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Depth-Averaged Modeling of Groundwater Flow and Transport

Peter K. Kitanidis

Department Civil and Environmental Engineering

Stanford University

COMSOL 2008

Outline

- Pedagogical Aspects ("Comsol in Education")
- Importance of 2-D Depth-Averaged Flow
- Some Examples

Pedagogical Aspects

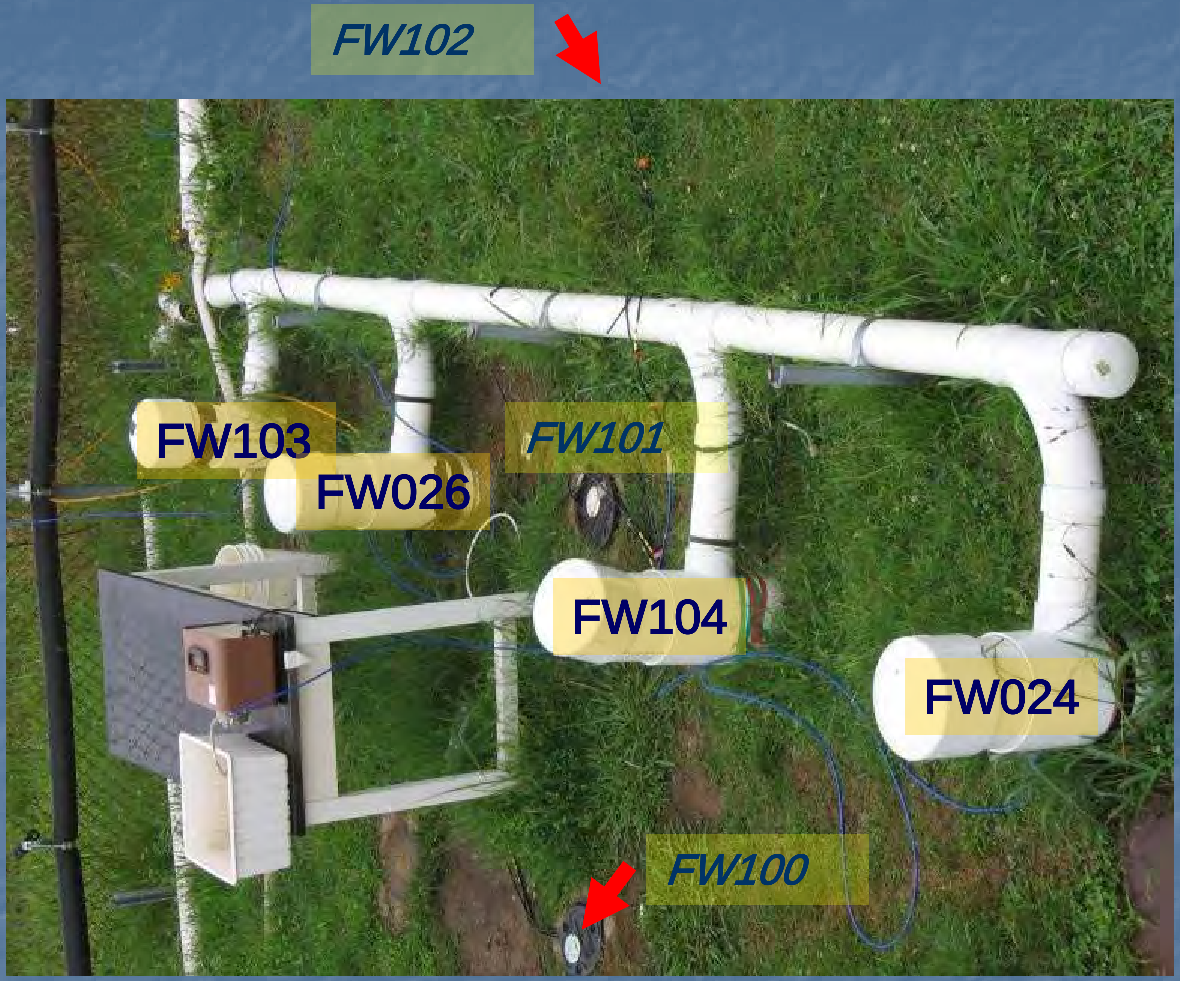
- We have largely completed a transition to numerical tools to teach:
  - Flow in porous media and
  - Groundwater flow.
- Challenges:
  - Hydrogeologists and Environmental Engineers have their own *style of learning* numerical methods
  - Little "glitches" in COMSOL appear to students like major stumbling blocks.

Pedagogical Aspects (cont.)

- A strategy that seems to work: Do a sequence of many problems that improve, simultaneously, grasp of mechanics and mathematical modeling skills.
- "Learn on the job" with minimal discussion of numerical methods.
- Start from simple problems and end up with actual applications.

Why 2-D Averaged?

- In many practical applications, flow is in thin and (nearly) horizontal layers. Head differences over the depth are small.
- 2-D modeling is easier computationally and in terms of data requirements.

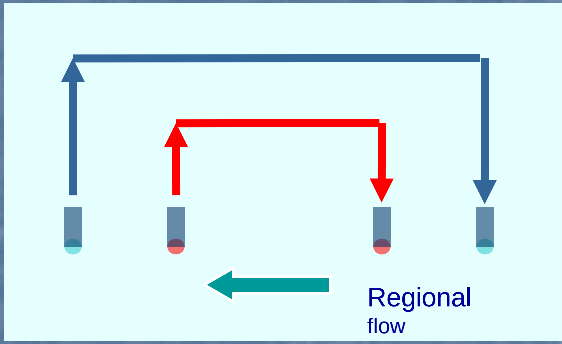


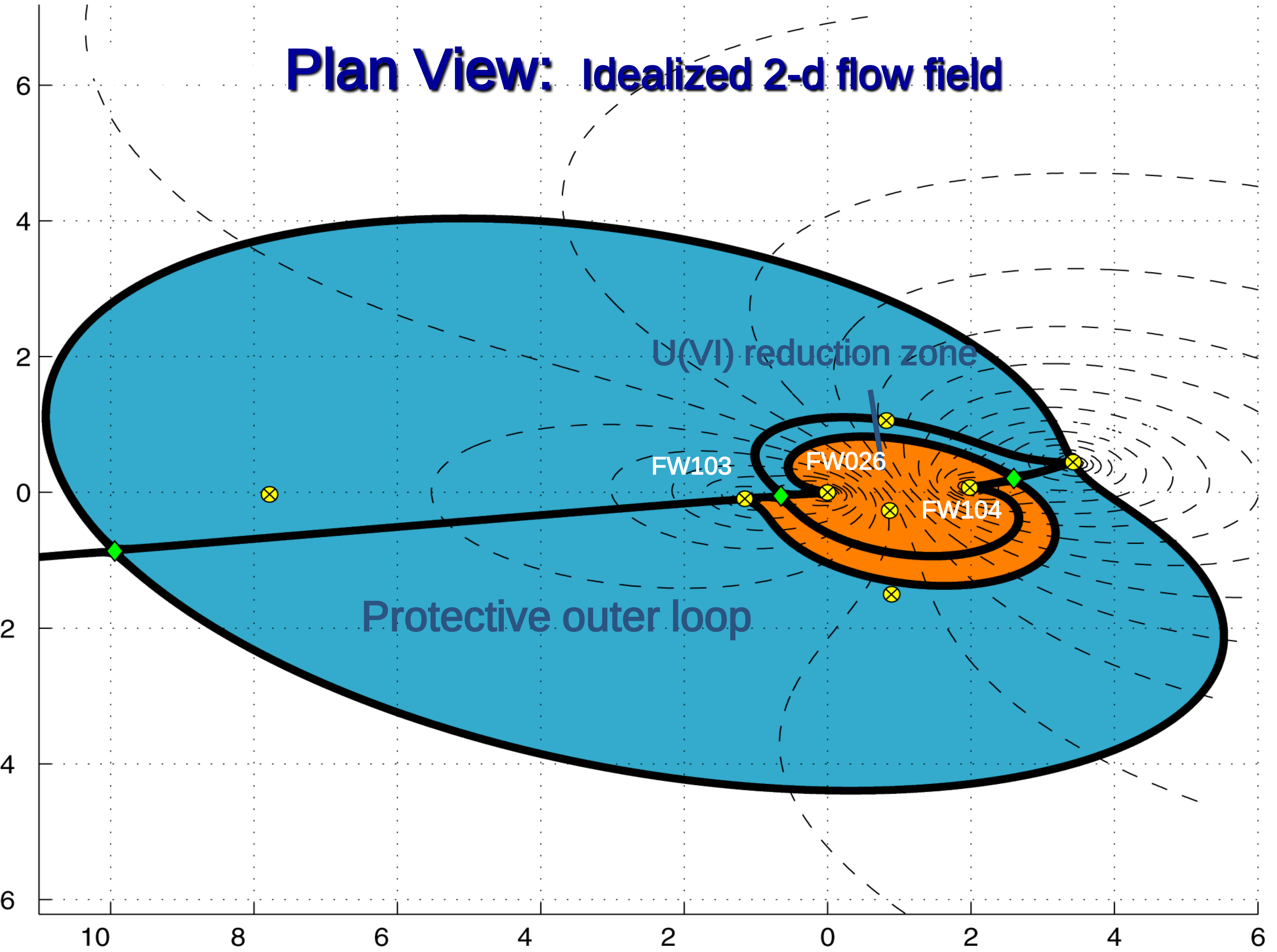
Injection

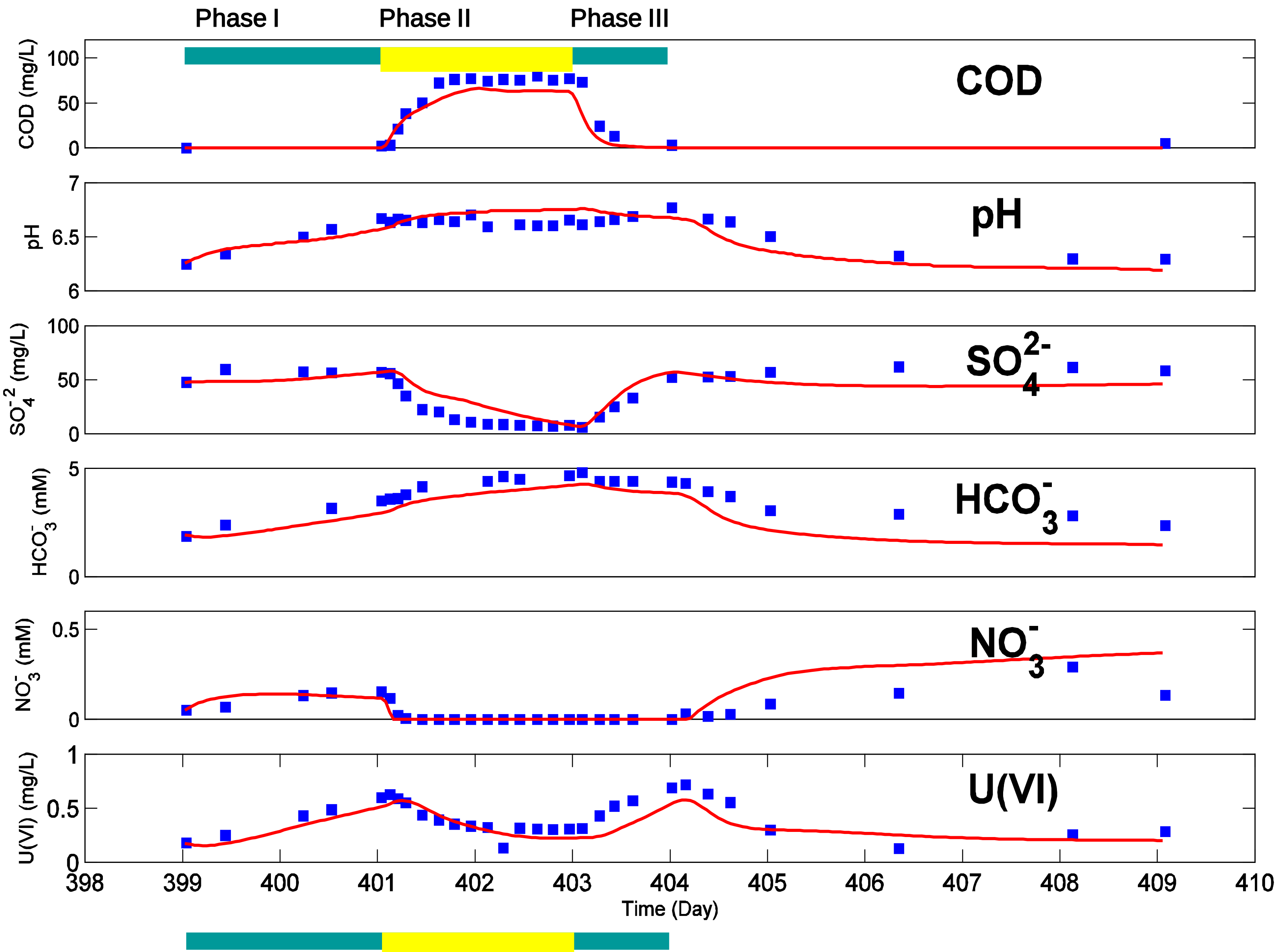
Extraction

And

MLS Wells

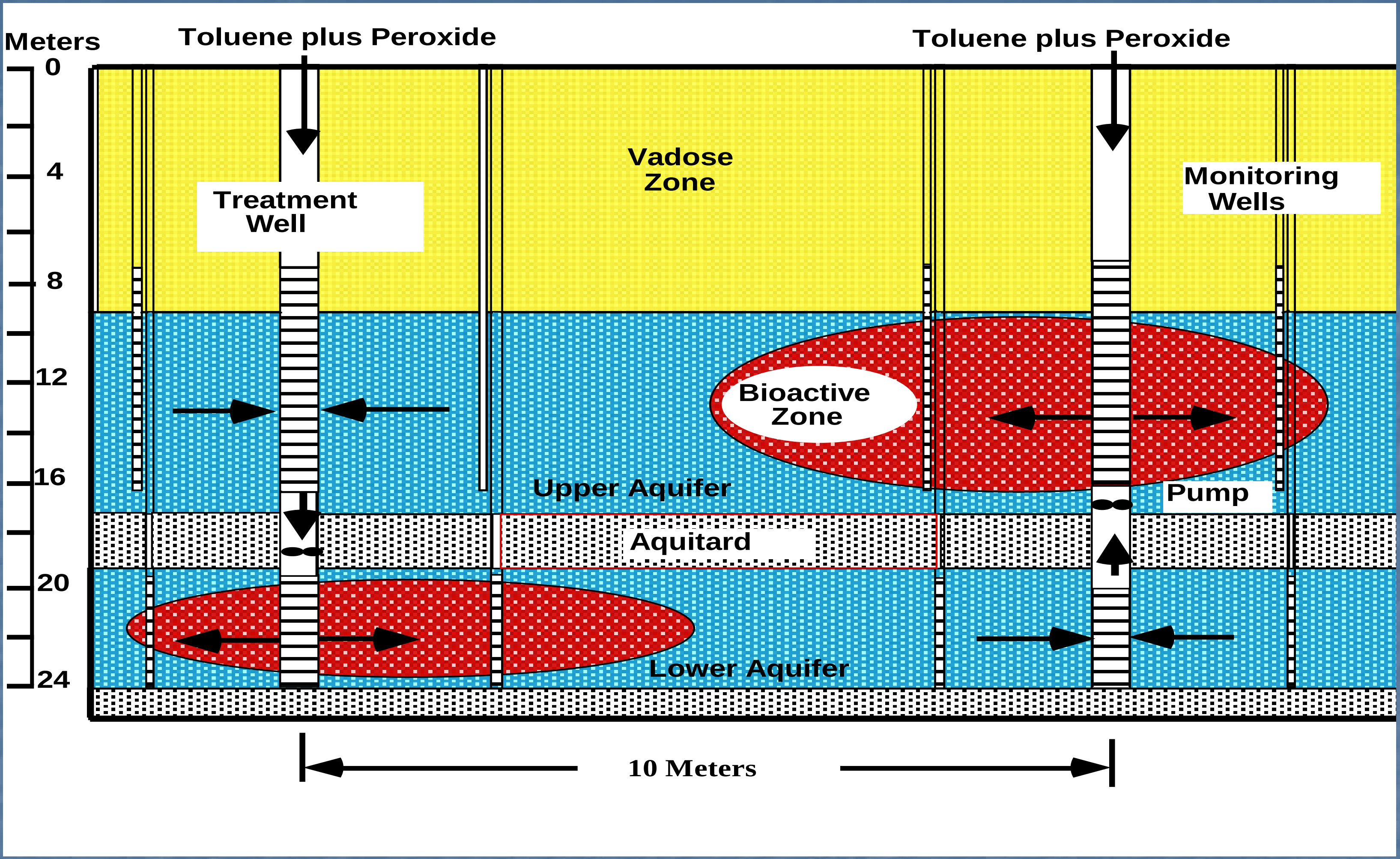



Plan View: Idealized 2-d flow field
U(VI) reduction zone
FW103
FW026
FW104
Protective outer loop
6
4
2
0
2
4
6
10
8
6
4
2
0
2
4
6



- Effective reduction rate: $v_{U(VI)}$=1mmol U(VI)/mg SRB-day

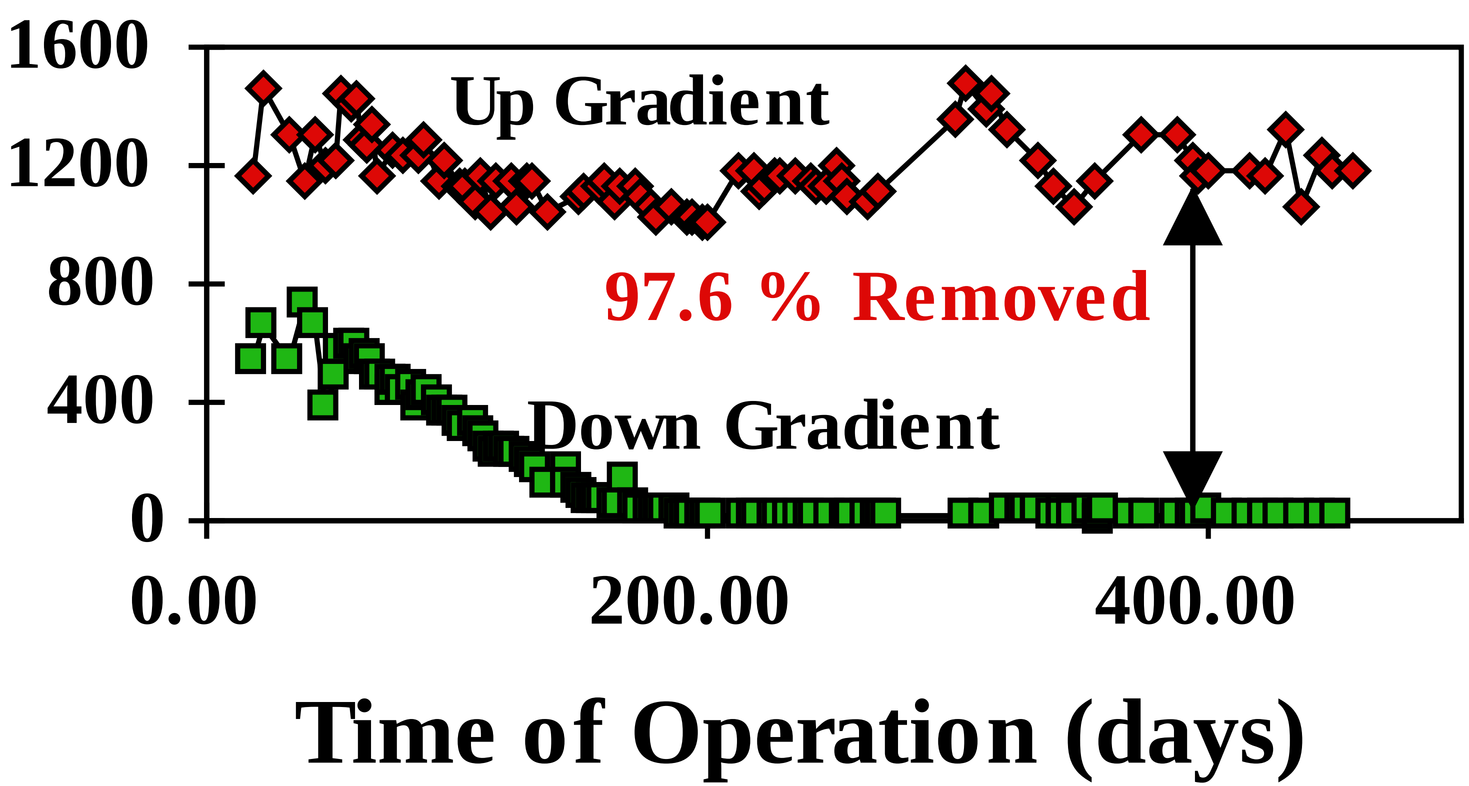
Delivery and Mixing in Wells: Edwards AFB

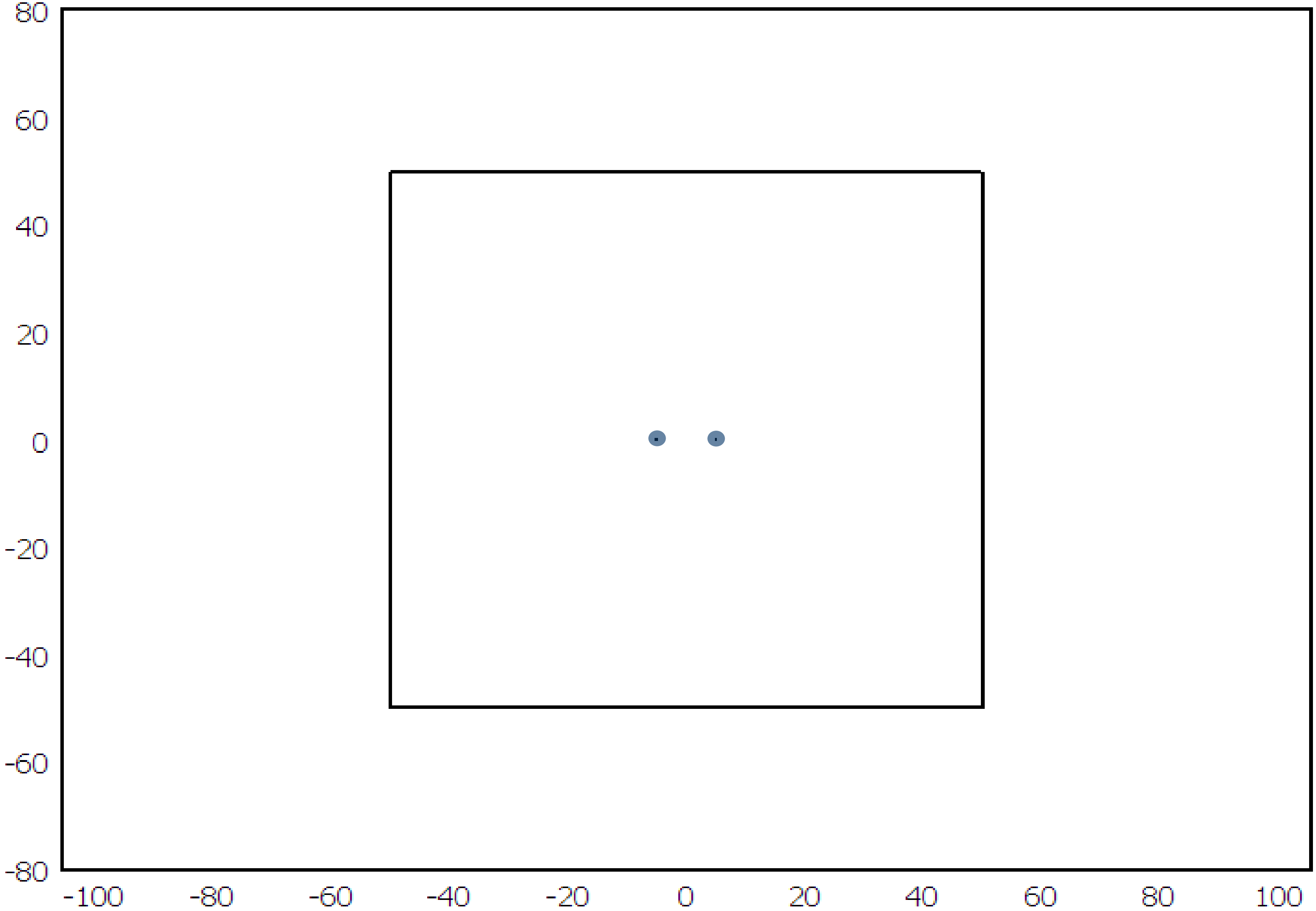


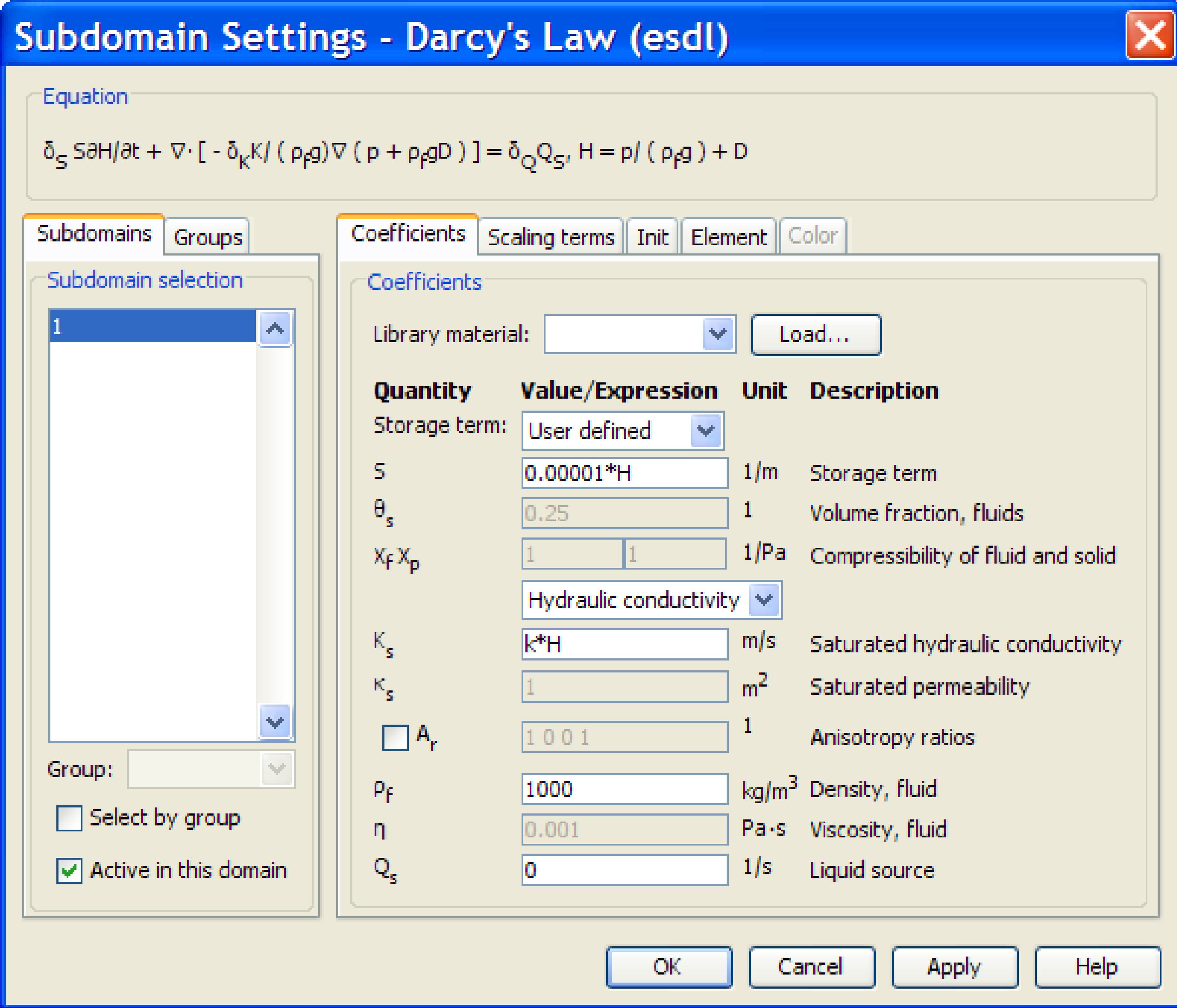
Idealized vertical cross-section

McCarty et al,. "Full-Scale Evaluation of in Situ Cometabolic Degradation of Trichloroethylene in Groundwater through Toluene Injection." *Environ. Sci. Technol.* 32, no. 1 (1998): 88-100.

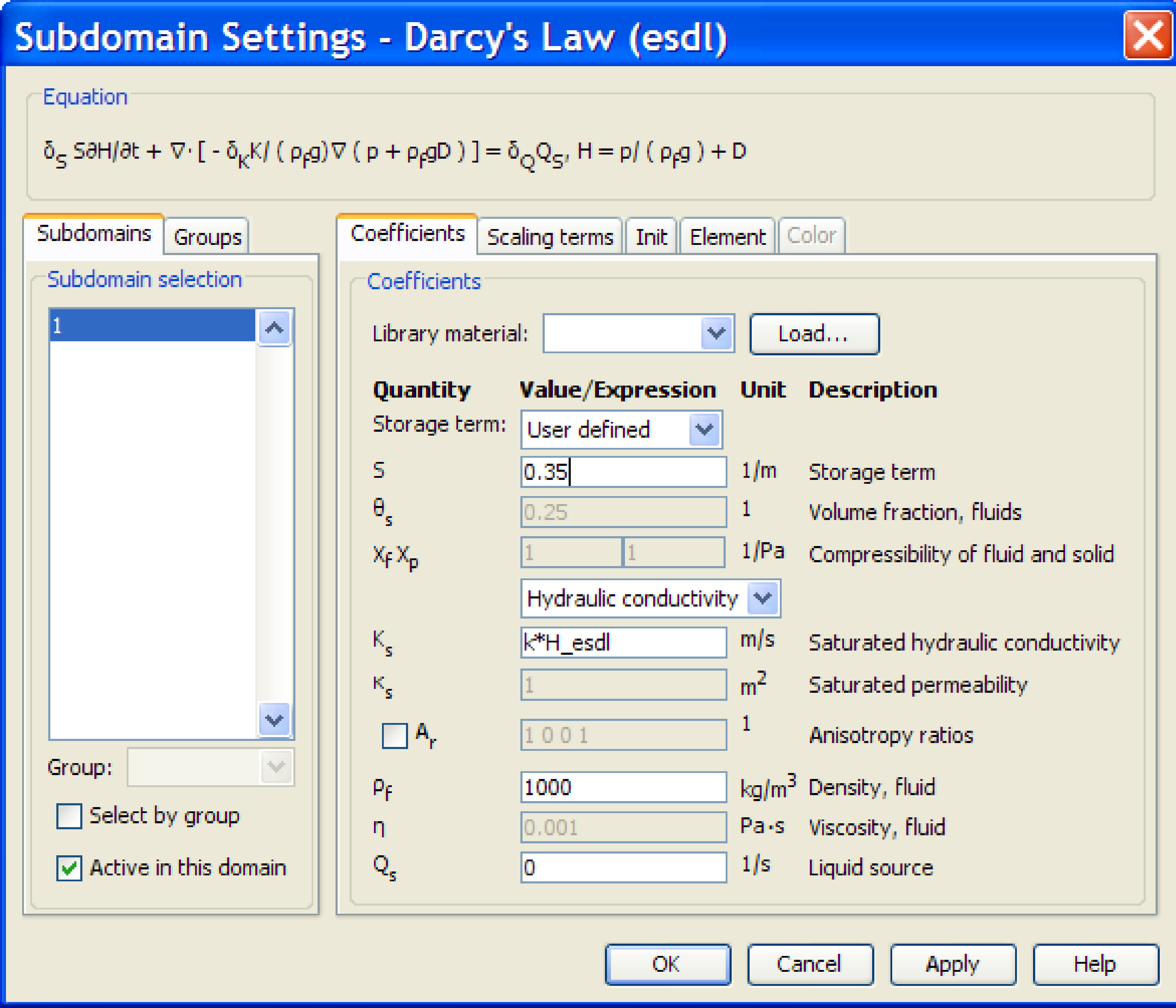
From Edwards AFB Pilot Study (McCarty et al.)




80
60
40
20
0
-20
-40
-60
-80
-100
-80
-60
-40
-20
0
20
40
60
80
100



Subdomain Settings - Darcy's Law (esdl)
Equation
δS S∂H/∂t + ∇·[- δK K/(ρf g)∇(p + ρf gD)] = δQ Qs, H = p/(ρf g) + D
Subdomains
Groups
Subdomain selection
1
Group:
Select by group
Active in this domain
Coefficients
Scaling terms
Init
Element
Color
Coefficients
Library material:
Load...
Quantity
Value/Expression
Unit
Description
Storage term:
User defined
S
0.00001*H
1/m
Storage term
θs
0.25
1
Volume fraction, fluids
Xf Xp
1
1
1/Pa
Compressibility of fluid and solid
Hydraulic conductivity
Ks
k*H
m/s
Saturated hydraulic conductivity
κs
1
m2
Saturated permeability
Ar
1 0 0 1
1
Anisotropy ratios
ρf
1000
kg/m3
Density, fluid
η
0.001
Pa·s
Viscosity, fluid
Qs
0
1/s
Liquid source
OK
Cancel
Apply
Help


Subdomain Settings - Darcy's Law (esdl)
Equation
δS S∂H/∂t + ∇·[- δKK/ (ρfg)∇ (p + ρfgD)] = δQQS, H = p/ (ρfg) + D
Subdomains
Groups
Subdomain selection
1
Group:
Select by group
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Coefficients
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Library material:
Load...
Quantity
Value/Expression
Unit
Description
Storage term:
User defined
S
0.35
1/m
Storage term
θs
0.25
1
Volume fraction, fluids
χf χp
1
1
1/Pa
Compressibility of fluid and solid
Hydraulic conductivity
Ks
k*H_esdl
m/s
Saturated hydraulic conductivity
κs
1
m2
Saturated permeability
Ar
1 0 0 1
1
Anisotropy ratios
ρf
1000
kg/m3
Density, fluid
η
0.001
Pa·s
Viscosity, fluid
Qs
0
1/s
Liquid source
OK
Cancel
Apply
Help

Global Equations

Equation: f(u, ut, utt, t) = 0

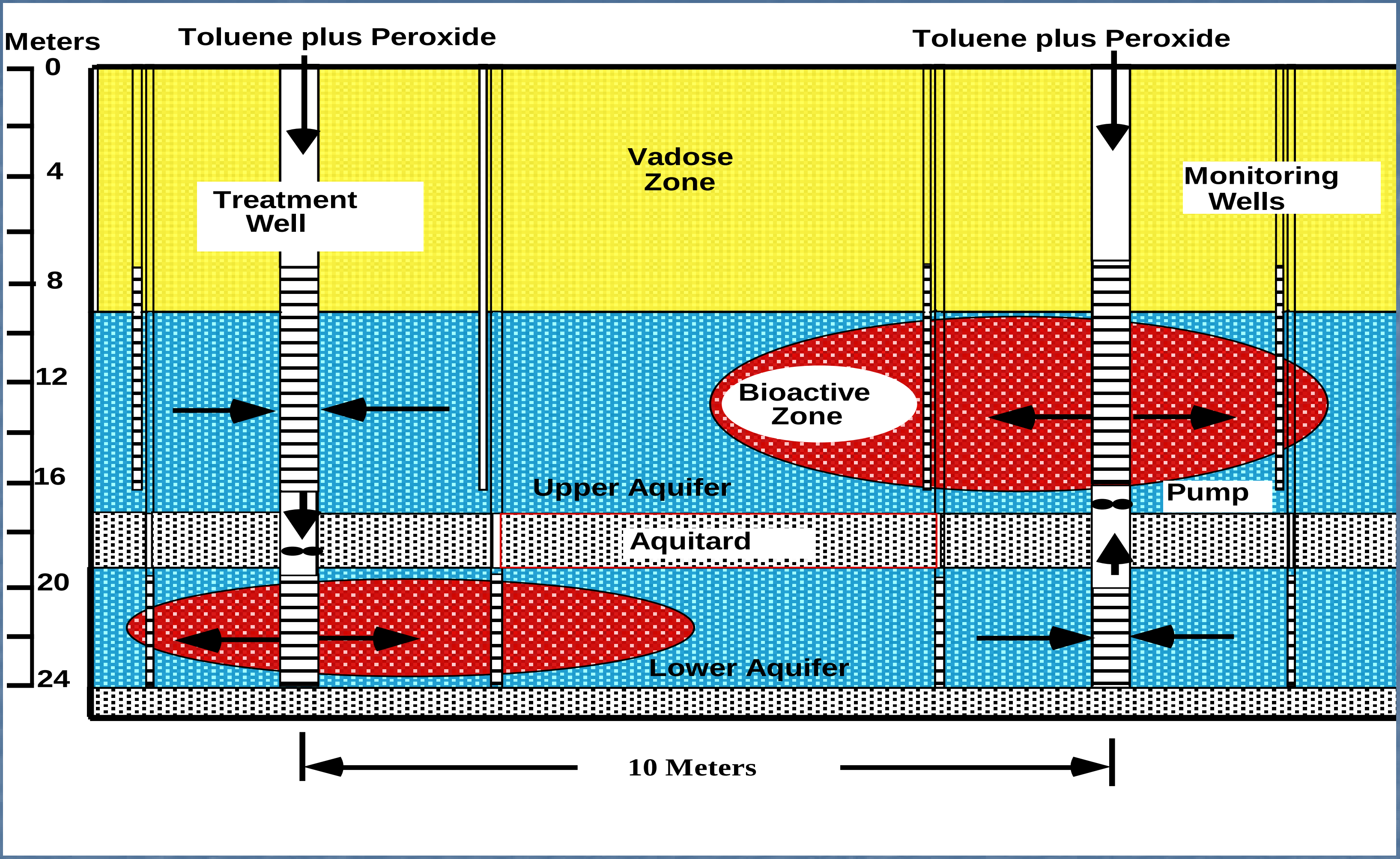
States | Weak

Name (u)	Equation f(u,ut,utt,t)	Init (u)	Init (ut)	Description
phie	OUTe+Q+pi*rw^2*phiet	16	0	
phii	OUTi-Q+pi*rw^2*phiit	28	0	

Base unit system: SI

OK | Cancel | Apply | Help

Delivery and Mixing in Wells: Edwards AFB



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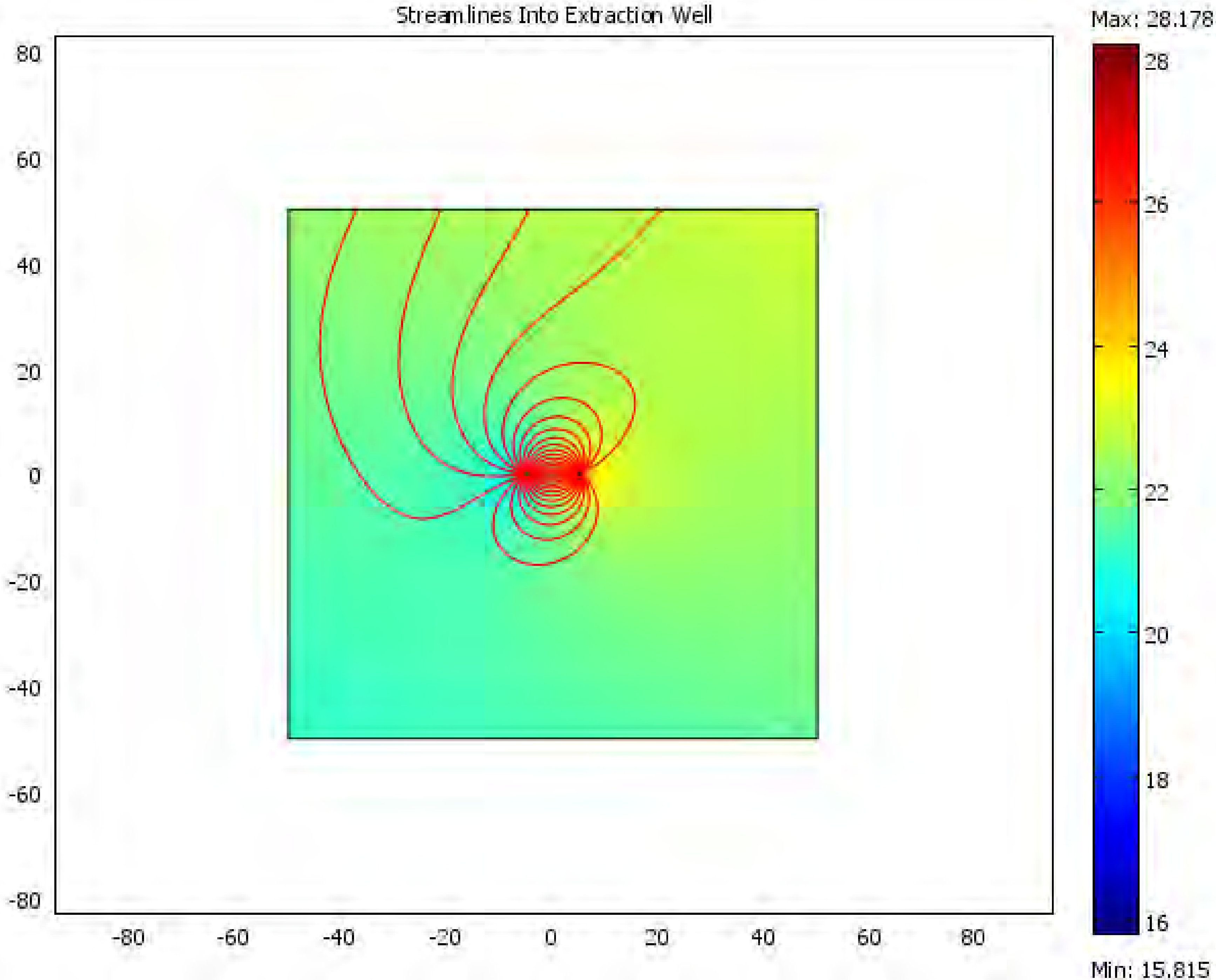
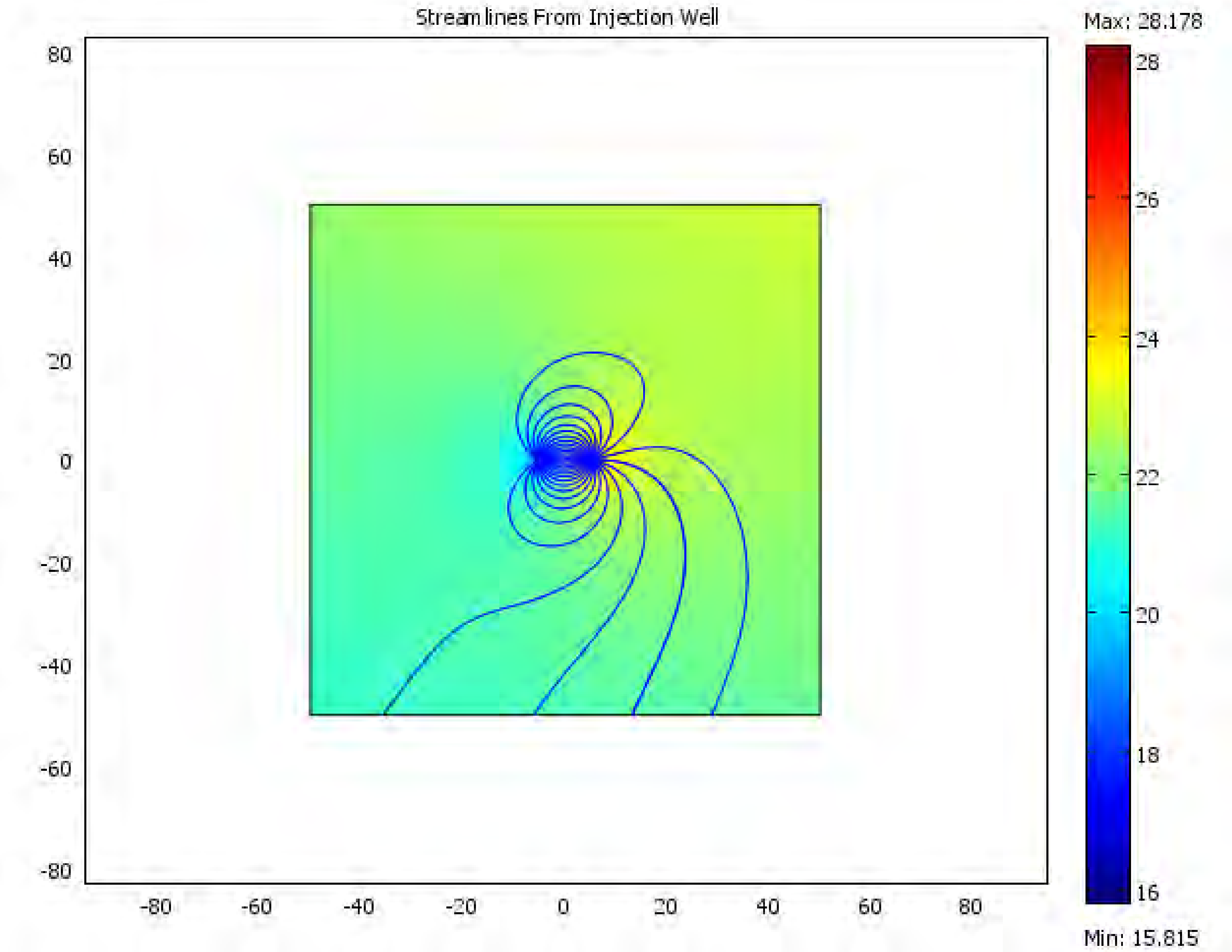

Streamlines Into Extraction Well
Max: 28.178
Min: 15.815
80
60
40
20
0
-20
-40
-60
-80
28
26
24
22
20
18
16



Streamlines From Injection Well
Max: 28.178
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Min: 15.815
80
60
40
20
0
-20
-40
-60
-80
-80
-60
-40
-20
0
20
40
60
80

Subdomain Settings - Solute Transport (esst)

Equation

$$\delta_{ts1}(\theta_s + \rho_b \partial c_p/\partial c)\partial c/\partial t + \nabla\cdot(-\theta_s D_L \nabla c) = -\mathbf{u}\cdot\nabla c + R_L + R_P + S_c$$

Subdomains | Groups

Subdomain selection

1

Group:

☐ Select by group

☑ Active in this domain

Flow and Media | Liquid | Solid | Init | Element | Color

Flow and media

Flow Field		Unit	
δ_{ts1}	1/86400	1	Time-scaling coefficient
θ_s	eta*H	1	Pore volume fraction
u	u_esdl	m/s	x-velocity
v	v_esdl	m/s	y-velocity
Q_s	0	1/s	Liquid source

OK | Cancel | Apply | Help

Several Other Issues

For example, dealing with transport:

- Recirculation;
- Sorption
- Multiple components and reactions (instantaneous, Monod kinetics, reversible).

Conclusion

For Groundwater Flow and Transport: COMSOL Multiphysics can be a valuable tool in teaching processes and in practical applications.