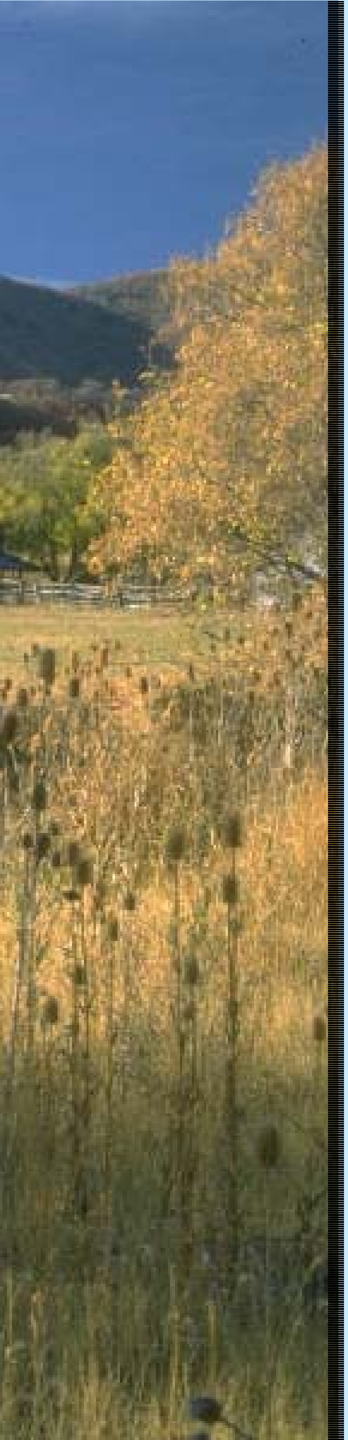


Estimating Times of Remediation Associated with Natural Attenuation

Francis H. Chapelle – U.S. Geological Survey

Mark A. Widdowson and Ed Mendez – Virginia Tech

Clifton C. Casey – Southern Division, NAVFACENGCOM

NAVFAC

Project Funding and Support

- YO817 project
- Initiated by **SOUTHDIV**
- Funded by **NAVFAC**
- Supported by **ARTT**

In the late 1980s, it was becoming clear that microbial biodegradation limited contaminant transport in groundwater systems

- Baedecker et al., 1988 (Bemidji, MN)
- Barker et al., 1987 (Borden field experiment). "Natural Attenuation of aromatic hydrocarbons in a shallow sand aquifer"
  - First use of term "natural attenuation"
  - Passive bioremediation, intrinsic bioremediation were other terms

How Should Regulatory Agencies Include Natural Attenuation Processes in Site-Specific Remediation Plans?

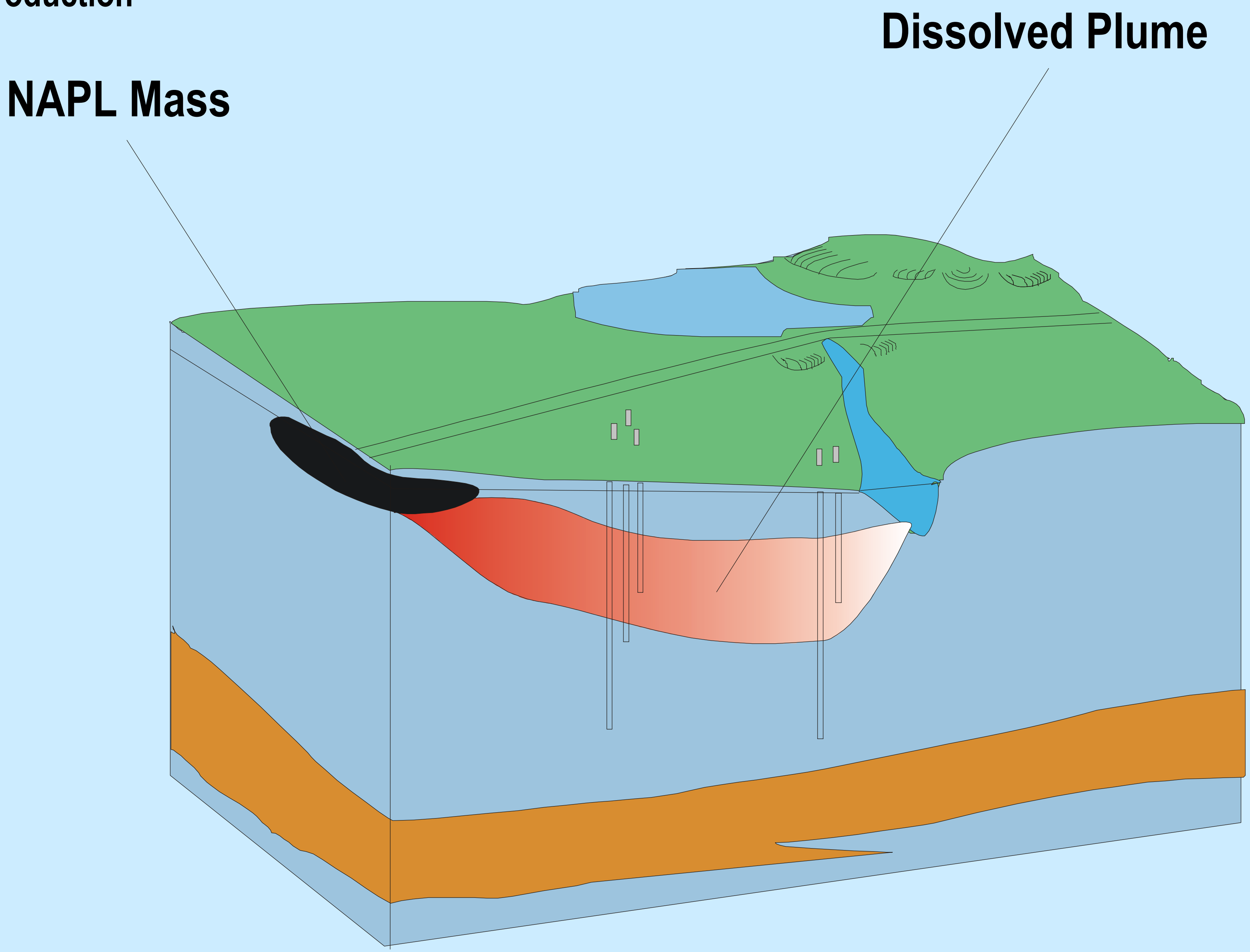
- According to the U.S. EPA, monitored natural attenuation can be selected as a remedial strategy **"only….where it will meet site remediation objectives within a timeframe that is reasonable compared to that offered by other methods."**

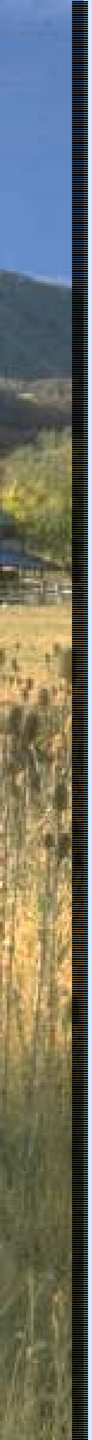
EPA OSWER Directive, 1999

This brought up the issue of Time of Remediation (TOR)

How do you estimate times of remediation?

- In 1999, there was no clear approach to this problem.


Dissolved Plume
NAPL Mass



There are many processes that contribute to contaminant removal (remediation by monitiored natural attenuation) [RMNA] in groundwater systems, including:

1. Advection
2. Dispersion
3. Biodegradation
4. Sorption
5. NAPL Dissolution

Each of these components is summed in the solute-transport equation, which can then be solved for time (t).

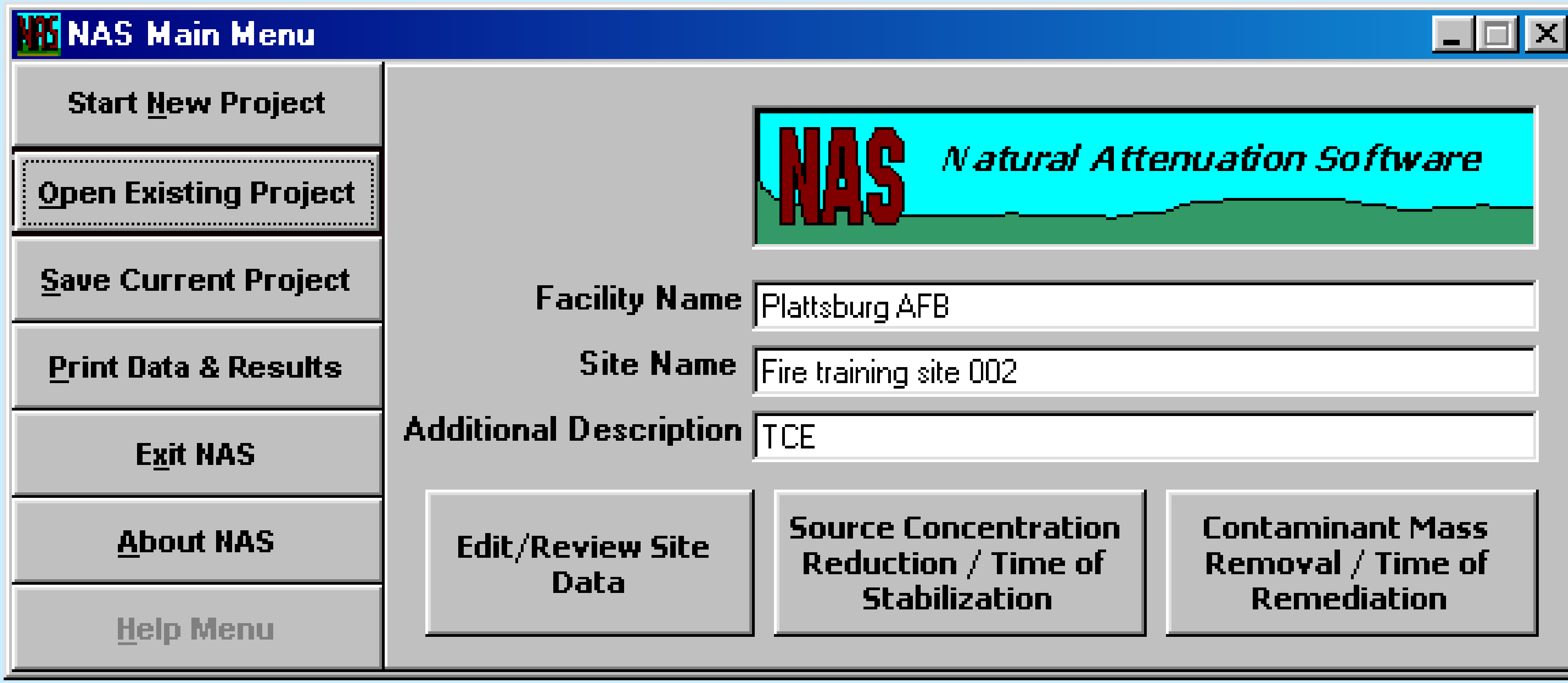
Advection | Dispersion | Sorption | Biodegradation | NAPL Dissolution

$$\frac{\partial C}{\partial t} = -v\frac{\partial C}{\partial x} + D\frac{\partial^2 C}{\partial x^2} - \frac{K_d \rho_b}{n}\frac{\partial C}{\partial t} - R_{bio} + R_{NAPL}$$

Historically, this approach has been difficult to utilize by project managers and regulators

- Requires an in depth knowledge of GW modeling
- Such models can be difficult to use
- Results are hard to analyze

NAS is a A Decision-Making Tool for Assessing Monitored Natural Attenuation and Estimating Cleanup Times



NAS is an interface that allows non-modelers to find solutions to the TOR problem

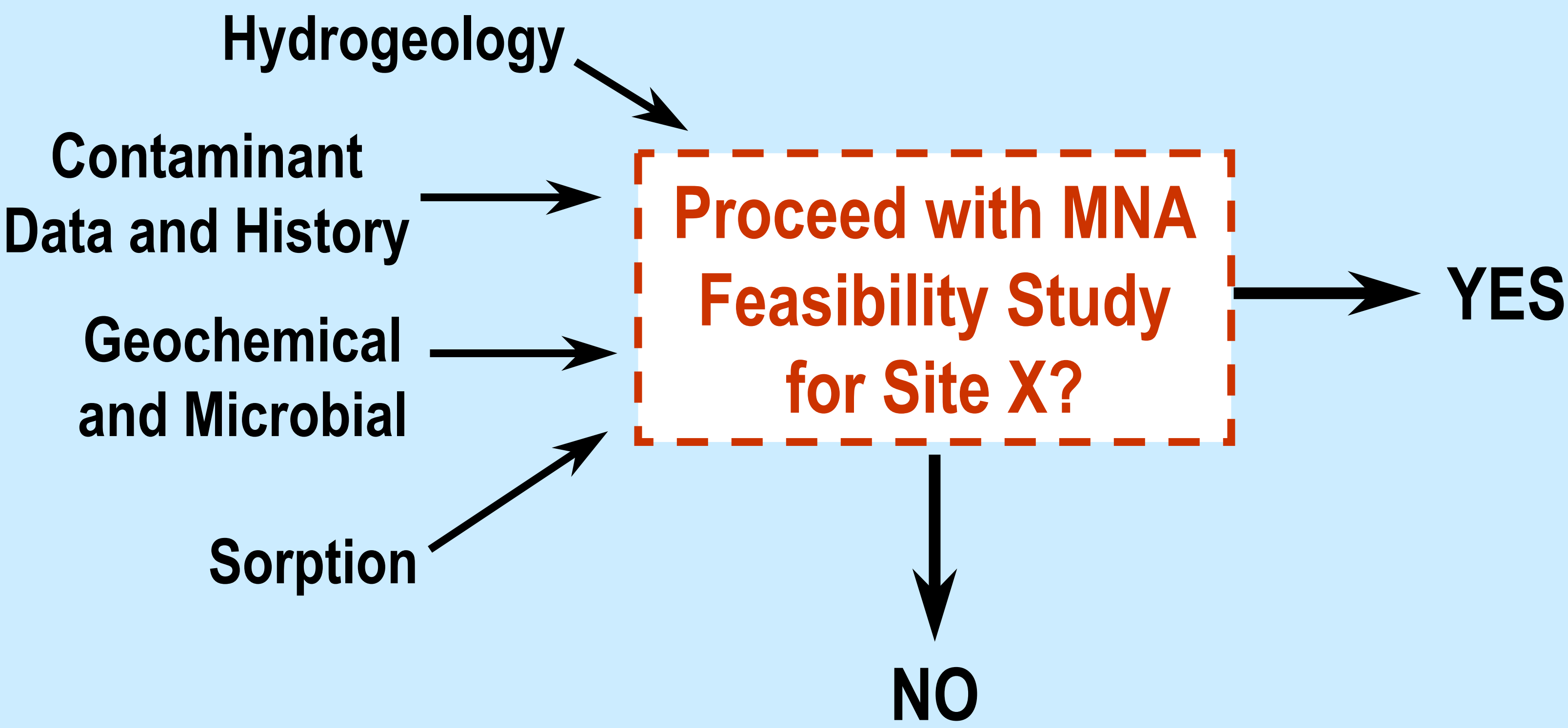
- Analytical Solutions for plume shrinkage questions
- Numerical Solutions for Time of NAPL Dissolution
- NAS prompts the user for required information, sets up the problem, and answers site-specific TOR questions.

NAS – Types of Problems and Source Contaminants

1. **Chlorinated Ethenes**
   - PCE or
   - TCE
2. **Petroleum Hydrocarbons**
   - BTEX
   - MTBE (optional)
   - Naphthalene (optional)

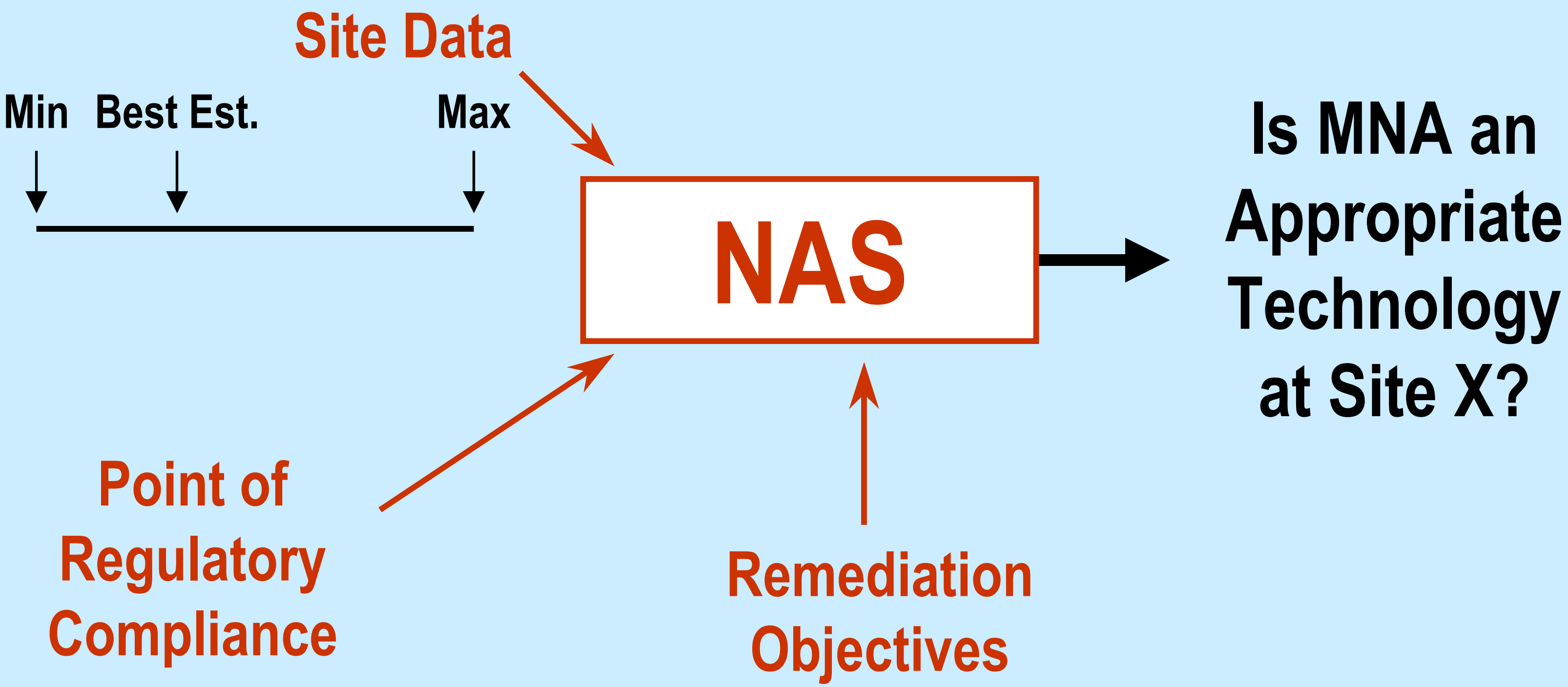
NA Screening Tools

Monitored Natural Attenuation (MNA)



NAS – A <u>Tool</u> for Decision-Making

Monitored Natural Attenuation (MNA)



NAS – Questions Addressed

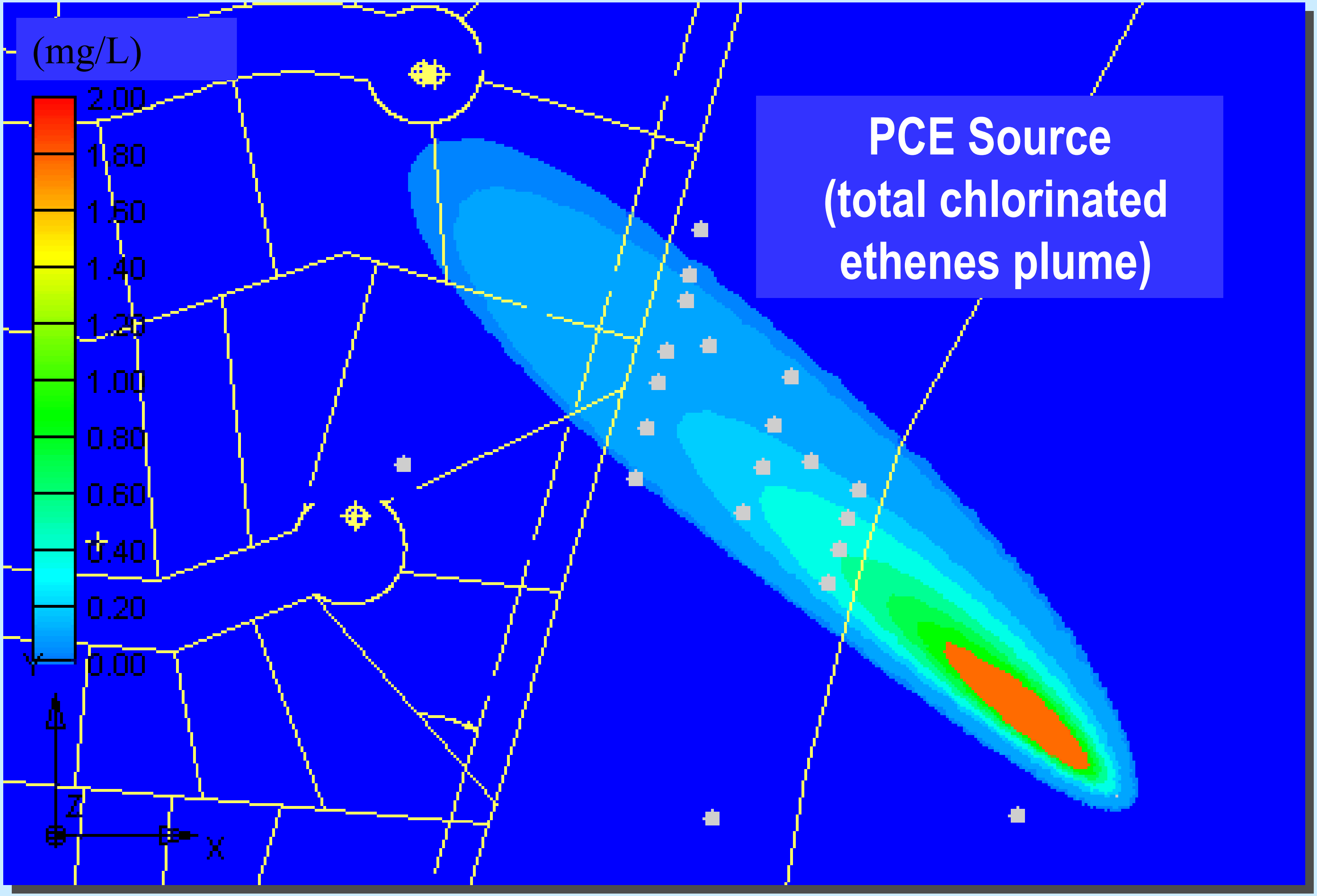
1. **Is MNA an appropriate technology at Site X?**

   <u>and</u>

   What degree of source remediation is required at Site X?

   - Distance of Plume Stabilization
   - Time of Plume Stabilization
   - Time of NAPL Dissolution

NAS Example –
Naval Submarine Base Kings Bay, GA



NAS Example – NSB Kings Bay, GA

Site Information

Site Information

Hydrogeology Data | Contaminant Data | Redox Indicator Data | Site Data Summary | Graphical Summary

1. Enter the following hydrogeologic and aquifer properties.

	Maximum	Average	Minimum
Hydraulic Conductivity [ft/yr]	3600.0	1440.0	720.0
Hydraulic Gradient [ft/ft]	0.048	0.048	0.048
Weight Percent Organic Matter (loss on ignition) [%]	0.19	0.19	0.19

	Average
Total Porosity [ft^3/ft^3]	0.25
Effective Porosity [ft^3/ft^3]	0.25
Contaminated Aquifer Thickness [ft]	20.0

Return To Main Menu

$$v = \frac{K}{Rn_e} i$$

NAS

Site Information

Hydrogeology Data | **Contaminant Data** | Redox Indicator Data | Site Data Summary | Graphical Summary

1. Enter the date when field measurements for contaminant concentration were collected:

Month November **Year** 1999

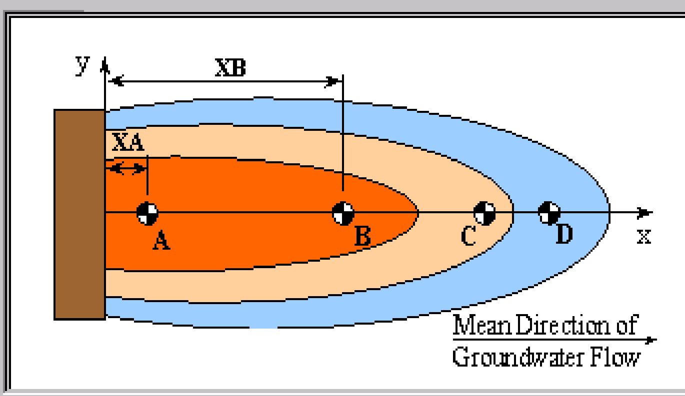
2. Enter the number of monitoring wells sampled for contaminant concentration along the centerline of the plume:

Currently, contaminant concentation data is reported for 6 wells.

Add/Delete Wells

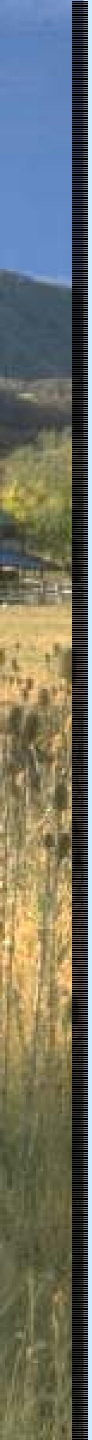
3. Enter the well name (optional), distance downgradient of the source (required), and contaminant concentrations measured at each monitoring point.

Well Name	Distance from Source [ft]	PCE [µg/L]	TCE [µg/L]	cis-DCE [µg/L]	VC [µg/L]
KBA-34	1.	3500.	1000.	BD	BD
usgs-3	110.	2.	511.	1270	112
KBA-13	160.	0.5	32.5	158	76
usgs-5	220.	BD	BD	54	166
usgs-10	380.	BD	BD	24	31
KBA-37	630.	BD	BD	10	2



NOTE: The origin of the NAS coordinate system (0,0) is located immediately downgradient of the area and along the centerline of the plume.

Return To Main Menu



NAS

Site Information

Hydrogeology Data | Contaminant Data | **Redox Indicator Data** | Site Data Summary | Graphical Summary

1. Enter the time when the redox indicator field measurements were collected:

- (•) **November 1999 (Collected at the same time as contaminant data.)**
- ( ) **Collected at a different time than contaminant data**

Month November **Year** 1999

2. NAS requires specification of dissolved oxygen (O2), ferrous iron (Fe2) and sulfate (SO4) at all redox well locations. Indicate which additional redox indicators were measured at your site:

	Yes	No
Nitrate (NO3):	[x]	[ ]
Manganese(II) (MN2):	[ ]	[x]
Hydrogen Sulfide (H2S):	[x]	[ ]
Methane(CH4):	[x]	[ ]
Hydrogen (H2):	[x]	[ ]

3. Number of redox indicators along the centerline of the plume.

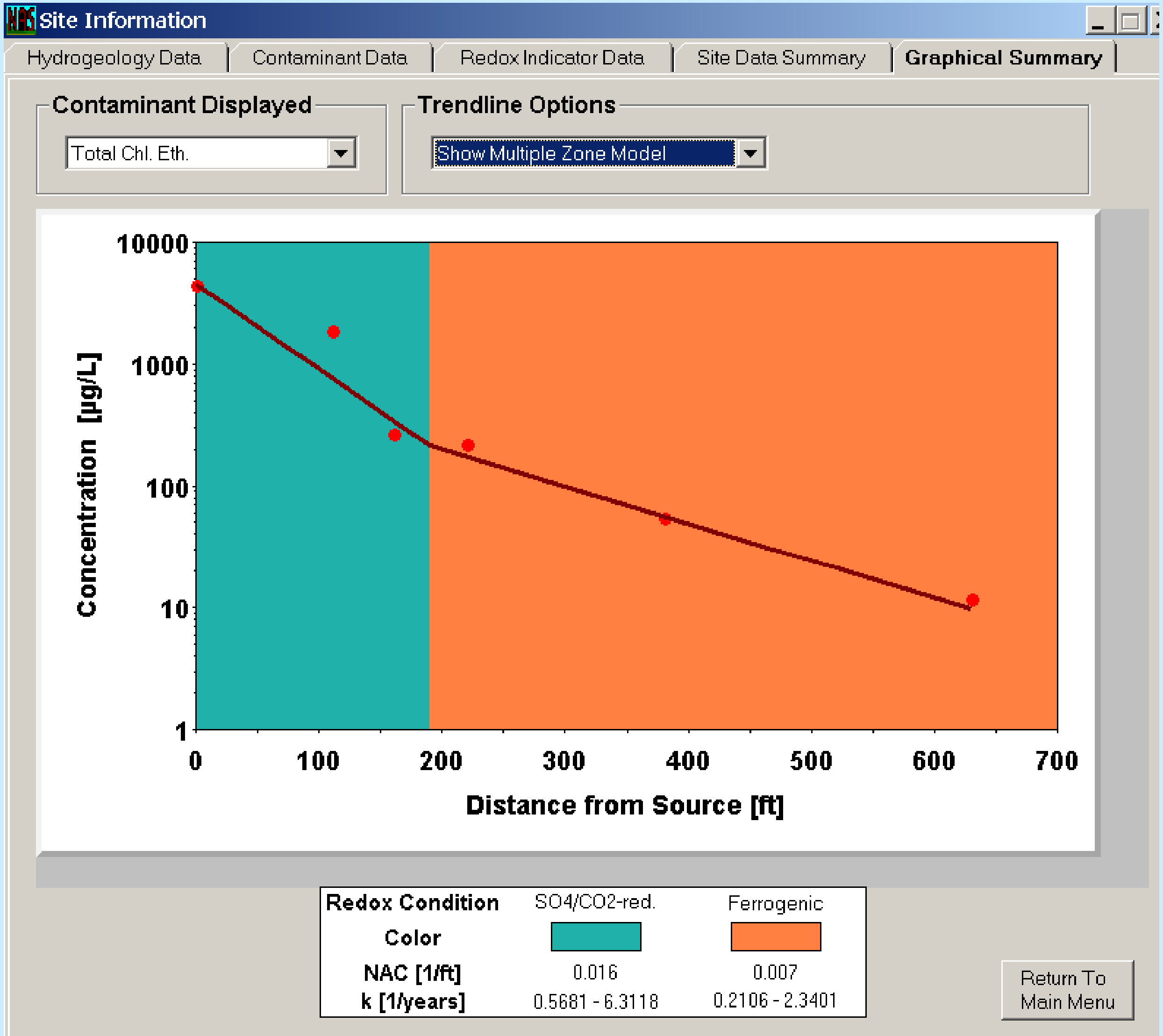
Currently, redox indicator concentration data is reported for 6 wells. **Add/Delete Wells**

4. Enter the well name (optional), distance downgradient of the source (required), and concentrations for indicators of redox potential measured at each monitoring point.

Well Name	Distance from Source [ft]	O2 (mg/L)	NO3 (mg/L)	Fe2 (mg/L)	S04 (mg/L)	H2S (mg/L)	CH4 (mg/L)	H2 (nM)	Redox Condition
KBA-34	1.	0	0	1	10	0	5	2	SO4/CO2-reducing
usgs-3	110.	0	0	0.39	6.48	0	3.8	1.66	SO4/CO2-reducing
KBA-13	160.	0	0	0.24	3.27	0.577	5.1	1.55	SO4/CO2-reducing
usgs-5	220.	0	0	0.26	0	0.385	5.6	0.5	Ferrogenic
usgs-10	380.	0	0	0.41	10	1.5	6	0.81	Ferrogenic
KBA-37	630.	0	0	0.3	10.2	0.1	0.3	0.3	Ferrogenic

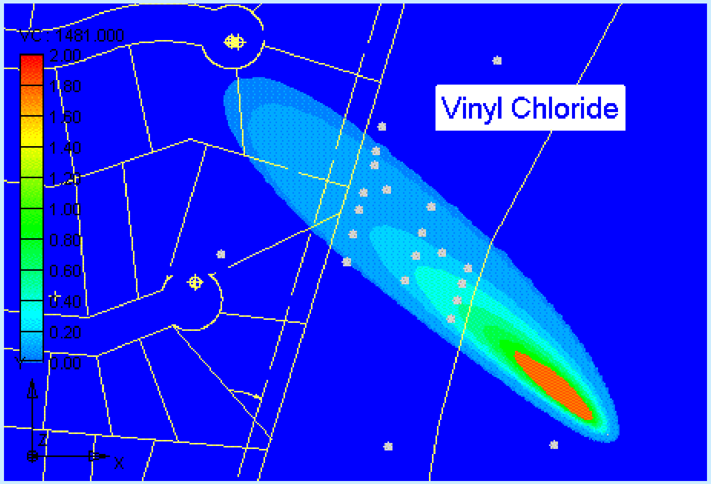
Update Redox Condition | Return To Main Menu

Estimates Biodegradation Rate Constants

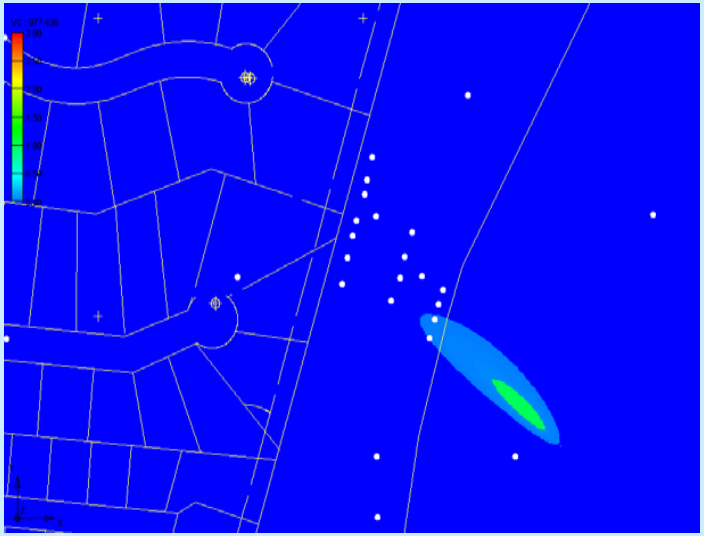


Distance and Time of Stabilization

How long will it take?



Source Area Removal,
1998



Collapsed Contaminant Plume,
At remediation Goal
2005?
2050?

Maximum Source Concentration and Time of Stabilization Calculations

Facility Name NAB Kings Bay

Site Name Landfill

Additional Description Part 2

1. Enter the distance from the contaminant source to the nearest downgradient point of compliance (POC).

Distance to POC 220.0 [ft] More Info on POC >>

2. Enter an estimate for the width of the contaminant source.

Contaminant Source Width 30.0 [ft]

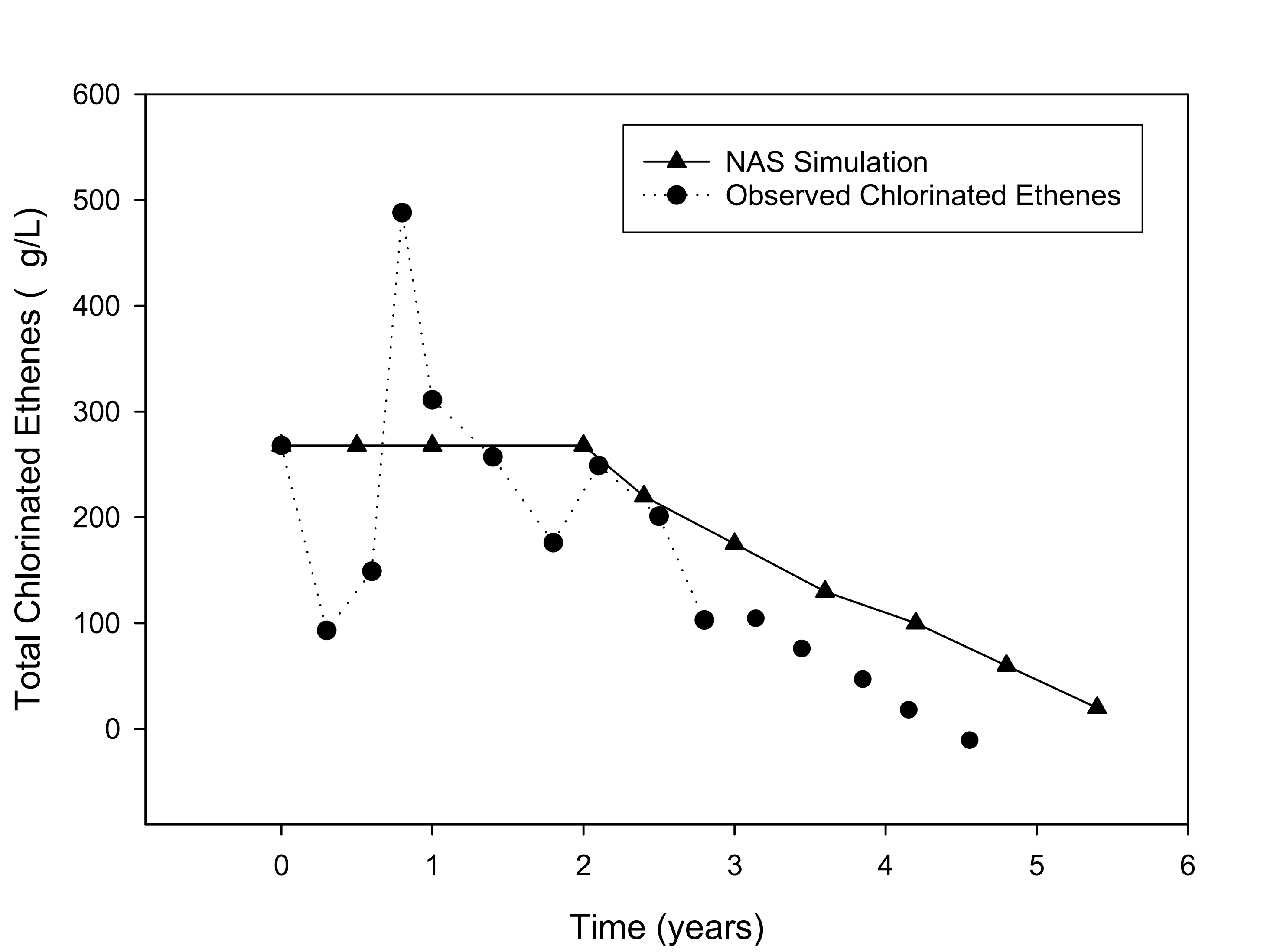
3. Enter the regulatory compliance concentration (RCC) at the POC, and calculate the Time of Stabilization (TOS) and Source Concentration Target.

	RCC [µg/L]		Source Conc. [µg/L]			TOS [years]			
			Well	Current	Target	Max	Average	Min	
Total Chl. Eth.	2.0	Calculate	1	4,500	106	14.9	7.0	1.4	Graphical View

More Info on RCC >>

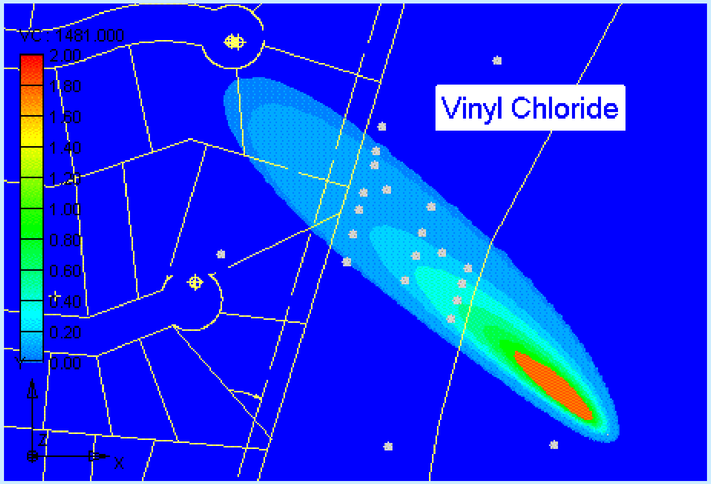
Return to Main Menu

NAS Simulation of KBA-13A



Time of NAPL Dissolution (TNAD)

How long will it take?



PCE Source Area
Emplaced 1960

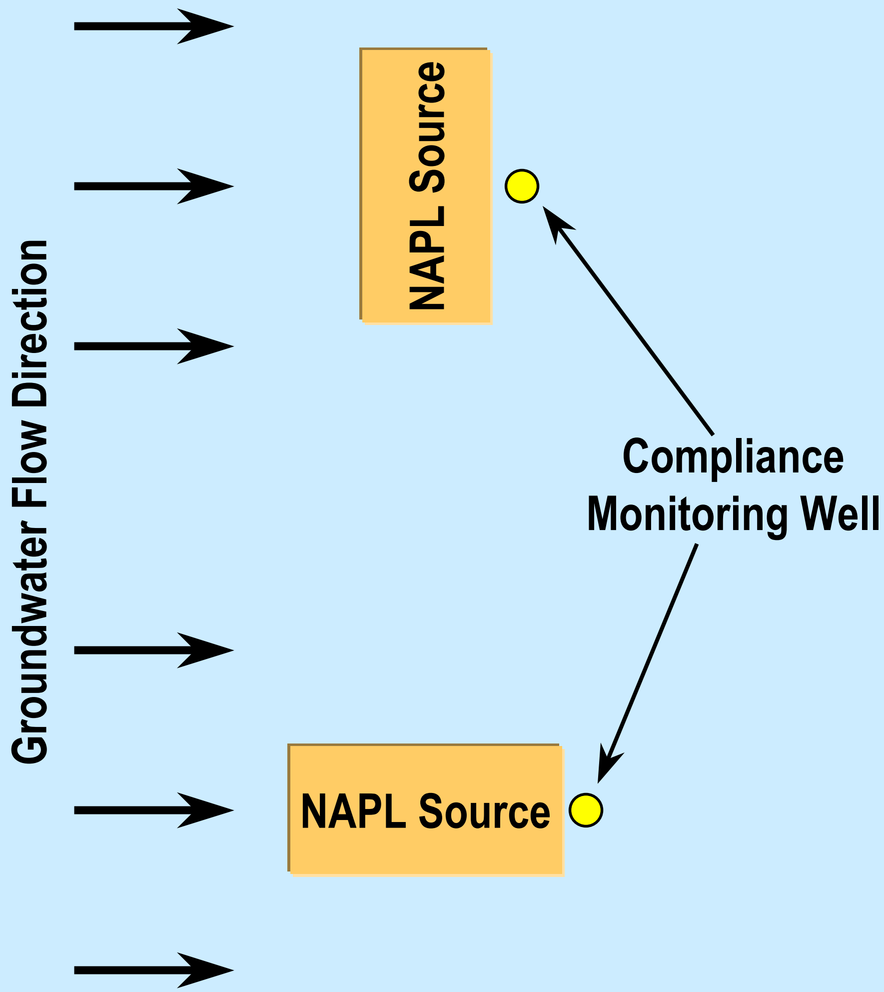
Source PCE
Fully Dissolved
2005?
2050?

Factors Affecting NAPL Dissolution

NAPL Properties

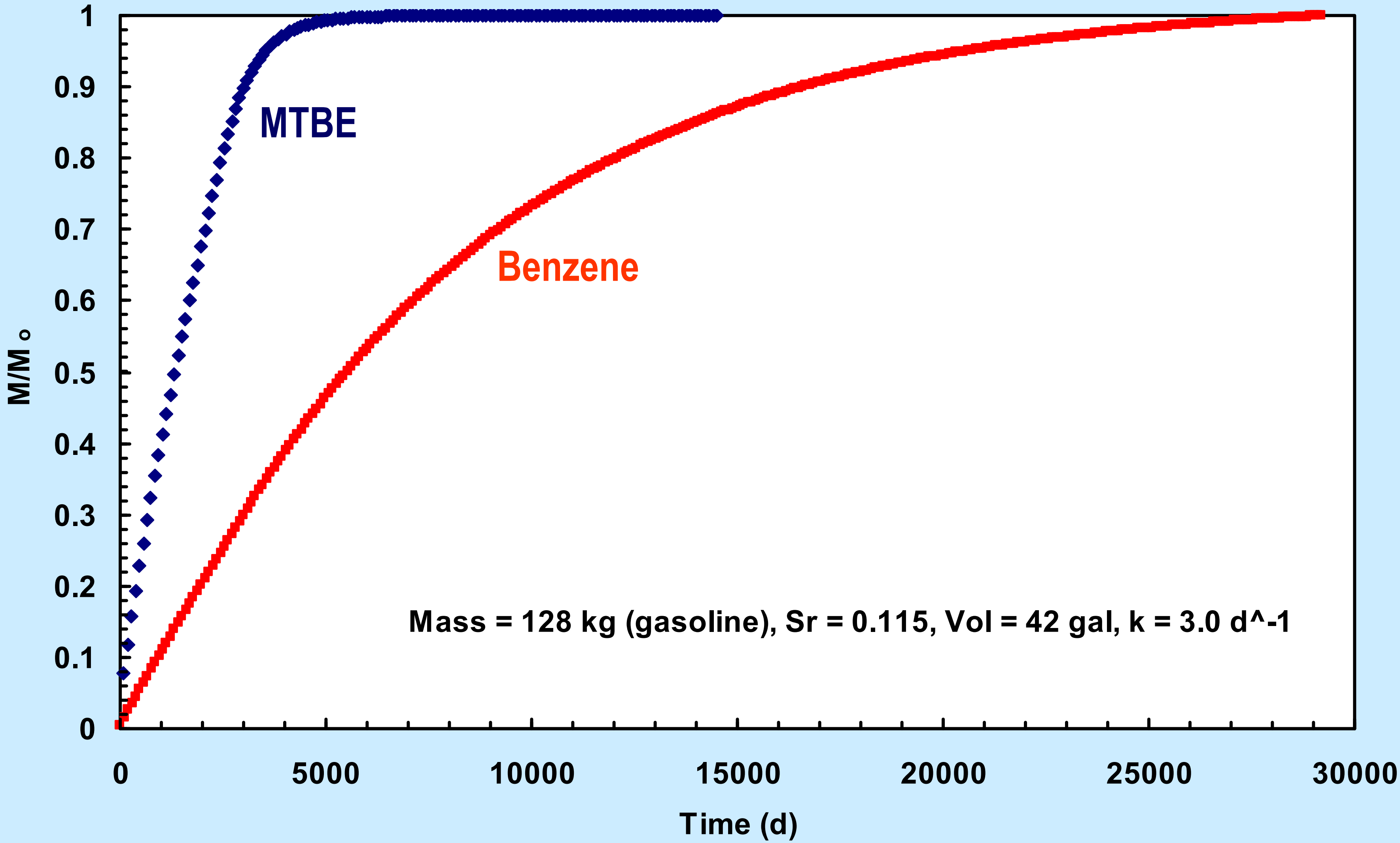
- NAPL mass
- Residual saturation
- Contaminant mass fraction
- Physical properties of NAPL components
- NAPL dissolution coefficient (k^{NAPL})
- Source geometry

Source Geometry



- For these two cases and with all things being equal, except the orientation of the source relative to the groundwater flow direction, would source geometry influence TOR?
- If the answer is yes, which case would result in the greater TOR?

NAPL Dissolution



Contaminant Mass Removal and Time of Remediation Estimate

NAPL Properties | Background EAs | Solution Options | TOR Results | Graphical Summary

1a. Specify how you wish to enter the estimated NAPL mass in the source area.

Average only.

b. Fill in the chart below.

	Average
NAPL Mass [lb]	550.0
NAPL Residual	4.53e-02

2a. Specify how you wish to evaluate the impact of source removal on time of remediation.

Estimate TOR for 3 NAPL Mass Removal Plans.

b. Fill in the chart below.

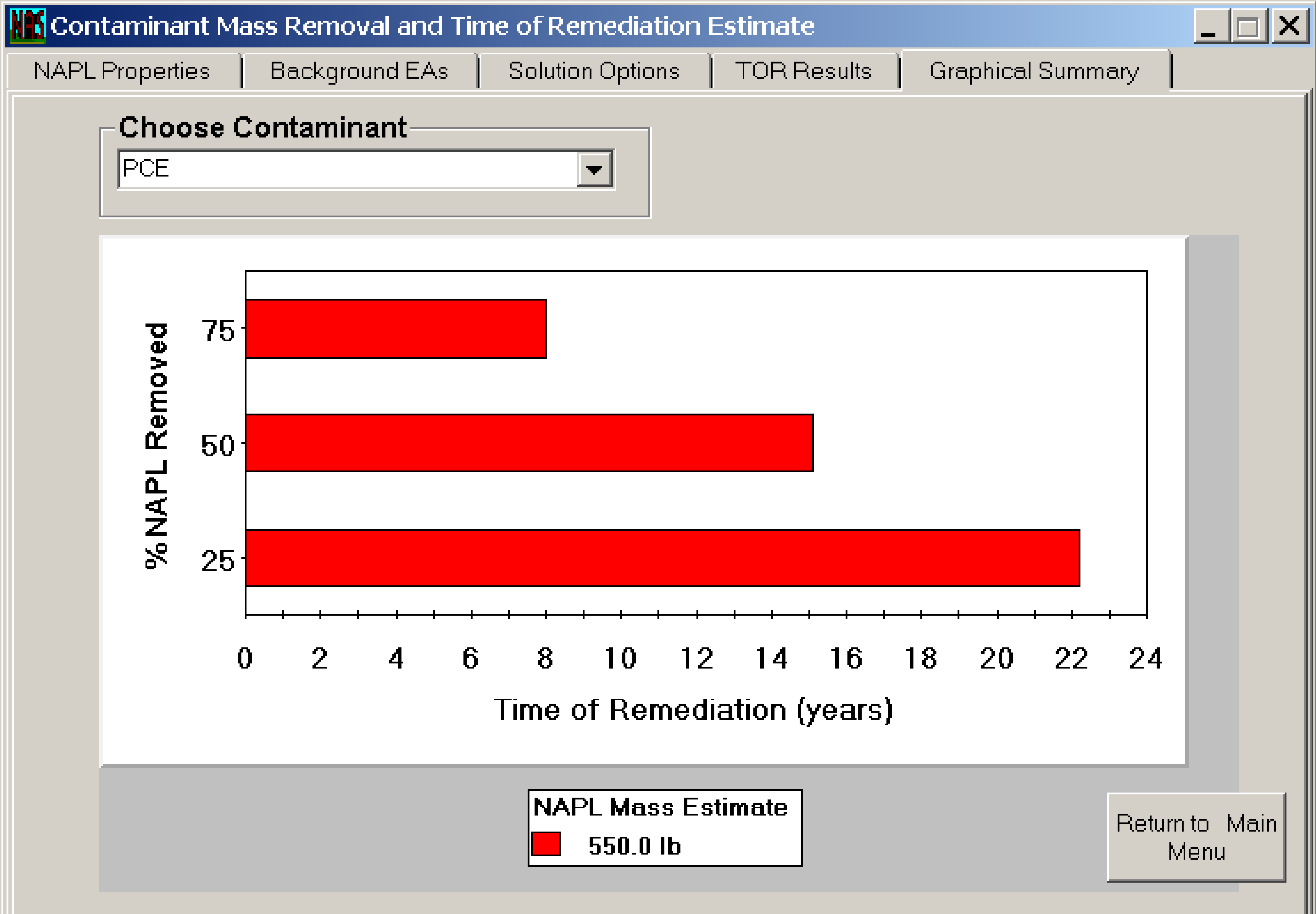
	Plan 1	**Plan 2**	**Plan 3**
% NAPL Removed	25	50	75

3. Specify the maximum time of analysis for TOR (up to 100 years).

Maximum Time of Analysis 25 **[years]**

Execute TOR Calculation

Return to Main Menu



Contaminant Mass Removal and Time of Remediation Estimate
NAPL Properties
Background EAs
Solution Options
TOR Results
Graphical Summary
Choose Contaminant
PCE
% NAPL Removed
75
50
25
0
2
4
6
8
10
12
14
16
18
20
22
24
Time of Remediation (years)
NAPL Mass Estimate
550.0 lb
Return to Main Menu

Conclusions

- The TOR problem is difficult but not unsolvable
- The NAS is a tool designed to facilitate TOR estimates
- NAS predictions are in line with monitoring data
- NAS has been used to reach regulatory closure of sites

NAS and *SEAM-3D* Software

- Acquiring NAS and SEAM-3D
  - NAS can be downloaded from: http://www.cee.vt.edu/nas/
  - *SEAM-3D* is part of Groundwater Modeling System (GMS) maintained by DoD
- Two-Day In-Depth Training for NAS
  - Southwest Division, July 22-23; Southern Division, August 5-6
  - Sign up through Engineering Service Center (ESC)

NAVFAC Points of Contact

- Cliff Casey
  - caseycc@efdsouth.navfac.navy.mil
  - (843) 820-5561
- Mark Kram
  - krammml@nfesc.navy.mil
  - (805) 982-2669
- Tim McEntee
  - mcenteetf@nfesc.navy.mil
  - (805) 982-1551