Estimating Formation Hyd. Cond. (K) from HPT Q/P Ratios

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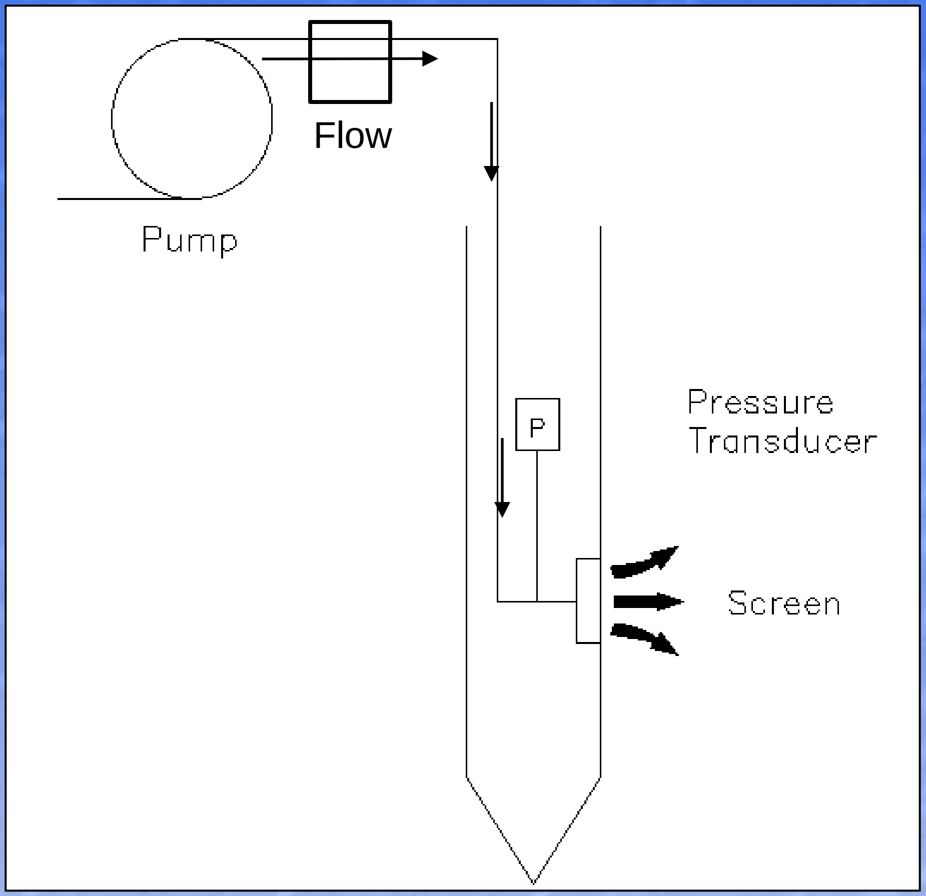
Geoprobe Systems

What is HPT ?
Hydraulic Profiling Tool

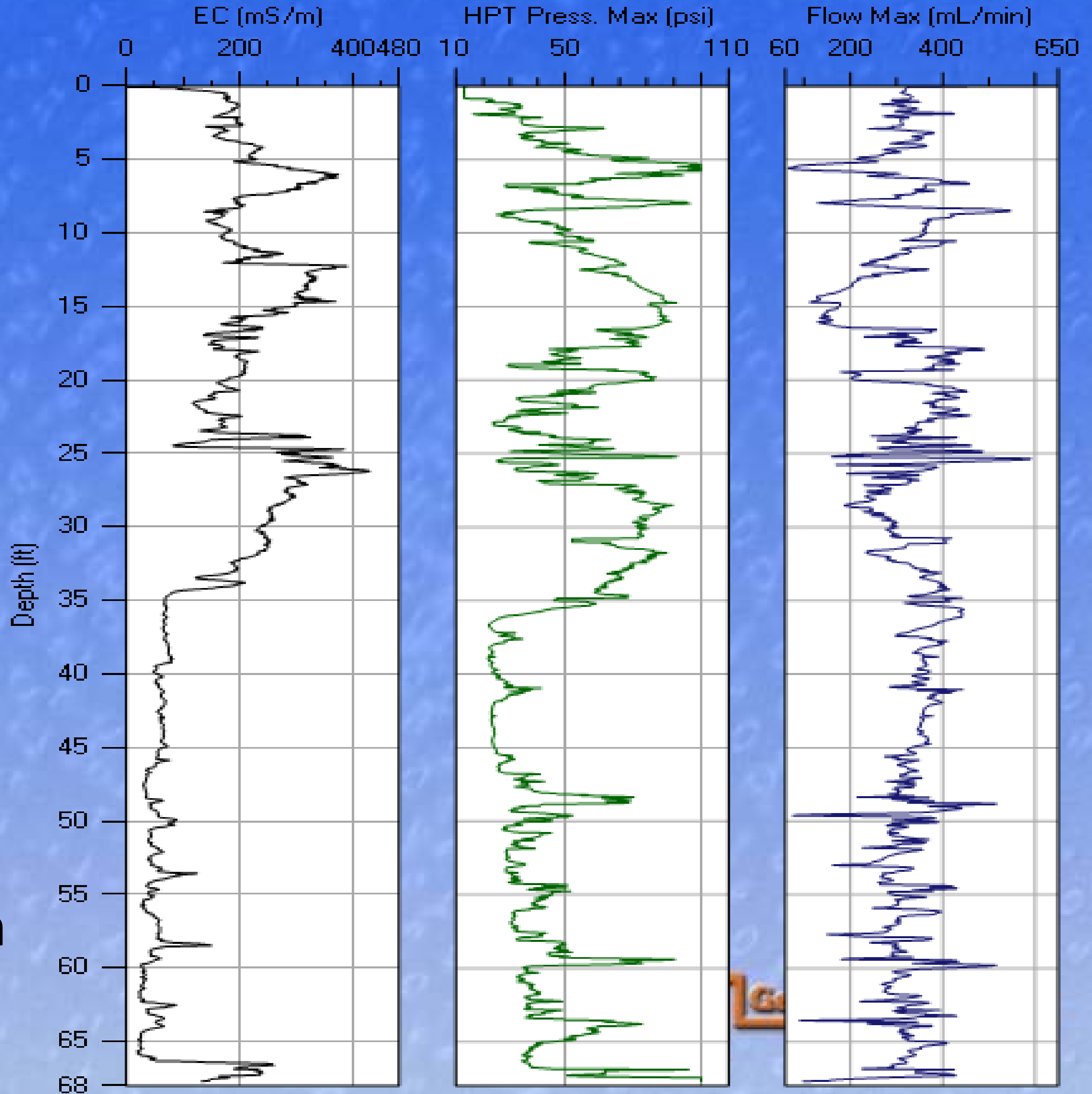


K ~ Q/P or K~1/P, where Q is constant.

Running an HPT log with CPT6625 Probe Unit in Clarks, NE, US

Example HPT Log Cottonwood Area

Problem Statement: We can visually interpret k from HPT Logs. Can we numerically estimate k from these logs?



Background Work
Estimation of k from CPTu data.

Estimating coefficient of consolidation from piezocone tests

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Data have been reviewed from sites in Europe and North and South America as well as published data from South Africa. The review has concentrated on dissipation data from piezocone tests (CPTU) to compare predicted coefficient of consolidation and permeability values using published interpretation techniques with available reference values. The results of this review have shown that the theoretical solutions provide reasonable estimates of the *in situ* coefficient of consolidation. Results were evaluated for pore-pressure data from different locations on the piezocone, and the least scatter in results was obtained with the pore-pressure element location immediately above the cone tip. A new correlation has been proposed to estimate *in situ* horizontal coefficient of permeability (k_h) from piezocone dissipation data.

Key words: *in situ*, coefficient consolidation, cone penetration test, permeability.

L'on a passé en revue des données provenant de sites en Europe et en Amérique du Nord et du Sud, de même que des données publiées en Afrique du Sud. L'on s'est arrêté particulièrement aux données de dissipation des essais de

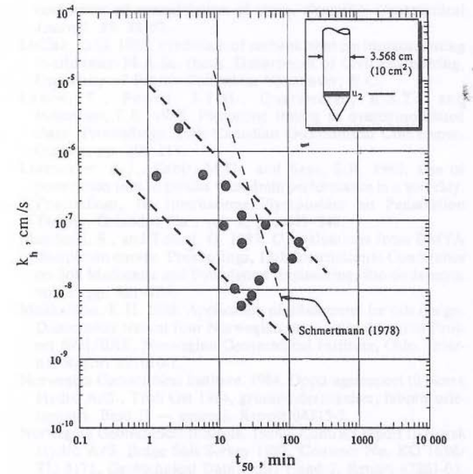


FIG. 10. Average values for laboratory-derived horizontal coefficient of permeability (k_h) and CPTU t_{50} for u_2 pore-pressure location.

estimate of the *in situ* horizontal coefficient of consolidation (c_h).

(2) The most consistent results showing the least scatter were obtained with the pore-pressure element location immediately above the cone tip (u_2).

(3) The expected reliability for estimating c_h for the u_2 position is about plus or minus one-half an order of magnitude, whereas for the u_1 position this increases to a full one order of magnitude. These magnitudes of expected reliability are consistent with previous published experience for the determination of c_h or c_v.

A tentative correlation between the rate of dissipation (t_{50}) and horizontal coefficient of permeability (k_h) has also been proposed, although considerable scatter exists in the data.

The application of these correlations requires that the CPTU must be performed with fully saturated pore-pressure elements. Although data from many sites have been compiled and reviewed, there is a need for continued research.

More Background Work …

ground water

Methods Note/

A Rapid Method for Hydraulic Profiling in Unconsolidated Formations

by Peter Dietrich[1], James J. Butler Jr.[2], and Klaus Faiß[3]

Abstract

Information on vertical variations in hydraulic conductivity (K) can often shed much light on how a contaminant will move in the subsurface. The direct-push injection logger has been developed to rapidly obtain such information in shallow unconsolidated settings. This small-diameter tool consists of a short screen located just behind a drive point. The tool is advanced into the subsurface while water is injected through the screen to keep it clear. Upon reaching a depth at which information about K is desired, advancement ceases and the injection rate and pressure are measured on the land surface. The rate and pressure values are used in a ratio that serves as a proxy for K. A vertical profile of this ratio can be transformed into a K profile through regressions with K estimates determined using other techniques. The viability of the approach was assessed at an extensively studied field site in eastern Germany. The assessment demonstrated that this tool can rapidly identify zones that may serve as conduits for or barriers to contaminant movement.

Introduction

One of the major challenges facing investigators of sites of ground water contamination is how to assess the threat posed by the contamination. Without reliable means to perform such assessments, it is difficult to effectively use resources for remediation activities...

This method requires a well that is screened across the units of interest. At many sites, such wells are not common because of regulatory concerns about vertical movement of contaminants within the screened interval. In shallow (less than 30 m) unconsolidated settings, direct-

K_{DPIL} ratios from both profiles. Although only four slug test K estimates were available, the K range spanned by those values and the large R^2 (0.958) indicate the possibility of a strong correlation between the K_{DPIL} ratio and K (Figure 4). The regression equation was therefore used to transform the K_{DPIL} ratios into K estimates. Figure 5 compares the K values calculated with the regression to the K estimates obtained from both the DPP and slug

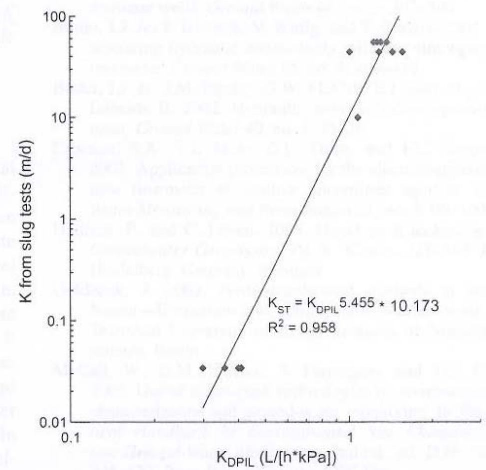
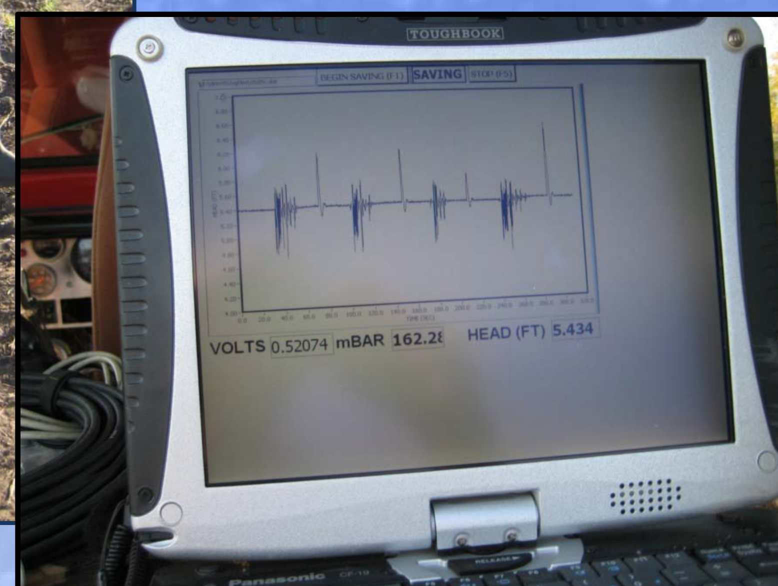


Figure 4. Regression analysis of K_{DPIL} ratio vs. K values from DP slug tests (K_{ST}). Four K_{DPIL} values are available for each depth at which a slug test was performed.

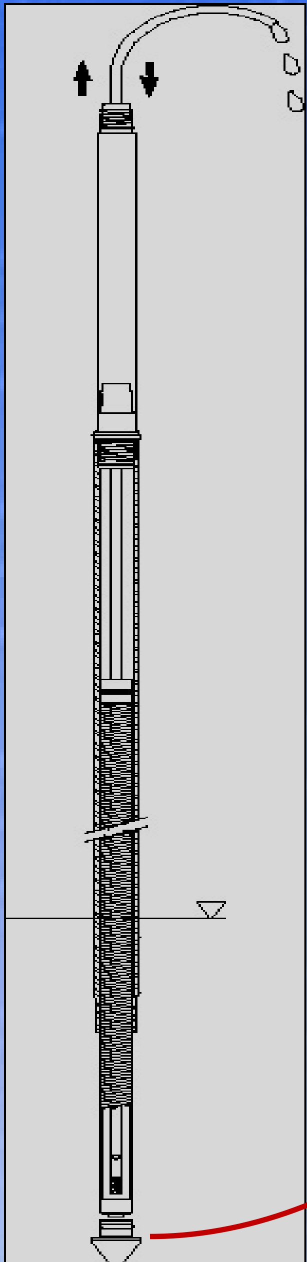
Dietrich et al, 2008

Method Employed: Compare HPT Q/P to offset Slug Tests.



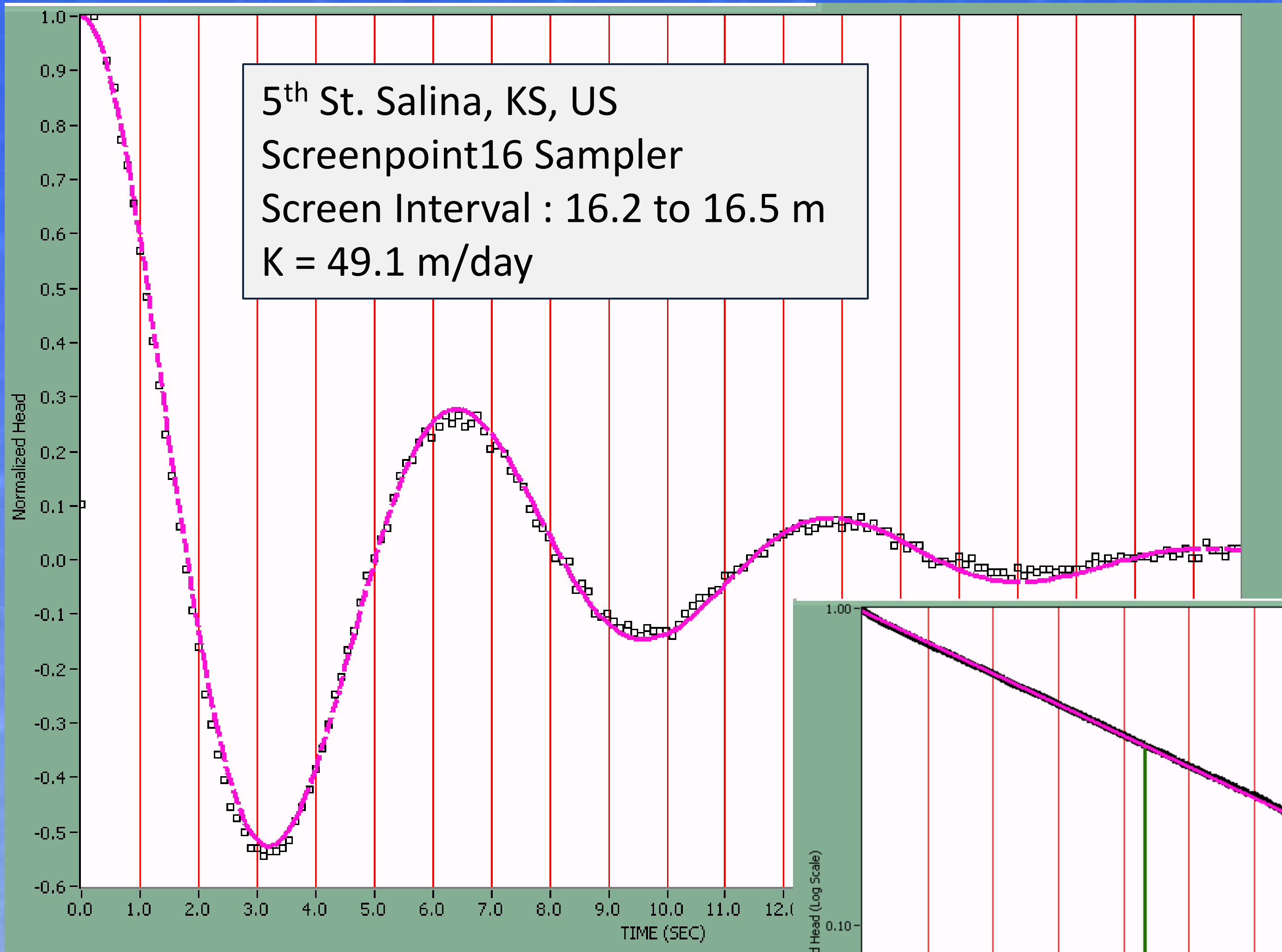
Wichita, KS Site

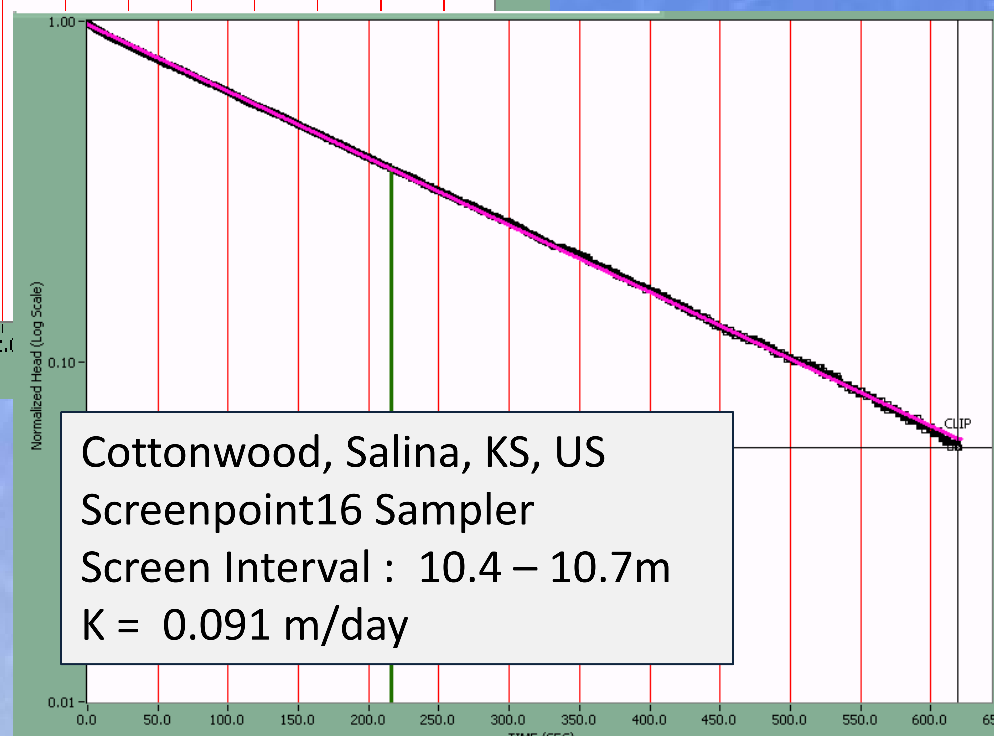
SP Groundwater Samplers and DP Wells



Development Required !

Slug Test Modeling





Under damped and over damped responses

Algorithm for Calculating Q/P Ratio

Raw HPT Flow Max data for each depth increment provides Q input

Raw HPT Pressure Max Data (Pm) is corrected to calculate the corrected Pressure (P*) for each depth increment

P* = Pm – (atmospheric pressure) – (hydrostatic pressure)

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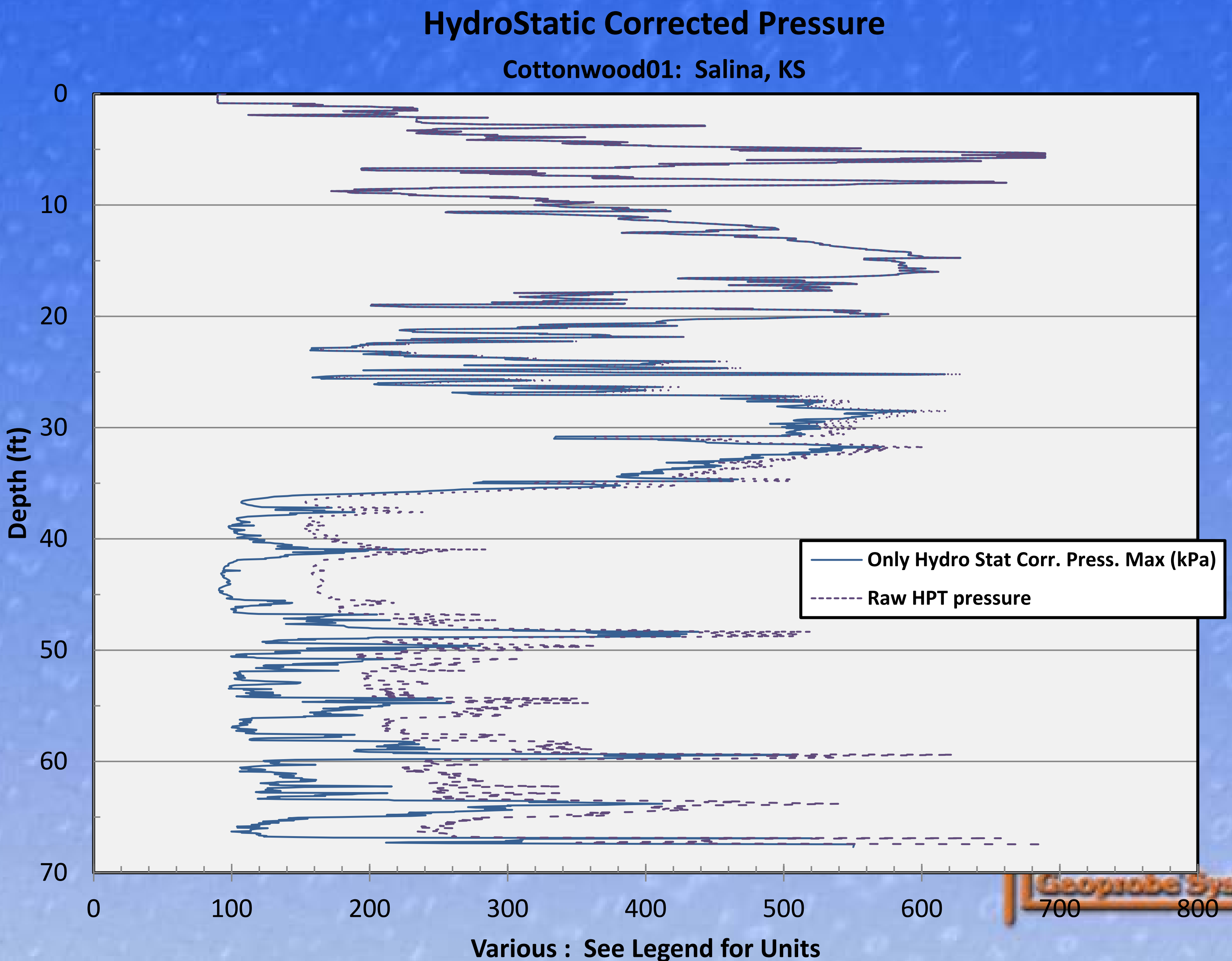
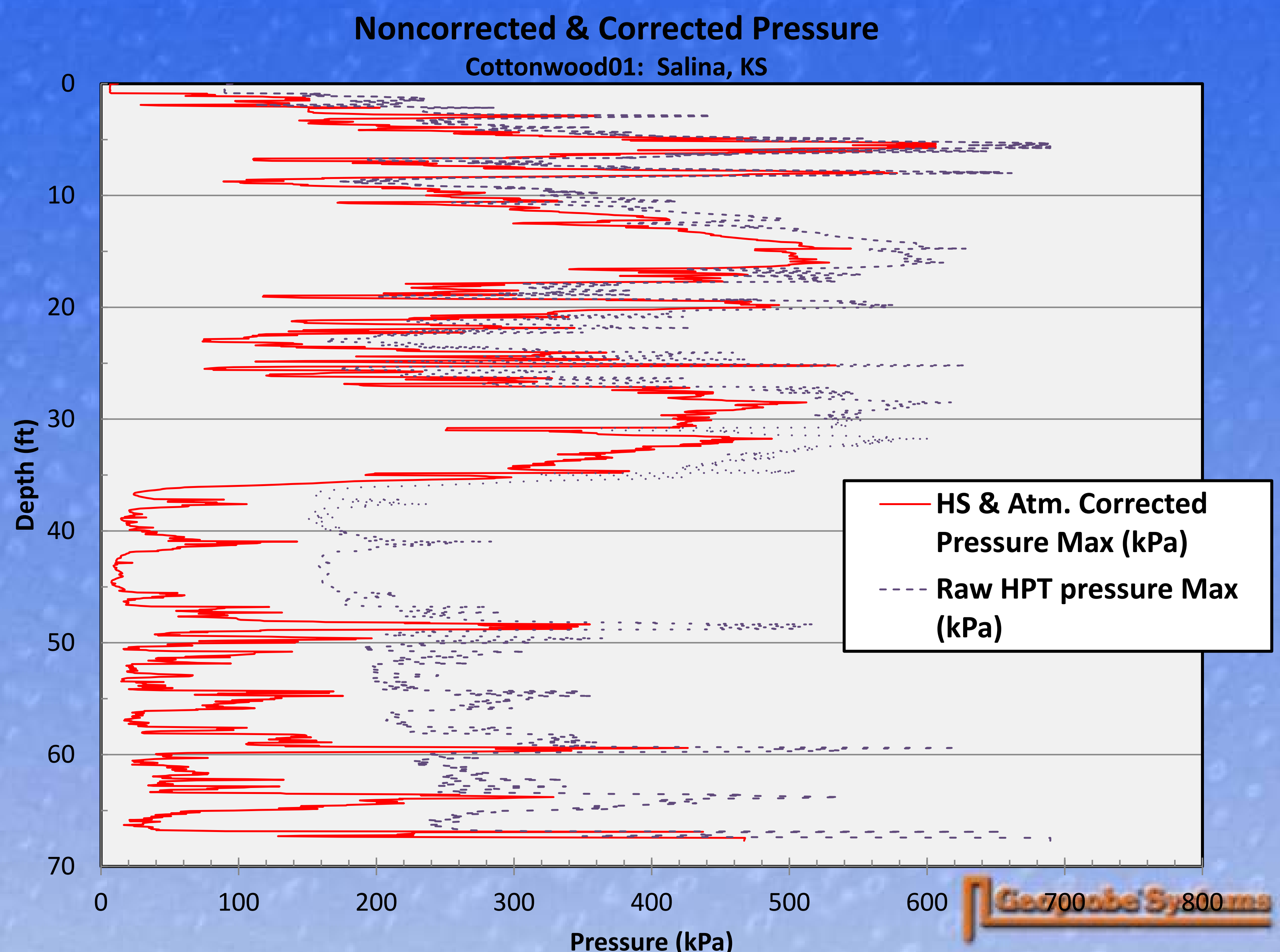


HydroStatic Corrected Pressure
Cottonwood01: Salina, KS
Depth (ft)
0
10
20
30
40
50
60
70
0
100
200
300
400
500
600
700
800
Various : See Legend for Units
Only Hydro Stat Corr. Press. Max (kPa)
Raw HPT pressure



Noncorrected & Corrected Pressure
Cottonwood01: Salina, KS
Depth (ft)
0
10
20
30
40
50
60
70
Pressure (kPa)
0
100
200
300
400
500
600
700
800
HS & Atm. Corrected Pressure Max (kPa)
Raw HPT pressure Max (kPa)
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Determining Q/P Ratio Across a Slug Tested Interval

For Example: slug tested over 13.00– 13.30 meter Interval

Depth (feet)	Q (ml/min)	P* kPa	**Q/P** (ml/[min*kPa])
13.000	300	150	2.0
13.015	320	160	2.0
13.030	280	140	2.0
13.045	360	120	3.0
13.060	etc.	etc.	Etc.
13.075	.	.	.
Etc.	.	.	.
.	.	.	.
.	.	.	.
13.300	280	140	2.0

Average Q/P = (Sum of Q/P)/N

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Multiple Field Sites with Paired Data

Site Name	Date	Well Type	Screen Interval
Salina 5th St	Winter 2006	SP15	30cm (+)
Monona, WI	Spring 2006	SP15	30cm (+)
Clarks, NE	Fall 2007	0.75” DP well	1.5m
Wichita, KS	Fall 2008	SP16	1.05m
Cottonwood (Salina, KS)	Feb. 2009	SP16	30cm (+)

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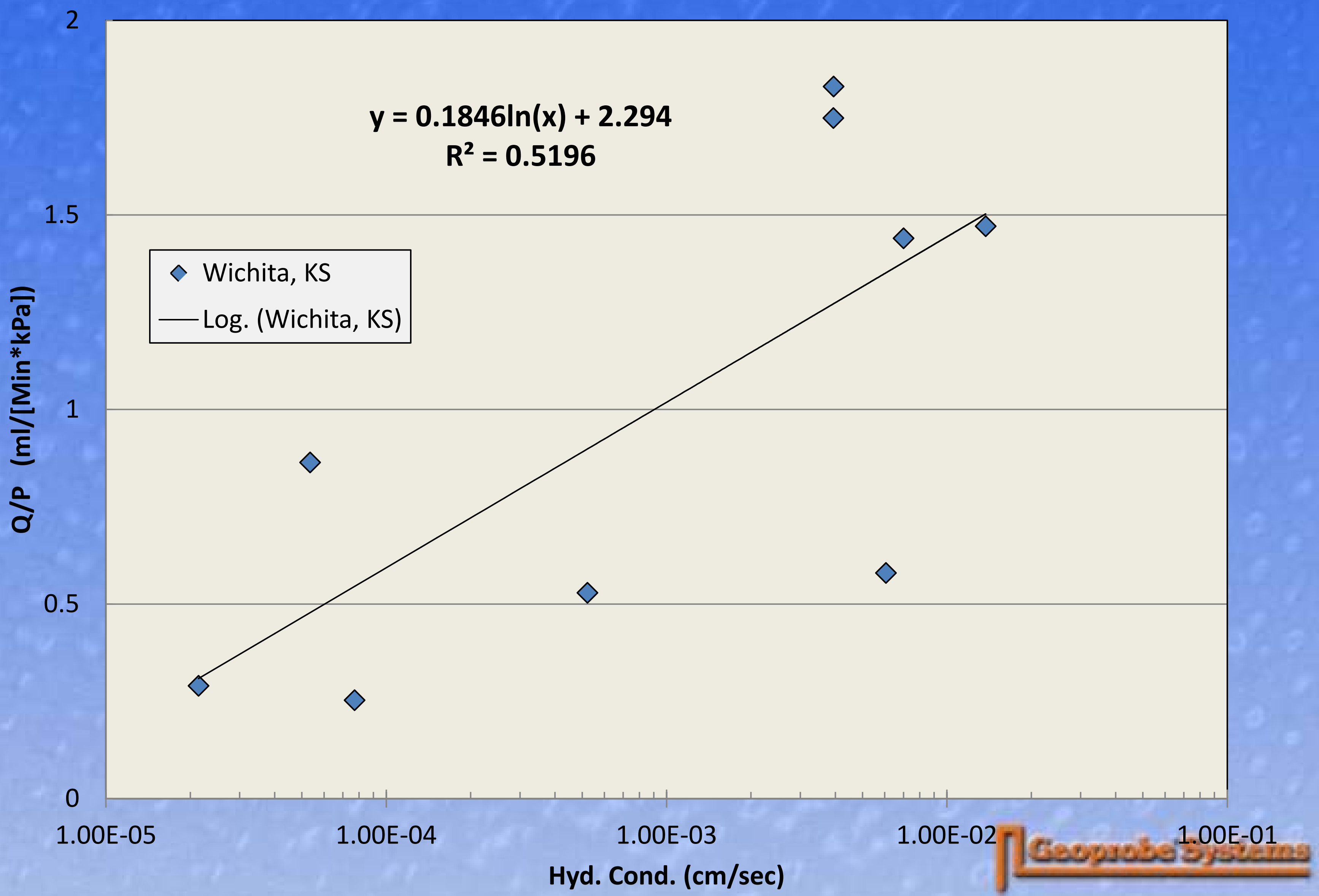
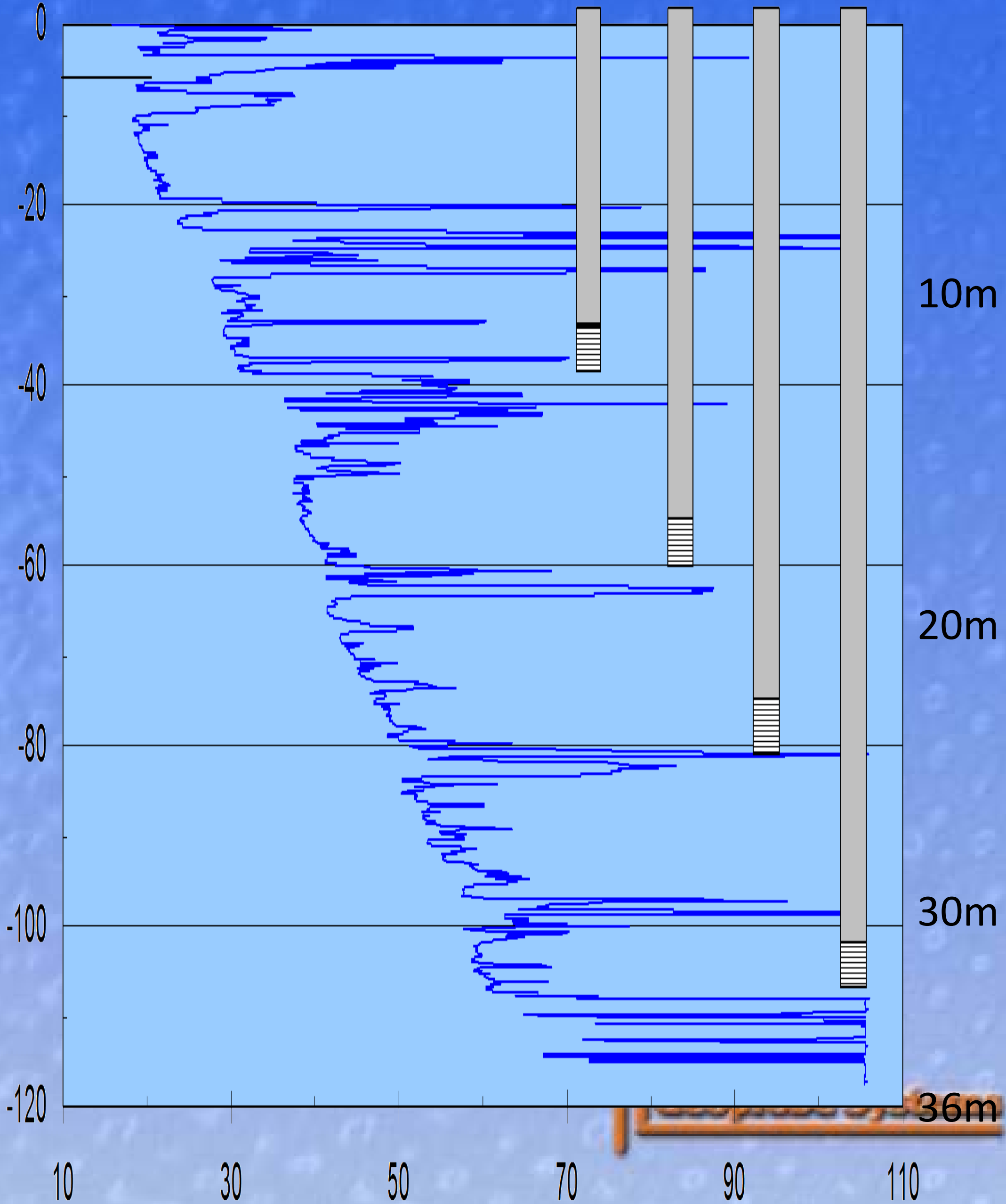
(+) At selected locations the screen was tested with 30cm, then 60cm and 90cm exposure.

Wichita HPT to K Comparison

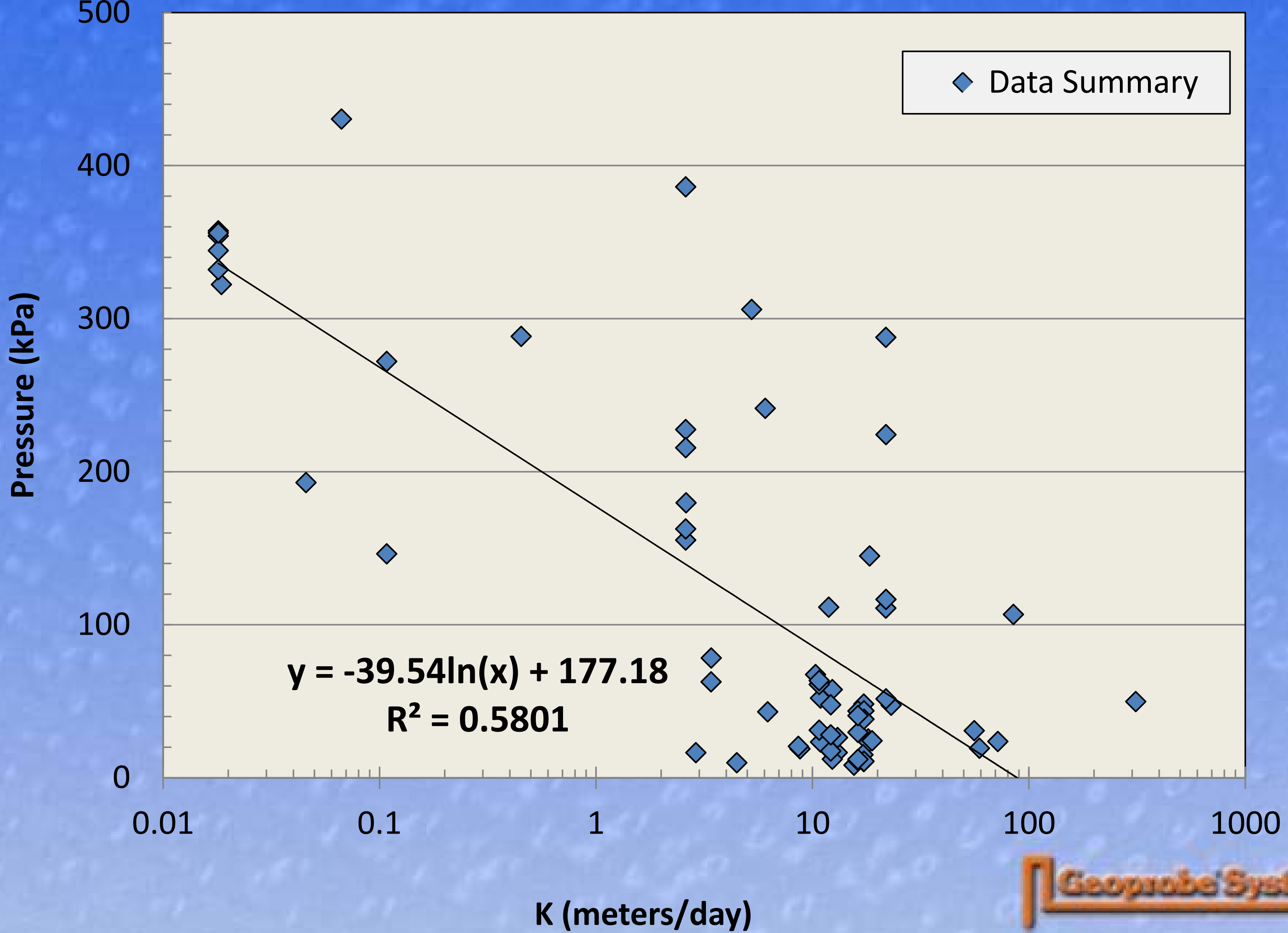


Clarks Field Site
A-Group Wells

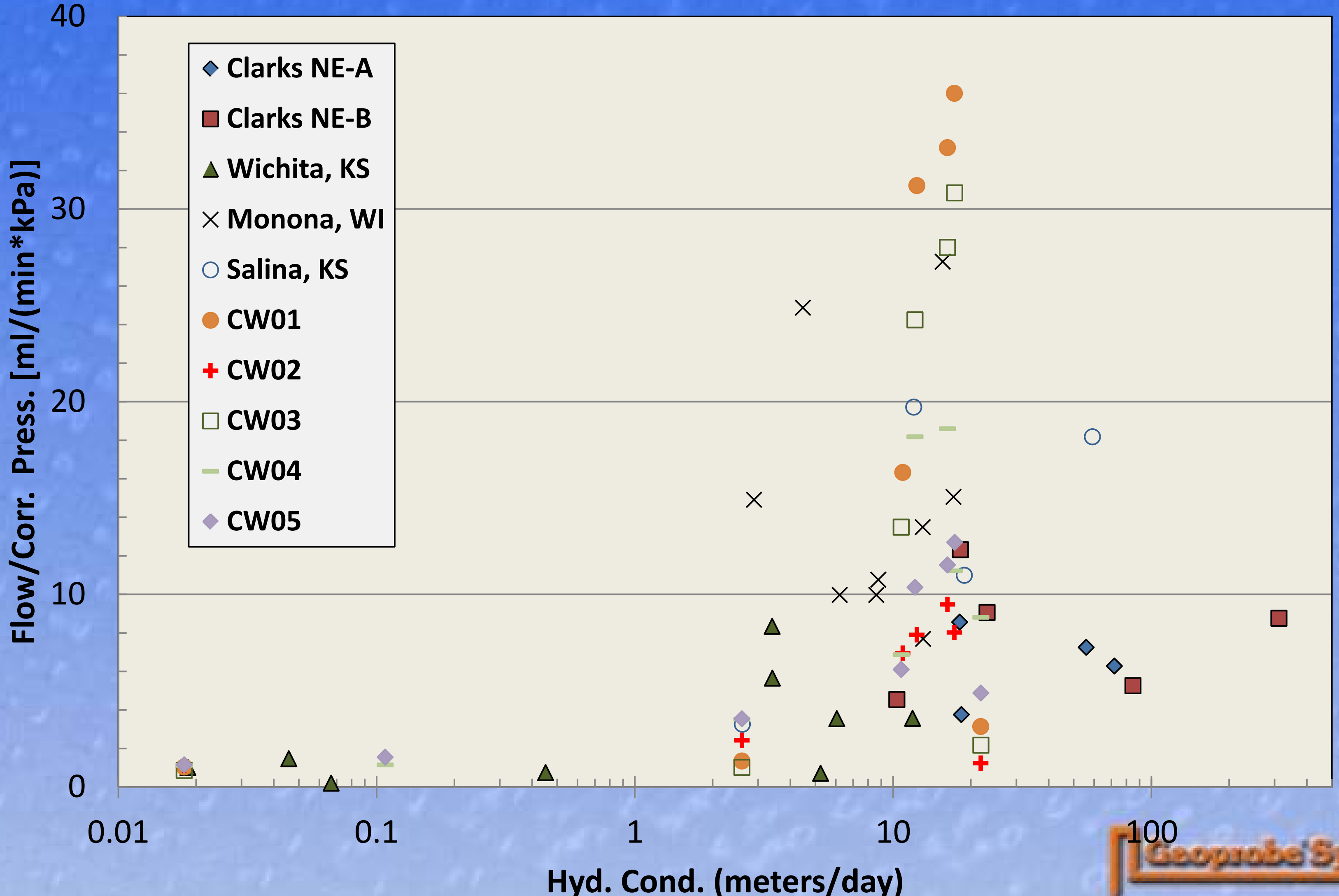


Well Spacing from log locations and formation variability

Multi-Site : P vs K



Multi-Site Data
Q/P vs Slug Test K



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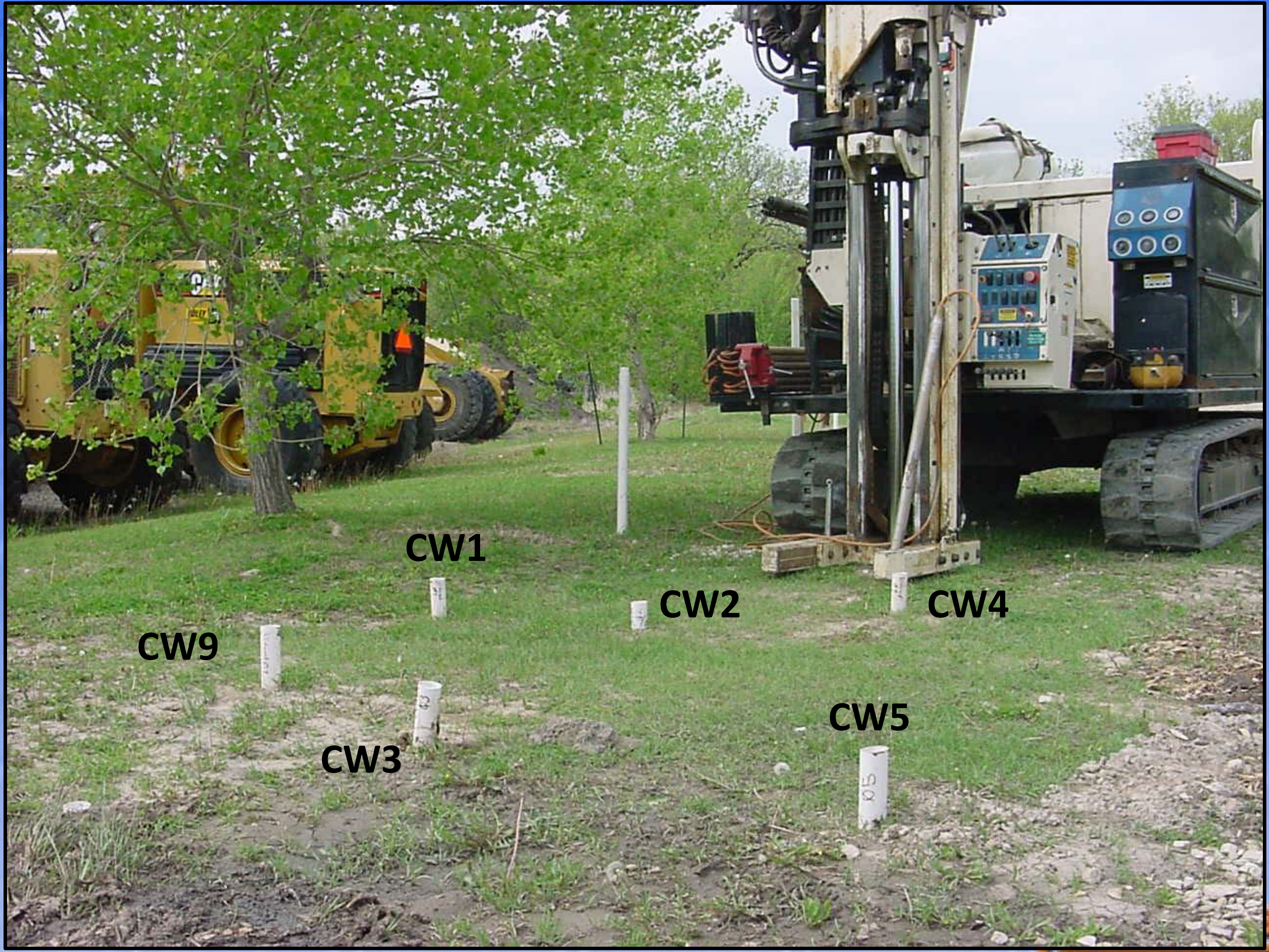
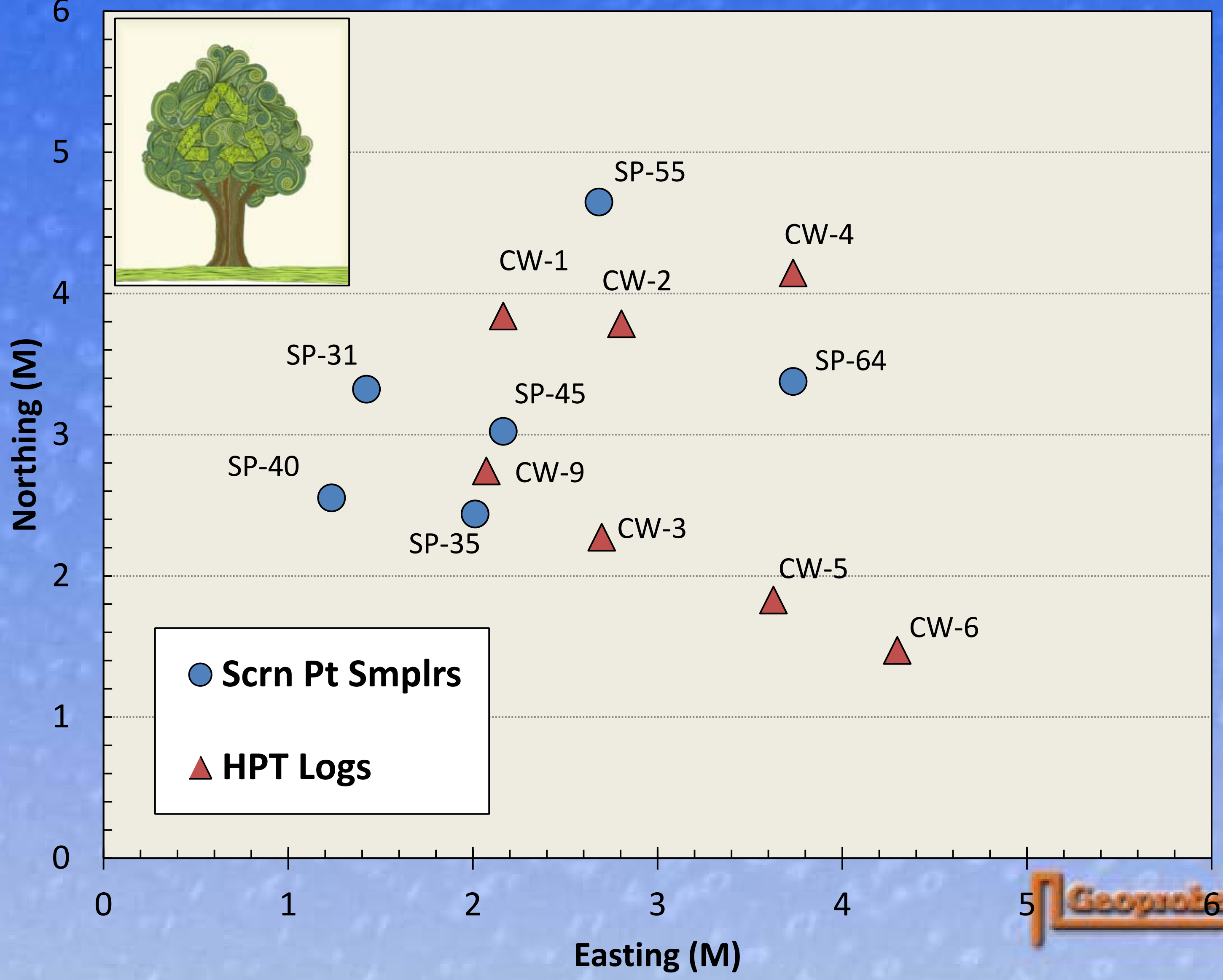
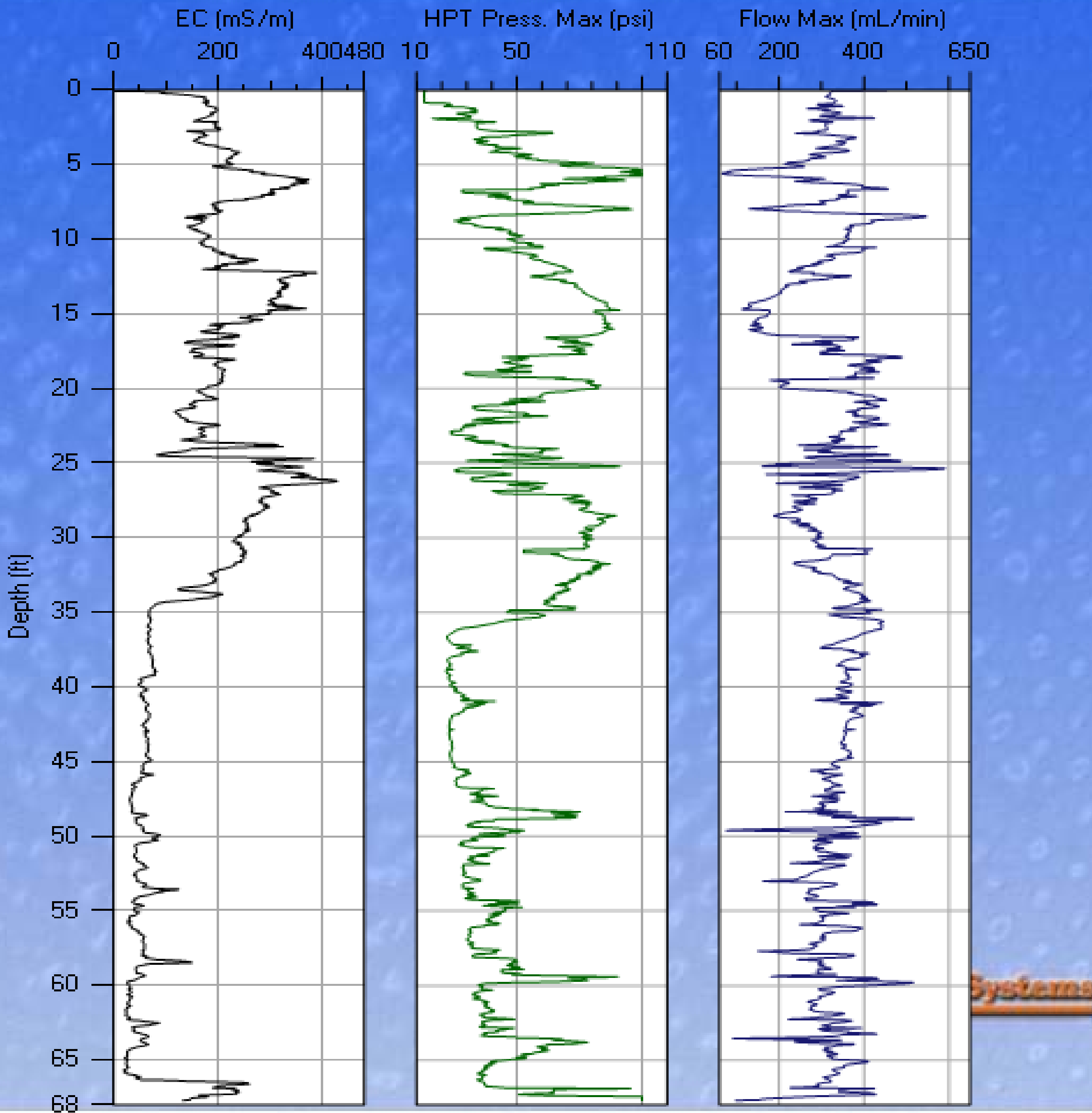
Cottonwood Area Used to Develop Basic Model



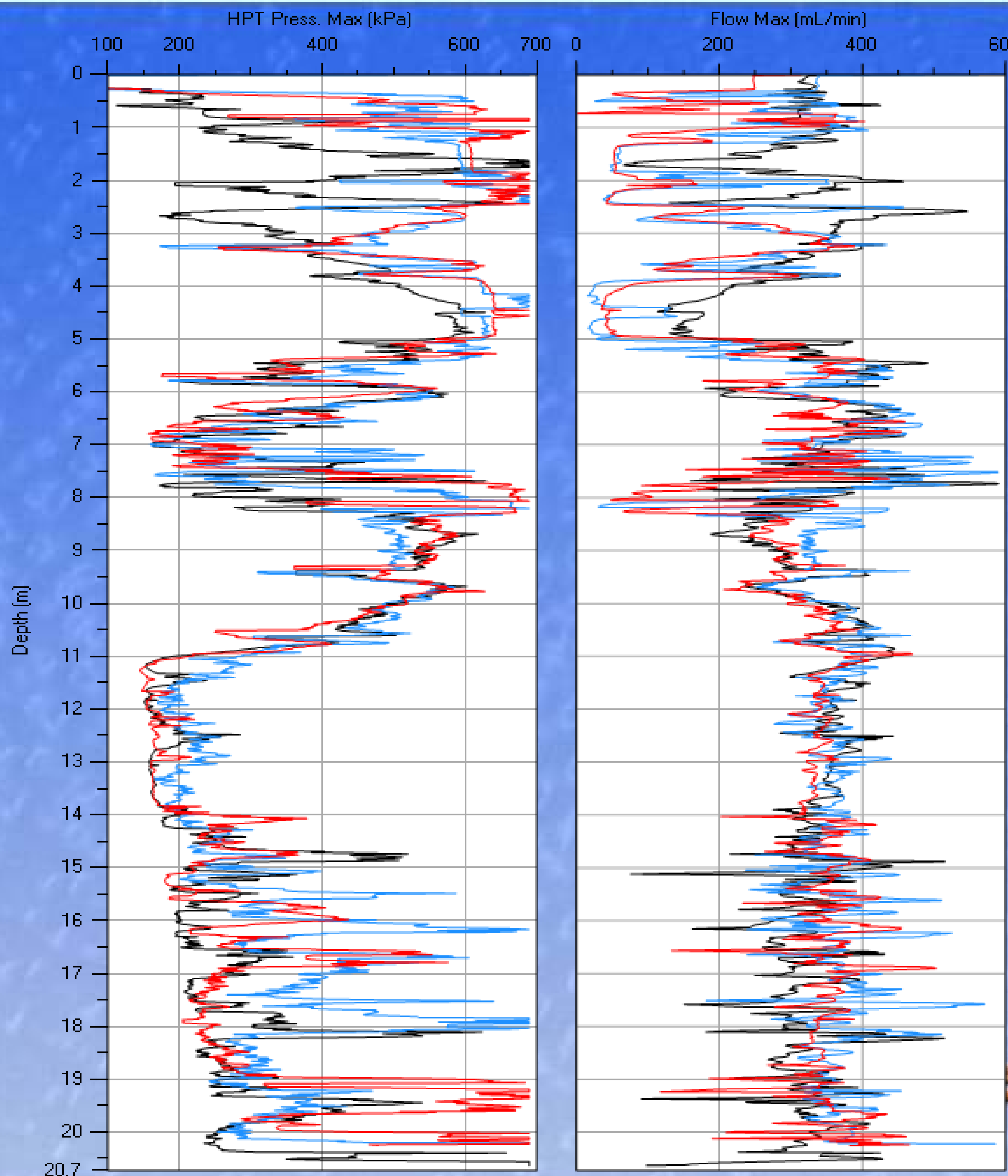
Cottonwood Area Sketch Map



Cottonwood HPT Log 1



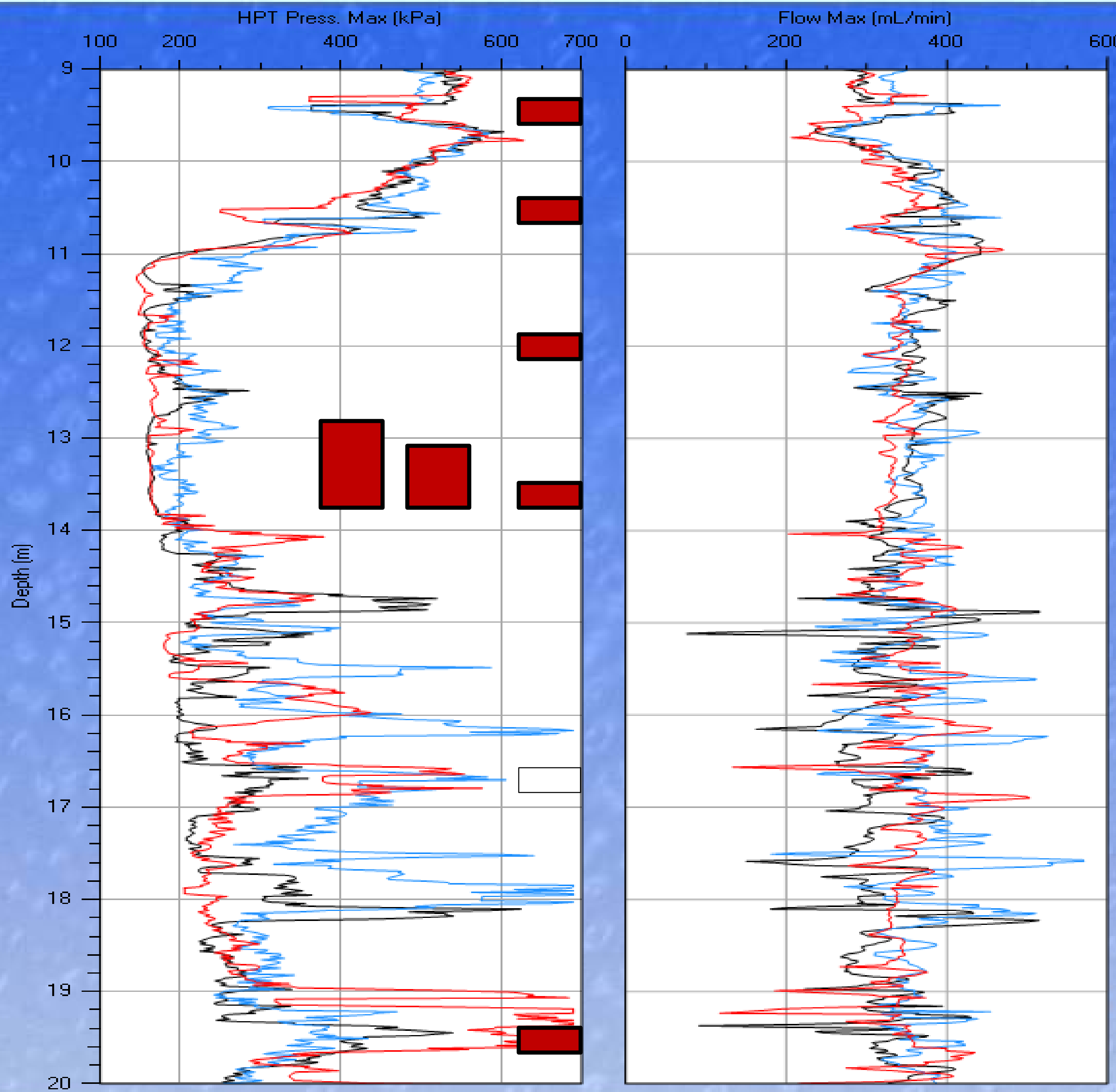
Cottonwood HPT Logs CW-1, 2 & 3

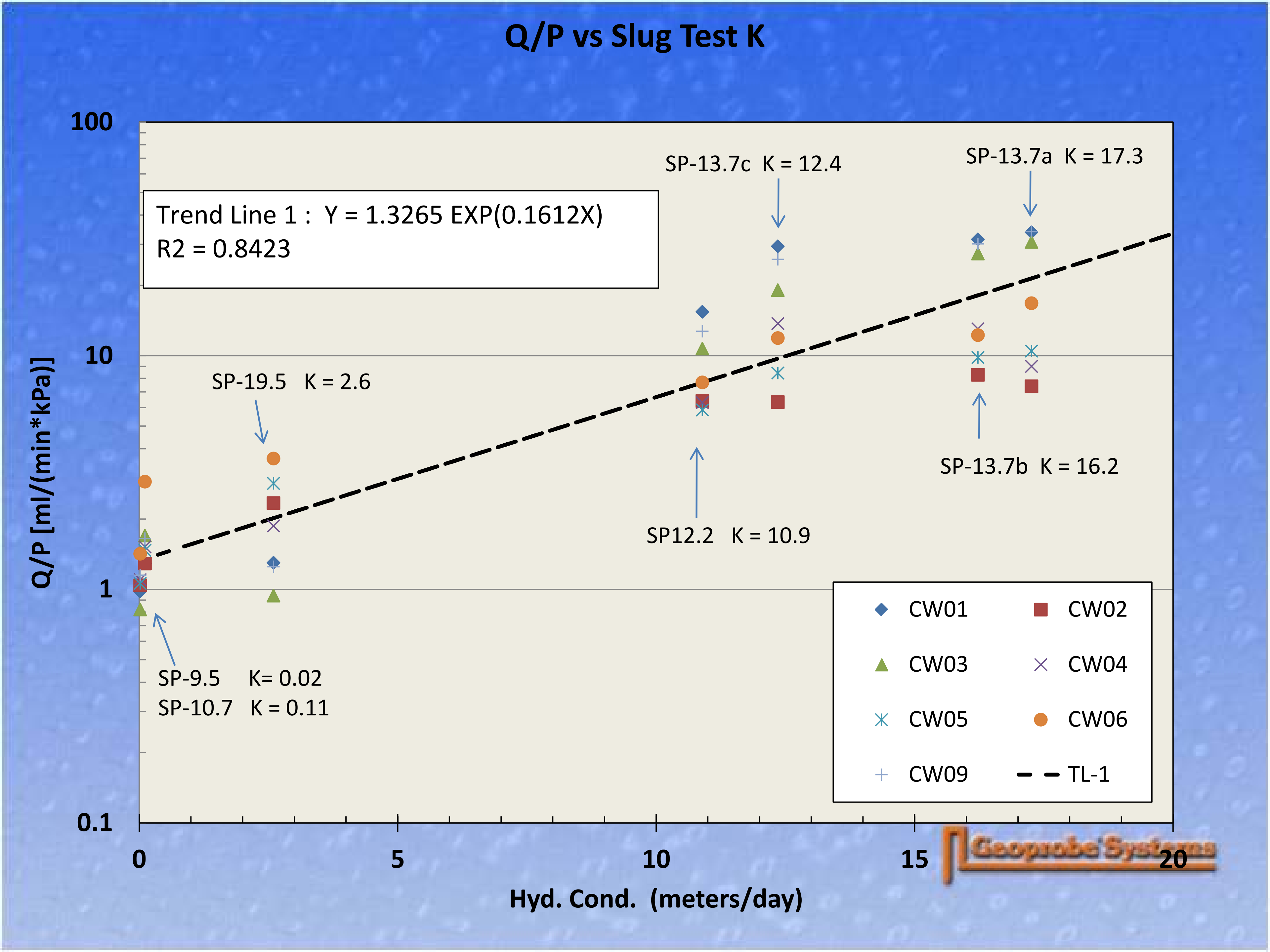


Small Scale vertical and lateral heterogeneity, especially in the lower aquifer materials (14 – 20m)

CW-1,2,3
9 – 20m

Screen Intervals Slug Tested





Q/P vs Slug Test K
Trend Line 1 : Y = 1.3265 EXP(0.1612X)
R2 = 0.8423
SP-13.7c K = 12.4
SP-13.7a K = 17.3
SP-19.5 K = 2.6
SP12.2 K = 10.9
SP-13.7b K = 16.2
SP-9.5 K= 0.02
SP-10.7 K = 0.11
100
10
1
0.1
0
5
10
15
20
Q/P [ml/(min*kPa)]
Hyd. Cond. (meters/day)
CW01
CW02
CW03
CW04
CW05
CW06
CW09
TL-1
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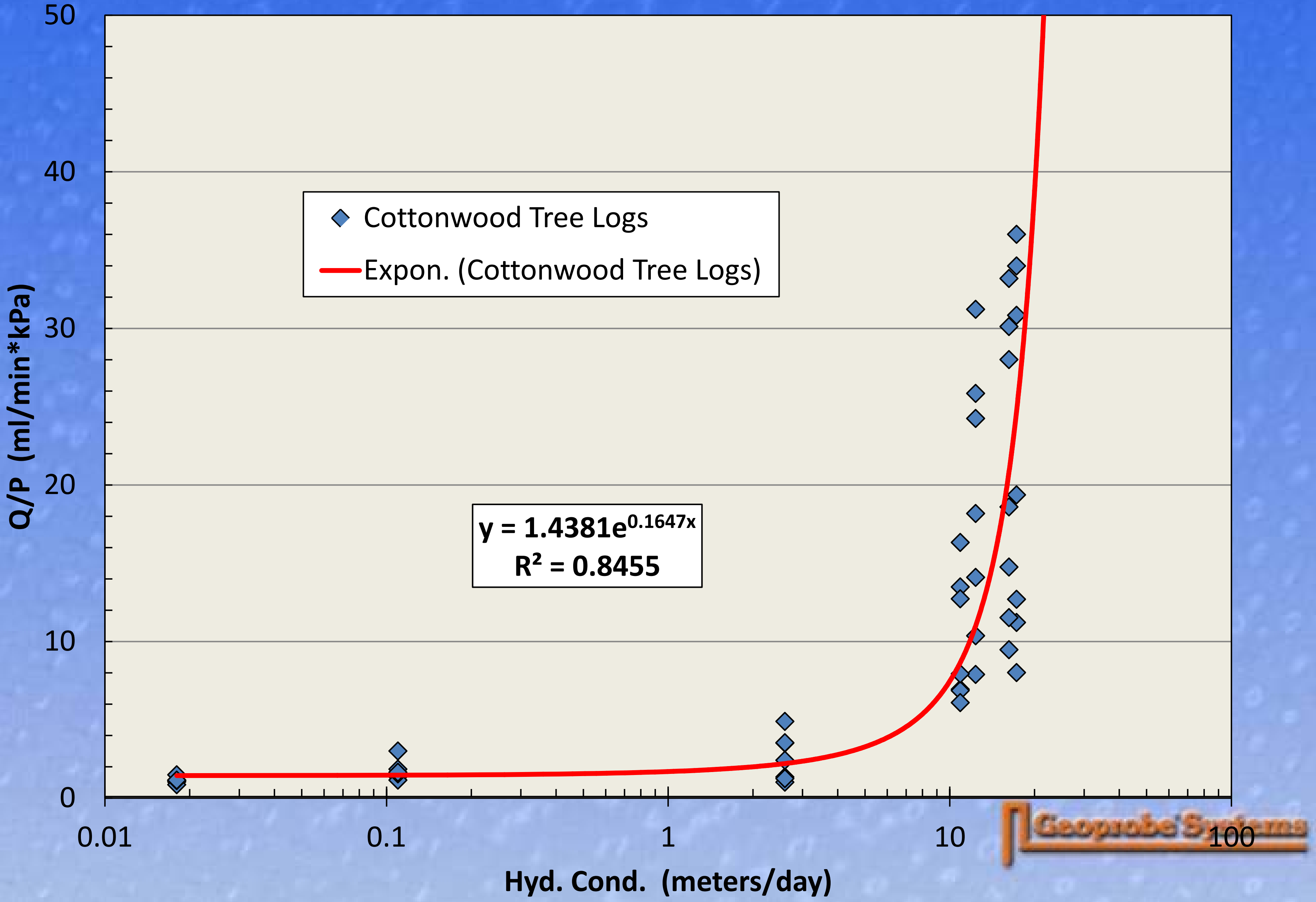
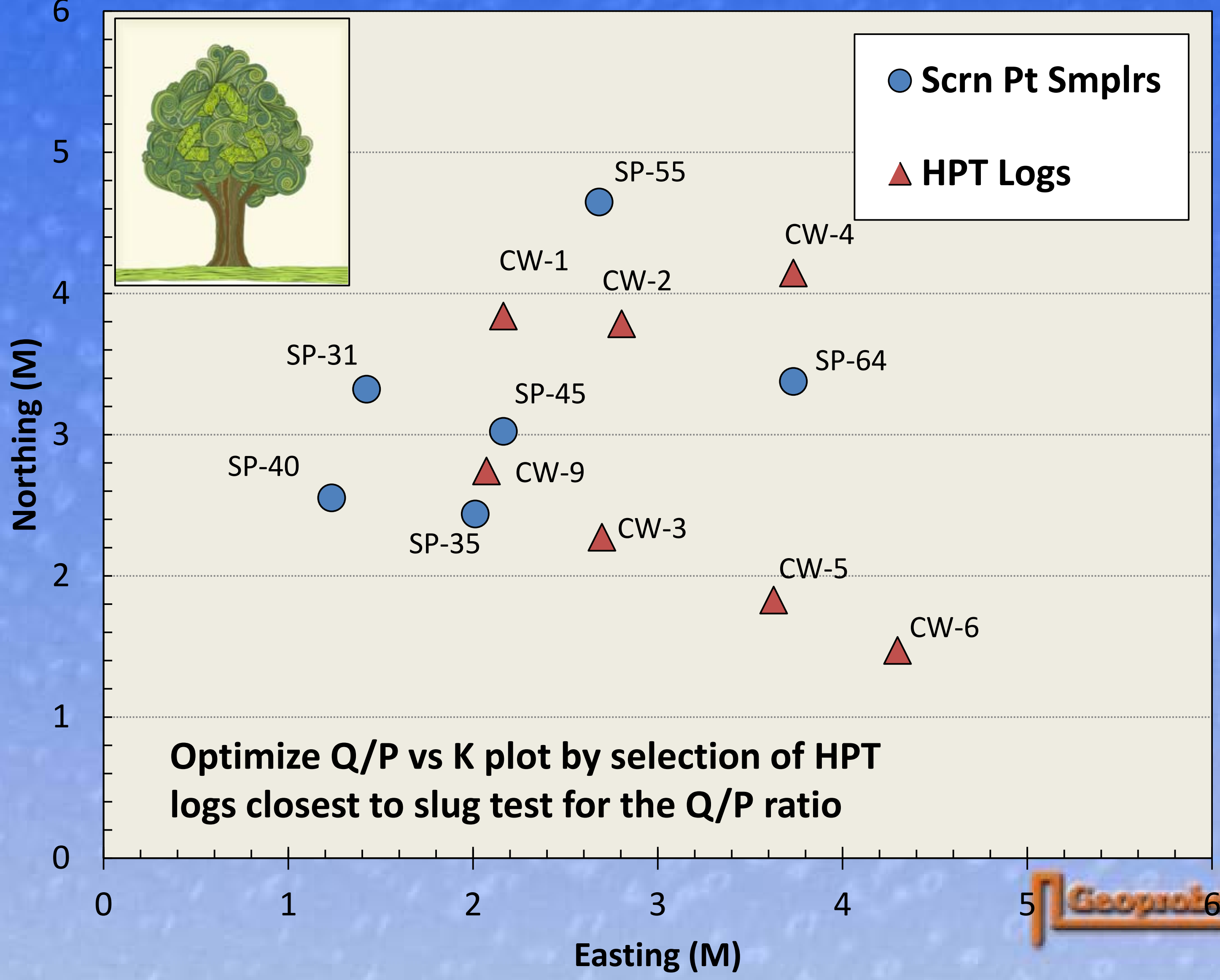
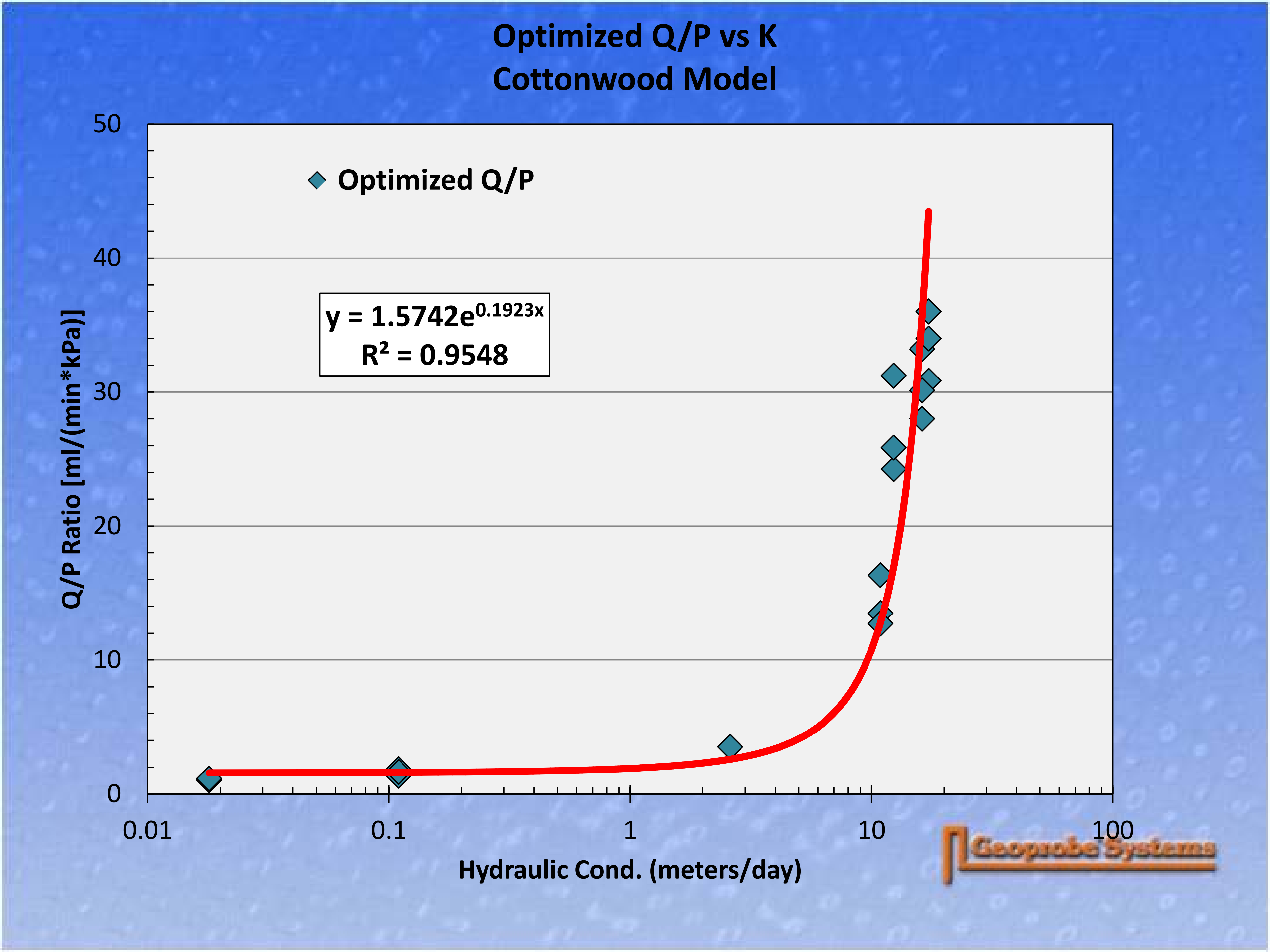
Q/P vs Slug Test K
Preliminary Cottonwood Model : All Logs



Cottonwood Area Sketch Map




Optimized Q/P vs K
Cottonwood Model
Optimized Q/P
y = 1.5742e^0.1923x
R² = 0.9548
Q/P Ratio [ml/(min*kPa)]
Hydraulic Cond. (meters/day)
0
10
20
30
40
50
0.01
0.1
1
10
100
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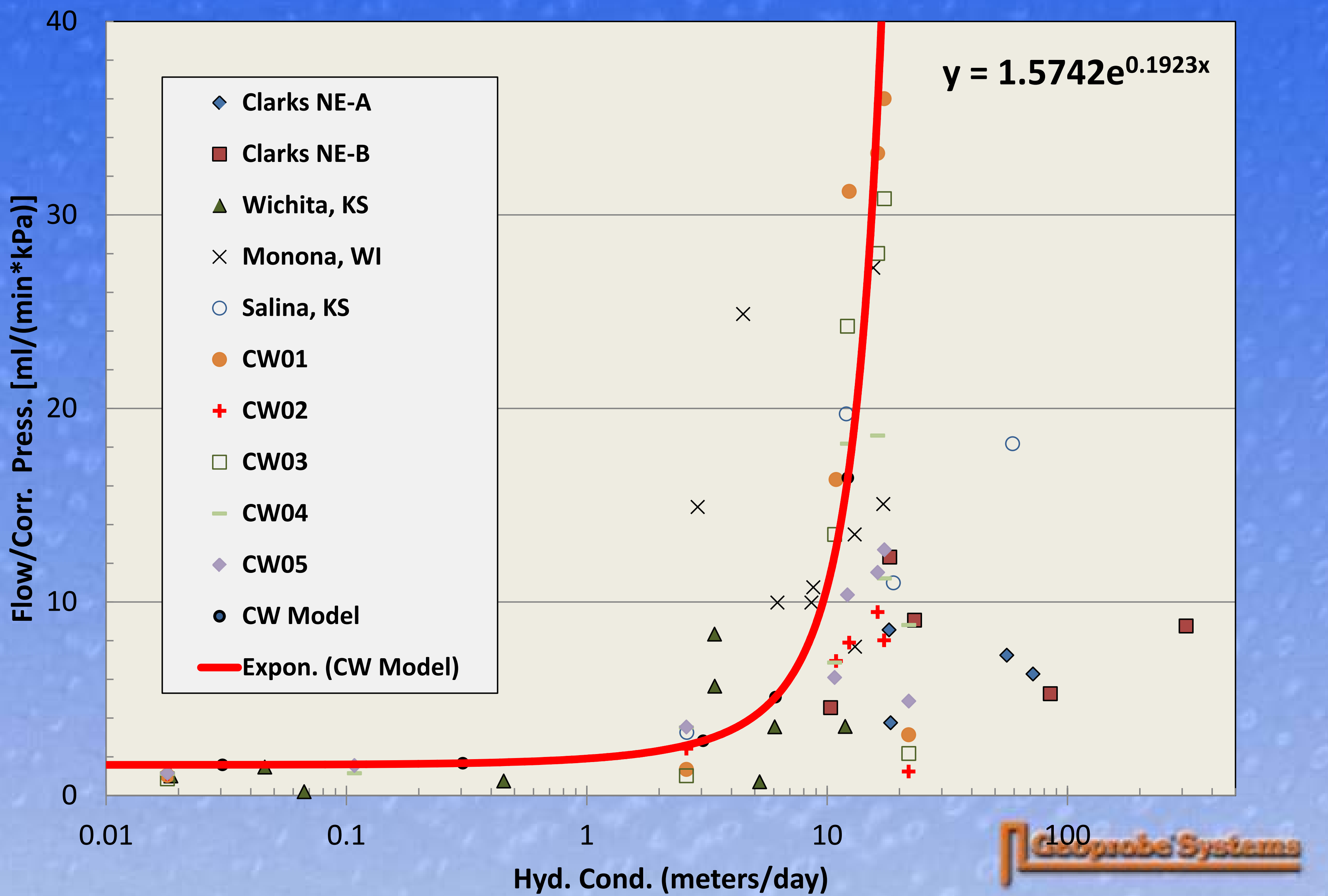
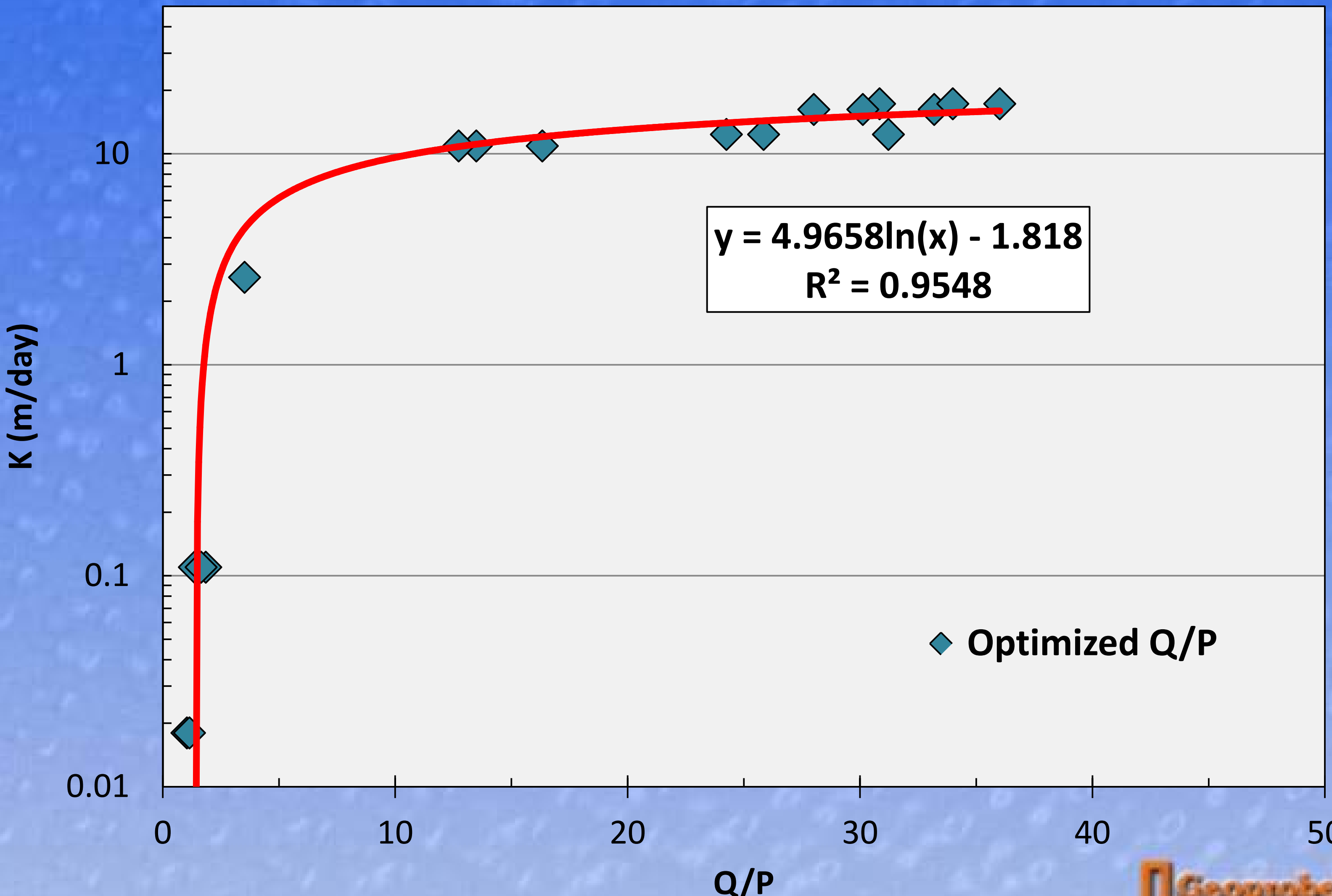
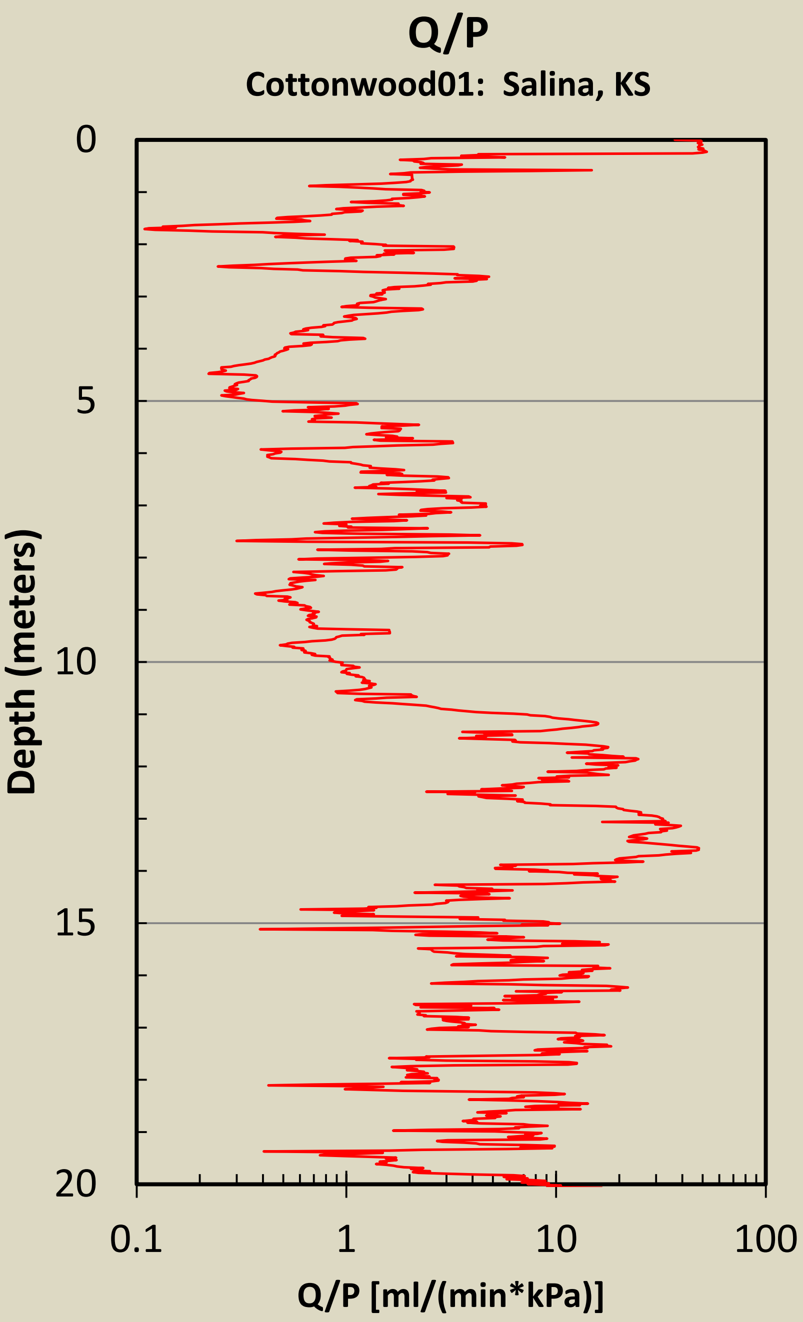
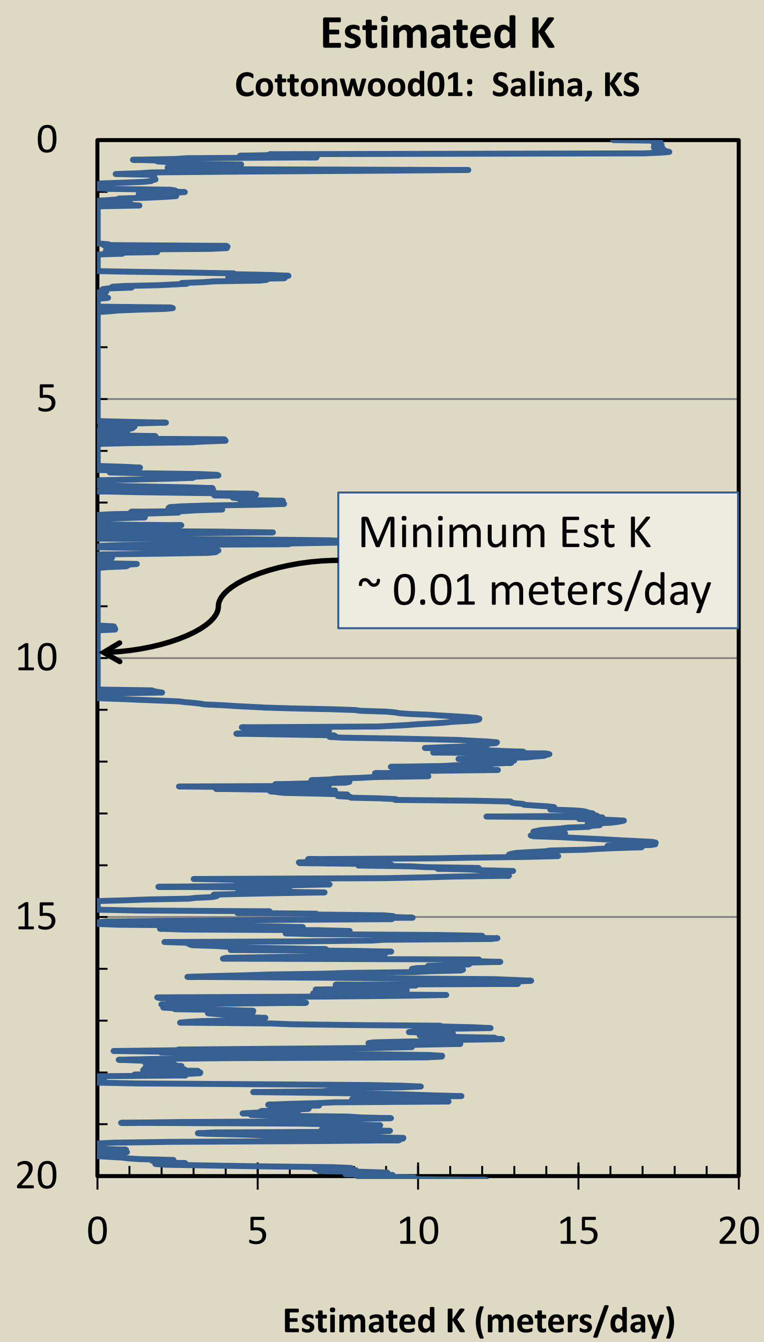
Multi-Site Data with Cottonwood Model



Extimation of K from HPT Q/P Ratio
Cottonwood Model




Q/P
Cottonwood01: Salina, KS
Depth (meters)
0
5
10
15
20
0.1
1
10
100
Q/P [ml/(min*kPa)]


Estimated K
Cottonwood01: Salina, KS
0
5
10
15
20
Minimum Est K
~ 0.01 meters/day
0
5
10
15
20
Estimated K (meters/day)

HPT Summary

- Requires about 1 hour for 20 meter log with 2 person team
- Pre- & Post Response test provide QC and ambient atmosphere pressure
- HPT probe is robust and hammering is possible
- System provides simultaneous EC log with HPT for independent confirmation of log results
- Targeted soil sampling is recommended
- Targeted slug testing is recommended for site specific confirmation of K estimates

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Model Summary

- HPT pressure must be atmosphere & hydrostatic pressure corrected before calculation of Q/P ratio

- Hydraulic conductivity estimates from HPT Q/P ratio are just that … Estimates

- Model curve(s) for Q/P estimation of K based on a nominal flow rate (~300ml/min in this example)

- Model curve provides a mathematical lower bound to measurable K (~0.01m/day, 1.0E-5 cm/sec)

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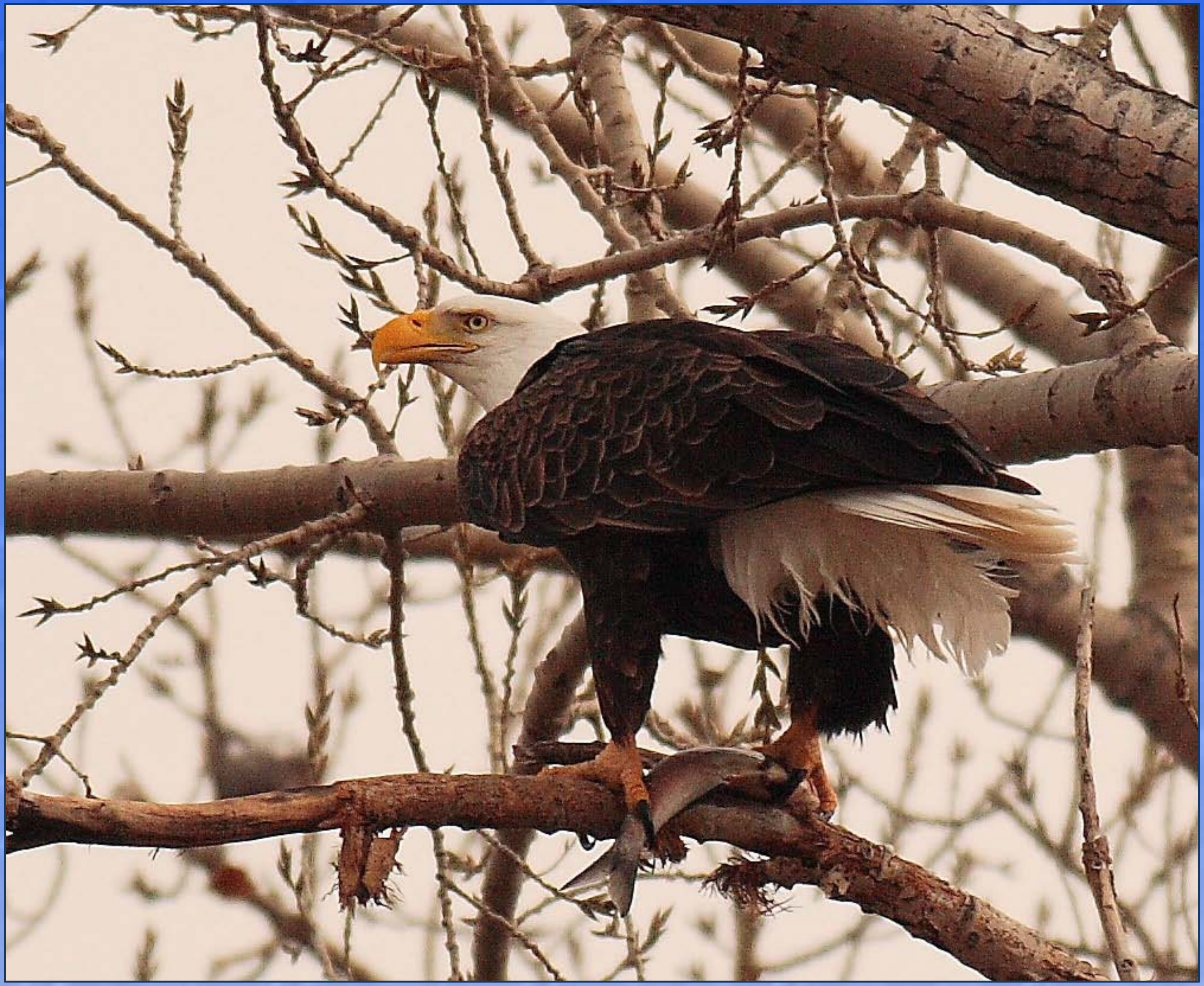

My thanks to my colleague Wes McCall who did the field work for this presentation and took the above photograph in central Kansas, U.S.A.

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Flow Resistance of HPT Port Screen and Constraints on Max K