Welcome to the CLU-IN Internet Seminar

Practical Models to Support Remediation Strategy Decision-Making - Part 4

Sponsored by: U.S. EPA Office of Superfund Remediation and Technology Innovation

Delivered: October 31, 2012, 1:00 PM - 3:00 PM, EDT (17:00-19:00 GMT)

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October 11, 2012, 2:00 PM - 4:00 PM, EDT (18:00-20:00 GMT)

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Although I'm sure that some of you have these rules memorized from previous CLU-IN events, let's run through them quickly for our new participants.

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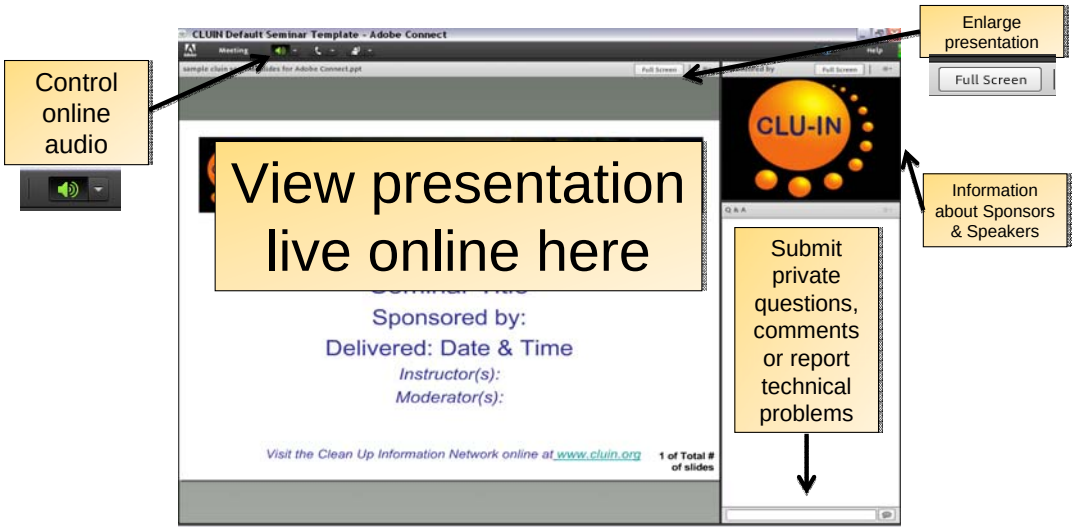
With that, please move to slide 3.

New online broadcast screenshot



Practical Models to Support Remediation Strategy Decision-Making

Ronald W. Falta, Ph.D.
Brian Looney, Ph.D.
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Module 4 - October 2012

Continuum of Tools Available to Support Environmental Cleanup

Input		Tools	Output
Limited		Hand Calculations	Basic
Site Data		Taxonomic Screening (Scenarios, scoring)	Binning / Screening
Site Data; Simplifying assumptions		"Simple" Analytical Models (Biochlor, BioBalance) ← REMChlor, REMFuel →	Exploratory or decision level
Complex; Site-specific		Numerical Models (MODFLOW, Tough, RT3D)	Complex

INSTRUCTORS: *Ron Falta, Ph.D.*

- **Professor, Dept. of Environmental Engineering & Earth Sciences, Clemson University**
  - Ph.D. Material Science & Mineral Engineering, U. of California, Berkley
  - M.S., B.S. Civil Engineering Auburn University
- **Instructor for subsurface remediation, groundwater modeling, and hydrogeology classes**
- **Developer of REMChlor and REMFuel Models**
- **Author of Numerous technical articles**
- **Key expertise:** Hydrogeology, contaminant transport/remediation, and multiphase flow in porous media

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INSTRUCTORS: *Charles J Newell,* Ph.D., P.E.

- **Vice President, GSI Environmental Inc.**
  - Diplomate in American Academy of Environmental Engineers
  - NGWA Certified Ground Water Professional
  - Adjunct Professor, Rice University
- **Ph.D. Environmental Engineering, Rice Univ.**
- **Co-Author 2 environmental engineering books; 5 environmental decision support software systems; numerous technical articles**
- **Expertise:** Site characterization, groundwater modeling, non-aqueous phase liquids, risk assessment, natural attenuation, bioremediation, software development, long term monitoring, non-point source studies

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INSTRUCTORS: *Vangelas, Looney, Farhat*

- **Karen Vangelas, Savannah River National Lab**
  - M.S. Environmental Engineering, Penn State
  - Groundwater, remediation
- **Brian Looney, Savannah River National Lab**
  - Ph.D. Environmental Engineering, U. of Minnesota
  - Vadose zone, remediation, groundwater modeling
- **Shahla Farhat, GSI Environmental**
  - Ph.D. Environmental Engineering, U. of North Carolina
  - Decision support tools, remediation, modeling

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BREAK FOR RESPONSES TO MODULE 3 QUESTIONS FROM PARTICIPANTS

Agenda

- **Class Objectives**
- **What Tools are Out There?**
- ***What Are the Key Questions?***
  - *Will Source Remediation Meet Site Goals?*
  - *What Will Happen if No Action is Taken?*
  - *Should I Combine Source and Plume Remediation?*
  - *What is the Remediation Time-Frame?*
  - *What is a Reasonable Remediation Objective?*
- **Wrap-Up**

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Simple Example: Change source, What is the Change in Plume Length?

- If we look at the long-term behavior of a plume with a source that has Γ=1, we find that source concentrations drop in proportion to the amount of remediation.
- Example: remove 90% of source, plume concentrations will eventually also drop by about 90%.
- This causes plumes to get shorter, but not by that much, even though the plume mass drops by 90%.

Example: Change source, What is the change in plume length?

Full plume differential equation

$$R\frac{\partial C}{\partial t} = -v\frac{\partial C}{\partial x} + \alpha_L \frac{\partial^2 C}{\partial x^2} + \alpha_T \frac{\partial^2 C}{\partial y^2} + \alpha_Z \frac{\partial^2 C}{\partial z^2} - \lambda C$$

Assume steady state, neglect dispersion

$$0 = -v\frac{\partial C}{\partial x} - \lambda C \qquad \frac{dC}{dx} = -\frac{\lambda}{v} C$$

$$at\ x = 0, \quad C = C_0$$

Solution

$$\ln\frac{C}{C_0} = \frac{-\lambda x}{v}$$

Example: How Much of the Source Needs to be Removed to Shrink Plume?

Analysis of leading order behavior from Falta et al., 2005: Assume linear response of discharge to source mass reduction and neglect dispersion. With prompt removal of "X" of the DNAPL, maximum plume length is

$$x = \frac{-v}{\lambda} \ln\left(\frac{C}{C_0(1-X)}\right)$$

Percent reduction in maximum plume length	20%	50%	70%	80%	90%
$C/C_0=10^{-2}$	0.60	0.90	0.96	0.975	0.984
$C/C_0=10^{-3}$	0.75	0.968	0.992	0.996	0.998
$C/C_0=10^{-4}$	0.84	0.990	0.998	0.9994	0.9997

Simple Example: Change Source, What is the Change in Plume Length?

Try $v = 60$ m/yr, $\lambda = .139$ yr^{-1}, $C_0 = 50{,}000$ ug/L, $C = 5$ ug/L, $X = 0.9$

(a) No remediation, x = ? (3976 m)

(b) Remove 90%, x = ? (2982 m)

So while the source remediation would reduce the plume mass by 90%, it would only reduce the plume length (as defined by C) by 25%.

Simple Example: *What if We Add Plume Remediation Here?*

Take the case with 90% source removal, and simulate plume remediation by increasing the plume decay rate by a factor of 3 to 0.417 yr^{-1}

a) No remediation, x=? (3976 m)

b) Remove 90%, x=? (2982 m)

c) Remove 90%, triple the plume decay rate x=? (994 m)

The combination of source and plume remediation reduces the plume length by 75%. However, the plume remediation was assumed to be permanent.

PCE Spill: *Try 2 Different Remediation Schemes with REMChlor, Focusing on Managing the Vinyl Chloride Plume*

1. **Try DNAPL source remediation alone: remove 90% of PCE DNAPL in 2009**
2. **Also include plume remediation:**
   - **set up an enhanced reductive dechlorination zone from 0 to 400 meters.**
   - **an enhanced aerobic degradation zone from 400 to 700 meters, in years 2009 to 2029.**

Should I Combine Source and Plume Remediation?

DNAPL release

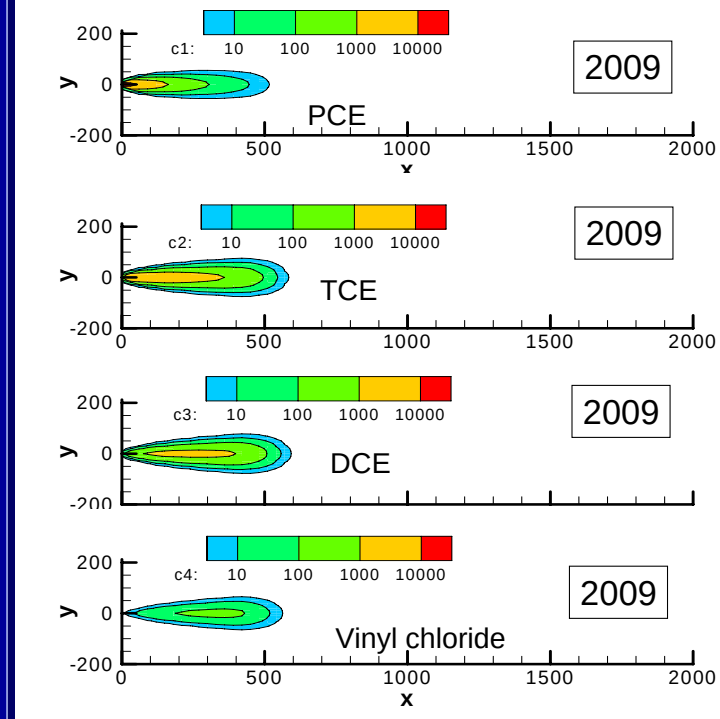
Release of 1620 kg PCE in 1979.

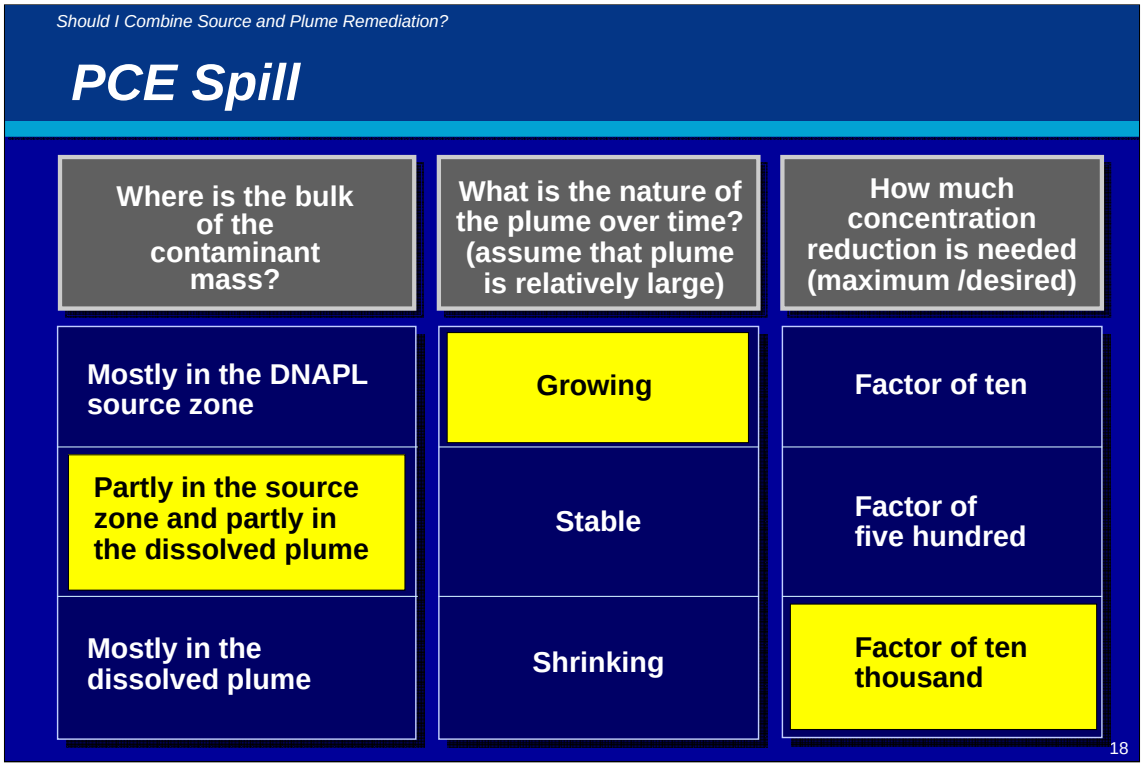
Plume reactions

PCE →TCE →DCE →VC

57% of the PCE DNAPL remains in the source zone

In 2009, plume is growing




Should I Combine Source and Plume Remediation?
PCE Spill
Where is the bulk of the contaminant mass?
What is the nature of the plume over time? (assume that plume is relatively large)
How much concentration reduction is needed (maximum /desired)
Mostly in the DNAPL source zone
Partly in the source zone and partly in the dissolved plume
Mostly in the dissolved plume
Growing
Stable
Shrinking
Factor of ten
Factor of five hundred
Factor of ten thousand
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Hands-On Computer Exercise

NUMBER 3

Now You Try Using REMChlor to Do PCE Spill/Cleanup

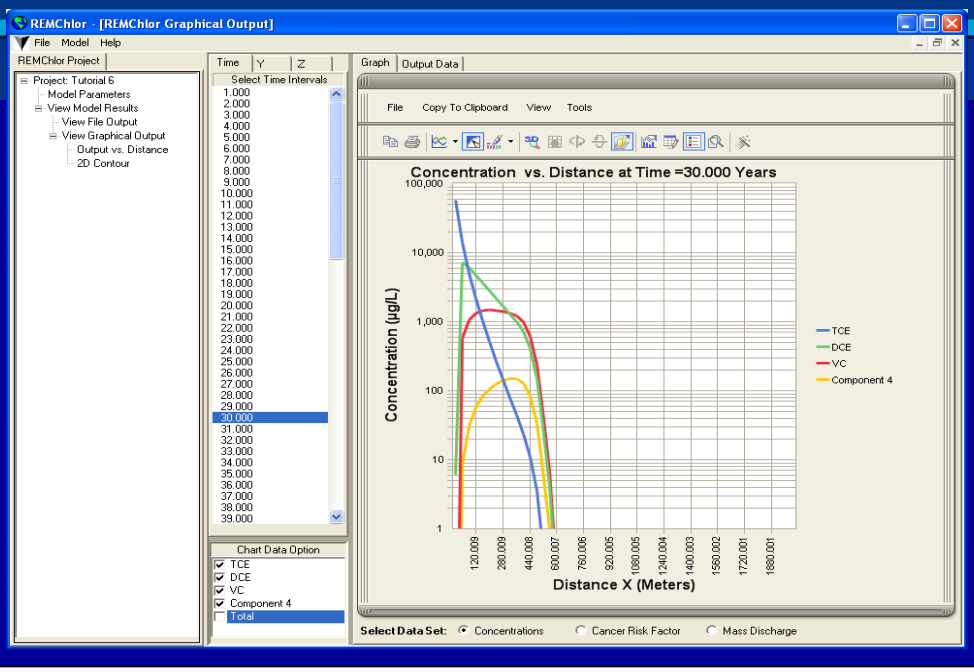
(Tutorials 6, 7, and 8)

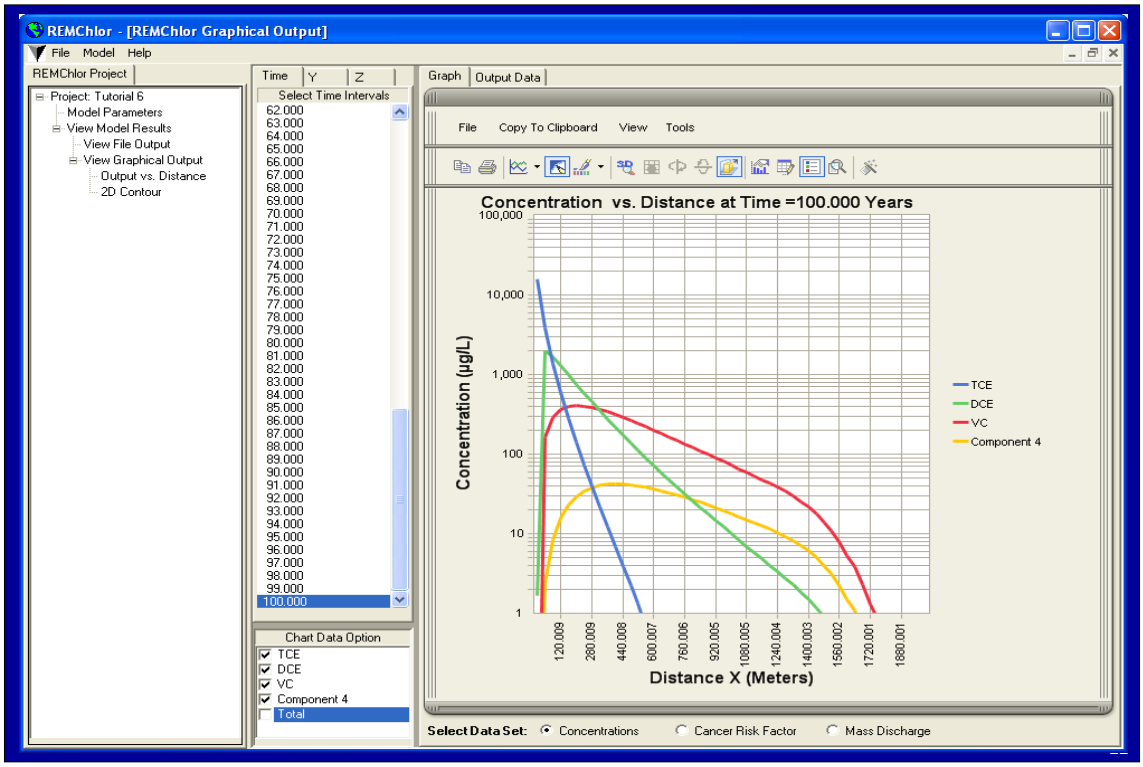
♦

PCE Spill: *Run Simulation to Investigate*

- What will happen if no action is taken?
- Will source remediation meet site goals? How effective must the source remediation be?
- Will enhanced biodegradation of the plume meet site goals? How effective (and long-lived) must the plume treatment be?
- Should I combine source and plume remediation? How much of each do I need before I get transition to MNA?

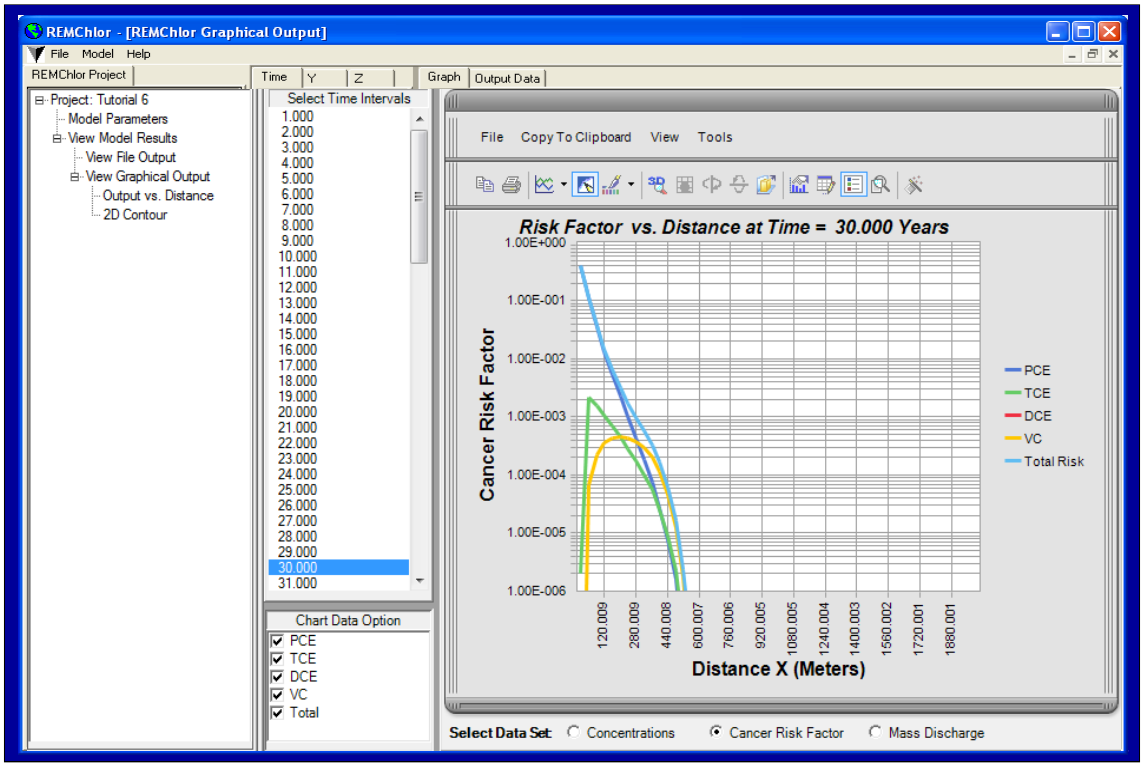
PCE Spill: *No Action Taken (Tutorial 6)*

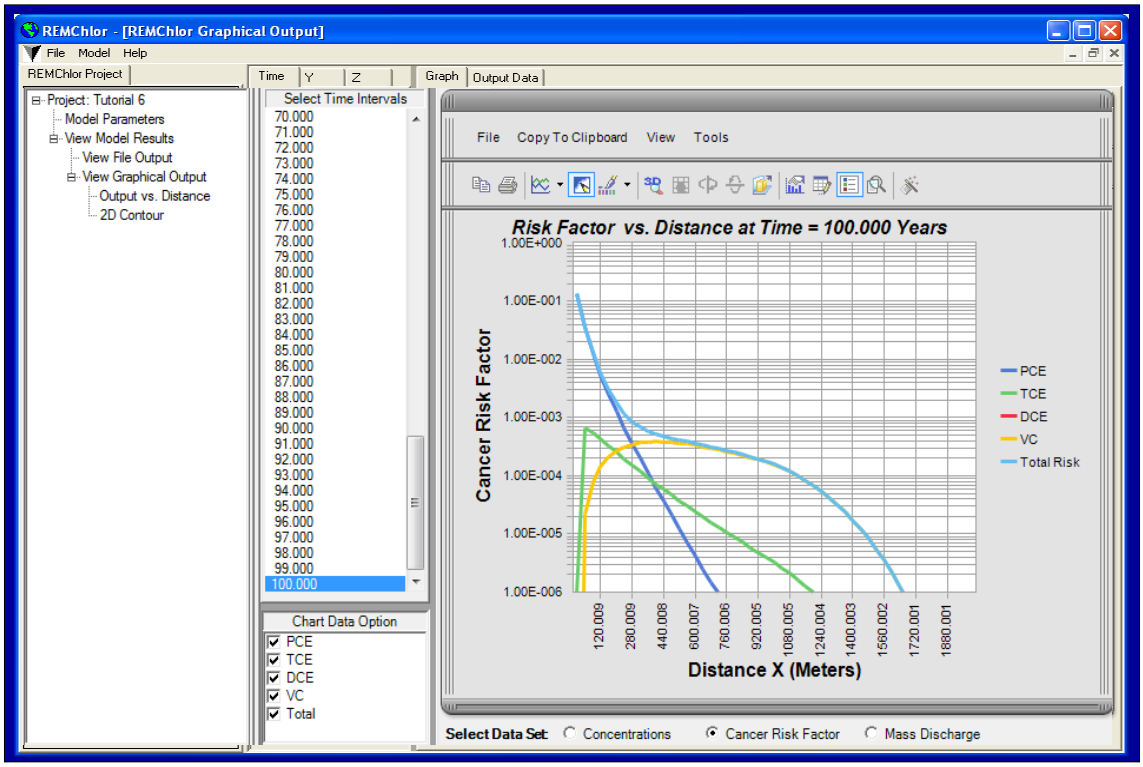



REMChlor - [REMChlor Graphical Output]
File Model Help
REMChlor Project
Project: Tutorial 6
Model Parameters
View Model Results
View File Output
View Graphical Output
Output vs. Distance
2D Contour
Time Y Z
Select Time Intervals
62.000
63.000
64.000
65.000
66.000
67.000
68.000
69.000
70.000
71.000
72.000
73.000
74.000
75.000
76.000
77.000
78.000
79.000
80.000
81.000
82.000
83.000
84.000
85.000
86.000
87.000
88.000
89.000
90.000
91.000
92.000
93.000
94.000
95.000
96.000
97.000
98.000
99.000
100.000
Chart Data Option
TCE
DCE
VC
Component 4
Total
Graph Output Data
File Copy To Clipboard View Tools
Concentration vs. Distance at Time =100.000 Years
Concentration (µg/L)
100,000
10,000
1,000
100
10
1
120.009
280.009
440.008
600.007
760.006
920.005
1080.005
1240.004
1400.003
1560.002
1720.001
1880.001
Distance X (Meters)
TCE
DCE
VC
Component 4
Select Data Set:
Concentrations
Cancer Risk Factor
Mass Discharge

Examine Cancer Risks – *Use Cancer Risk Slope Factors*

Chemical	Inhalation Slope Factor $(mg/kg\text{-}day)^{-1}$	Oral Slope Factor $(mg/kg\text{-}day)^{-1}$
Tetrachloroethylene (PCE)	0.021	0.540
Trichloroethylene (TCE)	0.007	0.013
Cis-1,2-Dichloroethylene (DCE)	not a carcinogen	not a carcinogen
Vinyl chloride (VC)	0.270	0.270

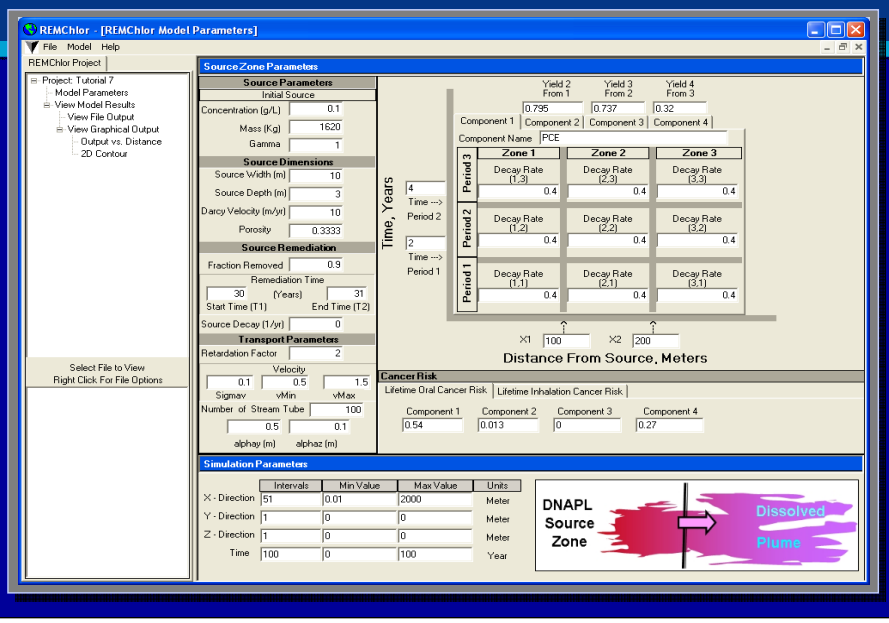

REMChlor - [REMChlor Graphical Output]
File Model Help
REMChlor Project
Project: Tutorial 6
Model Parameters
View Model Results
View File Output
View Graphical Output
Output vs. Distance
2D Contour
Time Y Z
Select Time Intervals
1.000
2.000
3.000
4.000
5.000
6.000
7.000
8.000
9.000
10.000
11.000
12.000
13.000
14.000
15.000
16.000
17.000
18.000
19.000
20.000
21.000
22.000
23.000
24.000
25.000
26.000
27.000
28.000
29.000
30.000
31.000
Chart Data Option
PCE
TCE
DCE
VC
Total
Graph Output Data
File Copy To Clipboard View Tools
Risk Factor vs. Distance at Time = 30.000 Years
Cancer Risk Factor
1.00E+000
1.00E-001
1.00E-002
1.00E-003
1.00E-004
1.00E-005
1.00E-006
120.009
280.009
440.008
600.007
760.006
920.005
1080.005
1240.004
1400.003
1560.002
1720.001
1880.001
Distance X (Meters)
PCE
TCE
DCE
VC
Total Risk
Select Data Set: Concentrations Cancer Risk Factor Mass Discharge


REMChlor - [REMChlor Graphical Output]
File Model Help
REMChlor Project
Project: Tutorial 6
Model Parameters
View Model Results
View File Output
View Graphical Output
Output vs. Distance
2D Contour
Time Y Z
Select Time Intervals
70.000
71.000
72.000
73.000
74.000
75.000
76.000
77.000
78.000
79.000
80.000
81.000
82.000
83.000
84.000
85.000
86.000
87.000
88.000
89.000
90.000
91.000
92.000
93.000
94.000
95.000
96.000
97.000
98.000
99.000
100.000
Chart Data Option
PCE
TCE
DCE
VC
Total
Graph Output Data
File Copy To Clipboard View Tools
Risk Factor vs. Distance at Time = 100.000 Years
Cancer Risk Factor
1.00E+000
1.00E-001
1.00E-002
1.00E-003
1.00E-004
1.00E-005
1.00E-006
120.009
280.009
440.008
600.007
760.006
920.005
1080.005
1240.004
1400.003
1560.002
1720.001
1880.001
Distance X (Meters)
PCE
TCE
DCE
VC
Total Risk
Select Data Set: Concentrations Cancer Risk Factor Mass Discharge

Now: *Try 2 Different Remediation Schemes with REMChlor, Focusing on Managing the Vinyl Chloride Plume*

1. **Try DNAPL source remediation alone: remove 90% of PCE DNAPL in 2009**
2. **Then include plume remediation:**
   - **set up an enhanced reductive dechlorination zone from 0 to 400 meters.**
   - **an enhanced aerobic degradation zone from 400 to 700 meters, in years 2009 to 2029.**

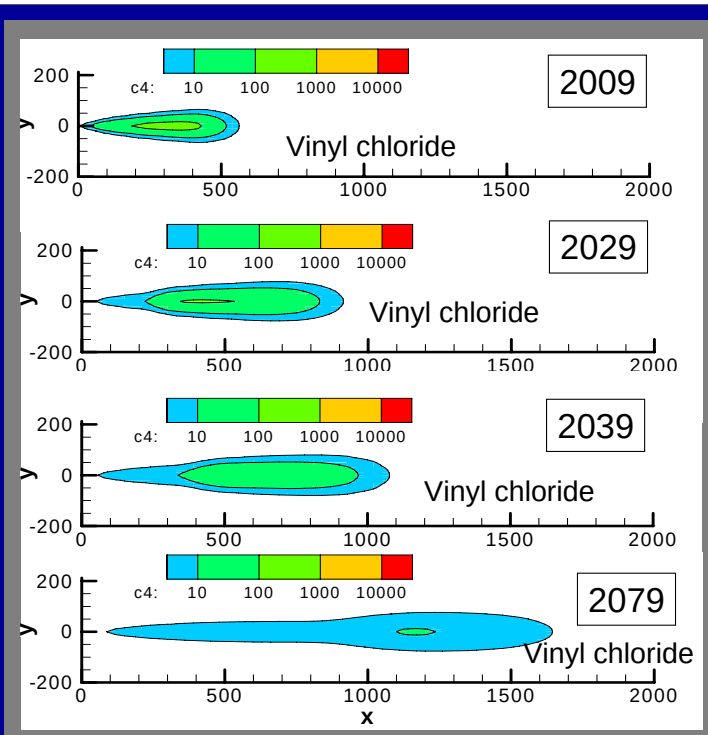
PCE Spill: *Simulate Source Remediation (modify Tutorial 6 or use Tutorial 7)*



PCE Spill

Source Remediation: Remove 90% of the remaining PCE DNAPL in 2009.

Only the vinyl chloride plume is shown.



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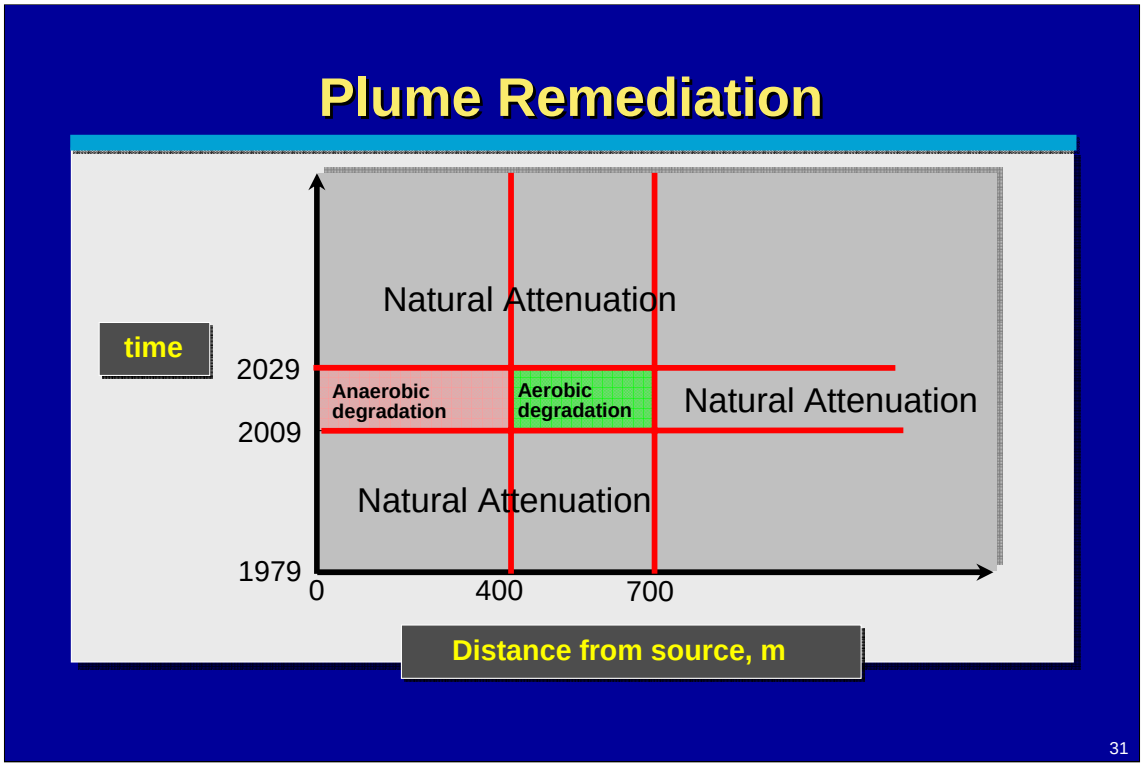
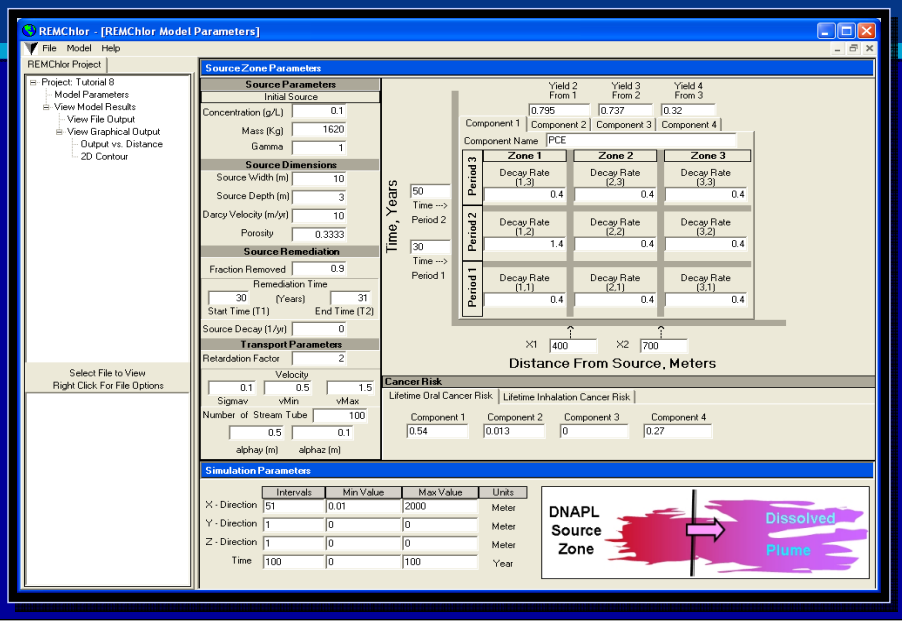
BREAK FOR QUESTIONS FROM PARTICIPANTS

PCE Spill: *Add Plume Remediation (modify Tutorial 6 or use Tutorial 8)*

- (A) Set up an enhanced reductive dechlorination zone 0-400 meters from 2009 to 2029.
- Increase PCE decay rate from 0.4 to 1.4 yr^{-1}, TCE from 0.15 to 1.5 yr^{-1}, and DCE from 0.1 to 0.2 yr^{-1}. No change in VC decay.
- (B) Set up an enhanced aerobic degradation zone from 400-700 meters, from 2009 to 2029.
- Increase DCE decay rate from 0.1 to 3.5 yr^{-1}, and VC decay rate from 0.2 to 3.6 yr^{-1}. PCE and TCE decay rates remain at background levels.


Plume Remediation
time
2029
2009
1979
Natural Attenuation
Anaerobic degradation
Aerobic degradation
Natural Attenuation
Natural Attenuation
0
400
700
Distance from source, m
31

PCE Spill: *Combined Source and Plume Remediation*



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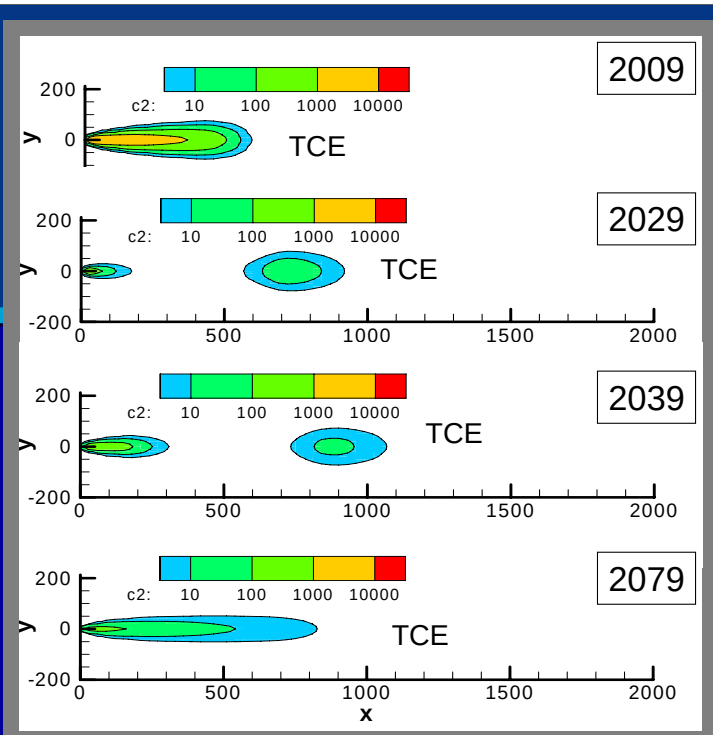
PCE Spill

Source and Plume Remediation

Only the TCE plume is shown here



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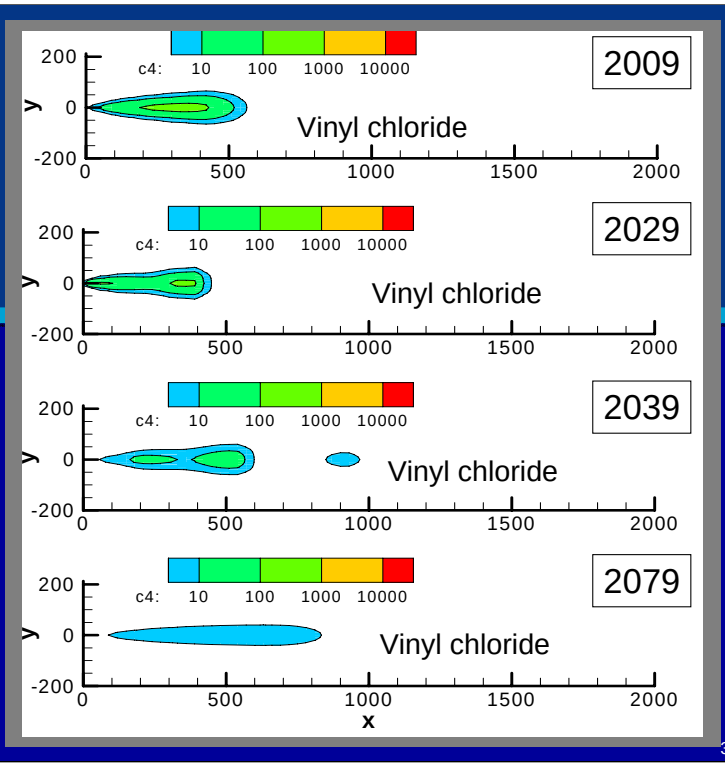
PCE Spill

Source and Plume Remediation

Only the vinyl chloride plume is shown



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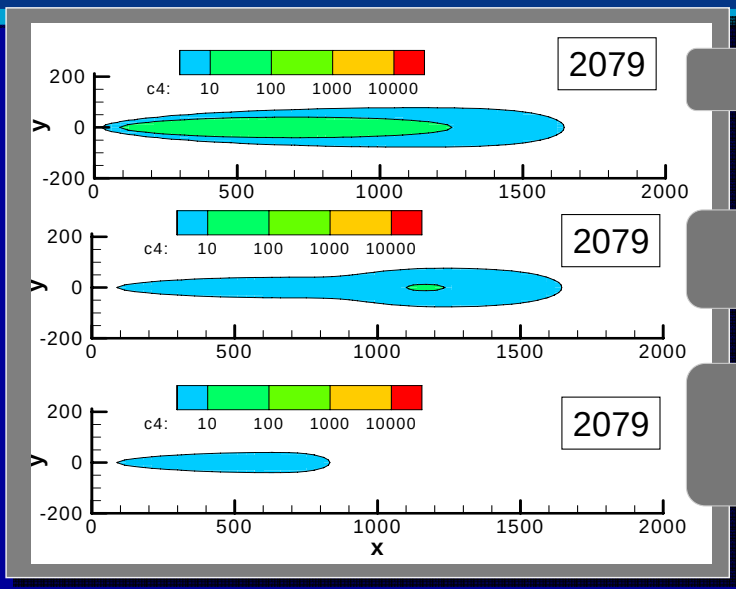
Compare Remediation Effects on Vinyl Chloride Plume



No Remediation

DNAPL Source Remediation

Source and Plume Remediation

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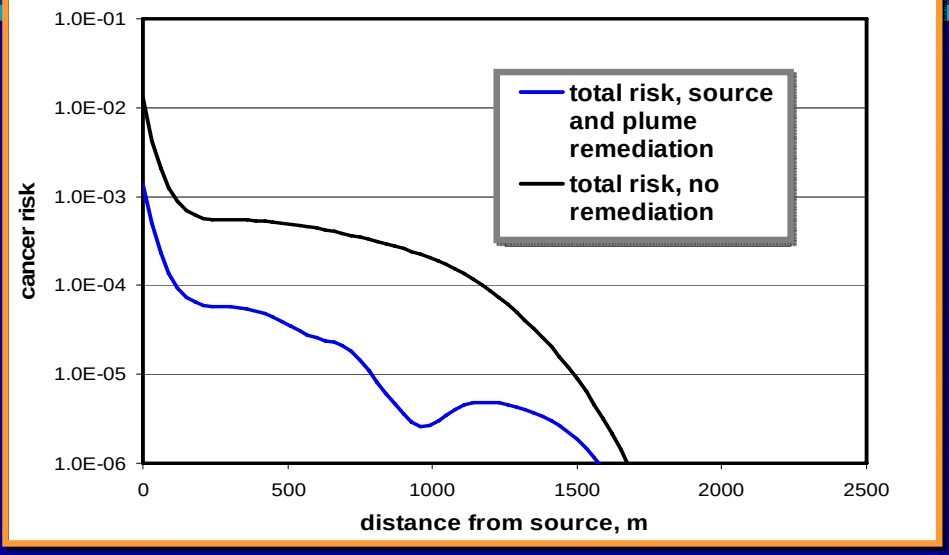
Lifetime Cancer Risks in 2079 (Exposure from 2049-2079)



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Observations on PCE Example

- This case was very difficult because of
  a) The persistent DNAPL source,
  b) The generation of hazardous daughter products in the plume, and
  c) The high source concentrations compared to MCLs.
- Source remediation alone may not be capable of reducing plume extent, although it greatly reduces plume mass.
- A combination of source and plume remediation appears to be capable of reducing the plume extent and longevity.

REMChlor REMFuel Key Points

1. These models allows plume to develop for any number of years before remediation (Neat!) (Very Important).
2. You can simulate three natural reaction zones.
3. You can remediate all or part of the plume by increasing degradation rates for three specific time periods (1 year? 5 years? You pick).
4. The plume will respond to all of these factors:

- natural attenuation processes
- + plume remediation
- + source decay
- + source remediation (eventually!)

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Agenda

- **Class Objectives**
- **What Tools are Out There?**
- ***What Are the Key Questions?***
  - *Will Source Remediation Meet Site Goals?*
  - *What Will Happen if No Action is Taken?*
  - *Should I Combine Source and Plume Remediation?*
  - *What is the Remediation Time-Frame?*
  - *What is a Reasonable Remediation Objective?*
- **Wrap-Up**

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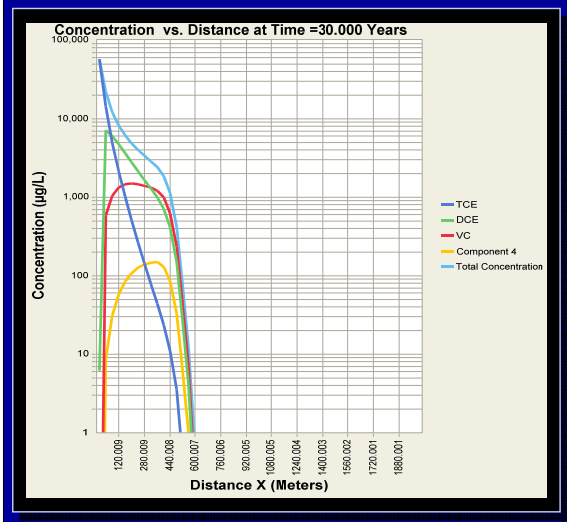
Using REMChlor to Evaluate Remediation Time-Frame

The output from REMChlor simulations can be used to assess various metrics of remediation with respect to time:

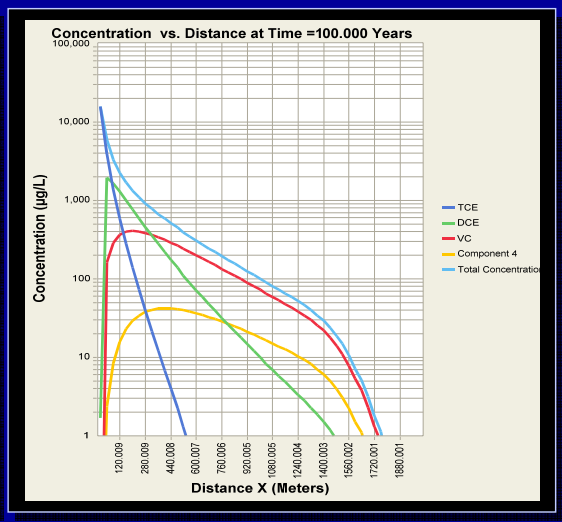
- Source concentration (use small but not zero x)
- Plume concentration of parent and daughter compounds
- Plume discharge of contaminants at different distances
- Lifetime excess cancer risk at different distances

Previous Example: No Action

2009



2079

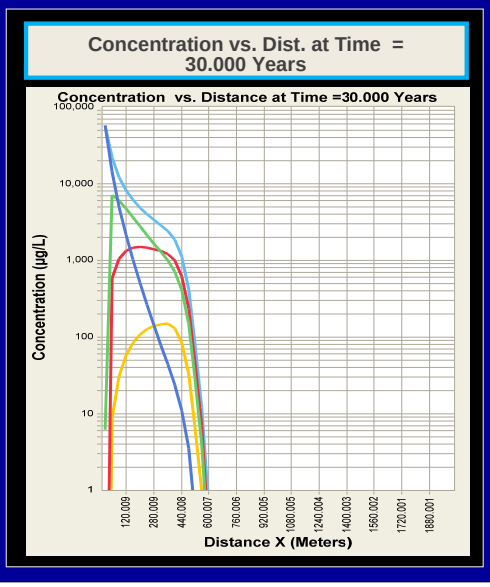


Concentration-Based Goal: Total VOC's do not Exceed 50 ug/L beyond 600 m

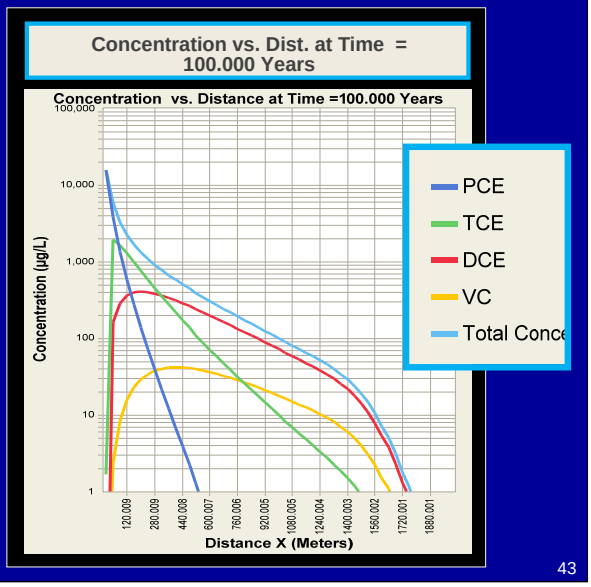
- **With no action, the 50 ug/L concentration contour will continue to grow, and will extend beyond 1200 m in 2079.**
- **This goal will be very challenging to meet because of the many orders of magnitude of concentration reduction required, and because the daughter products are also regulated.**

Previous Example: No Action

2009

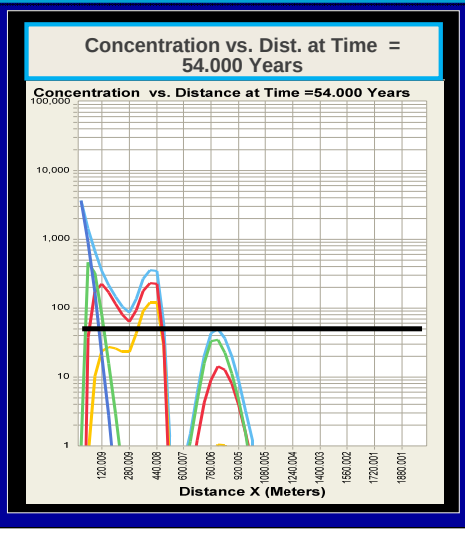


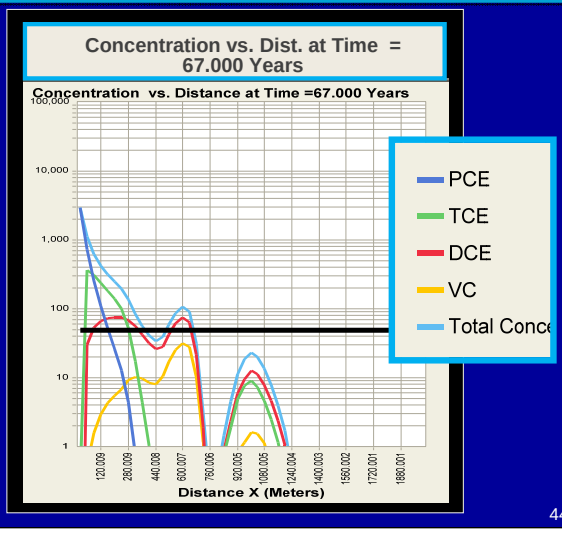
2079



Goal appears to be met at 54 years (2033), but a violation occurs at 67 years (2046)

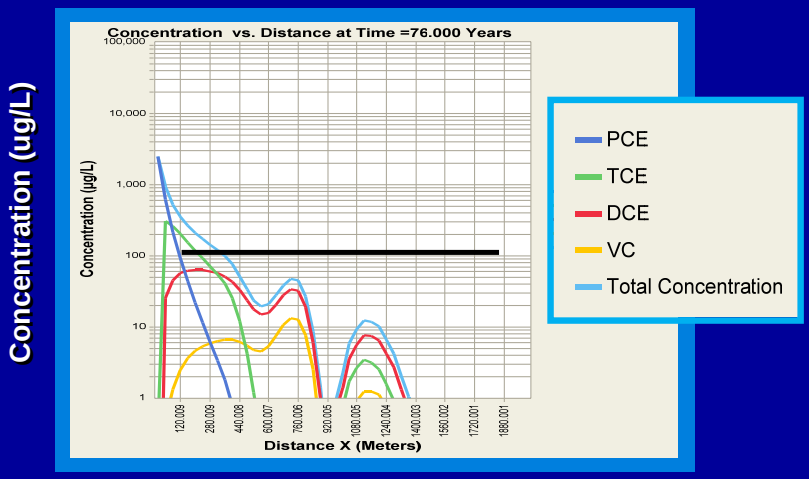
(involves both plume and source remediation)





Goal is finally met after 76 years (2055)

Concentration vs. Dist. at Time = 76.000 Years



Concentration (ug/L)

Distance (meters)

Homework Exercise

NUMBER 2

Impact to a Well

BREAK FOR QUESTIONS FROM PARTICIPANTS

New Ways to stay connected!

- Follow CLU-IN on Facebook, LinkedIn, or Twitter

https://www.facebook.com/EPACleanUpTech

https://twitter.com/#!/EPACleanUpTech

http://www.linkedin.com/groups/Clean-Up-Information-Network-CLUIN-4405740

Resources & Feedback

- To view a complete list of resources for this seminar, please visit the **Additional Resources**
- Please complete the **Feedback Form** to help ensure events like this are offered in the future

Need confirmation of your participation today?

Fill out the feedback form and check box for confirmation email.