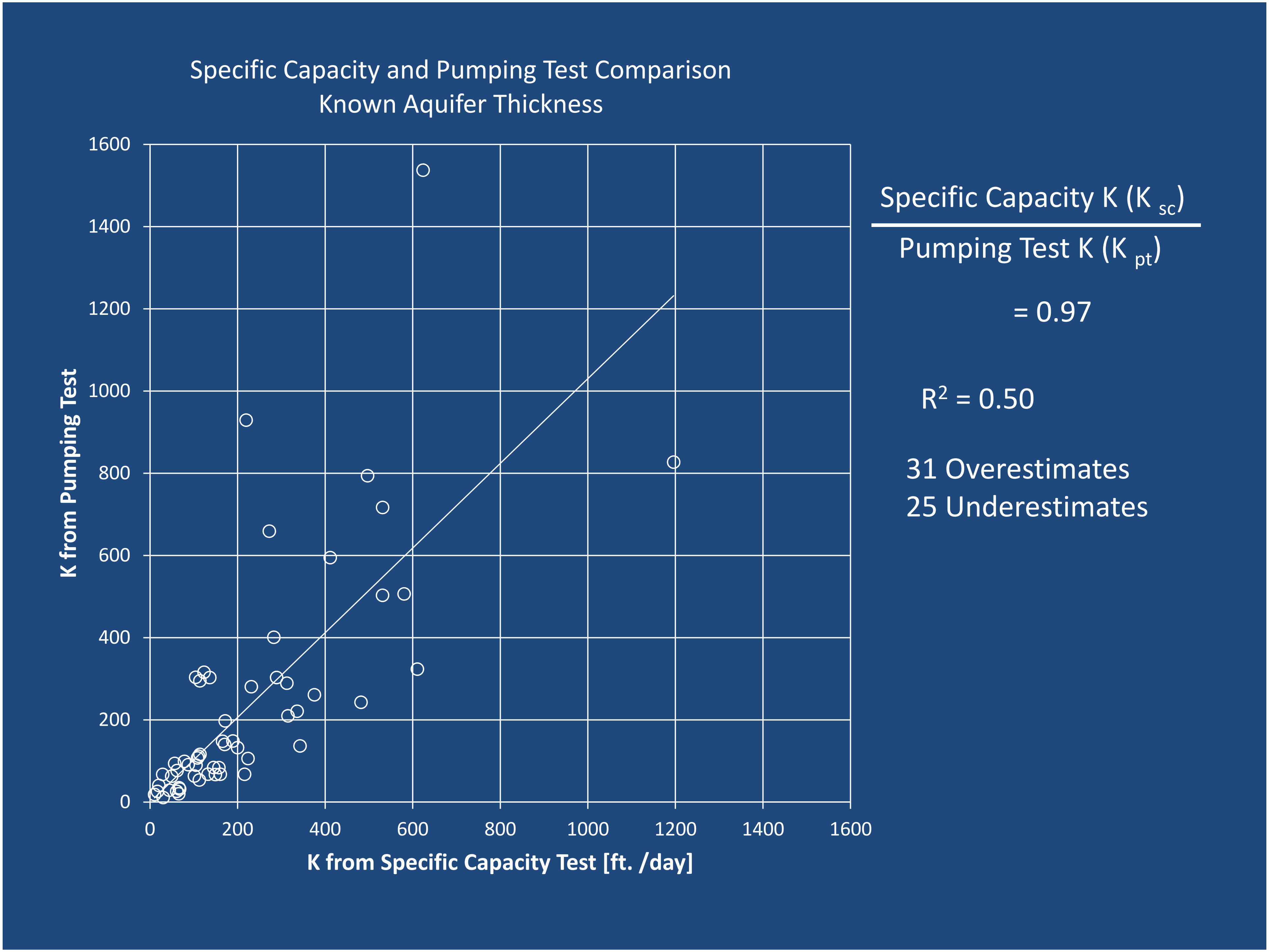
N=100 Pairs

The Comparison Set

AVERAGE WELL INFORMATION	
YEAR BUILT	1985.4
CASING DIAMETER [INCH]	11.9
DEPTH [FT.]	174.5
SCREEN LENGTH [FT.]	29.3
KNOWN AQUIFER THICKNESS [FT.] (N=56)	50.5
MINIMUM AQUIFER THICKNESS [FT.] (N=44)	50.0

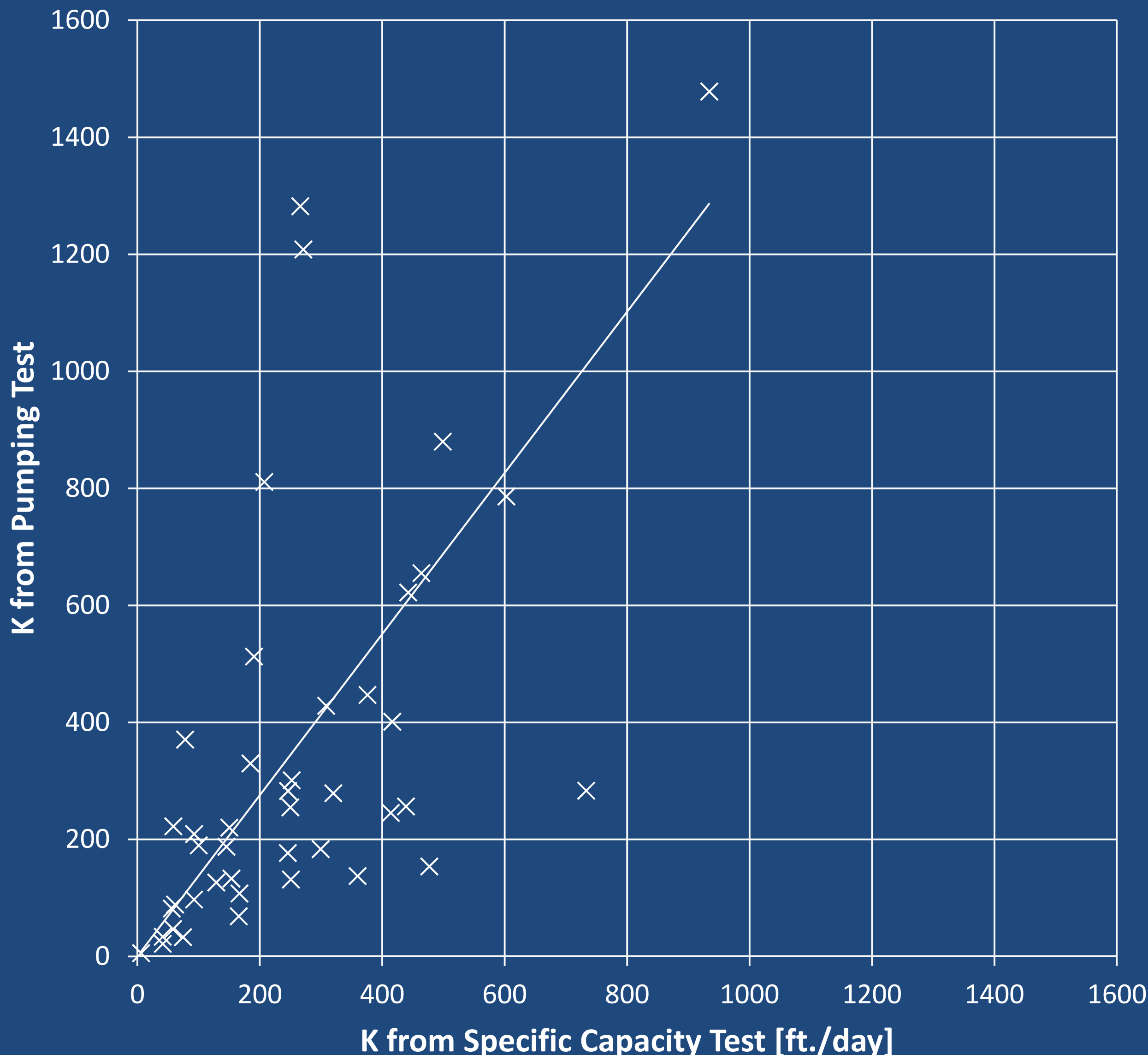
WELL USE	PERCENT
PUBLIC WATER SUPPLY	60%
IRRIGATION & INDUSTRIAL	35%
PUMP OUT	3%
TEST & MONITORING	2%

AVERAGE TEST INFORMATION	Pumping Test	Specific Capacity
DURATION [HOURS]	24	16
DISCHARGE [GPM]	605	664
TESTS WITH OBSERVATION WELLS [%]	76%	0%
ESTIMATED STORATIVITY	4.5E-03	1.5E-03



Specific Capacity and Pumping Test Comparison
Known Aquifer Thickness
1600
1400
1200
1000
800
600
400
200
0
0
200
400
600
800
1000
1200
1400
1600
K from Pumping Test
K from Specific Capacity Test [ft. /day]
Specific Capacity K (K sc)
Pumping Test K (K pt)
= 0.97
R2 = 0.50
31 Overestimates
25 Underestimates

Specific Capacity and Pumping Test Comparison
Minimum Aquifer Thickness



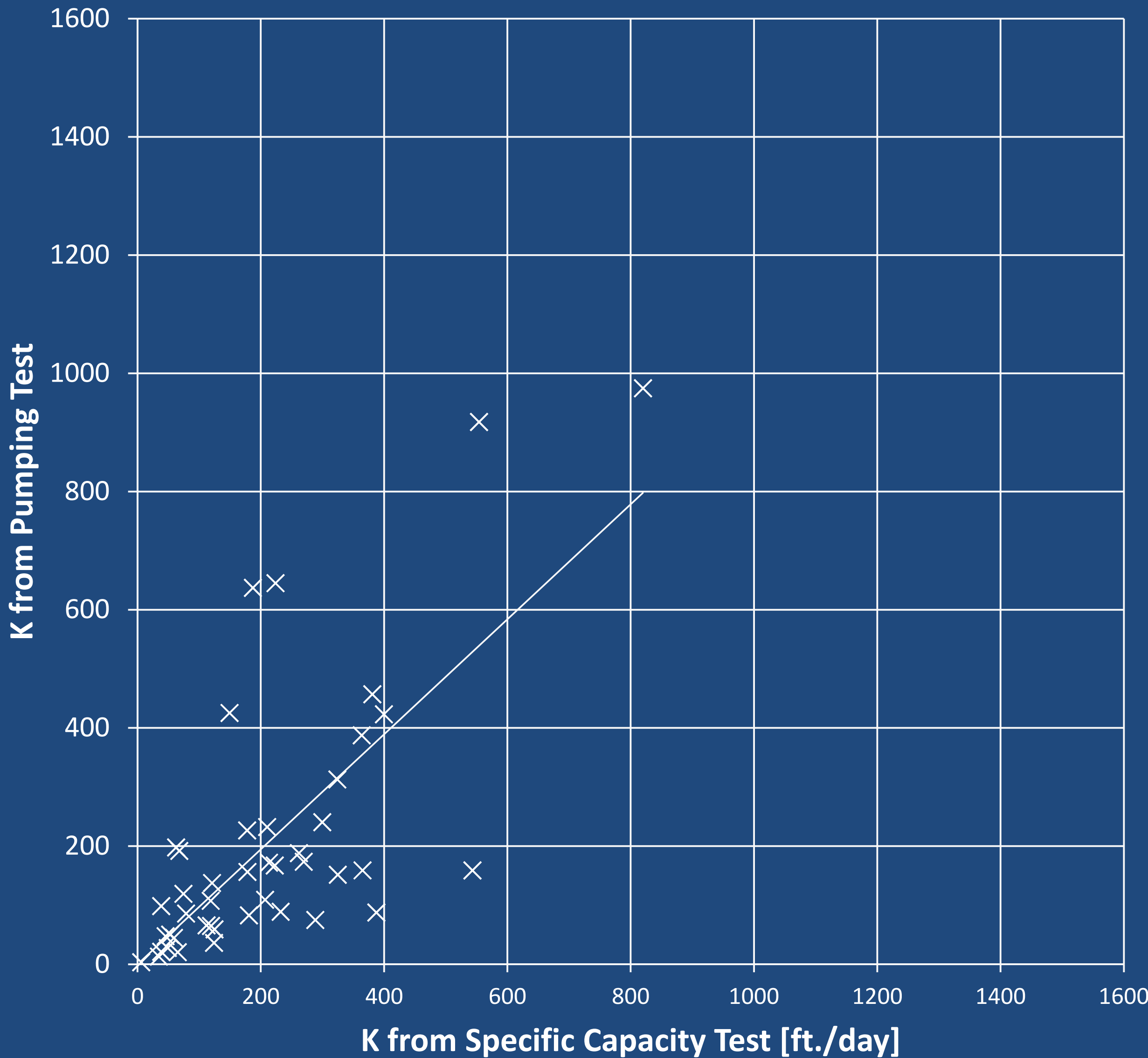
$$\frac{\text{Specific Capacity K } (K_{sc})}{\text{Pumping Test K } (K_{pt})} = 0.72$$

$R^2 = 0.48$

19 Overestimates

25 Underestimates

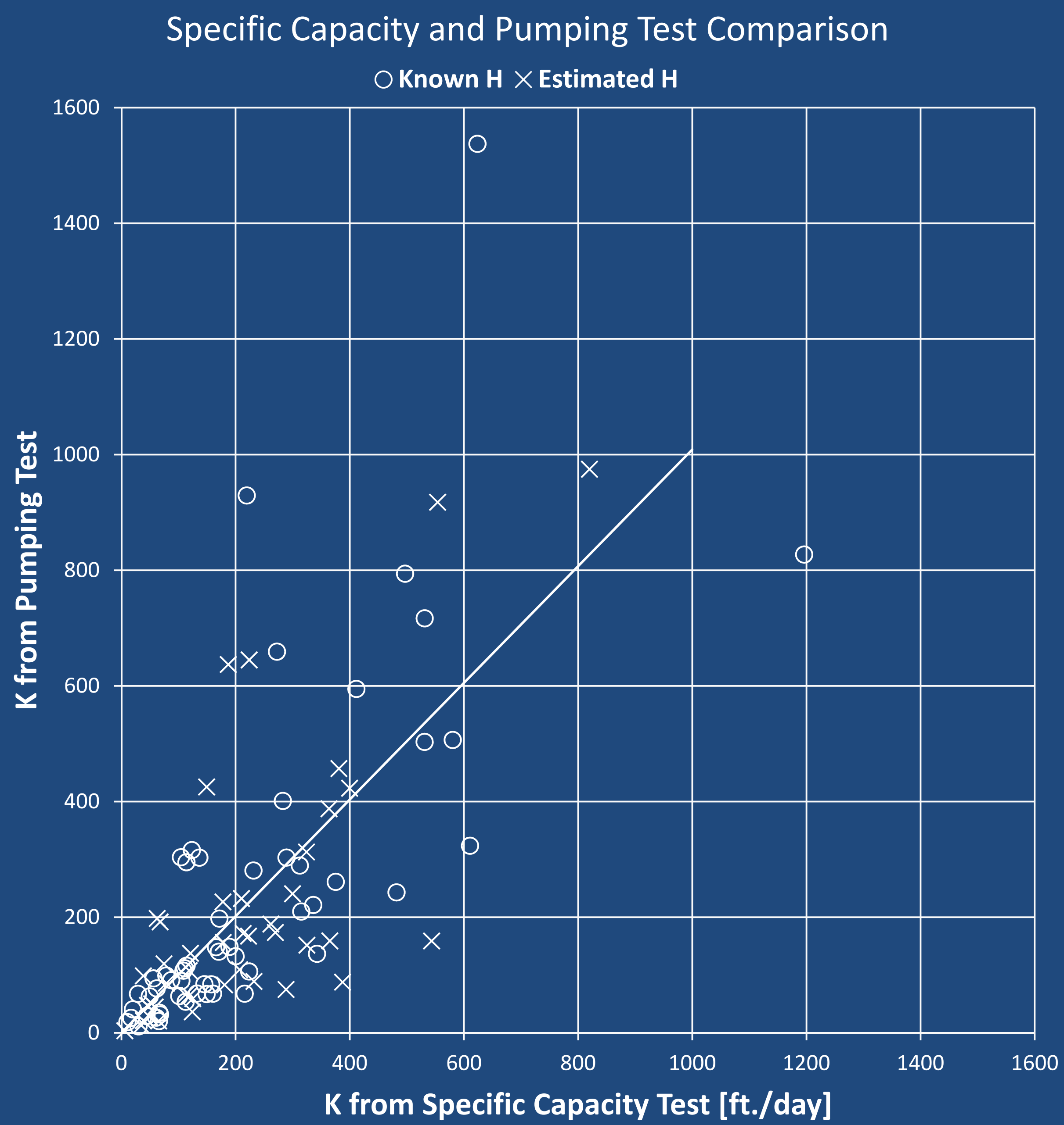
Specific Capacity and Pumping Test Comparison
Estimated Aquifer Thickness



$$\frac{\text{Specific Capacity K } (K_{sc})}{\text{Pumping Test K } (K_{pt})} = 1.03$$

$R^2 = 0.49$

27 Overestimates
21 Underestimates



$$\frac{\text{Specific Capacity K } (K_{sc})}{\text{Pumping Test K } (K_{pt})} = 0.99$$

$R^2 = 0.50$

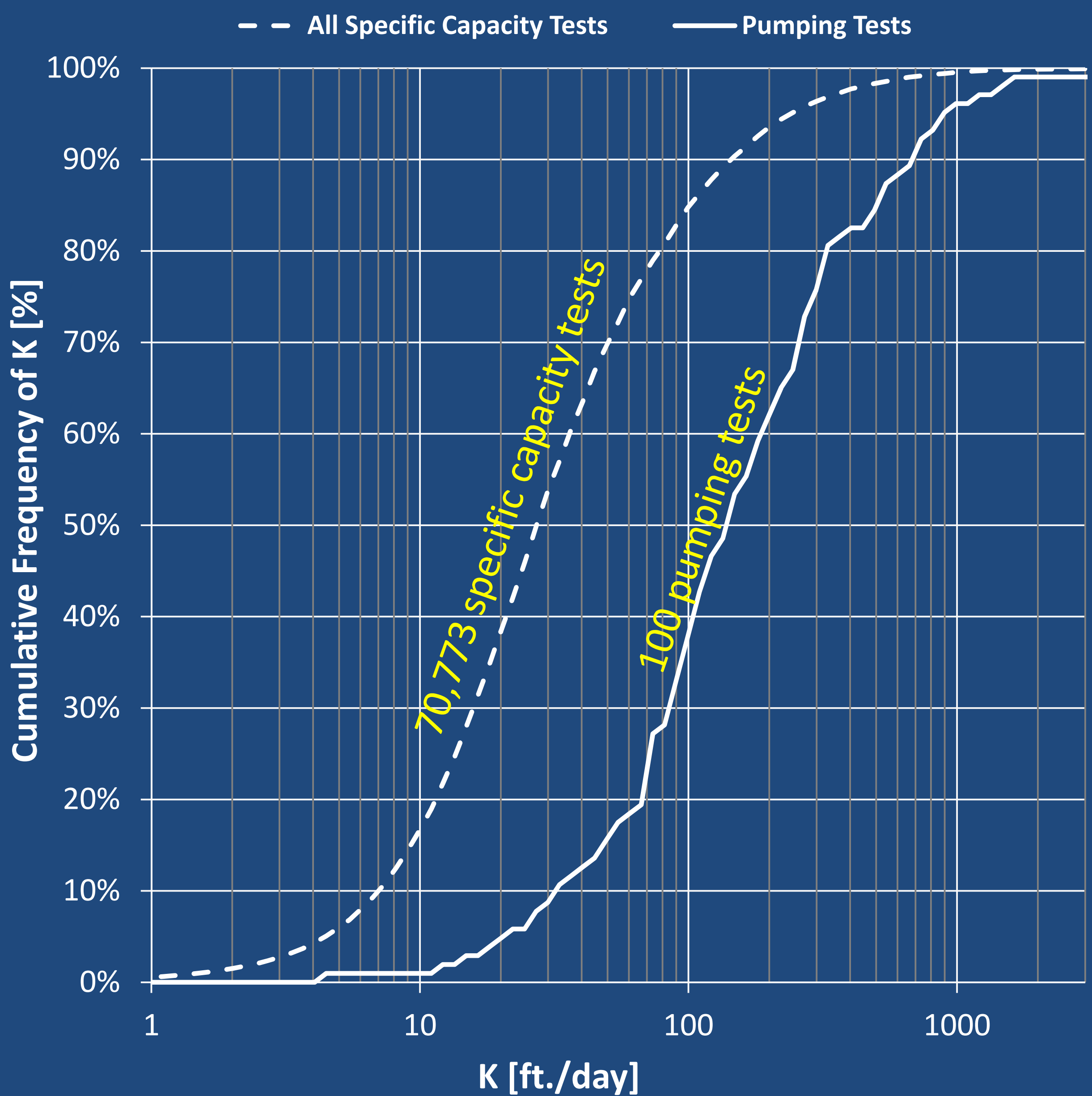
58 Overestimates

46 Underestimates

Additional Information from Specific Capacity Tests

- Apply the same methods to estimate K for the remaining 70,673 specific capacity tests.
- Compare the local specific capacity tests to the pumping tests.
- Evaluate spatial correlation of K values.

Frequency Distributions of K

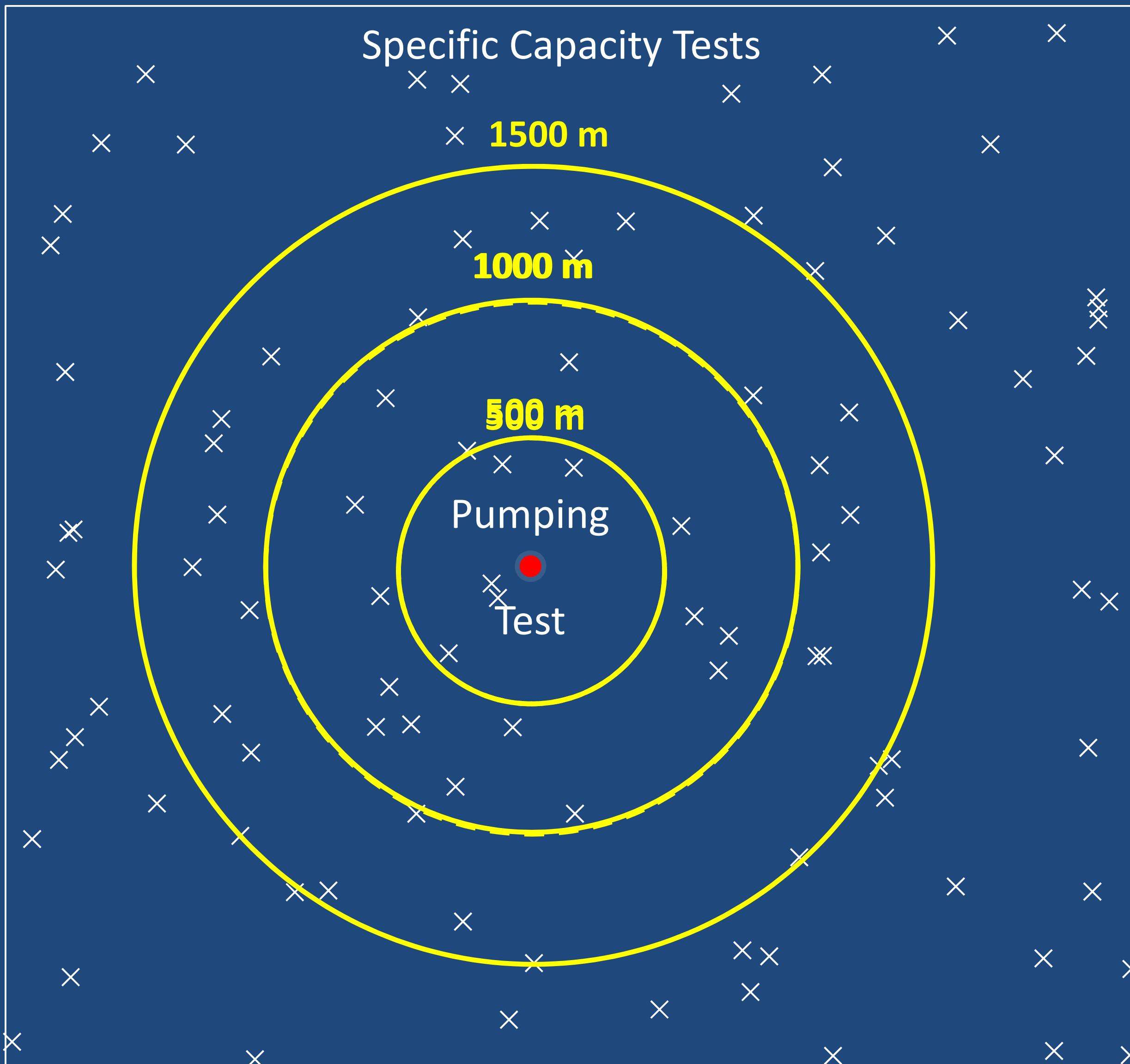


- Both test types have lognormal frequency distribution.
- Not the same populations.

Tests	Median K [ft./day]
100 Pumping Test	132
70,000 Specific Capacity Tests	27

- Heuristic for 50% range:
  - Lower = mean/2
  - Upper = mean * 2.5

Spatial Correlation of Pumping and Specific Capacity K



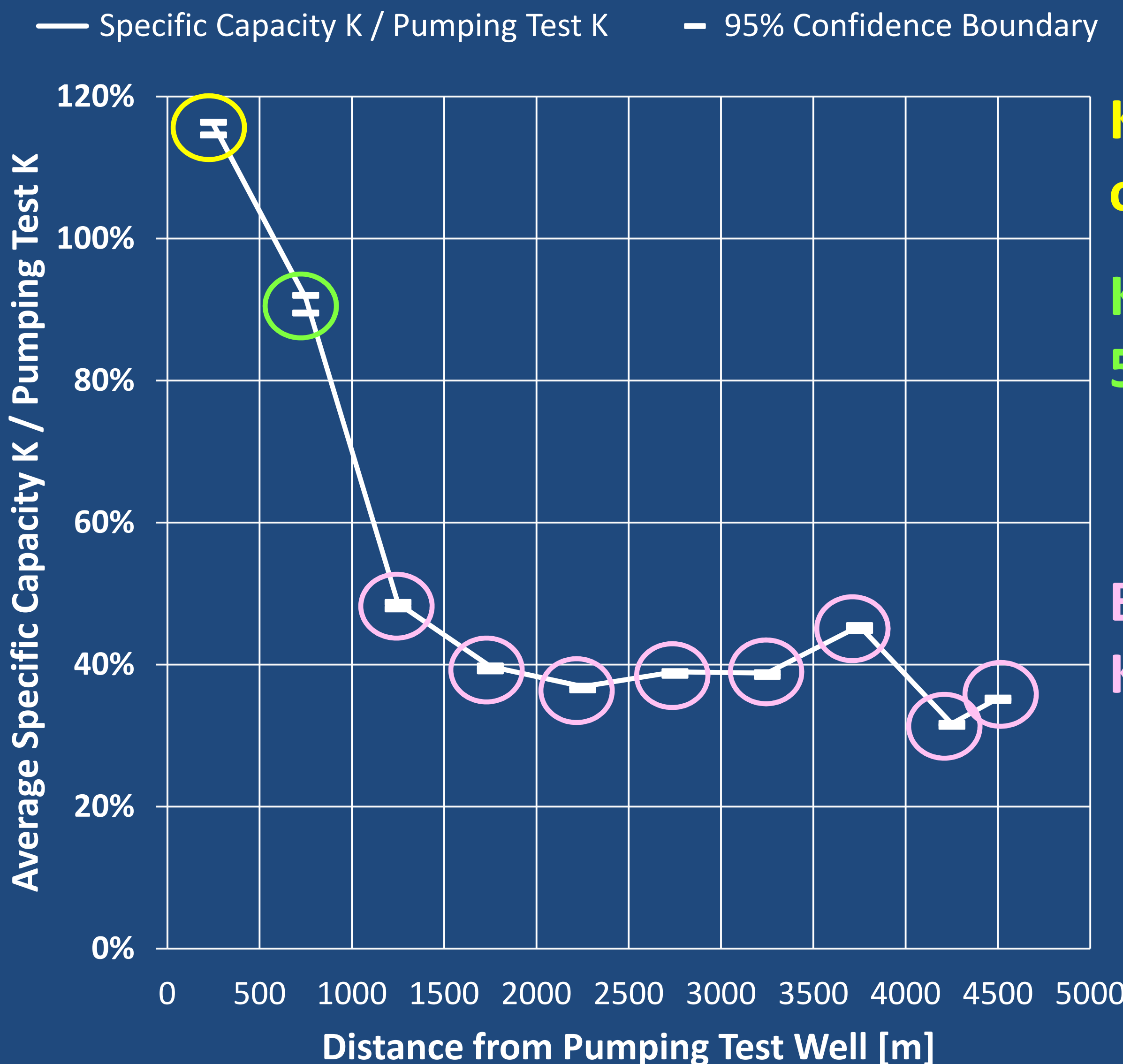
Normalize between pumping test wells:

$$\frac{\text{Specific Capacity K } (K_{sc})}{\text{Pumping Test K } (K_{pt})}$$

Excluding the K_{sc} of the Pumping Test Well

From (ft.)	To (ft.)	Mean K_{sp}/K_{pt}
0	500	116%
500	1000	92%
1000	1500	49%
…….	…….	…….

Spatial Correlation of Pumping and Specific Capacity Tests



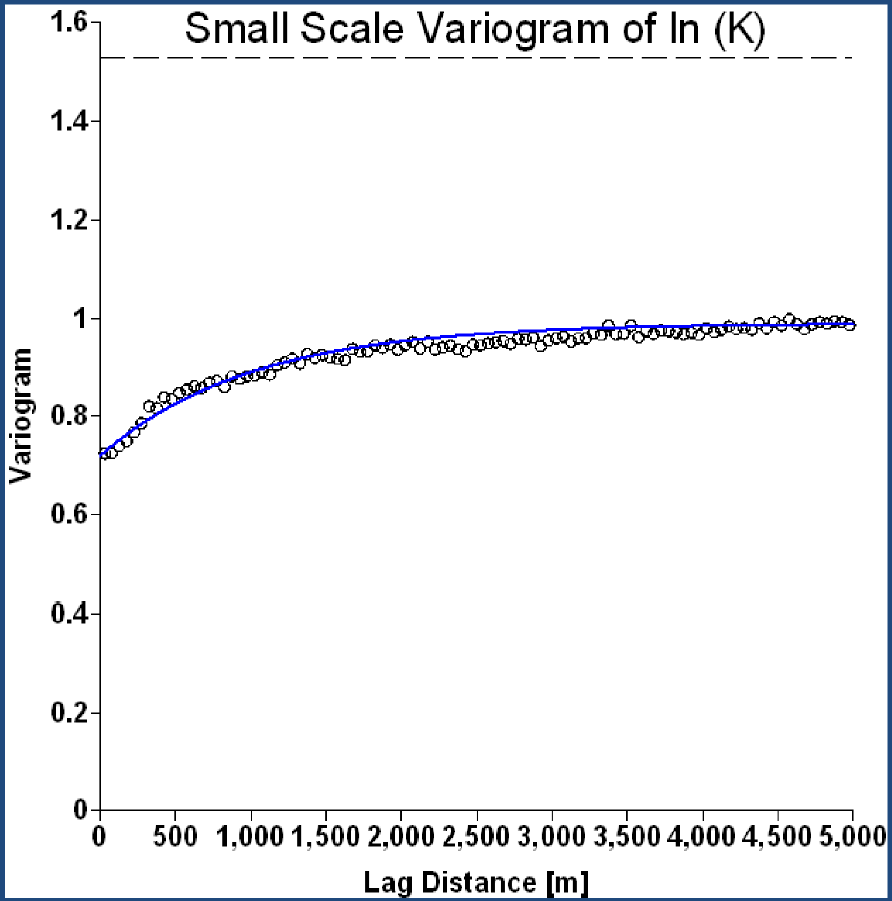
$K_{sp} > K_{pt}$ within 500 m. of pumping test wells

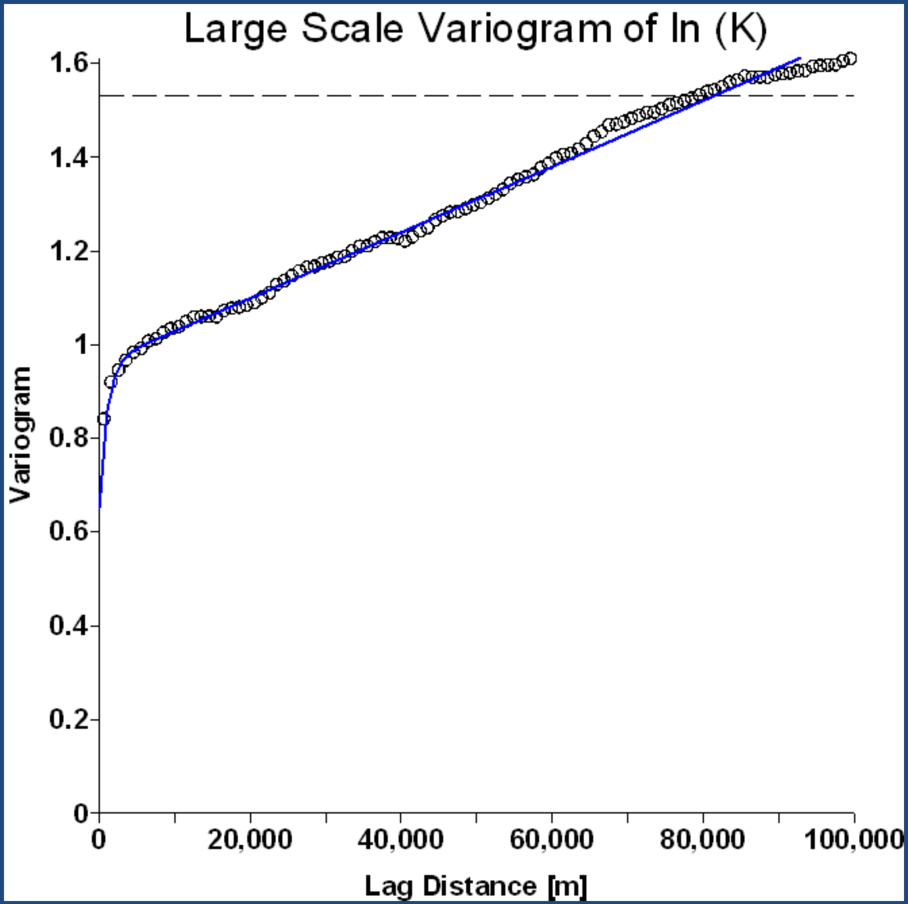
$K_{sp} / K_{pt} \approx 90\%$ between 500 and 1000 m.

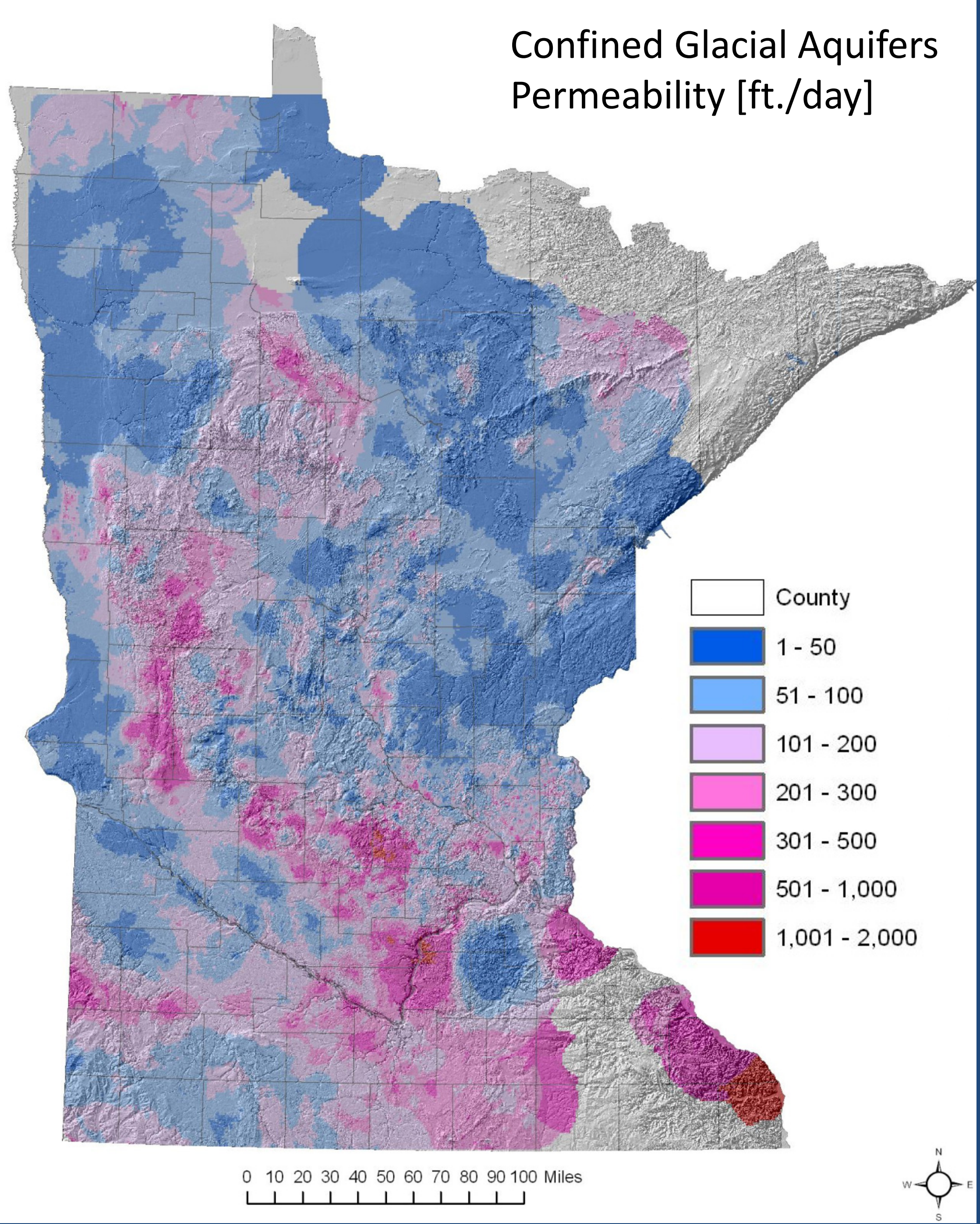
Beyond 1000 m $K_{sp} / K_{p} \approx 35$ to 45 %.

Spatial Correlation of Specific Capacity Tests

Source of Variability	Amount
Noise	41%
Small Scale Spatial Variability	20%
Large Scale Spatial Variability	39%







Confined Glacial Aquifers
Permeability [ft./day]
County
1 - 50
51 - 100
101 - 200
201 - 300
301 - 500
501 - 1,000
1,001 - 2,000
0 10 20 30 40 50 60 70 80 90 100 Miles
N
W
E
S

Conclusions for Confined Glacial Aquifers

- A pumping test is more valuable than a specific capacity test.
- Specific capacity K values are consistent with pumping test K values.
- Specific capacity K values are “noisy”.
- Hydraulic conductivity is spatially related.
  - Change exponentially over a few kilometers.
  - Change linearly over hundreds of kilometers.
- Pumping tests in this data set are located in higher hydraulic conductivity zones.