Welcome to the CLU-IN Internet Seminar

Practical Models to Support Remediation Strategy Decision-Making - Part 3

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

Delivered: October 24, 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)

Housekeeping

- Entire broadcast offered live via Adobe Connect
  - participants can listen and watch as the presenters advance through materials live
  - *Some materials may be available to download in advance, you are* ***recommended to participate live via the online broadcast***
- Audio is streamed online through by default
  - Use the speaker icon to control online playback
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- Q&A – use the Q&A pod to privately submit comments, questions and report technical problems
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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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You should note that throughout the seminar, we will ask for your feedback. You do not need to wait for Q&A breaks to ask questions or provide comments. To submit comments/questions and report technical problems, please use the ? Icon at the top of your screen. You can move forward/backward in the slides by using the single arrow buttons (left moves back 1 slide, right moves advances 1 slide). The double arrowed buttons will take you to 1st and last slides respectively. You may also advance to any slide using the numbered links that appear on the left side of your screen. The button with a house icon will take you back to main seminar page which displays our agenda, speaker information, links to the slides and additional resources. Lastly, the button with a computer disc can be used to download and save today's presentation materials.

With that, please move to slide 3.

New online broadcast screenshot

Practical Models to Support Remediation Strategy Decision-Making

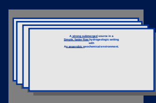
Ronald W. Falta, Ph.D
Brian Looney, Ph.D
Charles J. Newell, Ph.D, P.E.
Karen Vangelas
Shahla K. Farhat, Ph.D

Module 3 - October 2012

Seminar Disclaimer

- **The purpose of this presentation is to stimulate thought and discussion.**
- **Nothing in this presentation is intended to supersede or contravene the National Contingency Plan**

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

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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

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

GSI ENVIRONMENTAL

- **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 2 QUESTIONS FROM PARTICIPANTS

Question 1: *Will Source Remediation Meet Site Goals? General Conclusions*

- Source remediation can often remove 90% to 99.9% of a contaminant from the target volume.
- Source remediation can be expensive.
- Source remediation reduces the contaminant discharge that feeds the plume.
- It takes time for the plume to respond.

Question 1: Will Source Remediation Meet Site Goals? (cont'd)

- **Source remediation shortens the life of the source.**
- **Source remediation rarely achieves drinking water standards in the source zone immediately after deployment.**
- **The likely response of a plume to source remediation can be modeled using REMChlor or REMFuel.**

Will Source Remediation Meet Site Goals?

General Characteristics of Sites

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 NAPL source zone	Growing	Factor of ten
Partly in the source zone and partly in the dissolved plume	Stable	Factor of five hundred
Mostly in the dissolved plume	Shrinking	Factor of ten thousand

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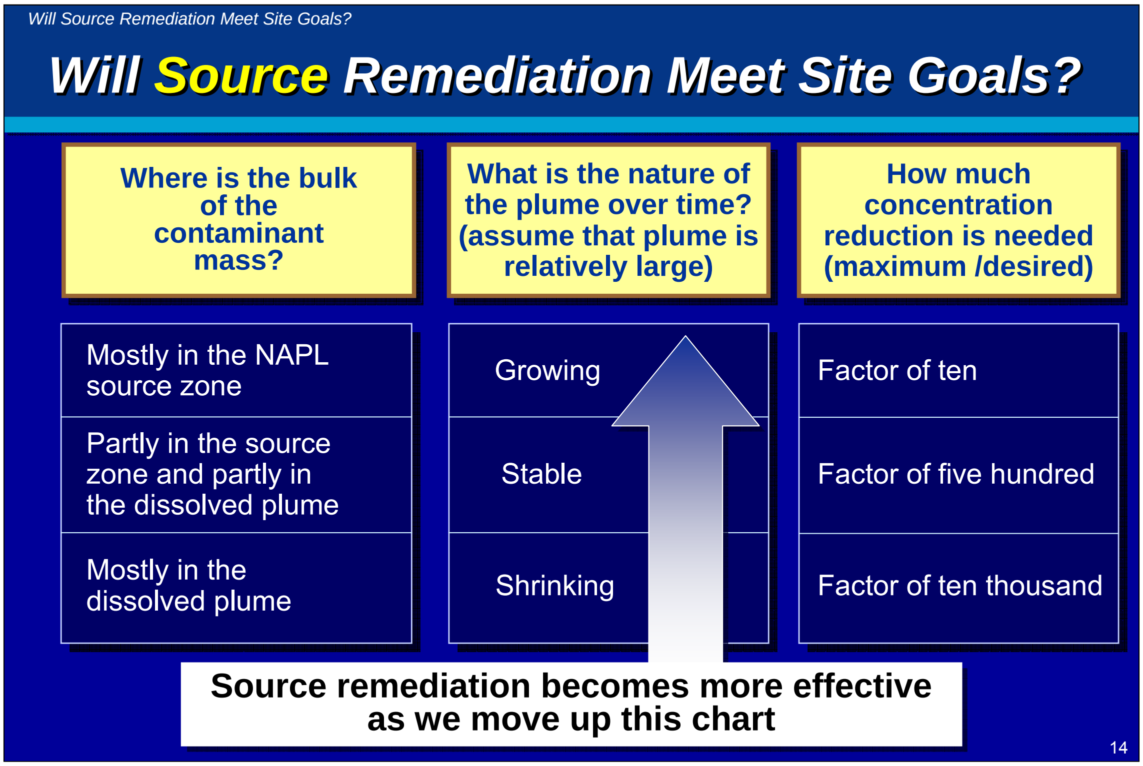
Will Source Remediation Meet Site Goals?
Will Source Remediation Meet Site Goals?
Where is the bulk of the contaminant mass?
What is the nature of the plume over time? (assume that plume is relatively large)
How much concentration reduction is needed (maximum /desired)
Mostly in the NAPL source zone
Growing
Factor of ten
Partly in the source zone and partly in the dissolved plume
Stable
Factor of five hundred
Mostly in the dissolved plume
Shrinking
Factor of ten thousand
Source remediation becomes more effective as we move up this chart
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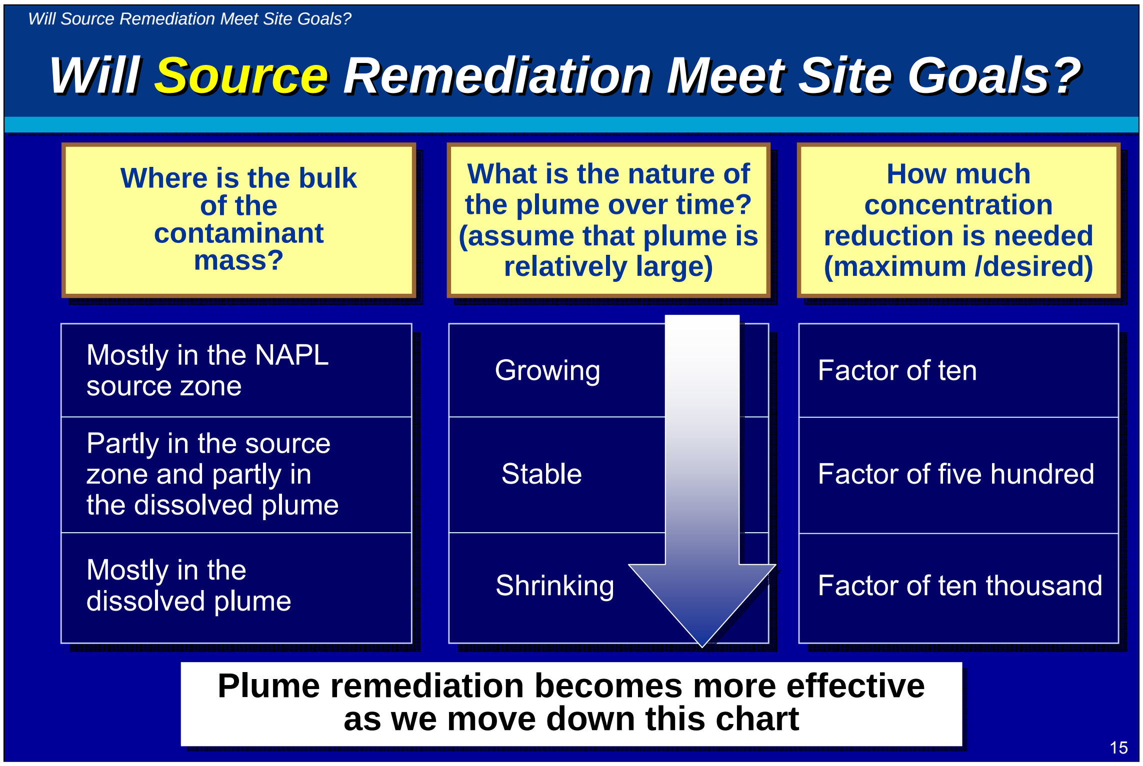
Will Source Remediation Meet Site Goals?
Will Source Remediation Meet Site Goals?
Where is the bulk of the contaminant mass?
What is the nature of the plume over time? (assume that plume is relatively large)
How much concentration reduction is needed (maximum /desired)
Mostly in the NAPL source zone
Growing
Factor of ten
Partly in the source zone and partly in the dissolved plume
Stable
Factor of five hundred
Mostly in the dissolved plume
Shrinking
Factor of ten thousand
Plume remediation becomes more effective as we move down this chart
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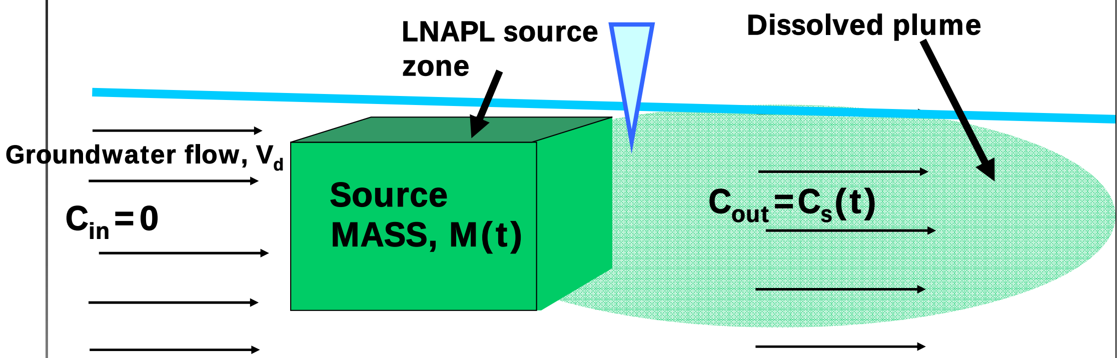
REMFuel

- New EPA model for UST sites (2012)
- It's FREE - download from EPA website
- Based on the REMChlor model for chlorinated sites (released in 2007)
- REMFuel extends REMChlor capability to model multiple hydrocarbons (BTEX) and additives (MTBE, EDB, DCA)
- Considers remediation of both the LNAPL source and the dissolved plumes

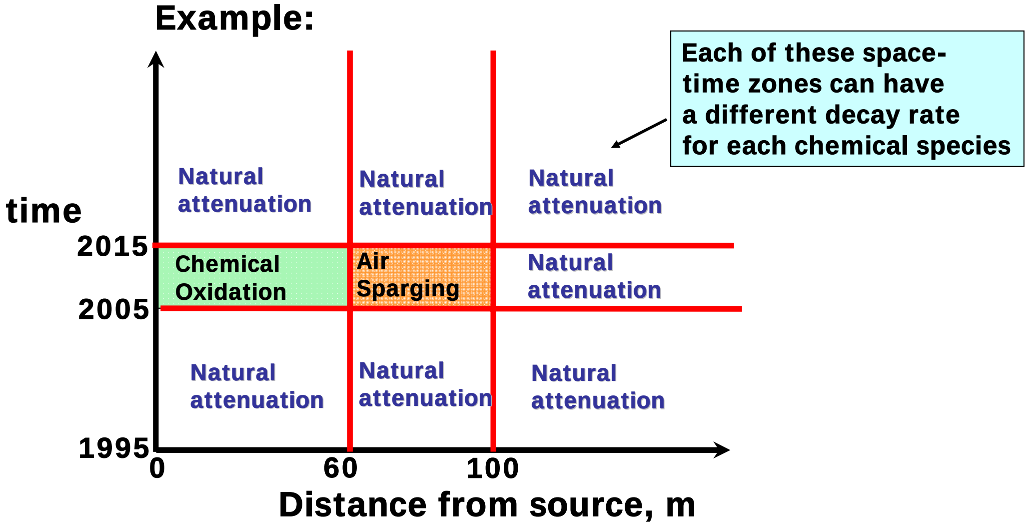
Source conceptual model is the same: Mass is mainly removed by flushing, and biodegradation in aqueous phase. **Remediation is simulated by removing a fraction of the source mass at the time of remediation**



$$\frac{dM(t)}{dt} = -Q(t)C_s(t) - \phi\forall\lambda_s C_s(t) \qquad C_s(t) = C_0\left(\frac{M(t)}{M_0}\right)^{\Gamma}$$

Plume Remediation Model – divide space and time into "reaction zones", solve the degradation reactions for each dissolved component in each zone

Example:



Consider coupled parent-daughter reactions in the plume

For example, we could model first order decay of MTBE into TBA:

$$rxn_{MTBE} = -\lambda_{MTBE} C_{MTBE}$$
$$rxn_{TBA} = y_{TBA/MTBE} \lambda_{MTBE} C_{MTBE} - \lambda_{TBA} C_{TBA}$$

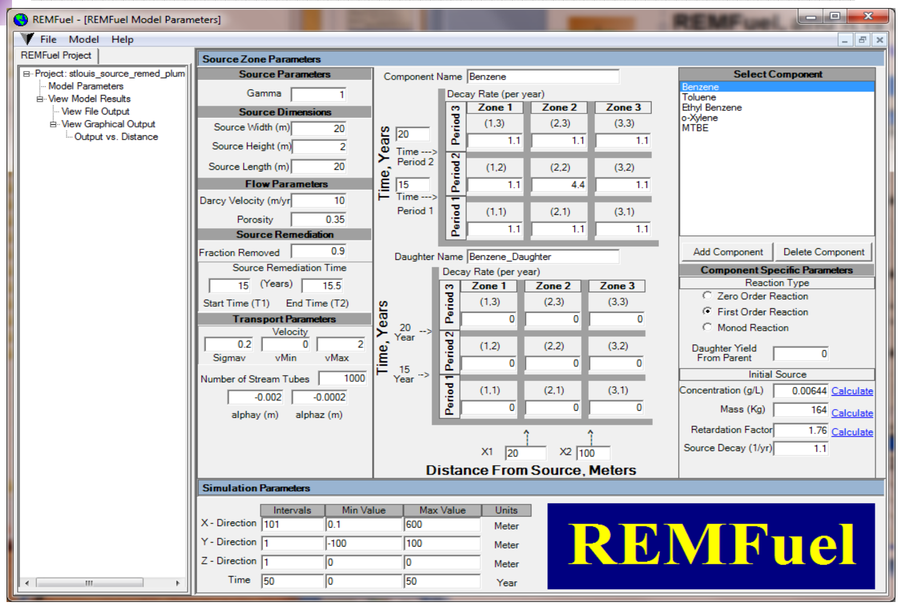
We would like for all of these decay rate constants to be functions of distance and time.

This lets us simulate enhanced plume remediation downgradient from the source

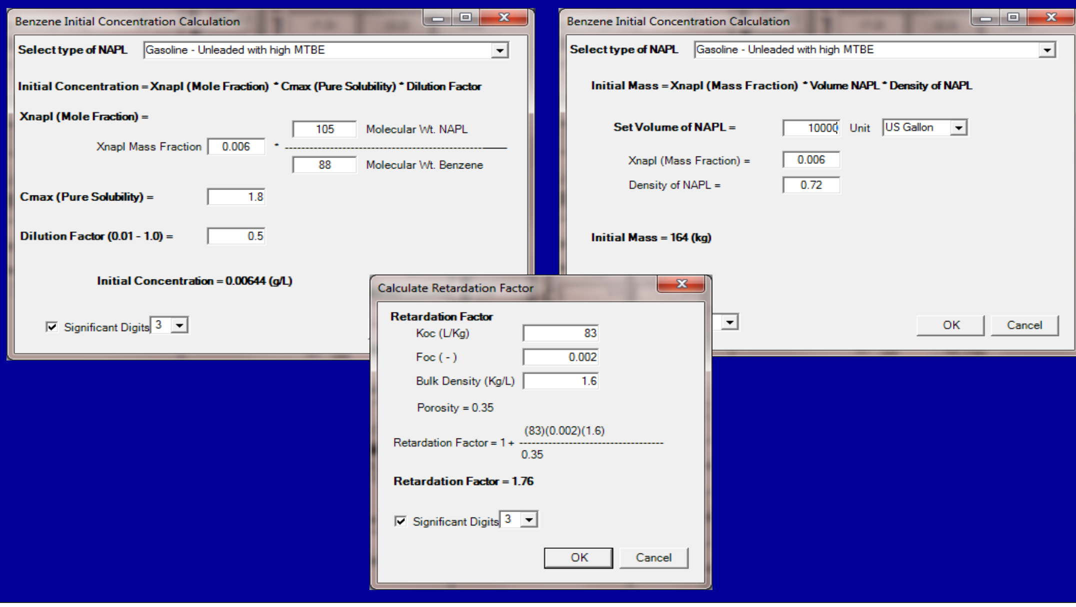
REMFuel also can model zero-order and Monod kinetics in the plume zone

CLEMSON UNIVERSITY

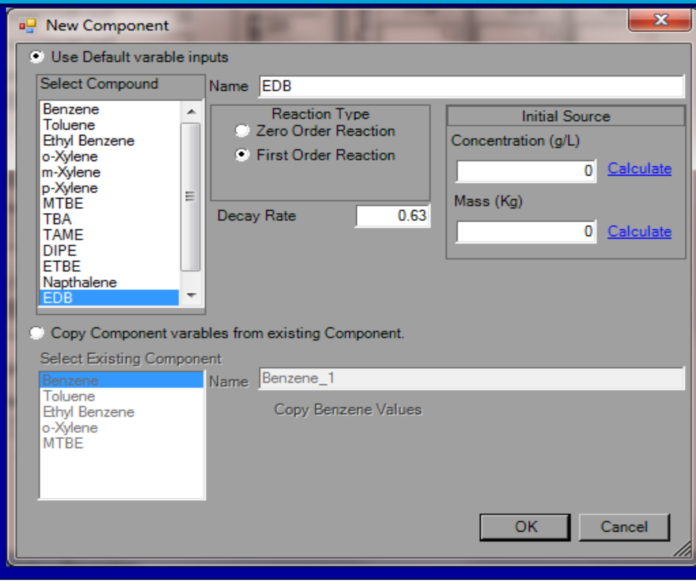
REMFuel interface is similar to REMChlor with a few important differences



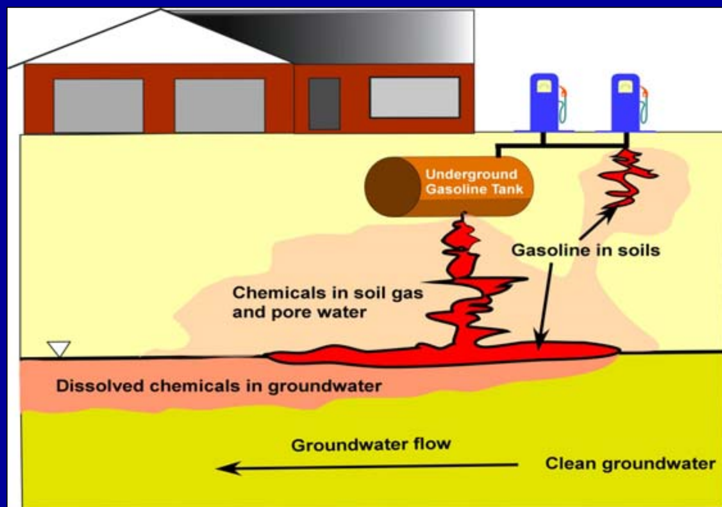
Built-in calculators for LNAPL components – mass, concentration, R. Database is also in User's Guide



LNAPL components can be chosen from built-in library or created; REMFuel can handle up to 20 at once (plus a degradation daughter product for each one)



Example: ***10,000 gallons of gasoline released in 1997, (unleaded regular with high MTBE). Groundwater pore velocity is 94 ft/yr, moderate degradation in plume***



Hands-On Computer Exercise

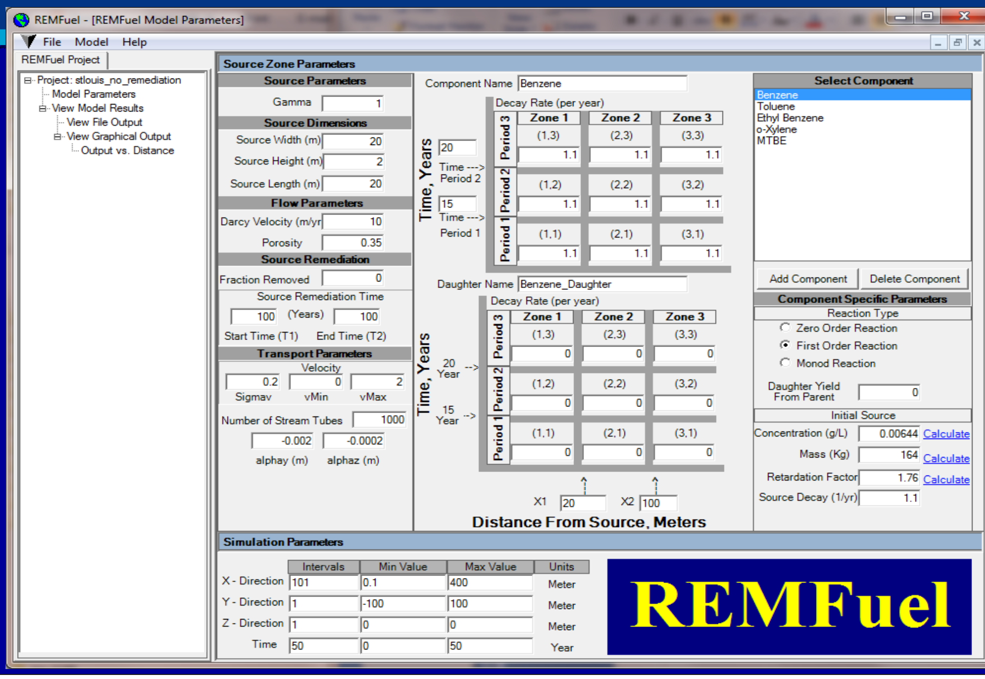
NUMBER 2

Now You Try Using REMFuel For a Site

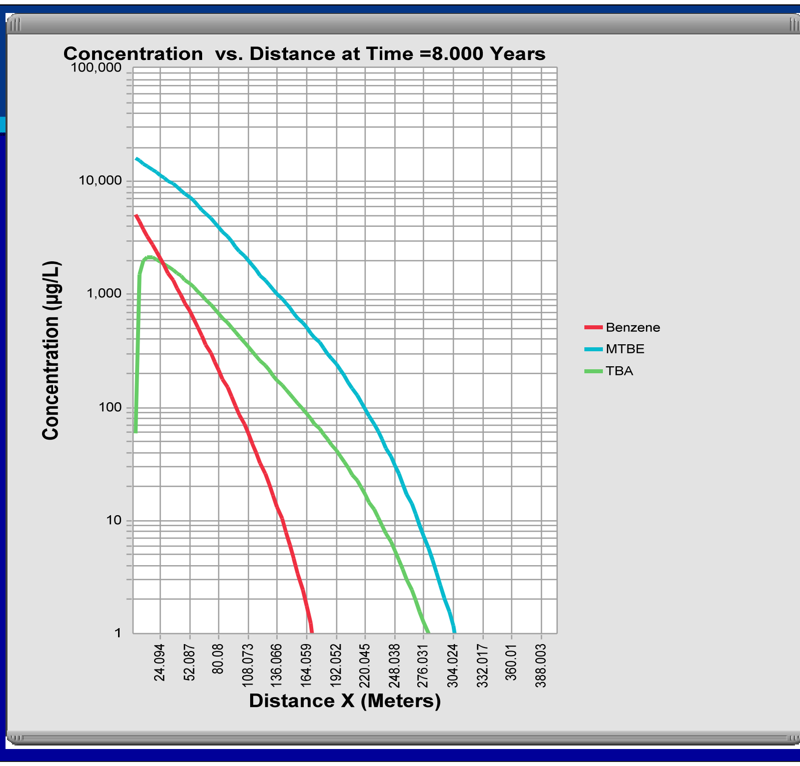
♦

Questions answered:
What will happen if no action taken?
Will source and plume remediation meet site goals?

Enter Source and Plume Parameters

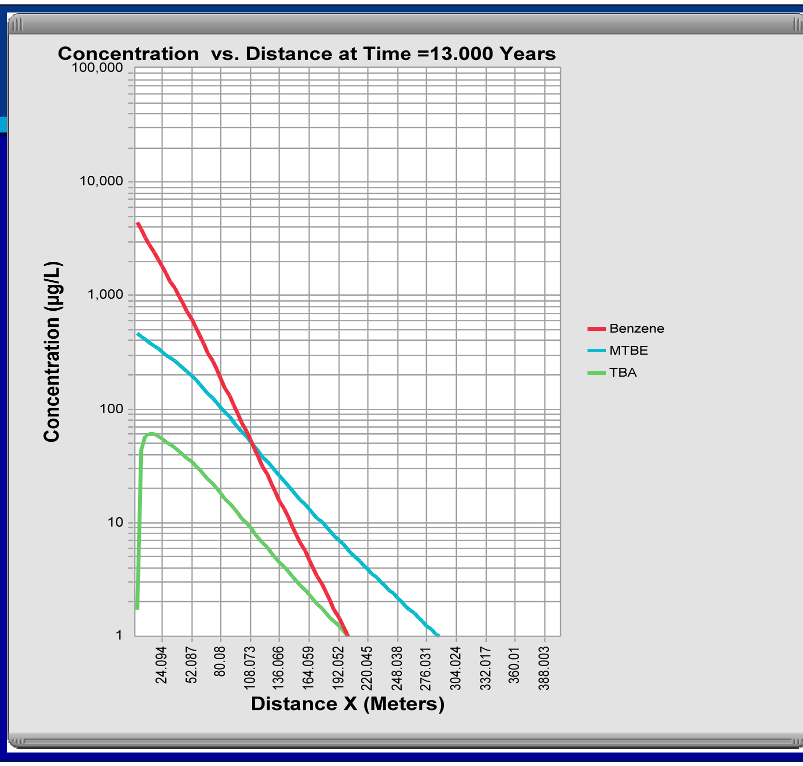


2005 plume



Concentration vs. Distance at Time =8.000 Years
100,000
10,000
1,000
100
10
1
Concentration (µg/L)
24.094
52.087
80.08
108.073
136.066
164.059
192.052
220.045
248.038
276.031
304.024
332.017
360.01
388.003
Distance X (Meters)
Benzene
MTBE
TBA

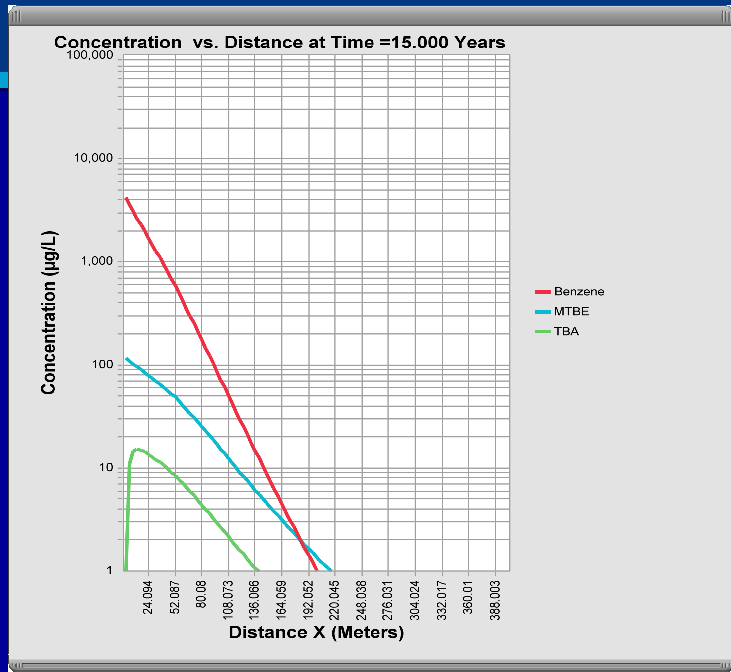
2010 plume



Concentration vs. Distance at Time =13.000 Years
100,000
10,000
1,000
100
10
1
Concentration (µg/L)
24.094
52.087
80.08
108.073
136.066
164.059
192.052
220.045
248.038
276.031
304.024
332.017
360.01
388.003
Distance X (Meters)
Benzene
MTBE
TBA

2012 plume

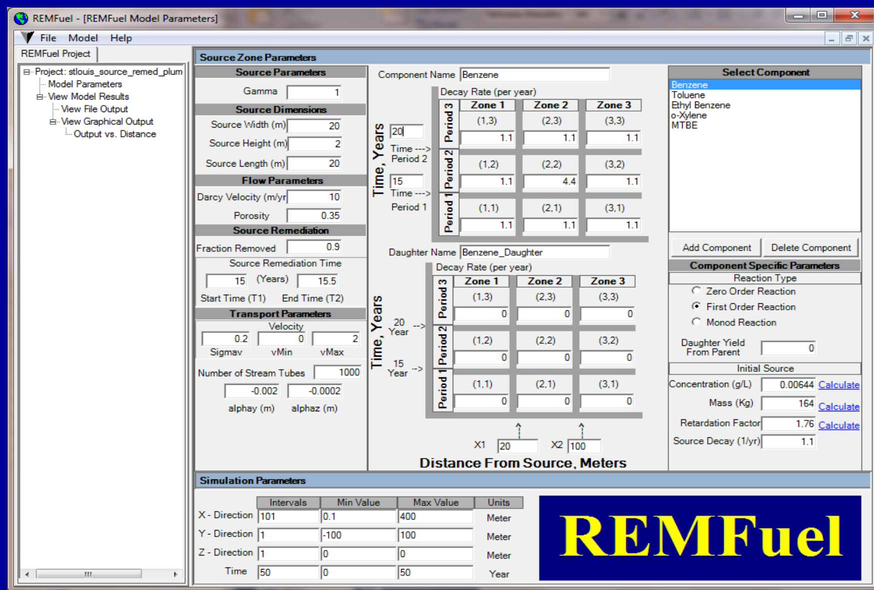
At this site, the MTBE and TBA plumes are shrinking. The benzene plume is stable, and fairly large



Add Source and Plume Remediation

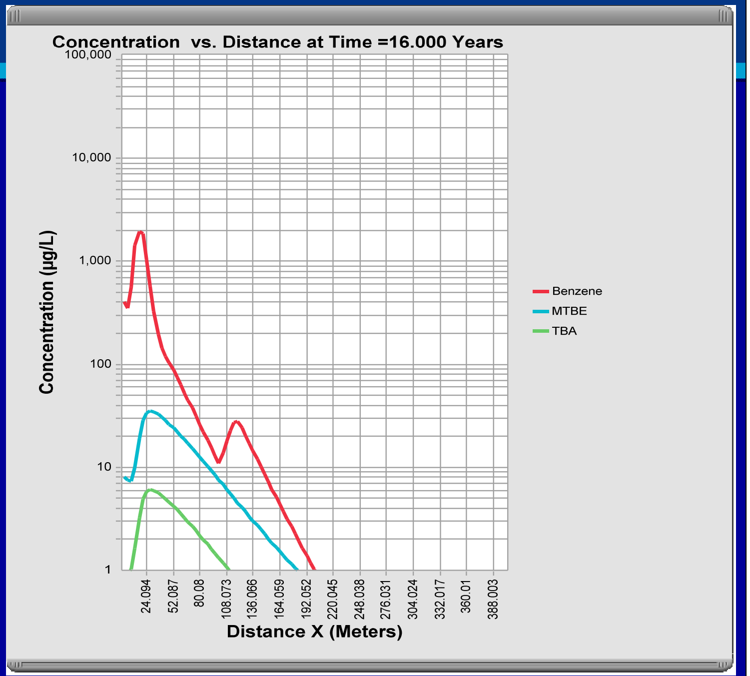
- Simulate aggressive source remediation in 2012, assume we can remove 90% of LNAPL
- Also simulate a plume remediation operation (air sparging, chemical oxidation, etc.) between 20 and 100 m, starting in 2012 and ending in 2017
- Assume plume remediation increases benzene and ethylbenzene decay rates by 4X; no effect on MTBE or TBA

REMFuel Input Page, only need to change a few lines



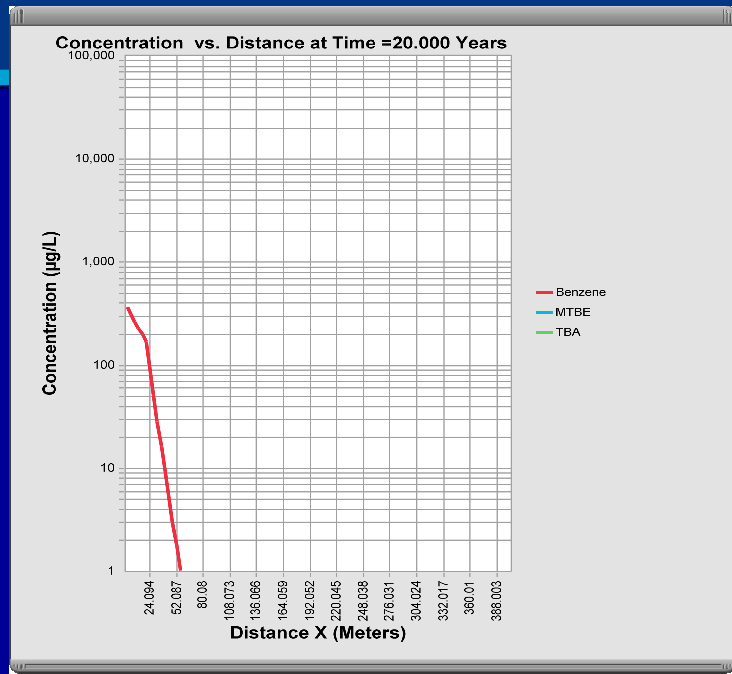
2013 plume

Effect of source remediation seen on benzene and MTBE; plume remediation only affected benzene here (20-100m)



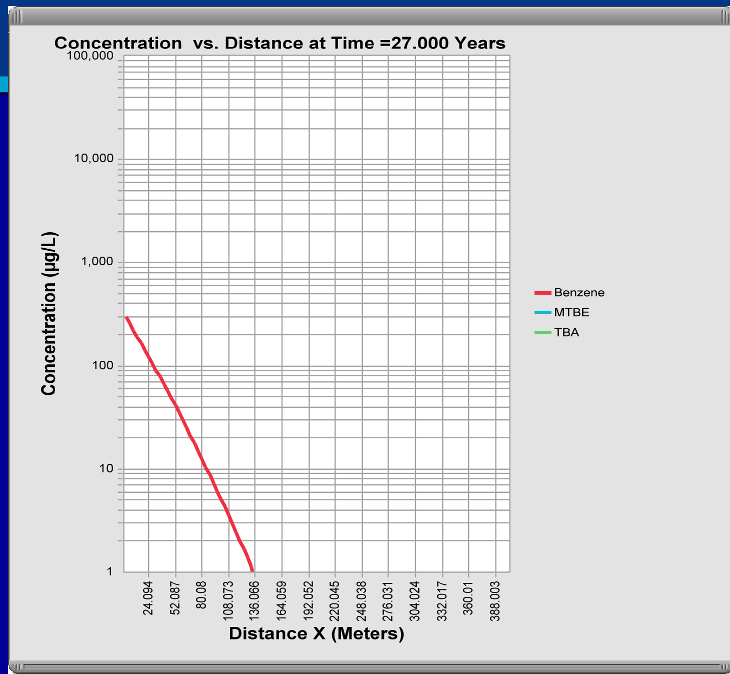
2017 plume

End of plume remediation period, only a short benzene plume left



2024 plume

Benzene plume rebounds a bit after plume remediation is discontinued, because some LNAPL remained in source zone. MTBE has disappeared.



BREAK FOR 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

More Complex Example Model Application – MNA with REMChlor

- Difficult case where natural attenuation is low
- Long-lived PCE source, high discharge to groundwater
- Low rates of PCE-TCE-DCE-VC decay
- Plume is defined by 1 ppb

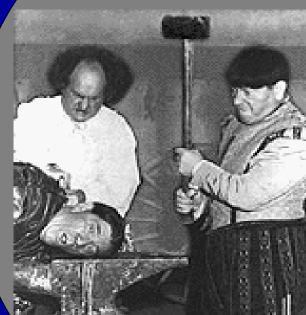
Show Me How It Works

N U M B E R 2

REMChlor Used to Evaluate MNA

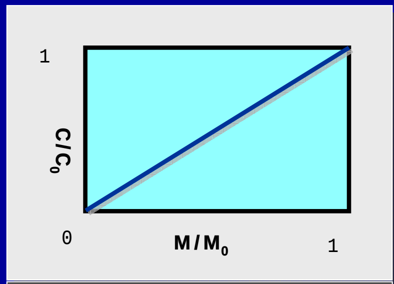
(Tutorial 6)

♦



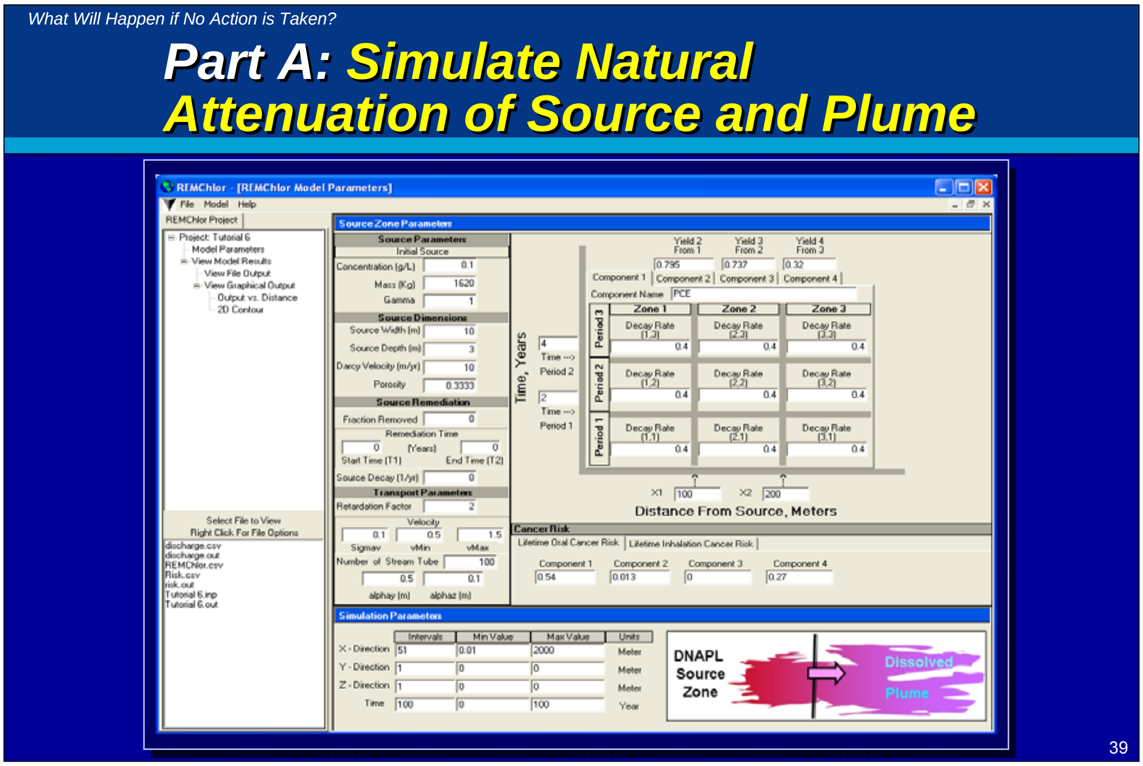
1,620 kg Release of PCE in 1979

- DNAPL source has Γ=1.0, C0=100 mg/L; water flow through source zone is 300 m^3 per year
- Assume reductive dechlorination from PCE → TCE → DCE → VC
- Assume that only ½ of DCE is converted to vinyl chloride (VC) by reductive dechlorination, the other ½ is destroyed
- Ground water pore velocity is 30 m/yr, R=2, decay rates are low: PCE, 0.4 yr^{-1}; TCE, 0.15 yr^{-1}; DCE, 0.1 yr^{-1}; VC, 0.2 yr^{-1}



Initial mass discharge to plume is 30 kg/year.

Plumes are contoured down to 1 ug/L.


What Will Happen if No Action is Taken?
Part A: Simulate Natural Attenuation of Source and Plume
REMChlor - [REMChlor Model Parameters]
Source Zone Parameters
Time, Years
Distance From Source, Meters
Cancer Risk
Simulation Parameters
DNAPL Source Zone
Dissolved Plume
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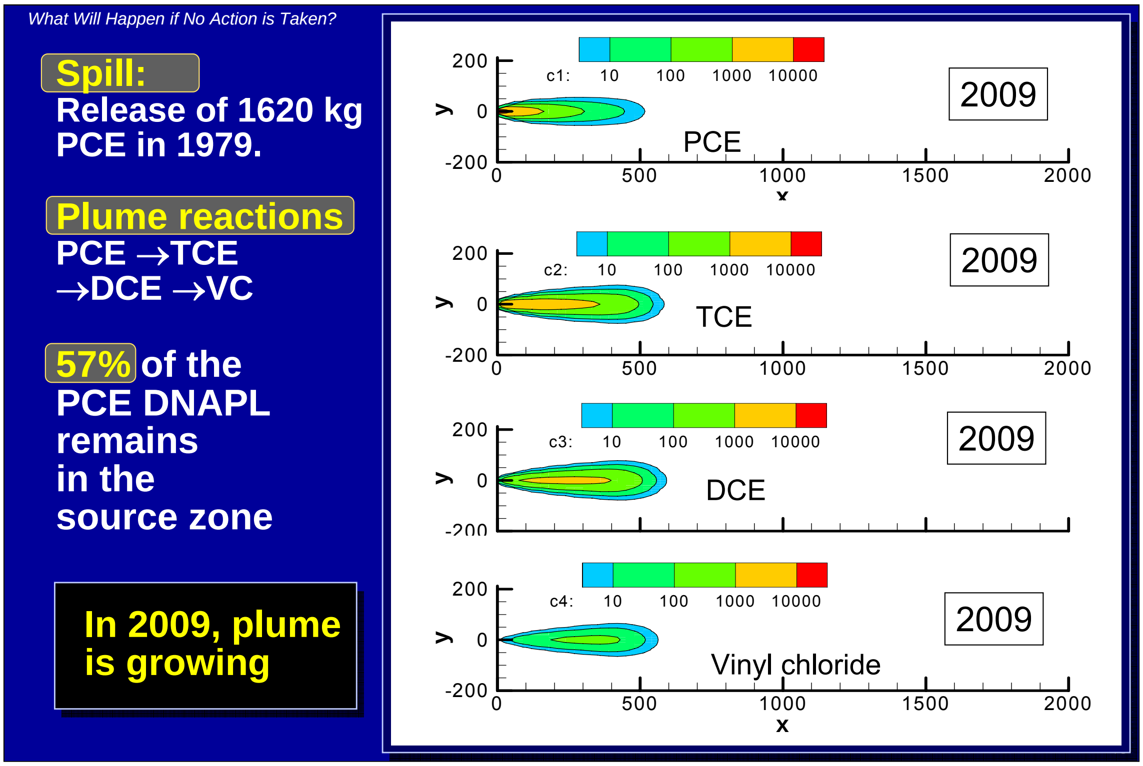
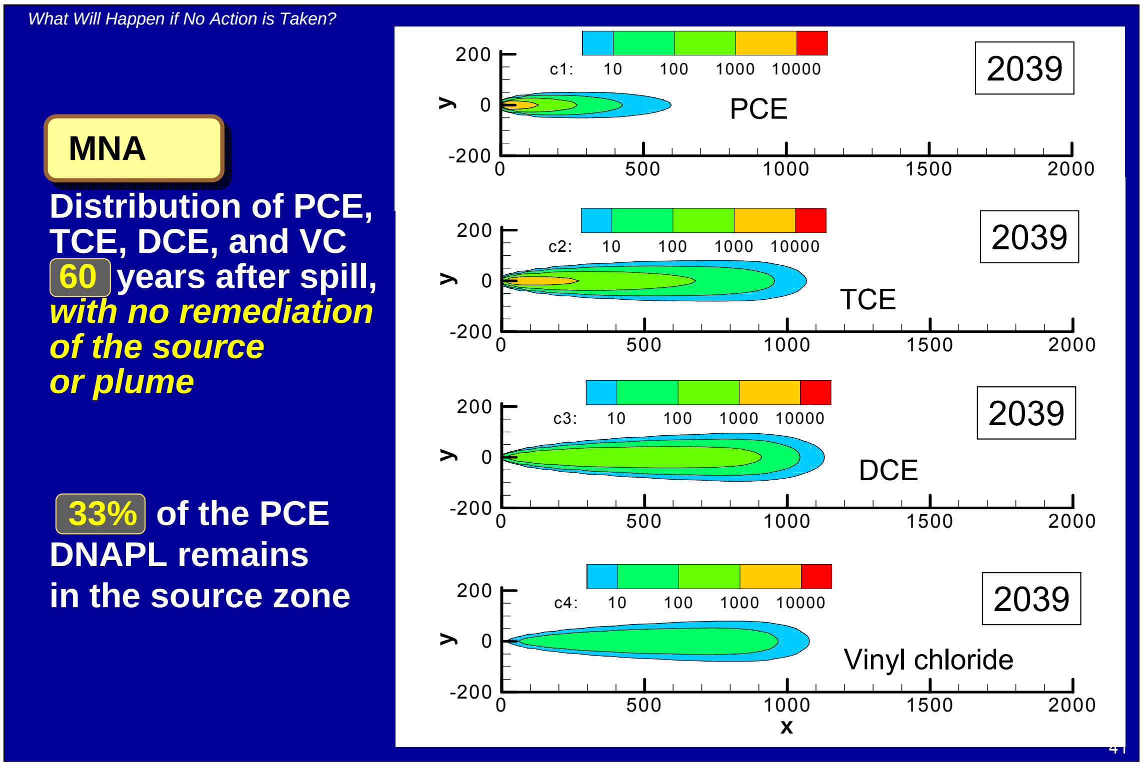
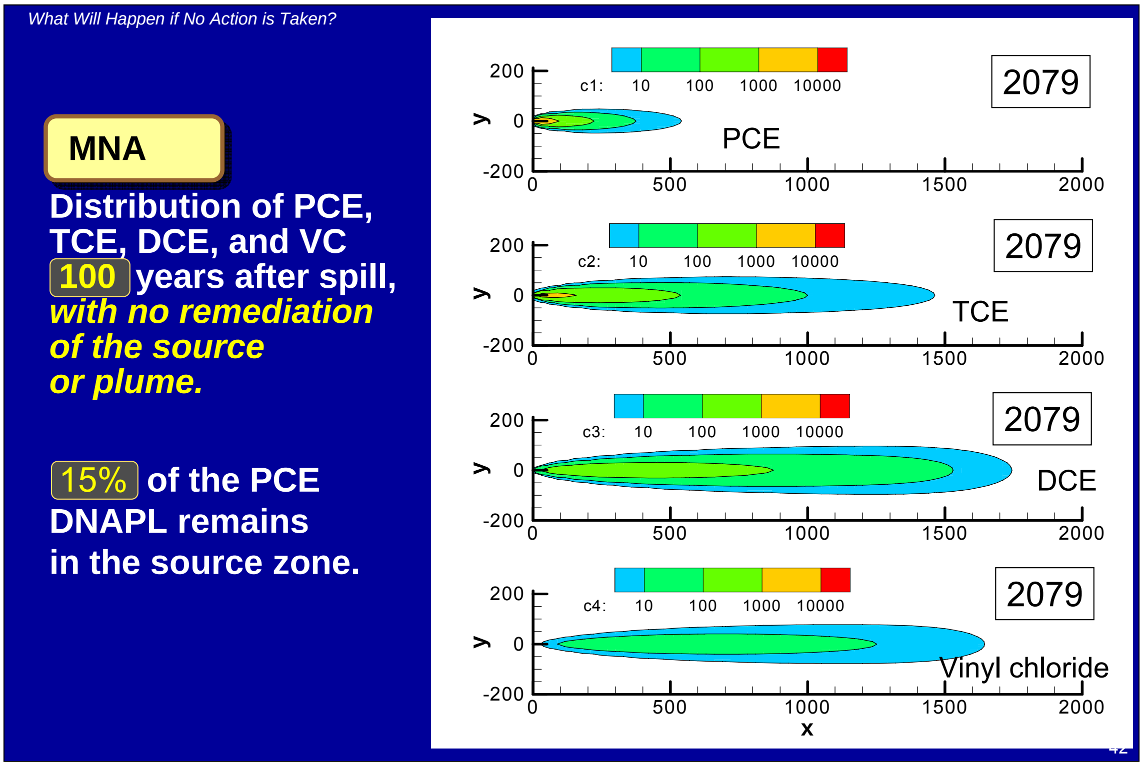

What Will Happen if No Action is Taken?
Spill:
Release of 1620 kg PCE in 1979.
Plume reactions
PCE →TCE →DCE →VC
57% of the PCE DNAPL remains in the source zone
In 2009, plume is growing
c1: 10 100 1000 10000
2009
PCE
c2: 10 100 1000 10000
2009
TCE
c3: 10 100 1000 10000
2009
DCE
c4: 10 100 1000 10000
2009
Vinyl chloride
y
x
200
0
-200
500
1000
1500
2000


What Will Happen if No Action is Taken?
MNA
Distribution of PCE, TCE, DCE, and VC 60 years after spill, with no remediation of the source or plume
33% of the PCE DNAPL remains in the source zone
c1: 10 100 1000 10000
2039
PCE
c2: 10 100 1000 10000
2039
TCE
c3: 10 100 1000 10000
2039
DCE
c4: 10 100 1000 10000
2039
Vinyl chloride
200
0
-200
y
0
500
1000
1500
2000
x


What Will Happen if No Action is Taken?
MNA
Distribution of PCE, TCE, DCE, and VC 100 years after spill, with no remediation of the source or plume.
15% of the PCE DNAPL remains in the source zone.
c1: 10 100 1000 10000
2079
PCE
c2: 10 100 1000 10000
2079
TCE
c3: 10 100 1000 10000
2079
DCE
c4: 10 100 1000 10000
2079
Vinyl chloride
y
x
200
0
-200
500
1000
1500
2000

What Will Happen if No Action is Taken?

PCE example

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	Growing	Factor of ten
Partly in the source zone and partly in the dissolved plume	Stable	Factor of five hundred
Mostly in the dissolved plume	Shrinking	Factor of ten thousand

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What Will Happen if No Action is Taken?

Cancer Risk From Drinking Water at a Given Location Over Time (REMChlor Also Includes the Inhalation Risk)

Compute chronic daily intake (CDI) of each carcinogen:

$$CDI_i = \frac{q_w}{mT_{life}} \int_{\max(0,t-T_{ex})}^{t} C_w^i(t)\,dt$$

Where

- q_w is the daily water intake (2 l/d)
- m is the body mass (70 kg)
- T_{life} is the 70 year lifetime averaging period
- t is the Time
- T_{ex} is the length of the exposure period (30 years)
- C_w is the concentration of the carcinogen in the well.

The CDI is essentially the cumulative dose of carcinogen.
With a cancer risk slope factor, SF, the cancer risk is then:

$$Risk_i = CDI_i \; x \; SF_i \qquad Risk_T = \sum Risk_i$$

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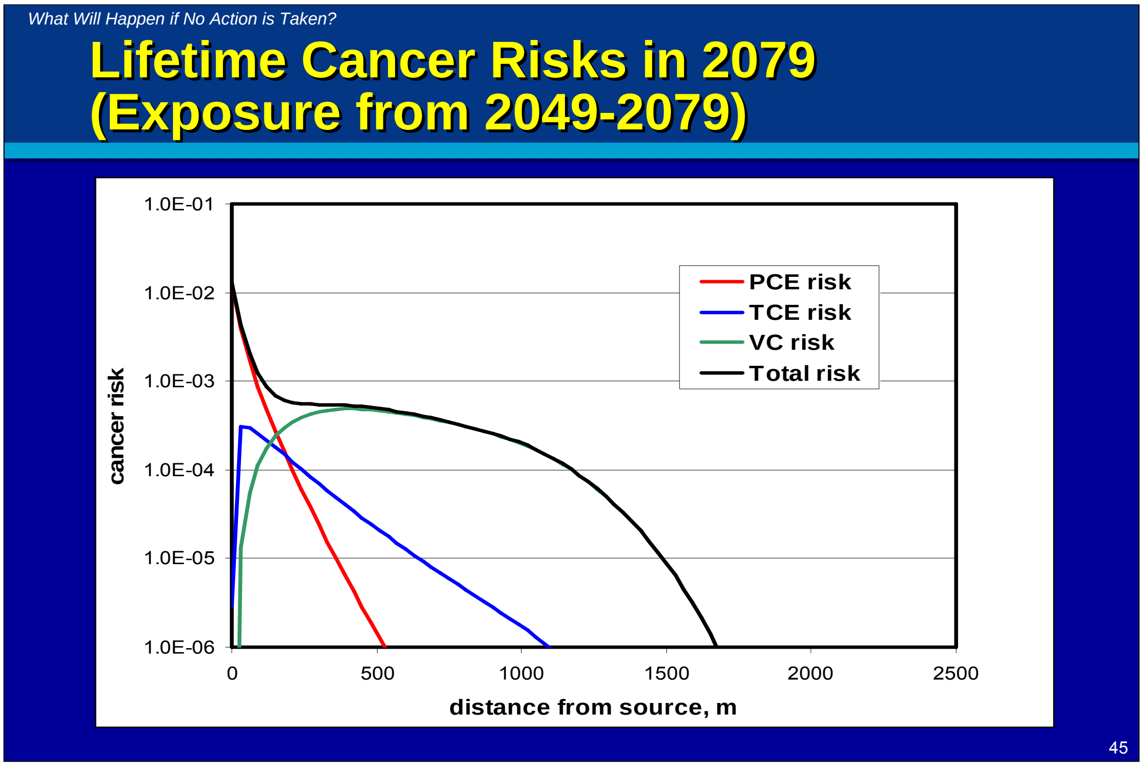
What Will Happen if No Action is Taken?
Lifetime Cancer Risks in 2079
(Exposure from 2049-2079)
cancer risk
1.0E-01
1.0E-02
1.0E-03
1.0E-04
1.0E-05
1.0E-06
0
500
1000
1500
2000
2500
distance from source, m
PCE risk
TCE risk
VC risk
Total risk
45

BREAK FOR QUESTIONS FROM PARTICIPANTS

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