Using the High-Resolution Piezocone to Determine Hydraulic Parameters and Mass Flux Distribution

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EPA Clu-In Internet Seminar
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TECHNICAL OBJECTIVES

- Demonstrate Use of High-Resolution Piezocone to Determine Direction and Rate of GW Flow in 3-D
  - Compare with Traditional Methods
  - Develop Models and Predict Plume Behavior

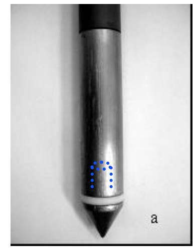
- Integrate High-Resolution Piezocone and Concentration Data into 3-D Flux Distributions via GMS Upgrades

- Introduce New Remediation Performance Monitoring Concept

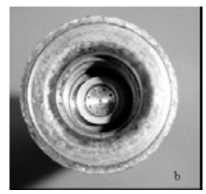
TECHNOLOGY DESCRIPTION

High-Resolution Piezocone:

- Direct-Push (DP) Sensor Probe that Converts Pore Pressure to Water Level or Hydraulic Head
- Head Values to ± 0.08ft (to >60' below w.t.)
- Can Measure Vertical Gradients
- Simultaneously Collect Soil Type and K
- K from Pressure Dissipation, Soil Type
- Minimal Worker Exposure to Contaminants
- System Installed on PWC San Diego SCAPS
- Licensed to AMS



Custom Transducer



SEEPAGE VELOCITY AND FLUX

Seepage velocity **(ν):**

$$\nu = \frac{Ki}{\rho} \quad \text{(length/time)}$$

where: K = hydraulic conductivity (*Piezocone*)

i = hydraulic gradient (*Piezocone*)

ρ = effective porosity (*Piezocone/Soil*)

Contaminant flux (F):

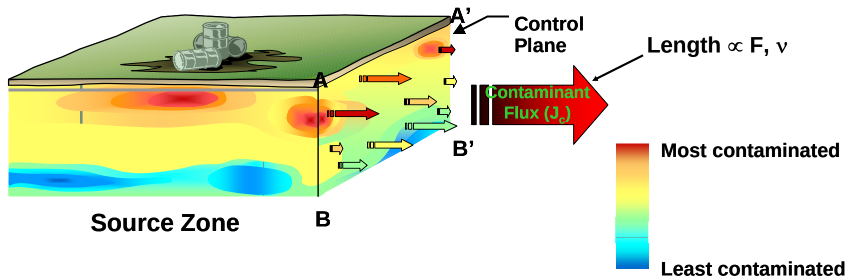
$$F = \nu\,[X]$$

(mass/length^2-time; mg/m^2-s)

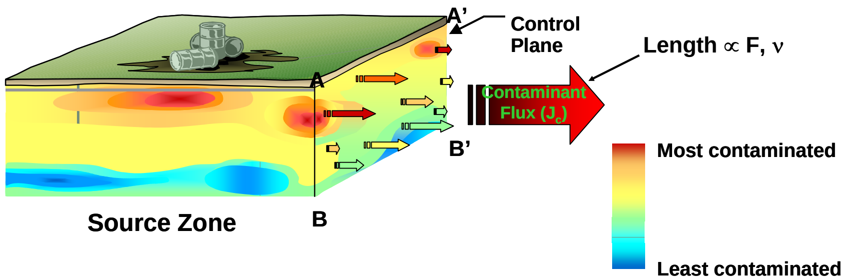
where: ν = seepage velocity (length/time; m/s)

[X] = concentration of solute (*MIP*, *etc.*) (mass/volume; mg/m^3)

CONCENTRATION VS. FLUX



CONCENTRATION VS. FLUX



High Concentration ≠ High Risk!!
Hydraulic Component - Piezocone

GMS MODIFICATIONS

Gradient, Velocity and Flux Calculations

- **Convert Scalar Head to Gradient [Key Step!]**

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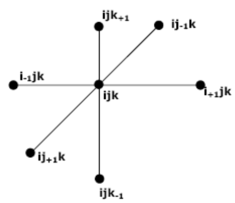
Calculating Hydraulic Gradient

For an interior node:



$$\frac{\partial h}{\partial x} = \frac{\dfrac{h_{i_{+1}jk} - h_{ijk}}{x_{i_{+1}jk} - x_{ijk}} + \dfrac{h_{ijk} - h_{i_{-1}jk}}{x_{ijk} - x_{i_{-1}jk}}}{2}$$

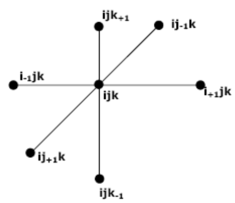
GMS MODIFICATIONS

Gradient, Velocity and Flux Calculations

- **Convert Scalar Head to Gradient [Key Step!]**
  - **Merging of 3-D Distributions to Solve for Velocity**
  - **Merging of Velocity and Concentration (MIP or Samples) Distributions to Solve for Contaminant Flux**

Calculating Hydraulic Gradient

For an interior node:



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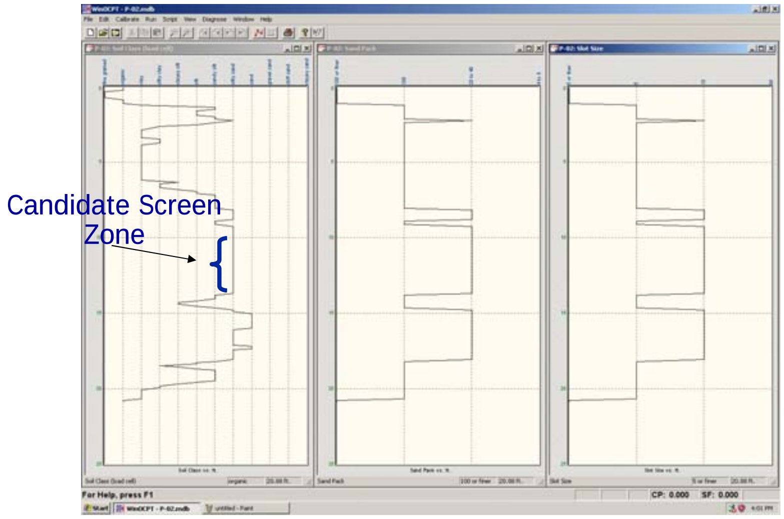
APPROACH

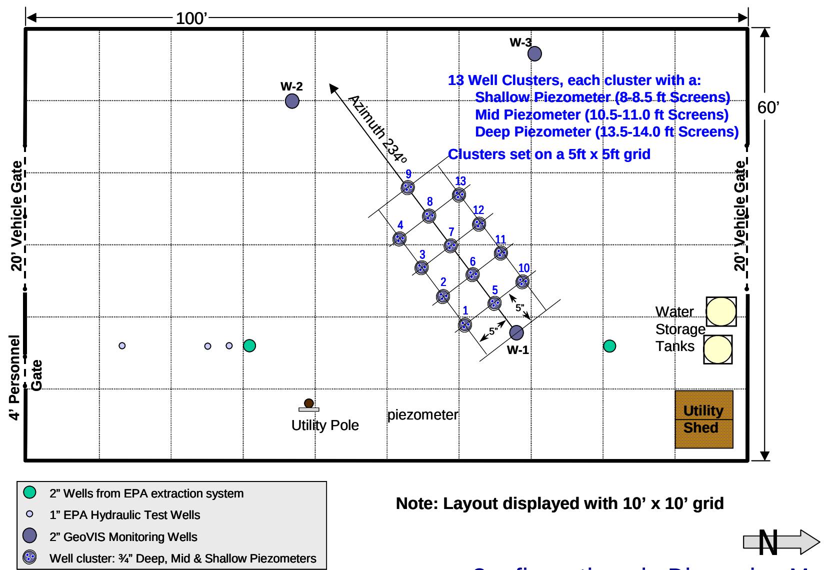
- Test Cell Orientation
  - Initial pushes for well design;
  - Well design and prelim. installations, gradient determination;
  - Initial $CaCl_2$ tracer tests with geophysics (time-lapse resistivity) to determine general flow direction
- Field Installations (Clustered Wells)
- Survey (Lat/Long/Elevation)
- Pneumatic and Conventional Slug Tests ("K – Field")
  - Modified Geoprobe test system
- Water Levels ("Conventional" 3-D Head and Gradient)
- HR Piezocone Pushes (K, head, eff. porosity)
- GMS Interpolations (ν, F), Modeling and Comparisons

CPT-BASED WELL DESIGN



Kram and Farrar Well Design Method

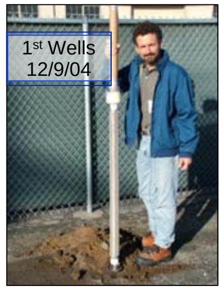
DEMONSTRATION CONFIGURATION



Configuration via Dispersive Model

FIELD EFFORTS


Site Characterization with High Resolution Piezocone 11/22/04

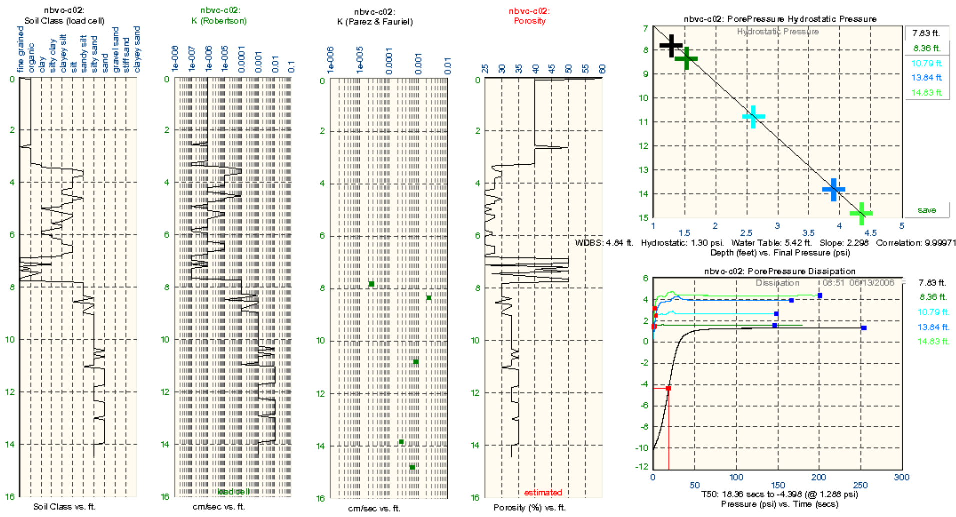

1st Wells 12/9/04


Well Development & Hydraulic Test 8/24/05


Installation ¾" Wells 7/28/05

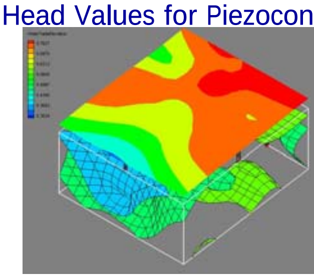

Field Demo 6/13/06

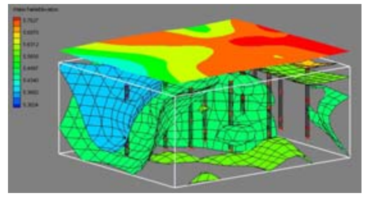
PIEZOCONE OUTPUT

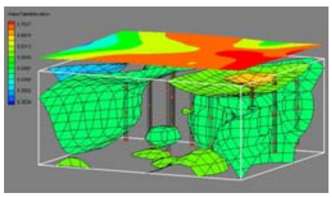


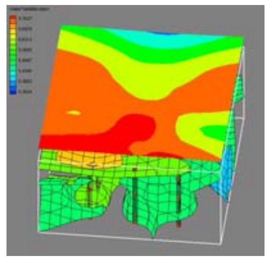
HIGH RESOLUTION PIEZOCONE TESTS (6/13/06)

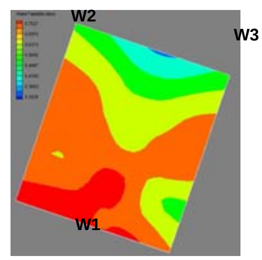
Head Values for Piezocone





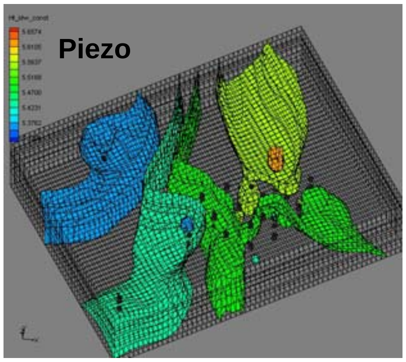


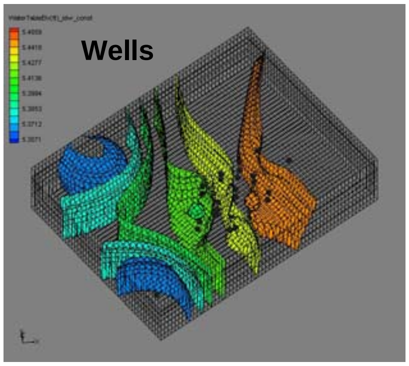




Displays shallow gradient

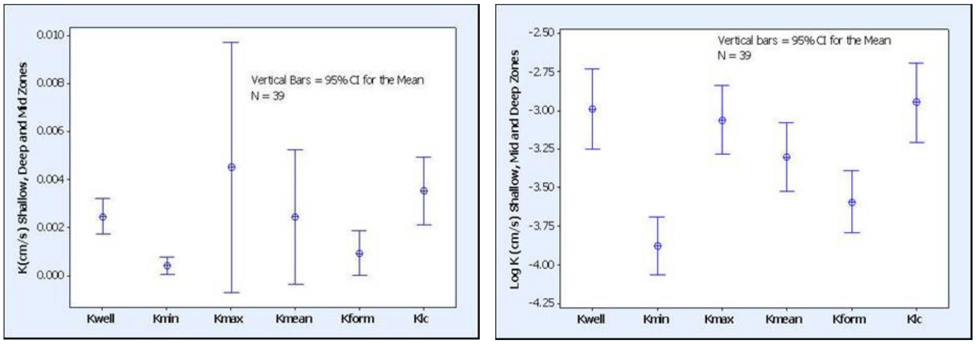
HEAD DETERMINATION
(3-D Interpolations)





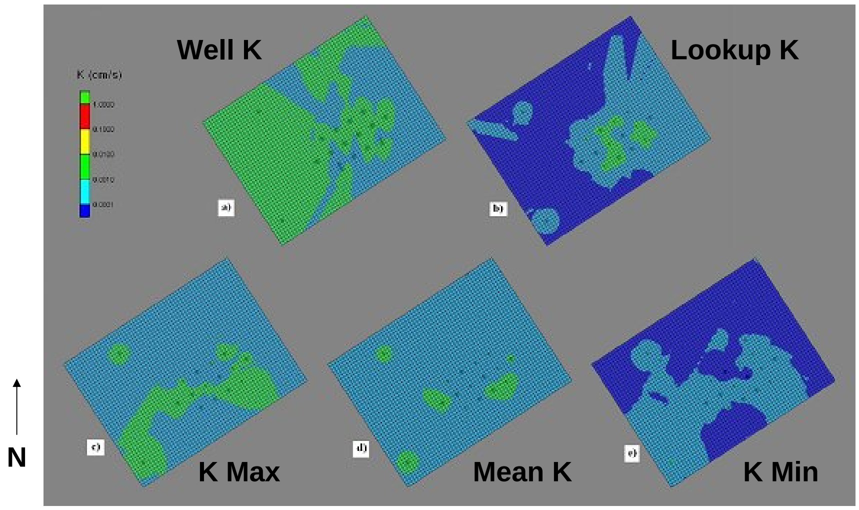
- Shallow gradient (5.49-5.41'; 5.45-5.38' range in clusters over 25')
- In practice, resolution exceptional (larger push spacing)

COMPARISON OF ALL K VALUES



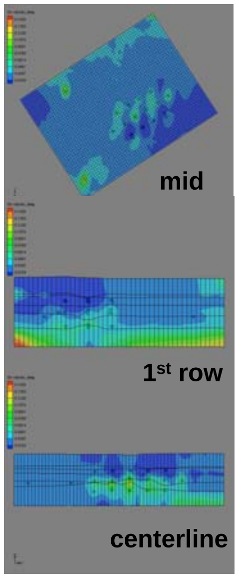
- K_{mean} and K_{lc} values within about a factor of 2 of K_{well} values;
- K_{min}, K_{max} and K_{form} values typically fall within factor of 5 or better of the K_{well} values;
- K values derived from piezocone pushes ranged much more widely than those derived from slug tests conducted in adjacent monitoring wells;
- Differences may be attributed to averaging of hydraulic conductivity values over the well screen versus more depth discrete determinations from the piezocone (e.g., more sensitive to vertical heterogeneities).

K BASED ON WELLS AND PROBE
(Mid Zone Interpolations)

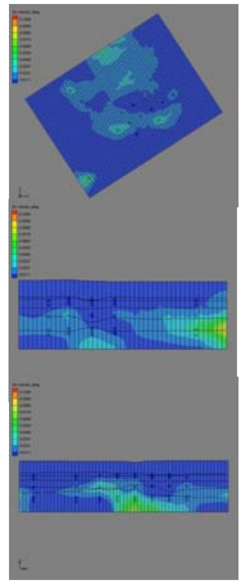


VELOCITY DETERMINATION
(cm / s)

Well

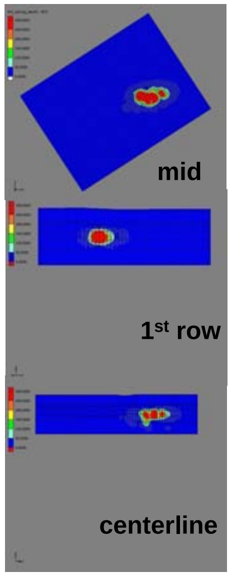


Piezo (mean K)

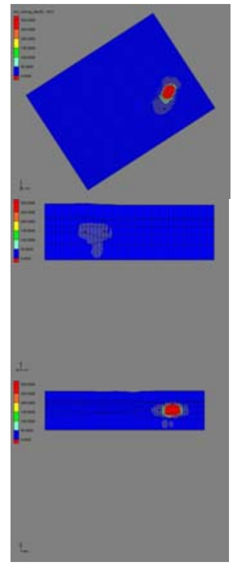


FLUX DETERMINATION
(Day 49 Projection)

Well



Piezo (mean K)

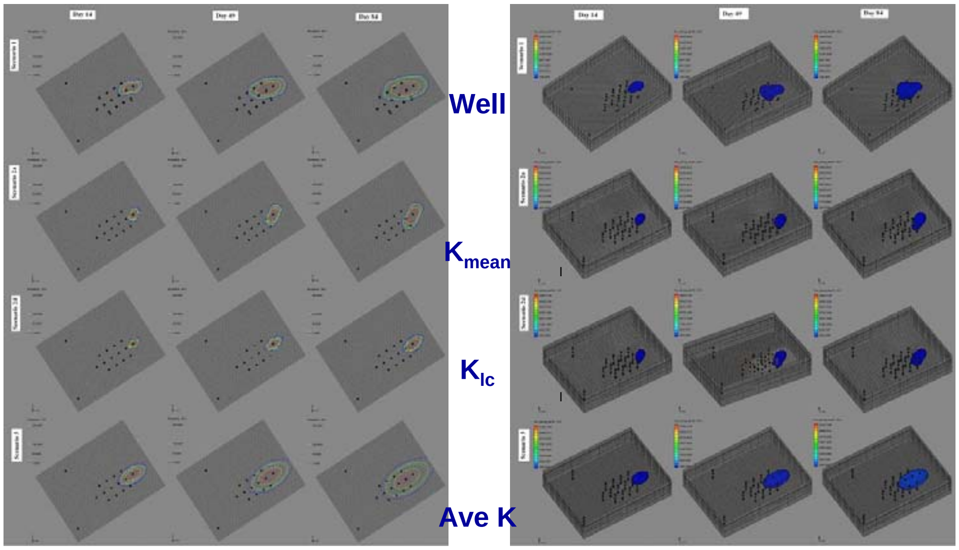


ug/ft^2-day

MODELING
Concentration and Flux

Scenario	Head	K	Porosity
1	Well	Well	Average
2a	SCAPS	SCAPS K_{mean}	SCAPS
2b	SCAPS	SCAPS K_{min}	SCAPS
2c	SCAPS	SCAPS K_{max}	SCAPS
2d	SCAPS	SCAPS K_{lookup}	SCAPS
3	Well	Well	SCAPS
4a	Well	SCAPS K_{mean}	SCAPS
4b	Well	SCAPS K_{min}	SCAPS
4c	Well	SCAPS K_{max}	SCAPS
4d	Well	SCAPS K_{lookup}	SCAPS
5	Unif. grad.	Average	Average

MODELING
Concentration and Flux

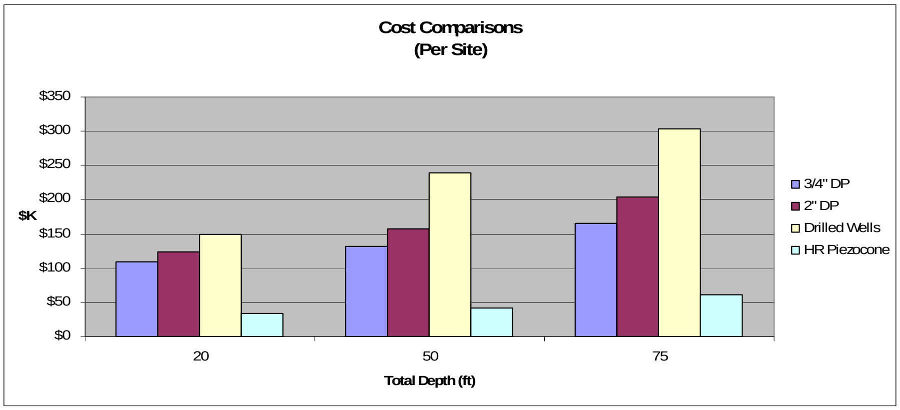


PERFORMANCE

Performance Summary.

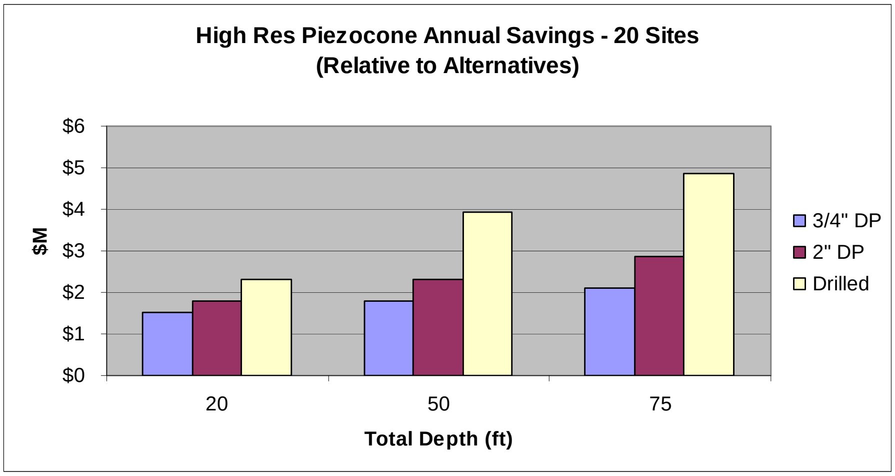
Performance Criteria	**Expected Performance Metric**	**Results**
Accuracy of high-resolution piezocone for determining head values, flow direction and gradients	± 0.08 ft head values	Met Criteria
Hydraulic conductivity (dissipation or soil type correlation)	± 0.5 to 1 order of magnitude	Met Criteria
Transport model based on probes	Predicted breakthrough times and concentrations within one order of magnitude; probe based model efficiency accounts for more than 15% of the variance associated with well based models	Met Criteria
Time required for generation of 3-D conceptual and transport models	At least 50% reduction in time	Met Criteria

FLUX CHARACTERIZATION
Cost Comparisons



"Apples to Apples" – HR Piez. with MIP vs. Wells, Aq. Tests, Samples
10 Locations/30 Wells

FLUX CHARACTERIZATION
Cost Comparisons



Early Savings of ~$1.5M to $4.8M

FLUX CHARACTERIZATION
Time Comparisons

	Days to Complete		
Depth (ft)	Direct-Push Wells	Drilled Wells	HR Piezocone
20	90	104	13
50	99	137	15
75	111	151	19

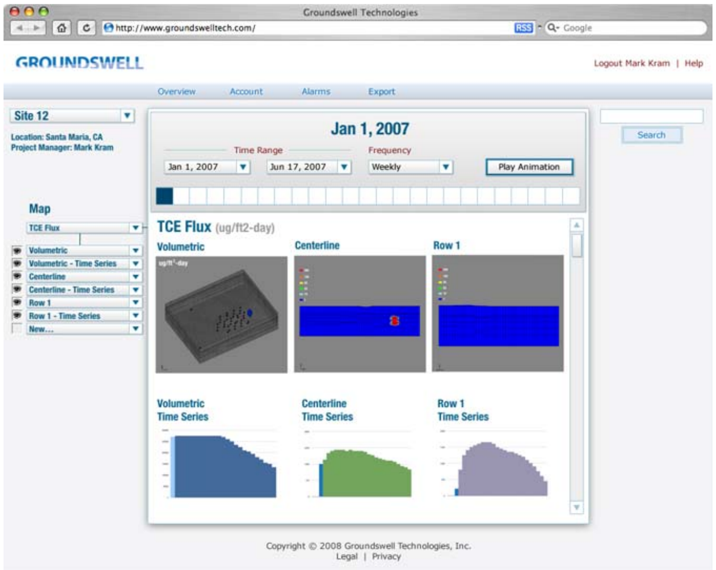
"Apples to Apples" – HR Piez. with MIP vs. Wells, Aq. Tests, Samples
10 Locations/30 Wells

CONTAMINANT FLUX MONITORING STEPS

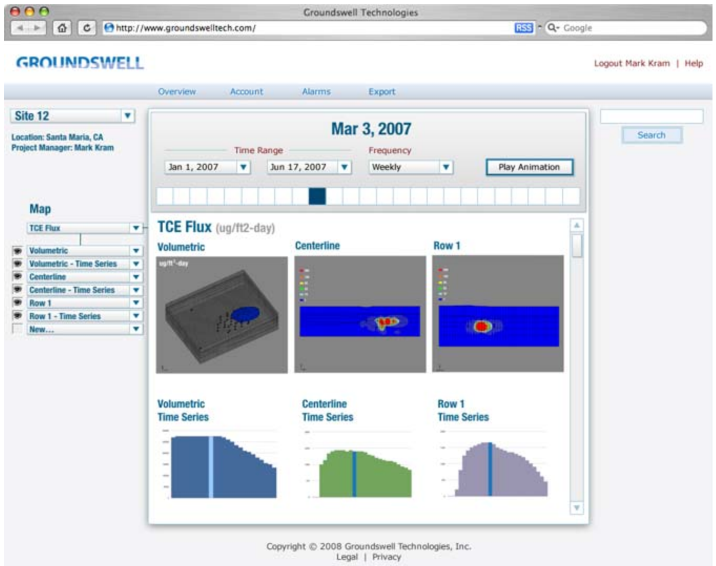
(Remediation Design/Effectiveness)

- Generate Initial Model (Seepage Velocity, Concentration Distributions)
  - Conventional Approaches
  - High-Resolution Piezocone/MIP
- Install Customized 3D Monitoring Well Network
  - ASTM
  - Kram and Farrar Method
- Monitor Water Level and Concentrations (Dynamic/Automate?)
- Track Flux Distributions (3D, Transects)
- Evaluate Remediation Effectiveness
  - Plume Status (Stable, Contraction, etc.)
  - Remediation Metric
  - Regulatory Metric?

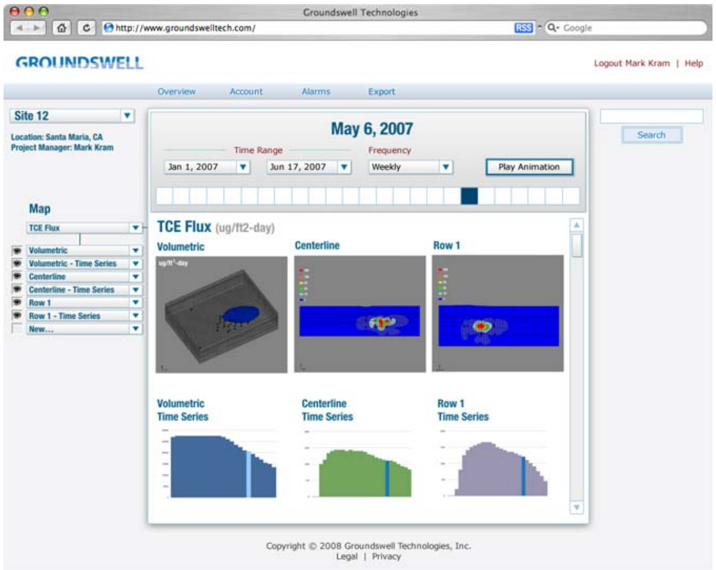
Future Conceptualization



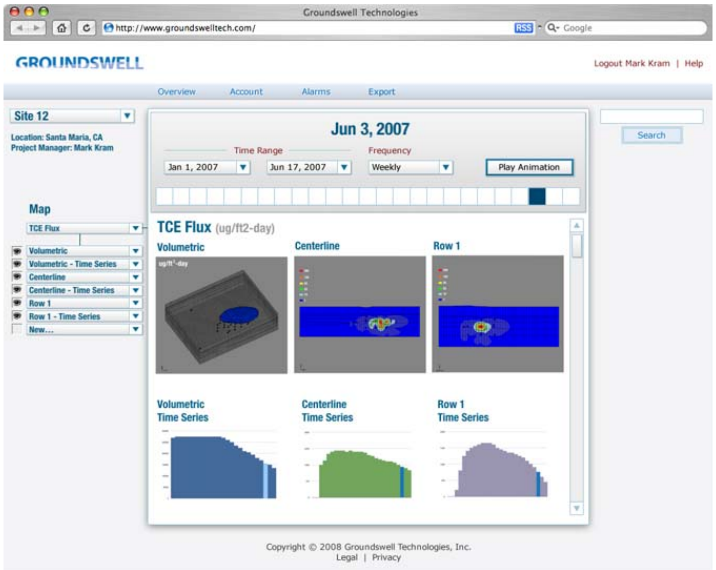
Future Conceptualization



Future Conceptualization



Future Conceptualization



FUTURE PLANS

Tech Transfer

- Army (Fall '08)
- Industry Licensing (AMS in Summer '07; Market Ready by December '08)
- ITRC Tech Reg
- ASTM D6067

Final Reports

- Released (May '08)
- Clu-In: http://www.clu-in.org/s.focus/c/pub/i/1558/

CONCLUSIONS

- High-Res Piezocone Preliminary Results Demonstrate Good Agreement with Short-Screened Well Data
- Highly Resolved 2D and 3D Distributions of Head, Gradient, K, Effective Porosity, and Seepage Velocity Now Possible Using HRP and GMS
- When Know Concentration Distribution, 3D Distributions of Contaminant Flux Possible Using HRP with GMS
- Exceptional Capabilities for Plume “Architecture” and Monitoring Network Design
- Remediation Performance Monitoring Potential
- Significant Cost/Time Saving Potential

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THANK YOU!
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