TECHNOLOGY GUIDE: The Transition Assessment Teaching Assistant (TA^2) Tool

SERDP ER20-1429

Transitioning from Active Remedies to Monitored Natural Attenuation (MNA)

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13. SUPPLEMENTARY NOTES

14. ABSTRACT
The objectives of this project are as follows:
•To provide an orientation to the Transition Assessment Teaching Assistant (TA^2) Tool.
•Free, web-based app developed for SERDP Project ER20-1429.

15. SUBJECT TERMS
Installation Restoration, groundwater remediation, groundwater management, design tool

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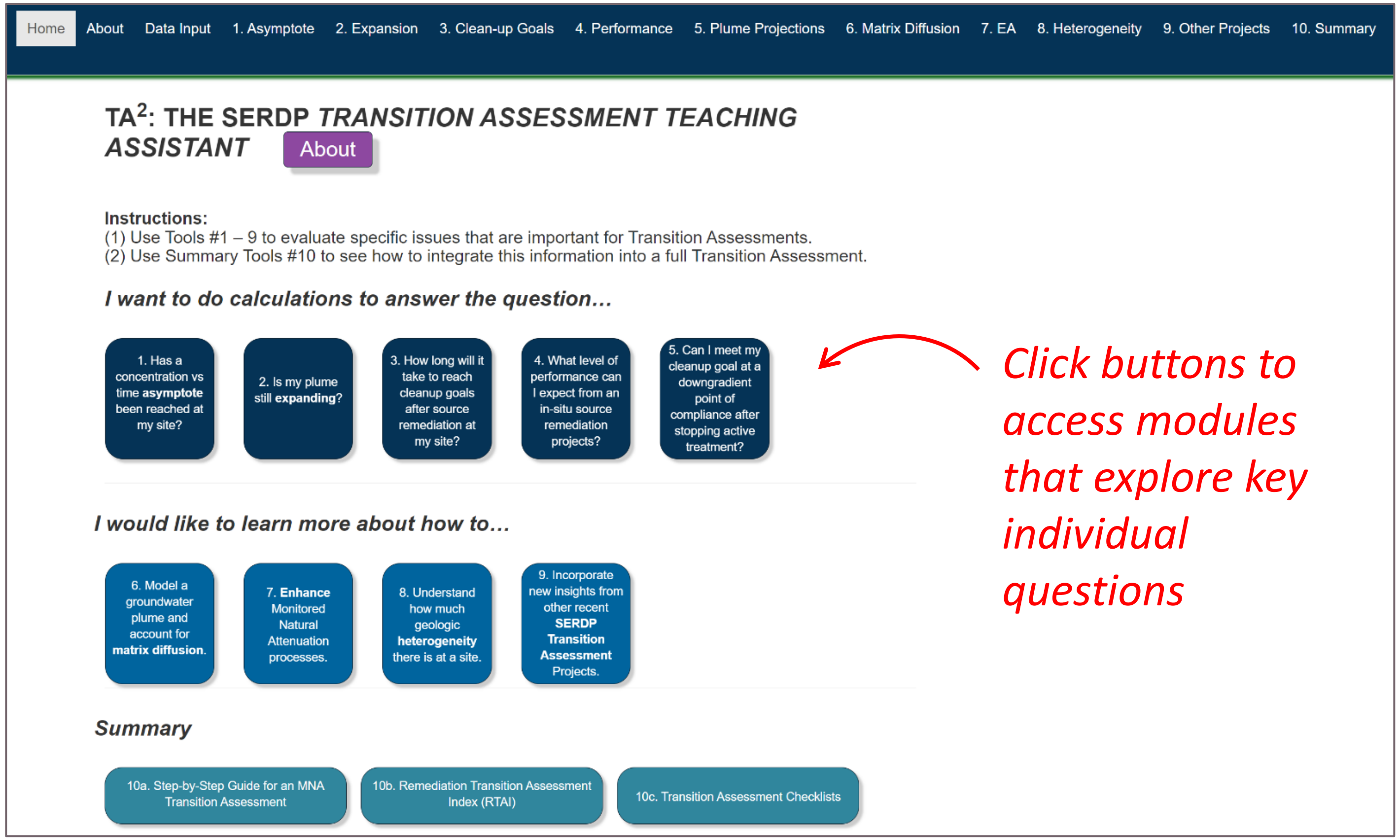
Objective and Approach



Click buttons to access modules that explore key individual questions

Objective:

- Provide an orientation to the Transition Assessment Teaching Assistant (TA^2) Tool
- Free, web-based app developed for SERDP Project ER20-1429

Approach:

- Walk-through a series of screenshots from the tool to highlight how it can be used

Overview

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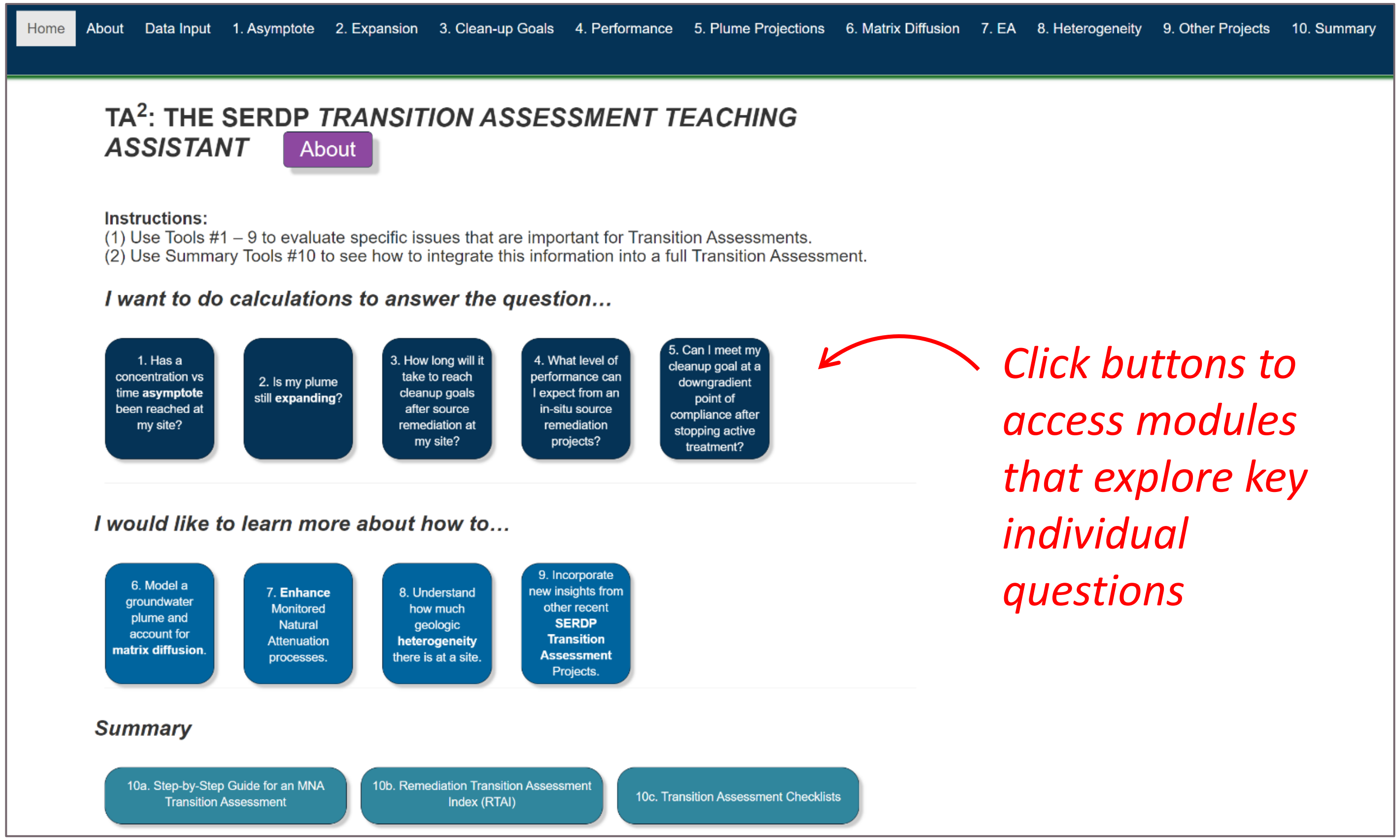

Click buttons to access modules that explore key individual questions

TA^2:

***T**ransition **A**ssessment*
***T**eaching **A**ssistant*

- Free web-based app
- Runs in a web browser
- No downloading requirements
- Data are stored locally
- Can be accessed at the [project webpage]

TA^2 Tool: *Concept and Structure*

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10 Modules
("Tools")

Quantitative Analysis Tools | **Qualitative Learning Tools**

User can go through a single module
(to answer specific question(s))
or multiple modules
(for more comprehensive TA)

TA^2 Tool: *Concept and Structure*

1. Has a concentration vs time **asymptote** been reached at my site?
2. Is my plume still **expanding**?
3. **How long** will it take to reach cleanup goals after source remediation at my site?
4. What level of **performance** can I expect from an in-situ source remediation project?
5. Can I meet my cleanup goal at a **downgradient** point of compliance after stopping active treatment?

10. Summary and Remediation Transition Assessment Index (RTAI)

6. Model a groundwater plume for a **Transition Assessment**
7. **Enhanced Monitored Natural Attenuation** processes
8. Understand how much geologic **heterogeneity** there is at a site
9. Learn from **other SERDP Transition Assessment Projects**

Quantitative Analysis Tools

Qualitative Learning Tools

Data Input Screen:

User enters concentration and location info to support analyses in other modules

SERDP ESTCP

Home | About | Data Input | 1. Asymptote | 2. Expansion | 3. Clean-up Goals | 4. Performance | 5. Plume Projections | 6. Matrix Diffusion | 7. EA | 8. Heterogeneity | 9. Other Projects | 10. Summary

Data Input

Enter concentration and time data in the table below to be used in Tools 1, 2, and 5.

Follow instructions to enter concentration data from different events for each monitoring well

Data Input Instructions:

- Use (Month/Day/Year) format for dates (ex. 01/01/2022).
- You need at least four independent sampling events to get trends.
- Do not enter any Flags or < or > signs, must be numerical data.
- The tool can only process up to 30 wells.
- Most of the samples should have detected values.
- For non-detects, use either ½ the reporting limit (RL) or the RL. Don't use zero.
- Don't enter duplicate values, either use the average or the first of the two duplicates.

How to Edit Data:

- Data can be copied and pasted directly into table by selecting cell(s) and using the keyboard shortcut to paste (Windows: Ctrl + V).
- Double click cells to edit text.
- Additional rows can be added or removed by right clicking on cell(s).
- Clicking the bottom left corner of selected cell(s) allows the user to drag that information to additional cell(s).
- Cells highlighted red indicate the value within that cell is not in the correct format (ex. characters are present in column that can only include numerical data).
- If the monitoring well name needs to be updated, use downloaded file from "Download Input File" button, revise the file with new monitoring well name, then upload the file by using "Upload Saved Data". The same procedure should be followed if you need to add new columns.

Download Input File | Upload Saved Data | No file selected

1. Concentration and Time Data for Tool 1 and 2 | 2. Concentration and Time Data for Tool 5 | 3. Monitoring Well Information for Tool 1 and 2 | 4. Monitoring Well Information for Tool 5

Event	Date (Month/Day/Year)	COC	Units	MW-1	PW-1	PW-3	PW-4	MW-4	MW-5	MW-6	MW
1	2012-09-28	TCE	µg/L	23.00	1400.00	1300.00	1302.00	37.10	7.00	7.00	
2	2012-12-22	TCE	µg/L	20.67	740.00	1900.00	1902.00	41.90	8.49	7.00	
3	2013-03-28	TCE	µg/L	18.33	840.00	1400.00	1402.00	13.00	10.70	7.00	
4	2013-06-26	TCE	µg/L	20.00	480.00	820.00	822.00	5.10	11.20	7.00	
5	2013-09-14	TCE	µg/L	14.00	350.00	700.00	702.00	11.50	11.00	7.00	
6	2013-12-29	TCE	µg/L	13.33	270.00	525.00	527.00	5.00	12.00	7.00	
7	2014-03-24	TCE	µg/L	15.33	290.00	535.00	537.00	4.00	15.00	7.00	
8	2014-06-18	TCE	µg/L	10.33	390.00	620.00	622.00	4.60	9.40	7.00	
9	2014-09-26	TCE	µg/L	9.67	315.00	420.00	422.00	1.85	10.00	8.49	1
10	2014-12-26	TCE	µg/L	12.00	290.00	440.00	442.00	1.83	11.60	10.70	1
11	2015-03-24	TCE	µg/L	13.30	280.00	440.00	442.00	1.80	14.30	11.20	1
12	2015-05-18	TCE	µg/L	10.40	300.00	320.00	322.00	1.20	10.00	11.00	1
13	2015-06-03	TCE	µg/L	10.20	210.00	280.00	282.00	1.00	5.00	12.00	1
14	2015-06-15	TCE	µg/L	10.10	150.00	200.00	202.00	1.20	3.00	15.00	
15	2015-06-29	TCE	µg/L	11.70	245.00	400.00	402.00	1.00	2.00	9.40	1
16	2015-07-13	TCE	µg/L	8.94	235.00	370.00	372.00	0.80	1.00	10.00	1

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Data Input

Enter concentration and time data in the table below to be used in Tools 1, 2, and 5.

For most datasets, it is likely easier to download the (Excel) input file, enter your data in the input file, and then upload the saved data

Download Input File | Upload Saved Data | No file selected

Data Input Instructions:

- Use (Month/Day/Year) format for dates (ex. 01/01/2022).
- You need at least four independent sampling events to get trends.
- Do not enter any Flags or < or > signs, must be numerical data.
- The tool can only process up to 30 wells.
- Most of the samples should have detected values.
- For non-detects, use either ½ the reporting limit (RL) or the RL. Don't use zero.
- Don't enter duplicate values, either use the average or the first of the two duplicates.

How to Edit Data:

- Data can be copied and pasted directly into table by selecting cell(s) and using the keyboard shortcut to paste (Windows: Ctrl + V).
- Double click cells to edit text.
- Additional rows can be added or removed by right clicking on cell(s).
- Clicking the bottom left corner of selected cell(s) allows the user to drag that information to additional cell(s).
- Cells highlighted red indicate the value within that cell is not in the correct format (ex. characters are present in column that can only include numerical data).
- If the monitoring well name needs to be updated, use downloaded file from "Download Input File" button, revise the file with new monitoring well name, then upload the file by using "Upload Saved Data". The same procedure should be followed if you need to add new columns.

1. Concentration and Time Data for Tool 1 and 2 | 2. Concentration and Time Data for Tool 5 | 3. Monitoring Well Information for Tool 1 and 2 | 4. Monitoring Well Information for Tool 5

Event	Date (Month/Day/Year)	COC	Units	MW-1	PW-1	PW-3	PW-4	MW-4	MW-5	MW-6	MW
1	2012-09-28	TCE	µg/L	23.00	1400.00	1300.00	1302.00	37.10	7.00	7.00	
2	2012-12-22	TCE	µg/L	20.67	740.00	1900.00	1902.00	41.90	8.49	7.00	
3	2013-03-28	TCE	µg/L	18.33	840.00	1400.00	1402.00	13.00	10.70	7.00	
4	2013-06-26	TCE	µg/L	20.00	480.00	820.00	822.00	5.10	11.20	7.00	
5	2013-09-14	TCE	µg/L	14.00	350.00	700.00	702.00	11.50	11.00	7.00	
6	2013-12-29	TCE	µg/L	13.33	270.00	525.00	527.00	5.00	12.00	7.00	
7	2014-03-24	TCE	µg/L	15.33	290.00	535.00	537.00	4.00	15.00	7.00	
8	2014-06-18	TCE	µg/L	10.33	390.00	620.00	622.00	4.60	9.40	7.00	
9	2014-09-26	TCE	µg/L	9.67	315.00	420.00	422.00	1.85	10.00	8.49	1
10	2014-12-26	TCE	µg/L	12.00	290.00	440.00	442.00	1.83	11.60	10.70	1
11	2015-03-24	TCE	µg/L	13.30	280.00	440.00	442.00	1.80	14.30	11.20	1
12	2015-05-18	TCE	µg/L	10.40	300.00	320.00	322.00	1.20	10.00	11.00	1
13	2015-06-03	TCE	µg/L	10.20	210.00	280.00	282.00	1.00	5.00	12.00	1
14	2015-06-15	TCE	µg/L	10.10	150.00	200.00	202.00	1.20	3.00	15.00	
15	2015-06-29	TCE	µg/L	11.70	245.00	400.00	402.00	1.00	2.00	9.40	1
16	2015-07-13	TCE	µg/L	8.94	235.00	370.00	372.00	0.80	1.00	10.00	1

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Data Input

Enter concentration and time data in the table below to be used in Tools 1, 2, and 5.

Tool 5 also uses concentration data from monitoring wells, but it has a different input file because it requires the data to be organized and labeled differently

Data Input Instructions:

- Use (Month/Day/Year) format for dates (ex. 01/01/2022).
- You need at least four independent sampling events to get trends.
- Do not enter any Flags or < or > signs, must be numerical data.
- The tool can only process up to 30 wells.
- Most of the samples should have detected values.
- For non-detects, use either ½ the reporting limit (RL) or the RL. Don't use zero.
- Don't enter duplicate values, either use the average or the first of the two duplicates.
- In the column "State", please enter either Pre-Remediation "PreRem", Post-Remediation "Post Rem".

How to Edit Data:

- Data can be copied and pasted directly into table by selecting cell(s) and using the keyboard shortcut to paste (Windows: Ctrl + V).
- Double click cells to edit text.
- Additional rows can be added or removed by right clicking on cell(s).
- Clicking the bottom left corner of selected cell(s) allows the user to drag that information to additional cell(s).
- Cells highlighted red indicate the value within that cell is not in the correct format (ex. characters are present in column that can only include numerical data).
- If the monitoring well name needs to be updated, use downloaded file from "Download Input File" button, revise the file with new monitoring well name, then upload the file by using "Upload Saved Data". The same procedure should be followed if you need to add new columns.

Download Input File | Upload Saved Data | No file selected

1. Concentration and Time Data for Tool 1 and 2 | 2. Concentration and Time Data for Tool 5 | 3. Monitoring Well Information for Tool 1 and 2 | 4. Monitoring Well Information for Tool 5

Event	Date (Month/Day/Year)	COC	Units	State	MW-02-008	MW-02-020	46PLTW8	MW-02-039	34PL
1	1995-08-01	PCE	μg/L	PreRem			2.80		
2	1996-09-04	PCE	μg/L	PreRem					
3	1997-06-17	PCE	μg/L	PreRem					
4	1996-09-10	PCE	μg/L	PreRem					
5	1997-06-18	PCE	μg/L	PreRem					
6	1999-07-14	PCE	μg/L	PreRem					
7	1999-07-20	PCE	μg/L	PreRem					
8	1995-08-01	TCE	μg/L	PreRem	27200.00	2.20	279.00		
9	1996-09-04	TCE	μg/L	PreRem				1300.00	
10	1997-06-17	TCE	μg/L	PreRem					
11	1996-09-10	TCE	μg/L	PreRem					
12	1997-06-18	TCE	μg/L	PreRem					
13	1999-07-14	TCE	μg/L	PreRem					
14	1999-07-20	TCE	μg/L	PreRem					
15	1995-08-01	totalDCE	μg/L	PreRem	51360.00	14943.50	3992.70		
16	1996-09-04	totalDCE	μg/L	PreRem				50.00	

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Data Input

Enter concentration and time data in the table below to be used in Tools 1, 2, and 5.

Follow instructions to enter location information (coordinates) from different for each monitoring well

Data Input Instructions:

- Add Latitude and Longitude information for the Monitoring Wells. Adding this information will allow results from Tool 2 to be mapped.
- Please see important note to correctly assign the location information.
- You can download these tables by clicking on the 'Download Input File' button above the table to the right. You can re-load previously saved data by clicking on the 'Upload Saved Data' button and choosing a previously saved data file.
- Please specify the category of wells in the "Well Grouping" column if you wish to analyze them grouped together. Otherwise, provide a single name for each well.

How to Edit Data:

- Data can be copied and pasted directly into table by selecting cell(s) and using the keyboard shortcut to paste (Windows: Ctrl + V).
- Double click cells to edit text.
- Additional rows can be added or removed by right clicking on cell(s).
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Download Input File | Upload Saved Data | No file selected

1. Concentration and Time Data for Tool 1 and 2 | 2. Concentration and Time Data for Tool 5 | 3. Monitoring Well Information for Tool 1 and 2 | 4. Monitoring Well Information for Tool 5

Important Note

If you possess either latitude/longitude coordinates or northing/easting coordinates (but not both), you are obligated to provide EPSG information from this website https://epsg.io/.
The tool will automatically calculate the missing coordinates from the EPSG information when the data file is uploaded. Here are other sources to estimate coordinates for monitoring locations if they are not otherwise available;

- Use surveying data from an official survey of the wells.
- Obtain a site map, georeferenced the map in a GIS system, and obtain the lat/long data.
- Estimate monitoring locations in a Google Earth map, add Placemarks, and get lat/long in decimal degrees.
- If you have data in degrees/min/sec, convert to decimal degrees at websites like this: https://www.latlong.net/degrees-minutes-seconds-to-decimal-degrees

It is crucial to ensure that the wells have consistent coordinate systems for northing/easting.

Monitoring Wells	Latitude	Longitude	Northing	Easting	EPSG	Well Grouping
PW-1	29.73	-95.41	9901379.05	3857876.02	2277.00	P&T Wells
PW-3	29.74	-95.42	9902076.31	3857177.91	2277.00	P&T Wells
PW-4	29.74	-95.42	9902076.31	3857177.91	2277.00	P&T Wells
MW-4	29.73	-95.41	9901073.08	3858366.19	2277.00	P&T Wells
MW-5	29.73	-95.41	9901430.83	3858223.26	2277.00	Plume Boundary
MW-6	29.73	-95.41	9901296.71	3858483.39	2277.00	Plume Boundary
MW-7	29.73	-95.41	9901558.09	3858630.69	2277.00	Plume Boundary
MW-8	29.73	-95.41	9901053.43	3857922.21	2277.00	Plume Boundary
MW-9	29.73	-95.41	9901028.32	3858177.52	2277.00	Plume Boundary
MW-1	29.73	-95.41	9900698.48	3858128.57	2277.00	P&T Wells

Both lat/long and northing/easting coordinates are needed for the tool to work, but help is provided if you don't know one or the other

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Data Input

Like the other datasets, it is easier to download the (Excel) input file, enter your data in the input file, and then upload the saved data

Enter concentration and time data in the table below to be used in Tools 1, 2, and 5.

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Data Input Instructions:

- Add Latitude and Longitude information for the Monitoring Wells. Adding this information will allow results from Tool 2 to be mapped.
- Please see important note to correctly assign the location information.
- You can download these tables by clicking on the 'Download Input File' button above the table to the right. You can re-load previously saved data by clicking on the 'Upload Saved Data' button and choosing a previously saved data file.
- Please specify the category of wells in the "Well Grouping" column if you wish to analyze them grouped together. Otherwise, provide a single name for each well.

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- Cells highlighted red indicate the value within that cell is not in the correct format (ex. characters are present in column that can only include numerical data).
- If the monitoring well name needs to be updated, use downloaded file from "Download Input File" button, revise the file with new monitoring well name, then upload the file by using "Upload Saved Data". The same procedure should be followed if you need to add new columns.

Important Note

If you possess either latitude/longitude coordinates or northing/easting coordinates (but not both), you are obligated to provide EPSG information from this website https://epsg.io/.
The tool will automatically calculate the missing coordinates from the EPSG information when the data file is uploaded. Here are other sources to estimate coordinates for monitoring locations if they are not otherwise available;

- Use surveying data from an official survey of the wells.
- Obtain a site map, georeferenced the map in a GIS system, and obtain the lat/long data.
- Estimate monitoring locations in a Google Earth map, add Placemarks, and get lat/long in decimal degrees.
- If you have data in degrees/min/sec, convert to decimal degrees at websites like this: https://www.latlong.net/degrees-minutes-seconds-to-decimal-degrees

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Data Input

Enter concentration and time data in the table below to be used in Tools 1, 2, and 5.

Tool 5 has a different input file for the monitoring well info to make sure that the tool-specific analyses are performed correctly

Data Input Instructions:

- Add Latitude and Longitude information for the Monitoring Wells. Adding this information will allow results from Tool 5 to calculate distance from source well.
- Please see important note to correctly assign the location information.
- You can download these tables by clicking on the 'Download Input File' button above the table to the right. You can re-load previously saved data by clicking on the 'Upload Saved Data' button and choosing a previously saved data file.
- Please specify the category of wells in the "Well Grouping" column by either 'Source Well', 'Plume Boundary', or 'Point of Compliance'. Please follow the exact wording/caption in here in order to run the Tool 5.

How to Edit Data:

- Data can be copied and pasted directly into table by selecting cell(s) and using the keyboard shortcut to paste (Windows: Ctrl + V).
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- If the monitoring well name needs to be updated, use downloaded file from "Download Input File" button, revise the file with new monitoring well name, then upload the file by using "Upload Saved Data". The same procedure should be followed if you need to add new columns.

Download Input File | Upload Saved Data | No file selected

1. Concentration and Time Data for Tool 1 and 2 | 2. Concentration and Time Data for Tool 5 | 3. Monitoring Well Information for Tool 1 and 2 | 4. Monitoring Well Information for Tool 5

Important Note

If you possess either latitude/longitude coordinates or northing/easting coordinates (but not both), you are obligated to provide EPSG information from this website https://epsg.io/.
The tool will automatically calculate the missing coordinates from the EPSG information when the data file is uploaded. Here are other sources to estimate coordinates for monitoring locations if they are not otherwise available;

- Use surveying data from an official survey of the wells.
- Obtain a site map, georeferenced the map in a GIS system, and obtain the lat/long data.
- Estimate monitoring locations in a Google Earth map, add Placemarks, and get lat/long in decimal degrees.
- If you have data in degrees/min/sec, convert to decimal degrees at websites like this: https://www.latlong.net/degrees-minutes-seconds-to-decimal-degrees

It is crucial to ensure that the wells have consistent coordinate systems for northing/easting.

Monitoring Wells	Latitude	Longitude	Northing	Easting	EPSG	Well Grouping	Distance from Source (ft)
MW-02-008	43.50	-73.63	1700606.74	721954.30	2260.00	Source Well	0.00
MW-02-020	43.50	-73.63	1700159.54	722799.02	2260.00	Plume Boundary	955.80
46PLTW8	43.50	-73.63	1700234.07	722948.09	2260.00	Plume Boundary	1061.37
MW-02-039	43.50	-73.63	1700159.54	723991.57	2260.00	Plume Boundary	2085.77
34PLTW12	43.50	-73.63	1699277.55	724103.37	2260.00	Plume Boundary	2526.90
MW-02-042	43.50	-73.62	1699376.93	724351.82	2260.00	Plume Boundary	2694.54
MW-02-023	43.50	-73.62	1698718.54	724873.55	2260.00	Plume Boundary	3476.69
MW-02-083	43.49	-73.62	1698979.41	725345.60	2260.00	Plume Boundary	3761.54

SERDP ESTCP

Home | About | Data Input | 1. Asymptote | 2. Expansion | 3. Clean-up Goals | 4. Performance | 5. Plume Projections | 6. Matrix Diffusion | 7. EA | 8. Heterogeneity | 9. Other Projects | 10. Summary

- Once data are entered into the Data Input tabs, they are automatically carried over to the relevant tools (Tool 1, Tool 2, and/or Tool 5)
- Data do not need to be re-entered – once is all it should take
- Because data have to be in specific formats, it is important to follow the directions provided in each tab
- It is highly recommended to download the Excel input files and use those for entering your data – this will save time and prevent errors

from "Download Input File" button, revise the file with new monitoring well name, then upload the file by using "Upload Saved Data". The same procedure should be followed if you need to add new columns.

MW-02-042	43.50	-73.62	1699376.93	724351.82	2260.00	Plume Boundary	2694.54
MW-02-023	43.50	-73.62	1698718.54	724873.55	2260.00	Plume Boundary	3476.69
MW-02-083	43.49	-73.62	1698979.41	725345.60	2260.00	Plume Boundary	3761.54

*Powered by **GSI Environmental** (2024)*

Tool 1:

Are you approaching a concentration vs. time ***asymptote?***

SERDP ESTCP

Home | About | Data Input | 1. Asymptote | 2. Expansion | 3. Clean-up Goals | 4. Performance | 5. Plume Projections | 6. Matrix Diffusion | 7. EA | 8. Heterogeneity | 9. Other Projects | 10. Summary

Tool 1. Am I Approaching a Concentration vs Time Asymptotic Condition at My Site?

Concentration vs. time data are plotted for individual wells or groups of wells

What Does this Tool Do?

1. It calculates source attenuation rates from a monitoring well's concentration vs. time data.
2. It provides a range of time to clean estimates based on a cleanup goal you enter.
3. It helps you determine if asymptotic conditions are present at this location.

How Does it Work?

1. Enter your monitoring well's concentration vs. time data under the 'Data Input' tab.
2. Go through Steps 1-5 to see rates, time to clean, and asymptote Lines of Evidence.

Step 1. Enter Data. See 'Data Input' tab for more information

Step 2. Select Wells to be included in analysis.

Individual Wells   Well Groups

MW-1

Step 3. Choose COC.

TCE

Step 4. Select method for combining data collected on the same day.

Geomean   Mean

Step 5. Select the concentration goal.

5 µg/L

Step 6. Select date range for data.

2012-09-28 to 2024-04-30

Step 7. Select Confidence Inteval (max 0.99).

0.95

Step 8. Select breakpoint between two different time periods.

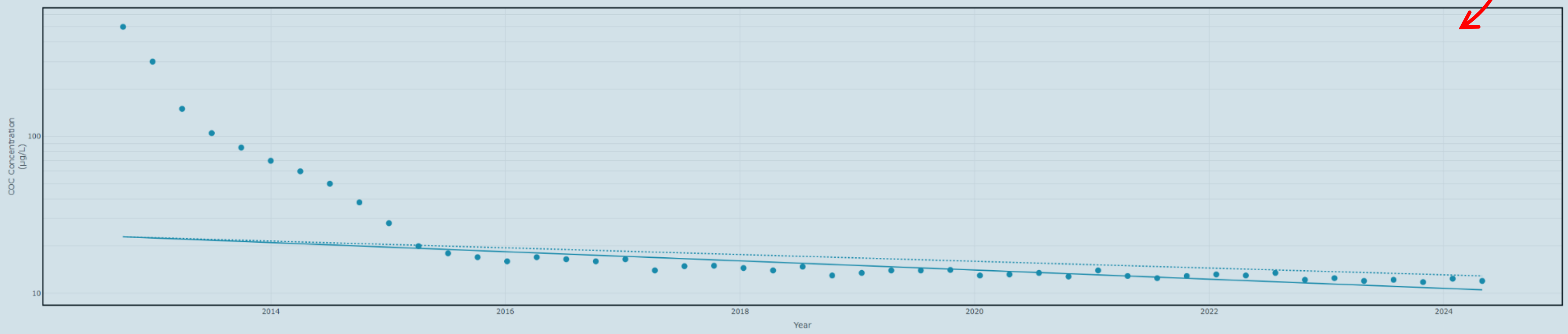
Breakpoint is indicated on plot with a dotted line. To manually select a breakpoint click data point on plot. To deselect, double click the figure where there is no data point.

Key Assumptions

1. The source attenuation trends can be represented by a first order decay relationship.
2. The upper bound of the source attenuation rate is given by the confidence interval selected in Step 7.
3. Five simple rules of thumb (heuristics) can provide evidence that for all practical purposes an asymptote in the concentration vs. time data has been reached.

Results | Data

Geomean Concentration of COC in Selected Wells Over Time



Overall Results

	First Order Source Attenuation Rates (per year)	Estimated Time-to-Clean	
		Year	Upper Bound Year
Entire Record	0.0292	2035	2043
Lower and upper bound years based on 95% confidence interval.			
Cell says 'increasing' when the apparent concentration trend is increasing over time.			

Initially, it will estimate a first-order attenuation rate for the entire monitoring period and the time to reach the cleanup goal

Asymptote Analysis

Why the interest in Asymptotes? From the National Research Council, 2013:

*"Specifically, if data indicate that contaminant concentrations are approaching an **asymptote**, resulting in exponential increases in the unit cost of the remedy, then there is limited benefit in its continued operation."*

*"If **asymptotic conditions** have occurred, a transition assessment is performed."*

Please select a breakpoint between two different time periods in the above figure.
Binary Segmentation suggest change point at 2012-12-29

Save Data and Analysis

SERDP ESTCP

Home | About | Data Input | 1. Asymptote | 2. Expansion | 3. Clean-up Goals | 4. Performance | 5. Plume Projections | 6. Matrix Diffusion | 7. EA | 8. Heterogeneity | 9. Other Projects | 10. Summary

Tool 1. Am I Approaching a Concentration vs Time Asymptotic Condition at My Site?

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1. It calculates source attenuation rates from a monitoring well's concentration vs. time data.
2. It provides a range of time to clean estimates based on a cleanup goal you enter.
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How Does it Work?

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Individual Wells | Well Groups

MW-1

Step 3. Choose COC.

TCE

Step 4. Select method for combining data collected on the same day.

Geomean | Mean

Step 5. Select the concentration goal.

5 µg/L ?

Step 6. Select date range for data.

2012-09-28 to 2024-04-30 ?

Step 7. Select Confidence Inteval (max 0.99).

0.95 ?

Step 8. Select breakpoint between two different time periods.

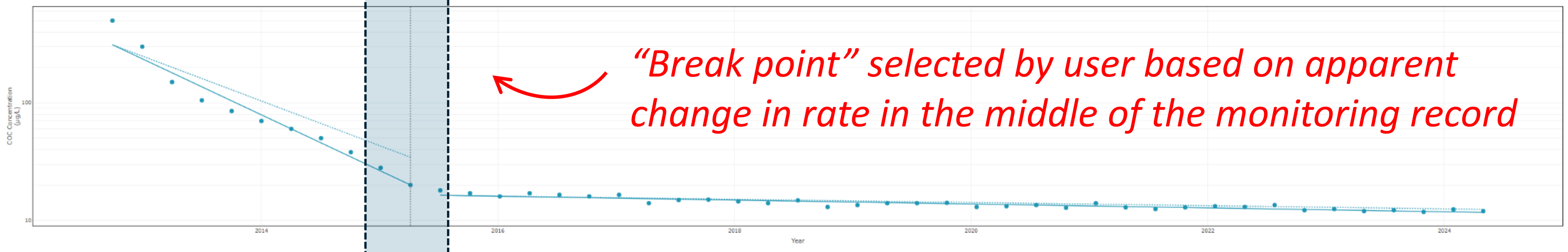
Breakpoint is indicated on plot with a dotted line. To manually select a breakpoint click data point on plot. To deselect, double click the figure where there is no data point.

Key Assumptions

1. The source attenuation trends can be represented by a first order decay relationship.
2. The upper bound of the source attenuation rate is given by the confidence interval selected in Step 7.
3. Five simple rules of thumb (heuristics) can provide evidence that for all practical purposes an asymptote in the concentration vs. time data has been reached.

Results | Data

Geomean Concentration of COC in Selected Wells Over Time



"Break point" selected by user based on apparent change in rate in the middle of the monitoring record

Overall Results

	First Order Source Attenuation Rates (per year)	Estimated Time-to-Clean Year	Estimated Time-to-Clean Upper Bound Year
Entire Record	0.0292	2035	2043
Period 1	0.473	2016	2017
Period 2	0.0165	2046	2053

Lower and upper bound years based on 95% confidence interval.

Cell says 'increasing' when the apparent concentration trend is increasing over time.

Tool calculates rate before and after the "break point" to see if the attenuation rate is slowing down during later periods (i.e., exhibiting asymptotic behavior) and its impact on remediation timeframe

Asymptote Analysis

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*"If **asymptotic conditions** have occurred, a transition assessment is performed."*

Possible Asymptotic Conditions	Is the Condition Met?
1. Are the two rates of attenuation for the two periods significantly different?	YES
2. Is attenuation rate in period 2 significantly close to 0?	NO
3. Is the attenuation rate of the first period more than two times the second rate?	YES
4. Is the the absolute difference between the last points on each regression line less than 10?	YES
5. Is the period 2 attenuation rate less than 0.0693 per year (10 year half-life)?	YES

4 of the **5** possible asymptotic conditions are present.

Save Data and Analysis

SERDP ESTCP

Home | About | Data Input | 1. Asymptote | 2. Expansion | 3. Clean-up Goals | 4. Performance | 5. Plume Projections | 6. Matrix Diffusion | 7. EA | 8. Heterogeneity | 9. Other Projects | 10. Summary

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Individual Wells · Well Groups

MW-1

Step 3. Choose COC.

TCE

Step 4. Select method for combining data collected on the same day.

Geomean · Mean

Step 5. Select the concentration goal.

5 µg/L ?

Step 6. Select date range for data.

2012-09-28 to 2024-04-30 ?

Step 7. Select Confidence Inteval (max 0.99).

0.95 ?

Step 8. Select breakpoint between two different time periods.

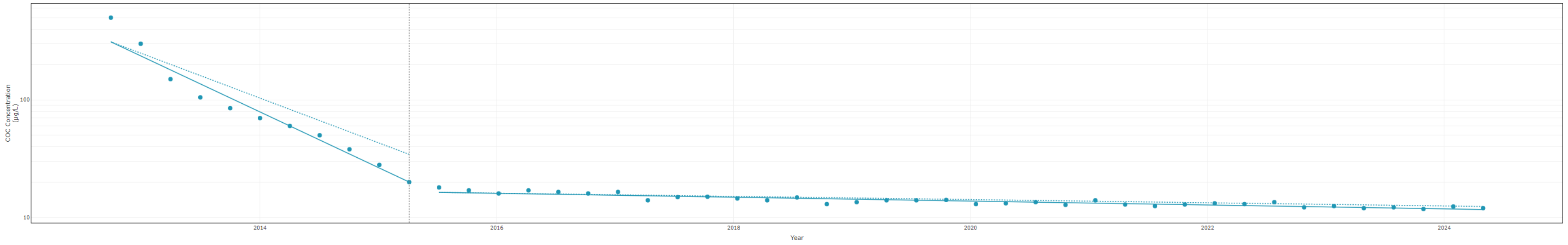
Breakpoint is indicated on plot with a dotted line. To manually select a breakpoint click data point on plot. To deselect, double click the figure where there is no data point.

Key Assumptions

1. The source attenuation trends can be represented by a first order decay relationship.
2. The upper bound of the source attenuation rate is given by the confidence interval selected in Step 7.
3. Five simple rules of thumb (heuristics) can provide evidence that for all practical purposes an asymptote in the concentration vs. time data has been reached.

Results | Data

Geomean Concentration of COC in Selected Wells Over Time



Overall Results

	First Order Source Attenuation Rates (per year)	Estimated Time-to-Clean	
		Year	Upper Bound Year
Entire Record	0.0292	2035	2043
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Lower and upper bound years based on 95% confidence interval.

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1. Are the two rates of attenuation for the two periods significantly different?	YES
2. Is attenuation rate in period 2 significantly close to 0?	NO
3. Is the attenuation rate of the first period more than two times the second rate?	YES
4. Is the the absolute difference between the last points on each regression line less than 10?	YES
5. Is the period 2 attenuation rate less than 0.0693 per year (10 year half-life)?	YES

4 of the **5** possible asymptotic conditions are present.

Save Data and Analysis

Tool assesses five different lines of evidence for "asymptotic" behavior – sites with multiple lines of evidence are better candidates for transitioning

Tool 2:

Is my plume stable or still expanding?

SERDP ESTCP

Home | About | Data Input | 1. Asymptote | 2. Expansion | 3. Clean-up Goals | 4. Performance | 5. Plume Projections | 6. Matrix Diffusion | 7. EA | 8. Heterogeneity | 9. Other Projects | 10. Summary

Tool 2. Is my plume still expanding?

What Does this Tool Do?

This tool uses concentration vs. time monitoring well data entered by the user to calculate trends in the data. The monitoring well data can be aggregated into three groups:

1. Source wells
2. Mid-plume wells
3. Downgradient wells (or any other grouping of wells)

The tool then uses a non-parametric trend test (Mann-Kendall Test) to determine if increasing or decreasing trends are present.

How Does it Work?

1. Enter your monitoring well's concentration vs. time data under the 'Data Input' tab.
2. Go through Steps 1-4 to get the trends and determine if your plume is still expanding.

Step 1. Enter Data. See 'Data Input' tab for more information

Step 2. Select Well Groupings to be included in analysis.

Plume Boundary

Step 3. Select data type to analyze.

Concentration Mass

Step 4. Choose COC.

TCE

Step 5. Select method for combining data.

Geomean Mean

Step 6 (Optional). Select the concentration goal.

5 µg/L ?

Results | Time Series Plot | Trend Map | Data

Calculates the concentration trend for all wells or subsets of wells to assess plume stability

OVERALL MANN-KENDALL TEST RESULTS

Groups of Wells	Trend	S Statistic	p-Value	Coefficient of Variation	Sen's Slope
Plume Boundary	Probably Decreasing	−198	0.0988	0.598	−0.0544

MANN-KENDALL TEST RESULTS BY WELL

Monitoring Well	Trend	S Statistic	p-Value	Coefficient of Variation	Sen's Slope
MW-5	No Trend	33	0.788	0.558	0
MW-6	No Trend	98	0.388	0.327	0
MW-7	No Trend	111	0.338	0.386	0
MW-8	Probably Decreasing	−212	0.0768	1.55	−0.0377
MW-9	Probably Decreasing	−212	0.0768	1.55	−0.0377

	Is the plume still expanding?
Plume Boundary	No

Save Data and Analysis

*Powered by **GSI Environmental** (2024)*

SERDP ESTCP

Home | About | Data Input | 1. Asymptote | 2. Expansion | 3. Clean-up Goals | 4. Performance | 5. Plume Projections | 6. Matrix Diffusion | 7. EA | 8. Heterogeneity | 9. Other Projects | 10. Summary

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The tool then uses a non-parametric trend test (Mann-Kendall Test) to determine if increasing or decreasing trends are present.

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Step 1. Enter Data. See 'Data Input' tab for more information

Step 2. Select Well Groupings to be included in analysis.

Plume Boundary

Step 3. Select data type to analyze.

◉ Concentration ○ Mass

Step 4. Choose COC.

TCE

Step 5. Select method for combining data.

◉ Geomean ○ Mean

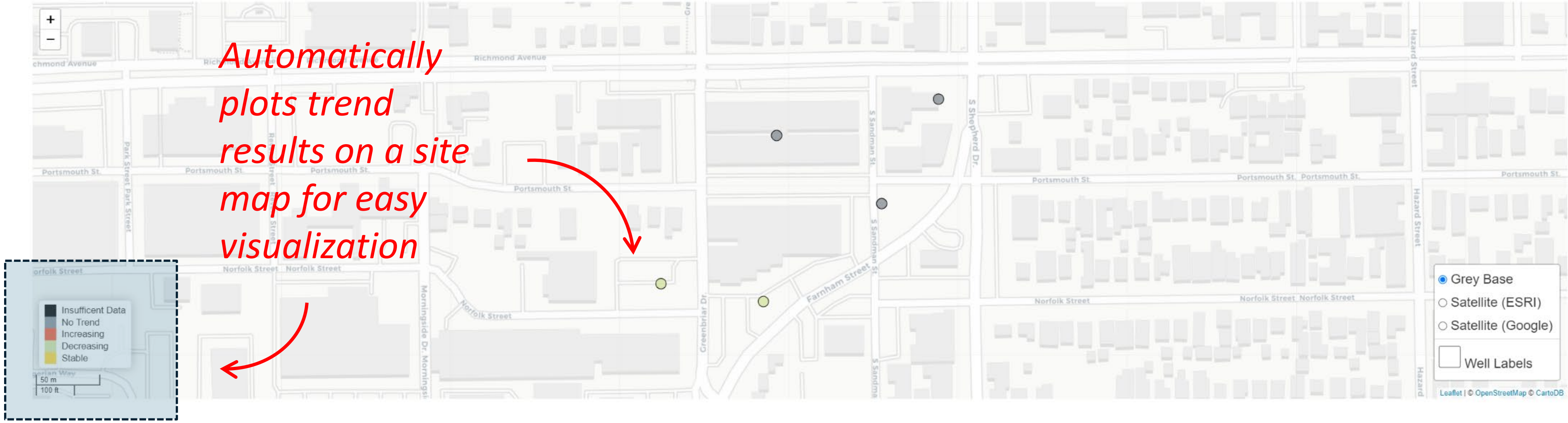
Step 6 (Optional). Select the concentration goal.

5 µg/L ?

Results | Time Series Plot | Trend Map | Data

Select Date to Display: Plume Boundary

Save Map



Automatically plots trend results on a site map for easy visualization

Save Data and Analysis

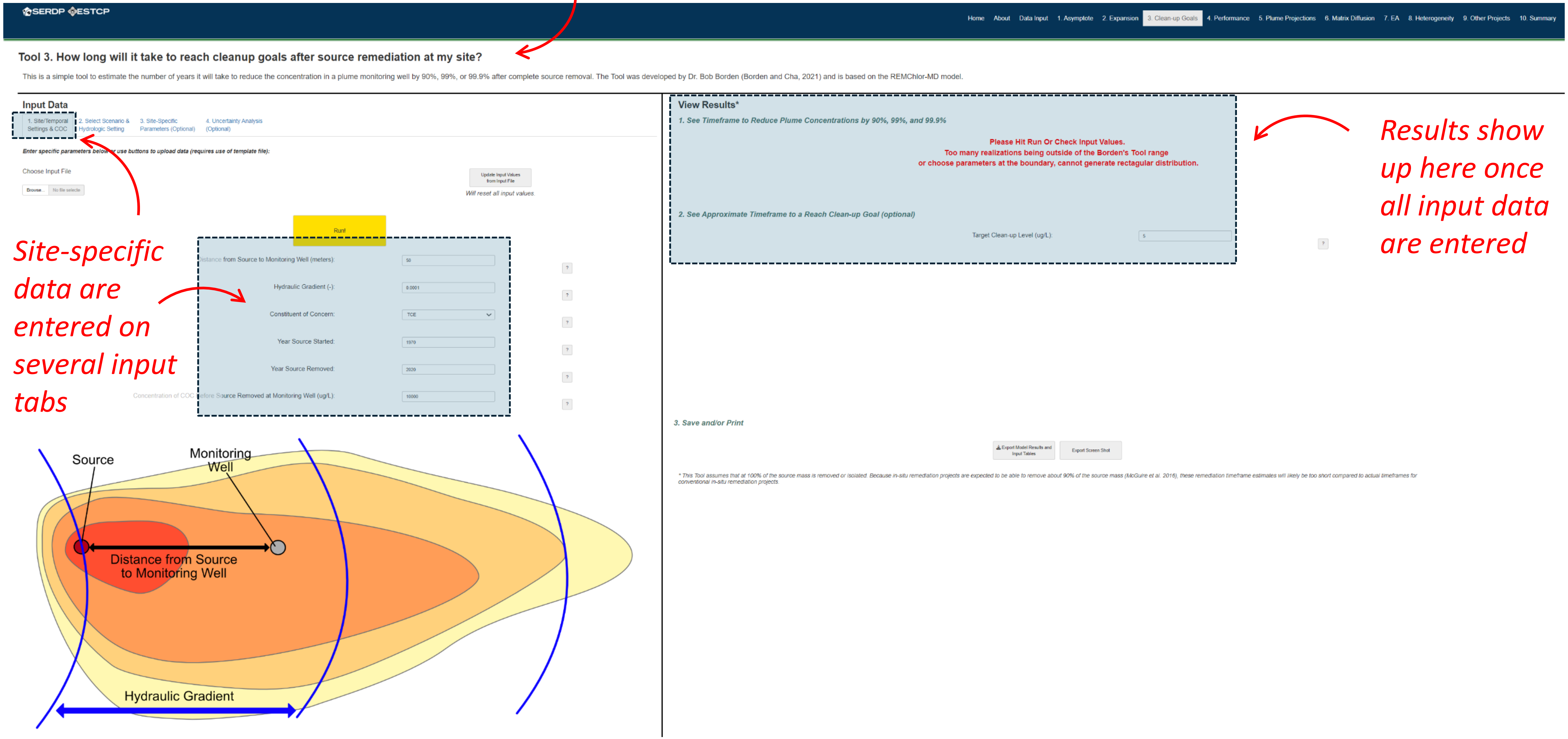
*Powered by **GSI Environmental** (2024)*

Tool 3:

If I remove the source now, how long will it take to reach my cleanup goal?
(i.e., remediation timeframe)

Predicts the site-specific remediation timeframe after removing source using REMChlor-MD modeling results

Site-specific data are entered on several input tabs



Results show up here once all input data are entered

SERDP ESTCP

Home | About | Data Input | 1. Asymptote | 2. Expansion | 3. Clean-up Goals | 4. Performance | 5. Plume Projections | 6. Matrix Diffusion | 7. EA | 8. Heterogeneity | 9. Other Projects | 10. Summary

Tool 3. How long will it take to reach cleanup goals after source remediation at my site?

This is a simple tool to estimate the number of years it will take to reduce the concentration in a plume monitoring well by 90%, 99%, or 99.9% after complete source removal. The Tool was developed by Dr. Bob Borden (Borden and Cha, 2021) and is based on the REMChlor-MD model.

Input Data

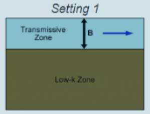
1. Site/Temporal Settings & COC | 2. Select Scenario & Hydrologic Setting | 3. Site-Specific Parameters (Optional) | 4. Uncertainty Analysis (Optional)

Select the hydrogeologic setting that best matches your site.

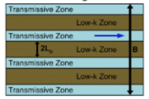
?

- ◉ Setting 1: Aquifer with aquitard (either below, above, or both)
- ○ Setting 2: Aquifer with no aquitard but layers/lenses
- ○ Setting 3: Aquifer with both aquitard and layers/lenses

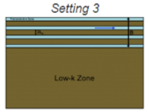
Setting 1



Setting 2



Setting 3



Select the aquifer setting that is most similar to your site

For All Scenarios:

Aquifer Thickness (meters): 1 ?

Transmissive Zone Soil Type: Gravel ?

Low-k Soil Type: Clay ?

◉ Do Not Include Low-k Degradation ○ Include Low-k Degradation ?

View Results*

1. See Timeframe to Reduce Plume Concentrations by 90%, 99%, and 99.9%

Please Hit Run Or Check Input Values.
Too many realizations being outside of the Borden's Tool range
or choose parameters at the boundary, cannot generate rectagular distribution.

2. See Approximate Timeframe to a Reach Clean-up Goal (optional)

Target Clean-up Level (ug/L): 5 ?

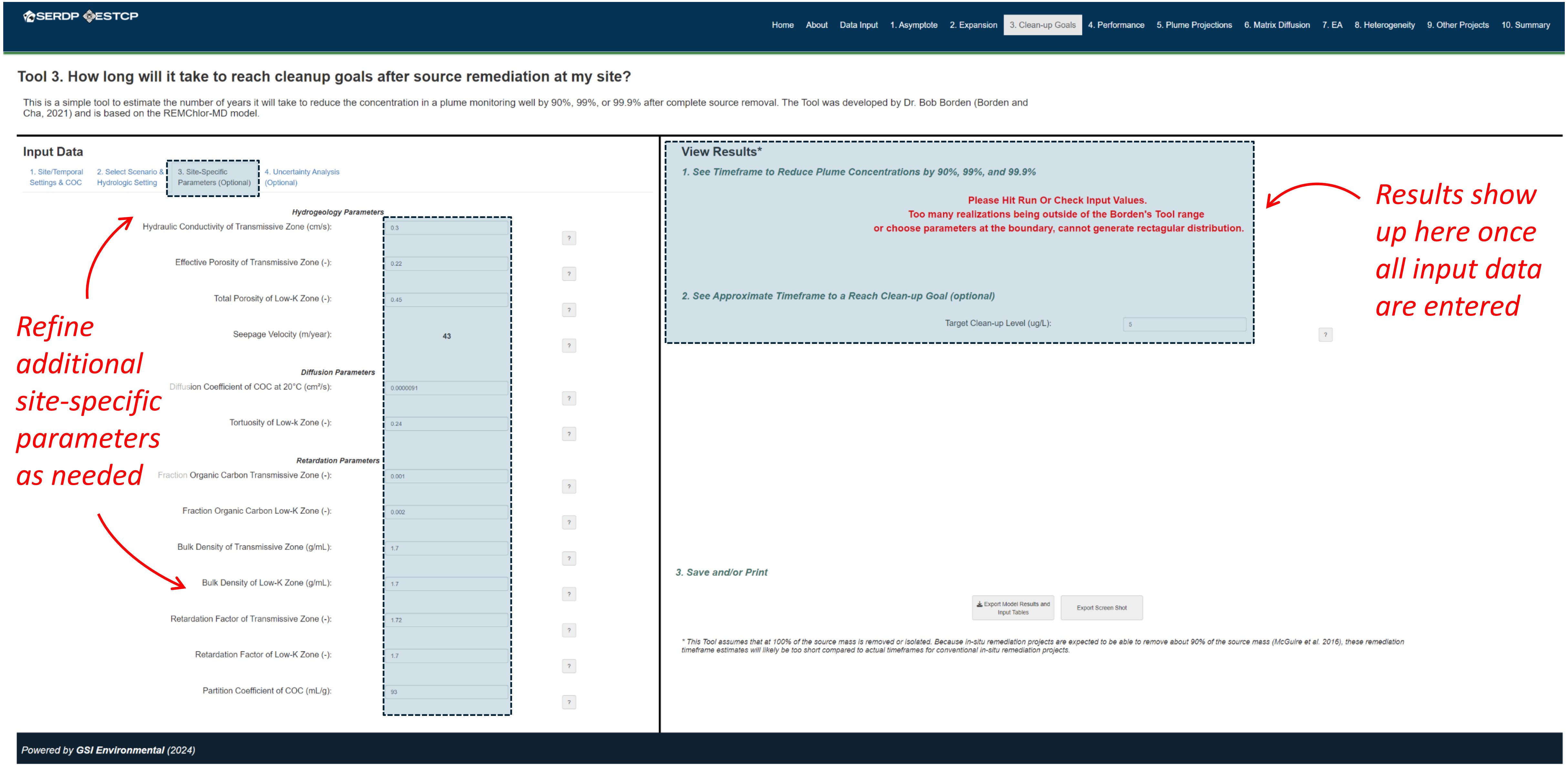
Results show up here once all input data are entered

3. Save and/or Print

Export Model Results and Input Tables | Export Screen Shot

** This Tool assumes that at 100% of the source mass is removed or isolated. Because in-situ remediation projects are expected to be able to remove about 90% of the source mass (McGuire et al. 2016), these remediation timeframe estimates will likely be too short compared to actual timeframes for conventional in-situ remediation projects.*

*Powered by **GSI Environmental** (2024)*



Refine additional site-specific parameters as needed

Results show up here once all input data are entered

SERDP ESTCP

Home | About | Data Input | 1. Asymptote | 2. Expansion | 3. Clean-up Goals | 4. Performance | 5. Plume Projections | 6. Matrix Diffusion | 7. EA | 8. Heterogeneity | 9. Other Projects | 10. Summary

Tool 3. How long will it take to reach cleanup goals after source remediation at my site?

This is a simple tool to estimate the number of years it will take to reduce the concentration in a plume monitoring well by 90%, 99%, or 99.9% after complete source removal. The Tool was developed by Dr. Bob Borden (Borden and Cha, 2021) and is based on the REMChlor-MD model.

Input Data

1. Site/Temporal Settings & COC | 2. Select Scenario & Hydrologic Setting | 3. Site-Specific Parameters (Optional) | 4. Uncertainty Analysis (Optional)

Enter specific parameters below or use buttons to upload data (requires use of template file):

Choose Input File

Browse... No file selecte

Update Input Values from Input File

Will reset all input values.

Run!

Hit "Run" once all input data are entered

Distance from Source to Monitoring Well (meters): 50

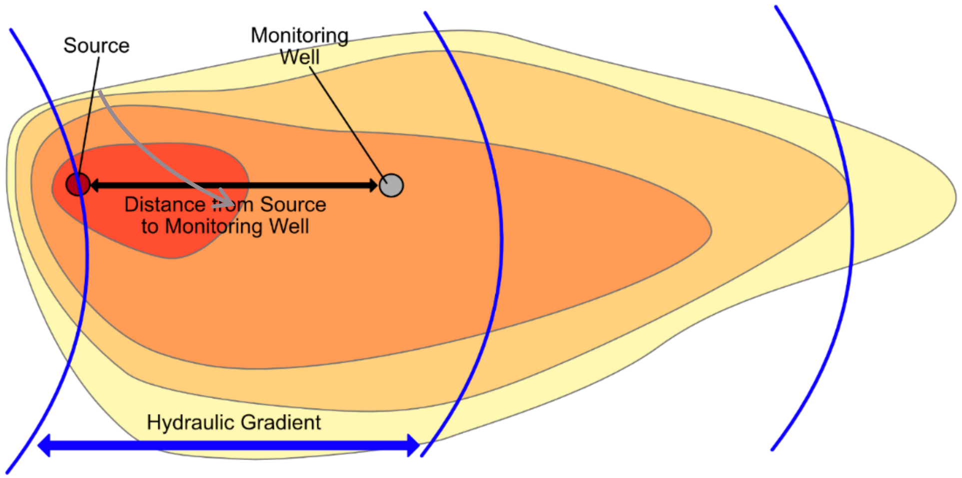
Hydraulic Gradient (-): 0.0001

Constituent of Concern: TCE

Year Source Started: 1970

Year Source Removed: 2020

Concentration of COC Before Source Removed at Monitoring Well (ug/L): 10000



View Results*

1. See Timeframe to Reduce Plume Concentrations by 90%, 99%, and 99.9%

Concentration Reduction	Concentration (ug/L)	Year Achieved	Estimated Ranges of Year Achieved	Years From Now (2024)
90% (1 OoM)	1000	2024	2021 - 2030	-
99% (2 OoMs)	100	2049	2032 - 2092	25
99.9% (3 OoMs)	10	2211	2069 - 2457	187

How long it will take to achieve 90%, 99%, and 99.9% concentration reductions

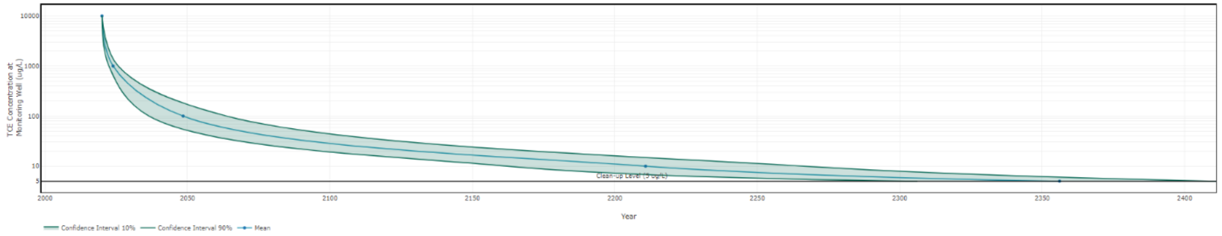
Travel Time from Source to Well: **1** years

Monte Carlo Number of Realizations: **1000** out of 1,000

2. See Approximate Timeframe to a Reach Clean-up Goal (optional)

Target Clean-up Level (ug/L): 5

The monitoring well will achieve the clean-up goal of 5 ug/L in **2369**.



3. Save and/or Print

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SERDP ESTCP

Home | About | Data Input | 1. Asymptote | 2. Expansion | 3. Clean-up Goals | 4. Performance | 5. Plume Projections | 6. Matrix Diffusion | 7. EA | 8. Heterogeneity | 9. Other Projects | 10. Summary

Tool 3. How long will it take to reach cleanup goals after source remediation at my site?

This is a simple tool to estimate the number of years it will take to reduce the concentration in a plume monitoring well by 90%, 99%, or 99.9% after complete source removal. The Tool was developed by Dr. Bob Borden (Borden and Cha, 2021) and is based on the REMChlor-MD model.

Input Data

1. Site/Temporal Settings & COC | 2. Select Scenario & Hydrologic Setting | 3. Site-Specific Parameters (Optional) | 4. Uncertainty Analysis (Optional)

Enter specific parameters below or use buttons to upload data (requires use of template file):

Choose Input File

Browse... No file selecte

Update Input Values from Input File

Will reset all input values.

Run!

Hit “Run” once all input data are entered

Distance from Source to Monitoring Well (meters): 50

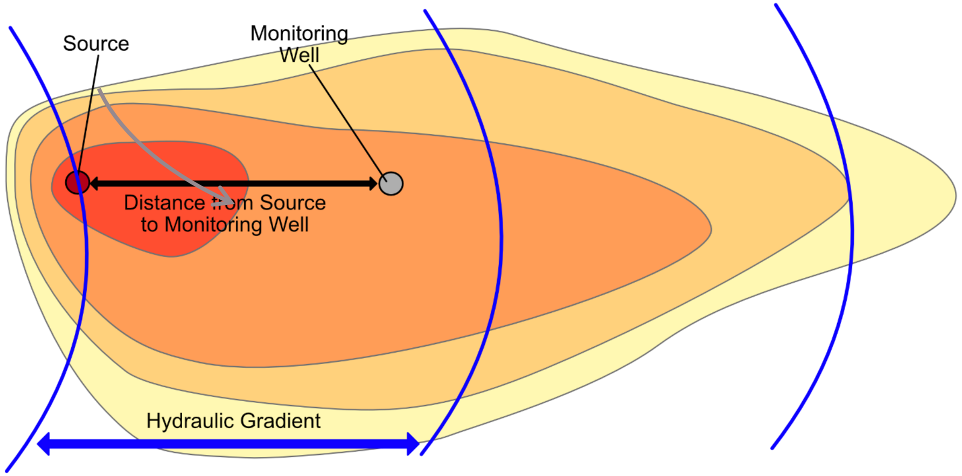
Hydraulic Gradient (-): 0.0001

Constituent of Concern: TCE

Year Source Started: 1970

Year Source Removed: 2020

Concentration of COC Before Source Removed at Monitoring Well (ug/L): 10000



View Results*

1. See Timeframe to Reduce Plume Concentrations by 90%, 99%, and 99.9%

Concentration Reduction	Concentration (ug/L)	Year Achieved	Estimated Ranges of Year Achieved	Years From Now (2024)
90% (1 OoM)	1000	2024	2021 - 2030	-
99% (2 OoMs)	100	2049	2032 - 2092	25
99.9% (3 OoMs)	10	2211	2069 - 2457	187

Travel Time from Source to Well: **1** years

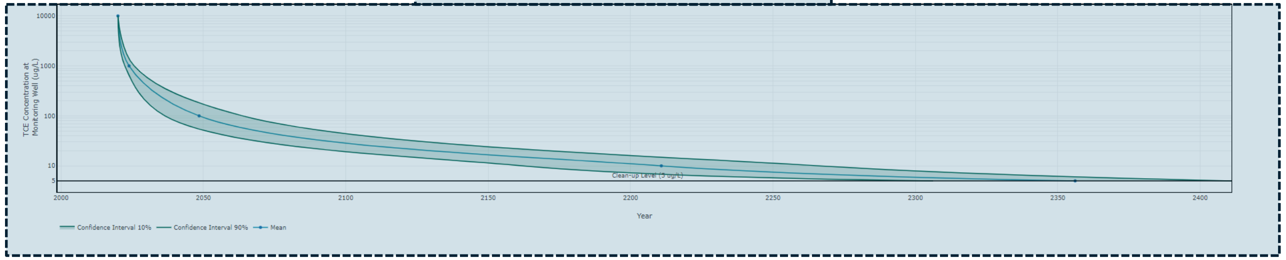
Monte Carlo Number of Realizations: **1000** out of 1,000

Estimates the year when the target cleanup level will be achieved (remediation timeframe)

2. See Approximate Timeframe to a Reach Clean-up Goal (optional)

Target Clean-up Level (ug/L): 5

The monitoring well will achieve the clean-up goal of 5 ug/L in **2369**.



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Plots the progress towards the target cleanup level over time (with uncertainty based on Monte Carlo analysis)

SERDP ESTCP

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Tool 3. How long will it take to reach cleanup goals after source remediation at my site?

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Input Data

1. Site/Temporal Settings & COC | 2. Select Scenario & Hydrologic Setting | 3. Site-Specific Parameters (Optional) | 4. Uncertainty Analysis (Optional)

Enter Upper and Lower Limit Values for the Following Parameters

Parameter:	Lower Limit:	Upper Limit:
Distance from Source to Monitoring Well (Current Value: **50.0** meters)	40	60
Hydraulic Conductivity of High K Zone (Current Value: **0.300** cm/s)	0.15	0.6
Hydraulic Gradient (Current Value: **0.000100**)	0.00008	0.00012
Effective Porosity (Current Value: **0.220**)	0.176	0.264
Year Source Started (Current Value: **1970**)	1960	1980
Aquifer Thickness (Current Value: **1.00** meters)	0.8	1.2
Tortuosity of Low-k Zone (Current Value: **0.240**)	0.216	0.264
Retardation Factor of Transmissive Zone (Current Value: **1.72**)	1.376	2.064
Retardation Factor of Low-K Zone (Current Value: **1.70**)	1.36	2.04

Use default parameters for Monte Carlo analysis or adjust on your own

View Results*

1. See Timeframe to Reduce Plume Concentrations by 90%, 99%, and 99.9%

Concentration Reduction	Concentration (ug/L)	Year Achieved	Estimated Ranges of Year Achieved	Years From Now (2024)
90% (1 OoM)	1000	2024	2021 - 2030	-
99% (2 OoMs)	100	2049	2032 - 2092	25
99.9% (3 OoMs)	10	2211	2069 - 2457	187

Travel Time from Source to Well: **1** years

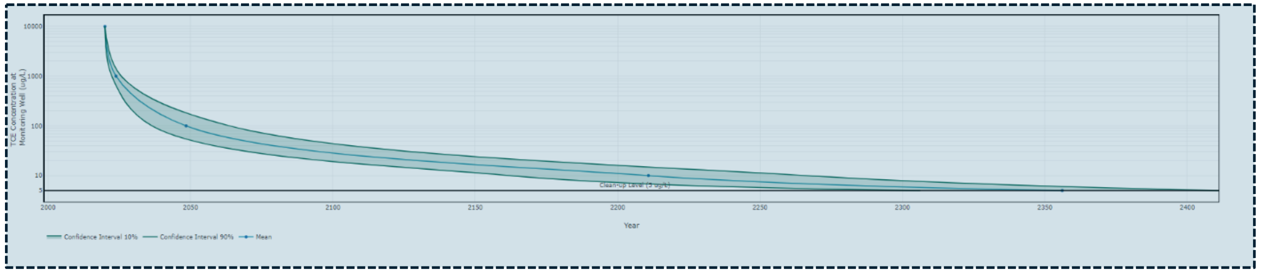
Monte Carlo Number of Realizations: **1000** out of 1,000

Monte Carlo analysis is used to establish uncertainty around remediation timeframe estimate

2. See Approximate Timeframe to a Reach Clean-up Goal (optional)

Target Clean-up Level (ug/L): 5

The monitoring well will achieve the clean-up goal of 5 ug/L in **2369**.



3. Save and/or Print

Export Model Results and Input Tables | Export Screen Shot

** This Tool assumes that at 100% of the source mass is removed or isolated. Because in-situ remediation projects are expected to be able to remove about 90% of the source mass (McGuire et al. 2016), these remediation timeframe estimates will likely be too short compared to actual timeframes for conventional in-situ remediation projects.*

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Tool 3. How long will it take to reach cleanup goals after source remediation at my site?

This is a simple tool to estimate the number of years it will take to reduce the concentration in a plume monitoring well by 90%, 99%, or 99.9% after complete source removal. The Tool was developed by Dr. Bob Borden (Borden and Cha, 2021) and is based on the REMChlor-MD model.

Input Data

1. Site/Temporal Settings & COC | 2. Select Scenario & Hydrologic Setting | 3. Site-Specific Parameters (Optional) | 4. Uncertainty Analysis (Optional)

Enter Upper and Lower Limit Values for the Following Parameters

Parameter:	Lower Limit:	Upper Limit:
Distance from Source to Monitoring Well (Current Value: **50.0** meters)	40	60
Hydraulic Conductivity of High K Zone (Current Value: **0.300** cm/s)	0.15	0.6
Hydraulic Gradient (Current Value: **0.000100**)	0.00008	0.00012
Effective Porosity (Current Value: **0.220**)	0.176	0.264
Year Source Started (Current Value: **1970**)	1960	1980
Aquifer Thickness (Current Value: **1.00** meters)	0.8	1.2
Tortuosity of Low-k Zone (Current Value: **0.240**)	0.216	0.264
Retardation Factor of Transmissive Zone (Current Value: **1.72**)	1.376	2.064
Retardation Factor of Low-K Zone (Current Value: **1.70**)	1.36	2.04

View Results*

1. See Timeframe to Reduce Plume Concentrations by 90%, 99%, and 99.9%

Concentration Reduction	Concentration (ug/L)	Year Achieved	Estimated Ranges of Year Achieved	Years From Now (2024)
90% (1 OoM)	1000	2024	2021 - 2030	-
99% (2 OoMs)	100	2049	2032 - 2092	25
99.9% (3 OoMs)	10	2211	2069 - 2457	187

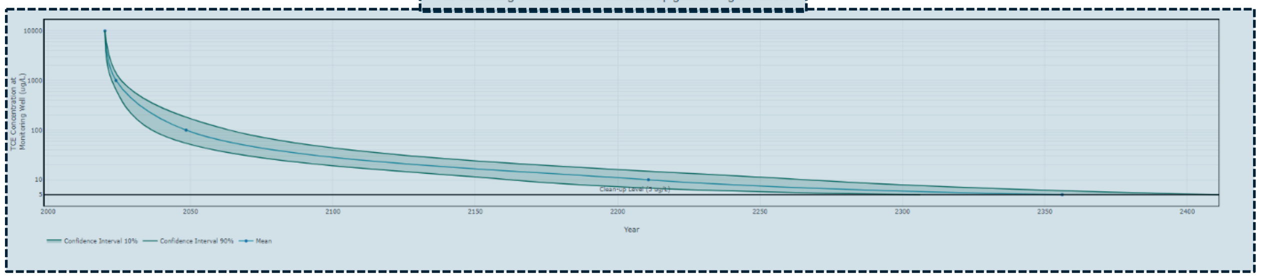
Travel Time from Source to Well: **1** years

Monte Carlo Number of Realizations: **1000** out of 1,000

2. See Approximate Timeframe to a Reach Clean-up Goal (optional)

Target Clean-up Level (ug/L): 5

The monitoring well will achieve the clean-up goal of 5 ug/L in **2369**.



3. Save and/or Print

Export Model Results and Input Tables | Export Screen Shot

** This Tool assumes that at 100% of the source mass is removed or isolated. Because in-situ remediation projects are expected to be able to remove about 90% of the source mass (McGuire et al. 2016), these remediation timeframe estimates will likely be too short compared to actual timeframes for conventional in-situ remediation projects.*

*Powered by **GSI Environmental** (2024)*

In this case, the remediation timeframe is very long (centuries) due to matrix diffusion impacts

Line of evidence that the site is a good candidate for transitioning away from active treatment approaches (i.e., remediation timeframe is long even if source is completely removed)

Tool 4:

What level of ***performance*** *can I expect from an in-situ source remediation project?*

Uses database derived from 235 sites to help show the range of performance you can expect from in situ source remediation project

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Tool 4. What level of performance can I expect from an in-situ source remediation project?

What Does this Tool Do?

This tool leverages the extensive ESTCP investment in understanding what has happened at remediation sites to create a semi-quantitative forecasting tool for understanding what level of performance might be achieved at a particular site. This is then used to predict whether the selected technology would be able to obtain the concentration reduction needed to achieve a site-specific cleanup goal.

How Does it Work?

1. Select variables for contaminant type, maximum concentration range, and technologies in Steps 1-3.
2. Input a site-specific cleanup goal and starting concentration in Steps 4-5.
3. Use the table at the right of the chart to see how close you will get to the site-specific cleanup goal based on the expected performance of the selected technology.
4. See data from the selected remediation projects using the "Data" tab.
5. Go through the "Remediation Potential Assessment" tab to answer more questions related to site-specific expectations of remediation performance

Step 1. Select sites with these constituents of concern (COCs)

Chlorinated Solvents ○ Benzene

All Chlorinated Solvents

Step 2. Select Sites with These Pre-Remediation Maximum Concentrations

All Sites

Step 3. Select an in-situ remediation source treatment technologies(COCs)

All Technologies

Step 4. Input Cleanup Goal (ug/L)

5

Step 5. Input Concentration at the Site (ug/L)

20

Select type of site and technology that you want to evaluate

Results | Data | Remediation Potential Assessment

Remediation Chart

Forecasting Results

Number of Remediation Projects: 253

	Middle Range	Low Range	High Range
Empirical Remediation Performance Stats			
% reduction	82	Increasing	100
OoM reduction	0.75	-1.4	5.1
After In-Situ Remediation is Performed, How Much Closer to the Cleanup Goal Will You Get?			
Forecast % reduction still needed	Goal Achieved	Increasing	Goal Achieved
OoM reduction still needed	Goal Achieved	2	Goal Achieved
% way to reach criteria (based on OoMs)	Goal Achieved	1	Goal Achieved

Each site is plotted based on the concentration before remediation (x-axis) and after remediation (y-axis)

What does this chart show?

This chart shows the performance of in-situ remediation technologies as defined by the change in the maximum concentration in the source zone groundwater **before and after remediation where:**

- The X-Axis shows the maximum concentration in groundwater *before remediation.*
- The Y-Axis shows the maximum concentration in groundwater *after remediation.*

Every one of the dots on the graph shows the performance of an actual in-situ remediation project where site reports were data mined to get representative source zone groundwater concentrations before and after remediation.

The diagonal lines are the Orders of Magnitude (OoM) Reduction where:

- 1 OoM = 90% Reduction in Concentration ("one '9')
- 2 OoM = 99% Reduction in Concentration ("two '9s')
- 3 OoM = 99.9% Reduction in Concentration ("three '9s')

The Blue dashed line shows the drinking water criteria (Maximum Concentration Level or MCL) for the contaminant of concern.

References

McGuire, T, D Adamson, C Newell, and P Kulkarni. 2016. "Performance and Costs for In-Situ Remediation at 235 Sites." Environmental Security Technology and Certification Program ER-201120 (https://www.serdp-estcp.org/Program-Areas/Environmental-Restoration/Contaminated-Groundwater/Persistent-Contamination/ER-201120/ER-201120). http://www.serdp-estcp.org.

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Tool 4. What level of performance can I expect from an in-situ source remediation project?

What Does this Tool Do?

This tool leverages the extensive ESTCP investment in understanding what has happened at remediation sites to create a semi-quantitative forecasting tool for understanding what level of performance might be achieved at a particular site. This is then used to predict whether the selected technology would be able to obtain the concentration reduction needed to achieve a site-specific cleanup goal.

How Does it Work?

1. Select variables for contaminant type, maximum concentration range, and technologies in Steps 1-3.
2. Input a site-specific cleanup goal and starting concentration in Steps 4-5.
3. Use the table at the right of the chart to see how close you will get to the site-specific cleanup goal based on the expected performance of the selected technology.
4. See data from the selected remediation projects using the "Data" tab.
5. Go through the "Remediation Potential Assessment" tab to answer more questions related to site-specific expectations of remediation performance

Step 1. Select sites with these constituents of concern (COCs)

Chlorinated Solvents | Benzene

All Chlorinated Solvents

Step 2. Select Sites with These Pre-Remediation Maximum Concentrations

All Sites

Step 3. Select an in-situ remediation source treatment technologies(COCs)

All Technologies

Step 4. Input Cleanup Goal (ug/L)

5

?

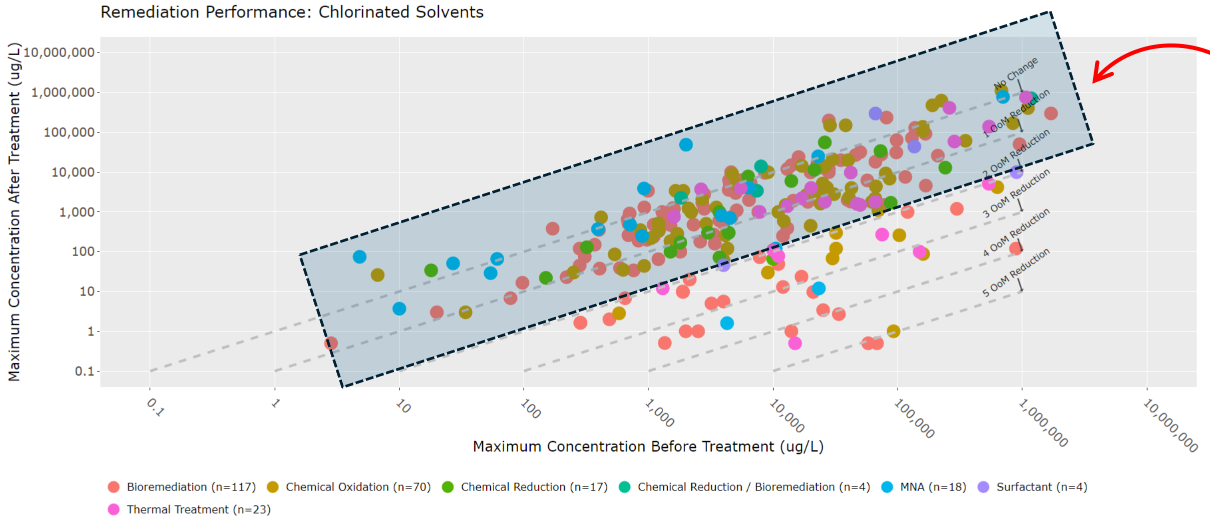
Step 5. Input Concentration at the Site (ug/L)

20

?

Results | Data | Remediation Potential Assessment

Remediation Chart



Forecasting Results

Number of Remediation Projects: 253

	Middle Range	Low Range	High Range
Empirical Remediation Performance Stats			
% reduction	82	Increasing	100
OoM reduction	0.75	-1.4	5.1
After In-Situ Remediation Is Performed, How Much Closer to the Cleanup Goal Will You Get?			

Sites that plot in the upper left had moderate or even poor performance (concentration reductions of < 2 orders of magnitude after remediation)

What does this chart show?

This chart shows the performance of in-situ remediation technologies as defined by the change in the maximum concentration in the source zone groundwater **before and after remediation where:**

- The X-Axis shows the maximum concentration in groundwater *before remediation.*
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Every one of the dots on the graph shows the performance of an actual in-situ remediation project where site reports were data mined to get representative source zone groundwater concentrations before and after remediation.

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- 3 OoM = 99.9% Reduction in Concentration ("three '9s')

The Blue dashed line shows the drinking water criteria (Maximum Concentration Level or MCL) for the contaminant of concern.

References

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Tool 4. What level of performance can I expect from an in-situ source remediation project?

What Does this Tool Do?

This tool leverages the extensive ESTCP investment in understanding what has happened at remediation sites to create a semi-quantitative forecasting tool for understanding what level of performance might be achieved at a particular site. This is then used to predict whether the selected technology would be able to obtain the concentration reduction needed to achieve a site-specific cleanup goal.

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Step 1. Select sites with these constituents of concern (COCs)

Chlorinated Solvents Benzene

All Chlorinated Solvents

Step 2. Select Sites with These Pre-Remediation Maximum Concentrations

All Sites

Step 3. Select an in-situ remediation source treatment technologies(COCs)

All Technologies

Step 4. Input Cleanup Goal (ug/L)

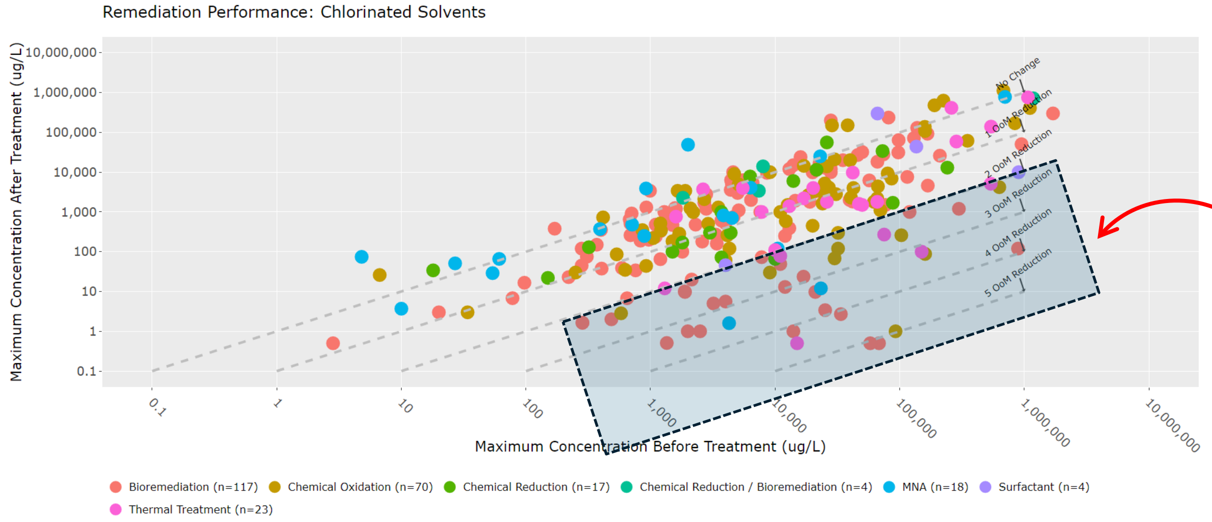
5

Step 5. Input Concentration at the Site (ug/L)

20

Results | Data | Remediation Potential Assessment

Remediation Chart



Forecasting Results

Number of Remediation Projects: 253

	Middle Range	Low Range	High Range
Empirical Remediation Performance Stats			
% reduction	82	Increasing	100
OoM reduction	0.75	-1.4	5.1
After In-Situ Remediation is Performed, How Much Closer to the Cleanup Goal Will You Get?			
Forecast % reduction still needed	Goal Achieved	Increasing	Goal Achieved
OoM reduction still needed	Goal Achieved	2	Goal Achieved
% way to reach criteria (based on OoMs)	Goal Achieved	1	Goal Achieved

Sites that plot in the lower right had better performance (concentration reductions of > 2 orders of magnitude after remediation)

What does this chart show?

This chart shows the performance of in-situ remediation technologies as defined by the change in the maximum concentration in the source zone groundwater **before and after remediation where:**

- The X-Axis shows the maximum concentration in groundwater *before remediation.*
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Every one of the dots on the graph shows the performance of an actual in-situ remediation project where site reports were data mined to get representative source zone groundwater concentrations before and after remediation.

The diagonal lines are the Orders of Magnitude (OoM) Reduction where:

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References

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Tool 4. What level of performance can I expect from an in-situ source remediation project?

What Does this Tool Do?

This tool leverages the extensive ESTCP investment in understanding what has happened at remediation sites to create a semi-quantitative forecasting tool for understanding what level of performance might be achieved at a particular site. This is then used to predict whether the selected technology would be able to obtain the concentration reduction needed to achieve a site-specific cleanup goal.

How Does it Work?

1. Select variables for contaminant type, maximum concentration range, and technologies in Steps 1-3.
2. Input a site-specific cleanup goal and starting concentration in Steps 4-5.
3. Use the table at the right of the chart to see how close you will get to the site-specific cleanup goal based on the expected performance of the selected technology.
4. See data from the selected remediation projects using the "Data" tab.
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Step 1. Select sites with these constituents of concern (COCs)

Chlorinated Solvents ○ Benzene

All Chlorinated Solvents

Step 2. Select Sites with These Pre-Remediation Maximum Concentrations

All Sites

Step 3. Select an in-situ remediation source treatment technologies(COCs)

All Technologies

Step 4. Input Cleanup Goal (ug/L)

5

Step 5. Input Concentration at the Site (ug/L)

20

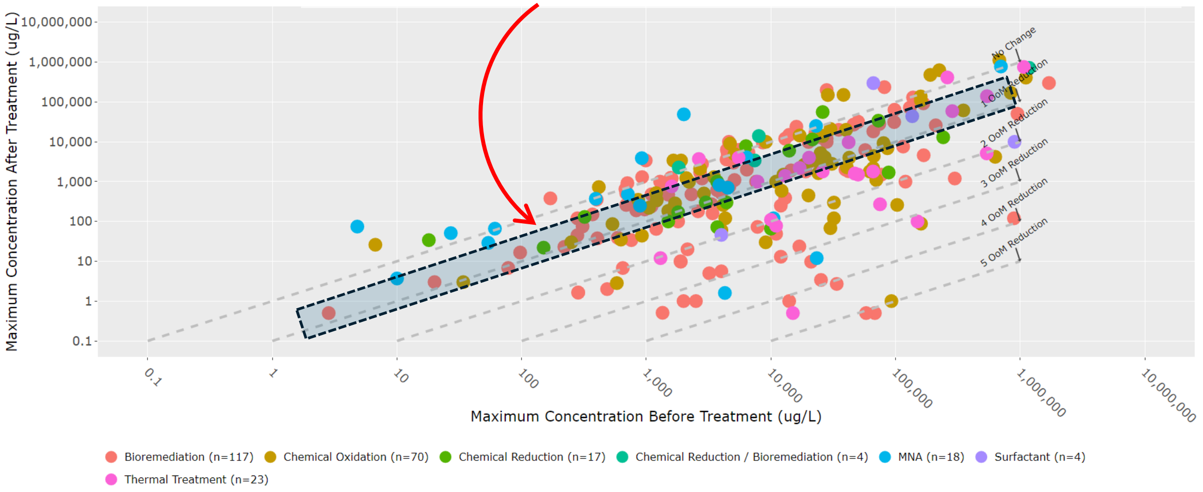
Site-specific values for cleanup goal and concentration before remediation

Results | Data | Remediation Potential Assessment

Median in situ remediation project reduces concentrations by just under 1 OoM

Remediation Chart

Remediation Performance: Chlorinated Solvents



Forecasting Results

Number of Remediation Projects: 253

	Middle Range	Low Range	High Range
Empirical Remediation Performance Stats			
% reduction	82	Increasing	100
OoM reduction	0.75	-1.4	5.1
After In-Situ Remediation is Performed, How Much Closer to the Cleanup Goal Will You Get?			
Forecast % reduction still needed	Goal Achieved	Increasing	Goal Achieved
OoM reduction still needed	Goal Achieved	2	Goal Achieved
% way to reach criteria (based on OoMs)	Goal Achieved	1	Goal Achieved

Summarizes data from all selected sites, including how close you might get to site-specific cleanup goals after remediation

What does this chart show?

This chart shows the performance of in-situ remediation technologies as defined by the change in the maximum concentration in the source zone groundwater **before and after remediation where:**

- The X-Axis shows the maximum concentration in groundwater *before remediation.*
- The Y-Axis shows the maximum concentration in groundwater *after remediation.*

Every one of the dots on the graph shows the performance of an actual in-situ remediation project where site reports were data mined to get representative source zone groundwater concentrations before and after remediation.

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- 3 OoM = 99.9% Reduction in Concentration ("three '9s'")

The Blue dashed line shows the drinking water criteria (Maximum Concentration Level or MCL) for the contaminant of concern.

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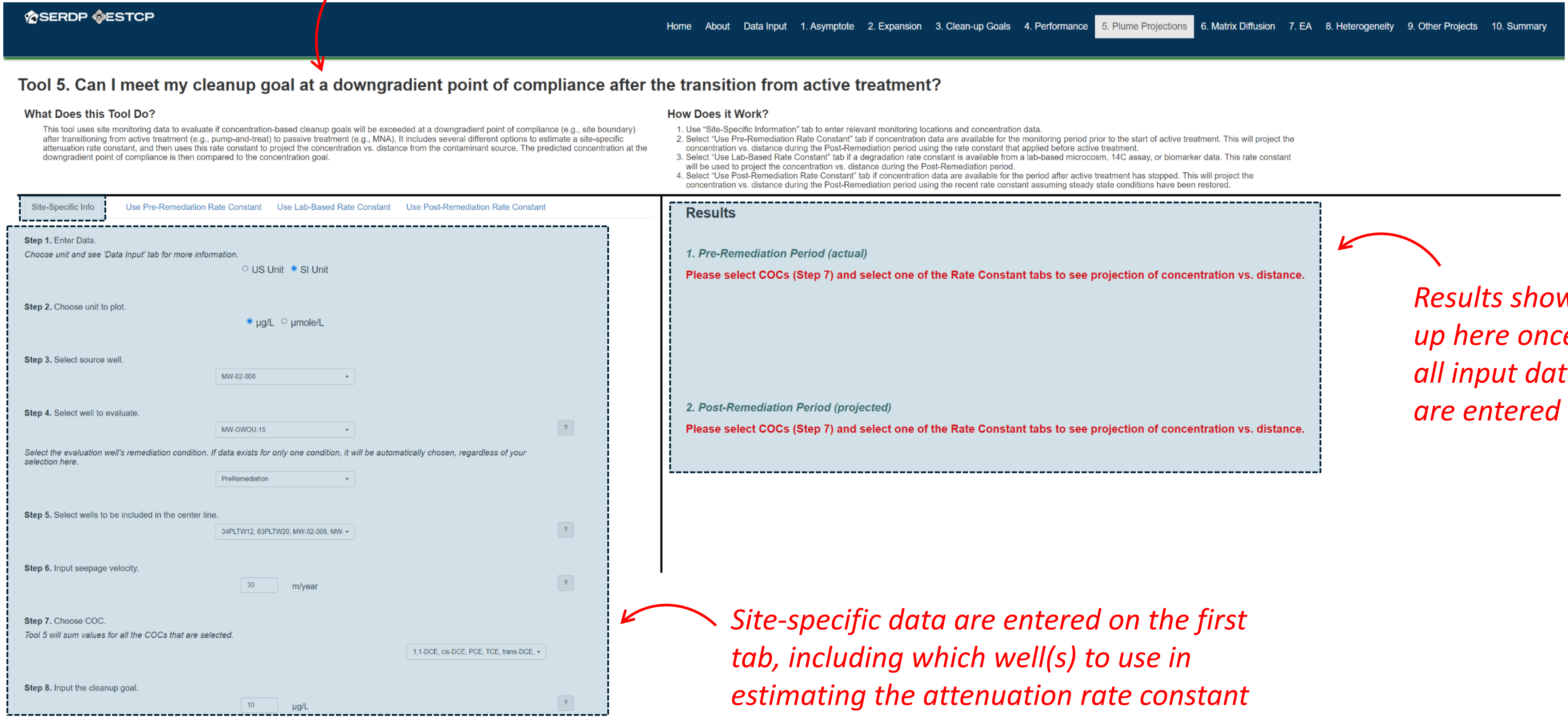
Tool 5:

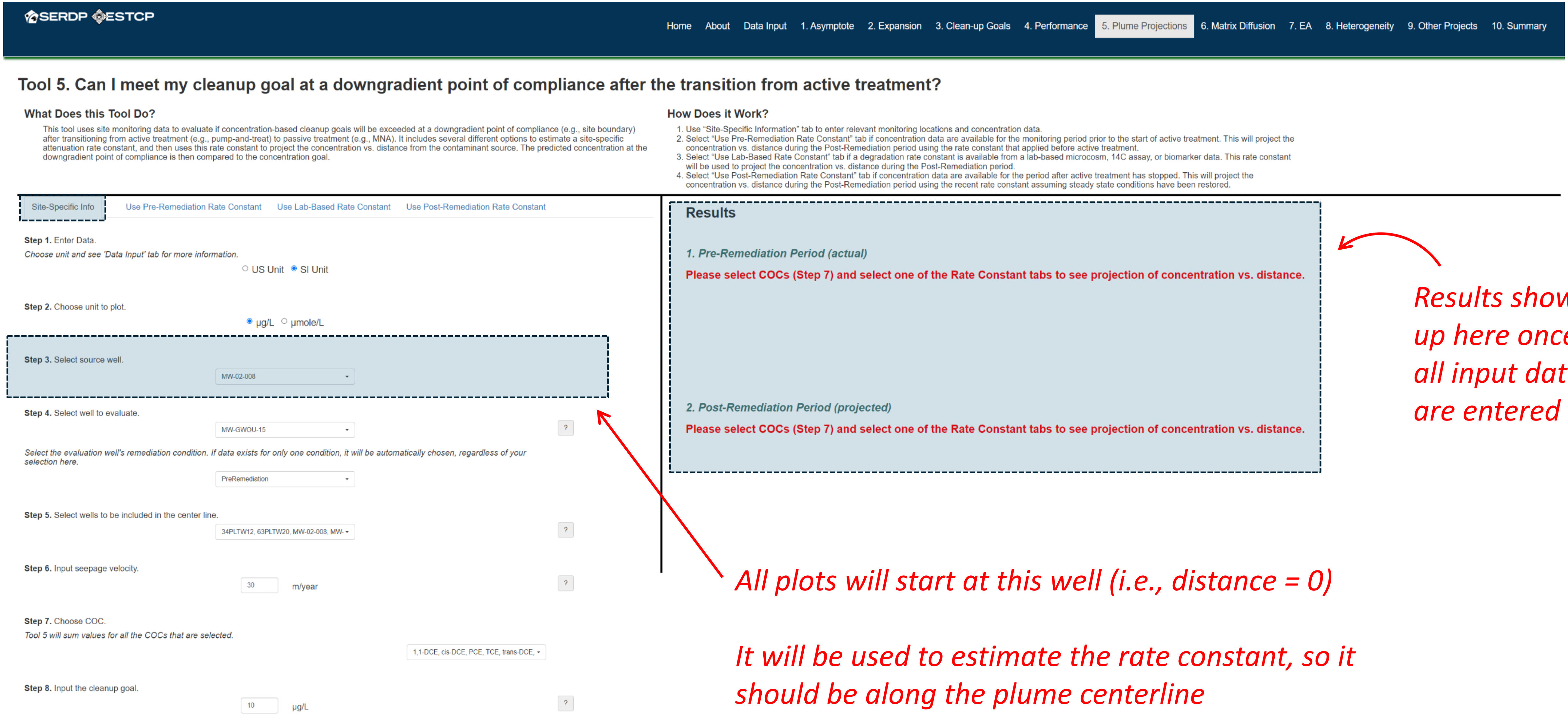
Can I meet my cleanup goal at a downgradient point of compliance after stopping active treatment?

Estimates natural attenuation rates to help project the plume concentration vs. distance and determine if cleanup goal can be met at a downgradient point of compliance



Results show up here once all input data are entered

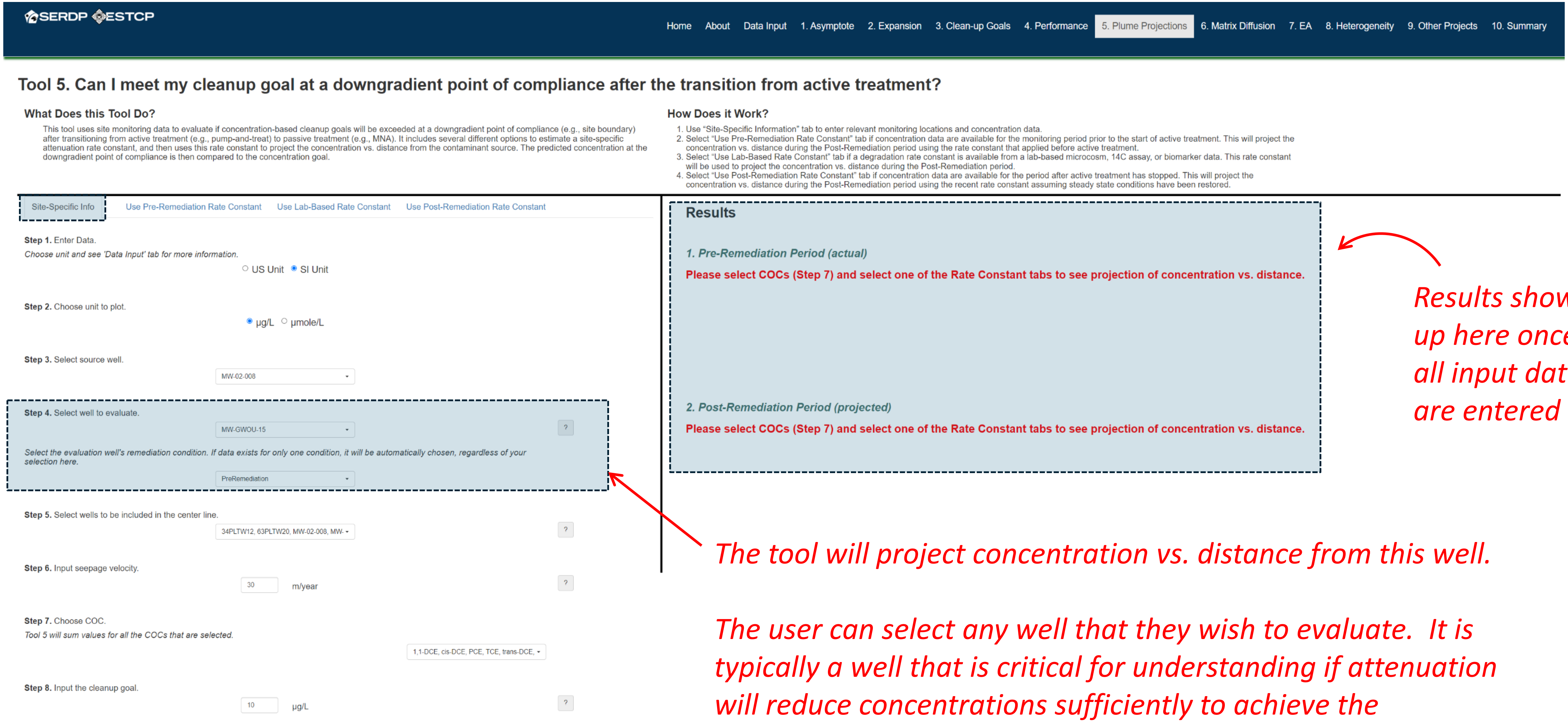
Site-specific data are entered on the first tab, including which well(s) to use in estimating the attenuation rate constant



Results show up here once all input data are entered

All plots will start at this well (i.e., distance = 0)

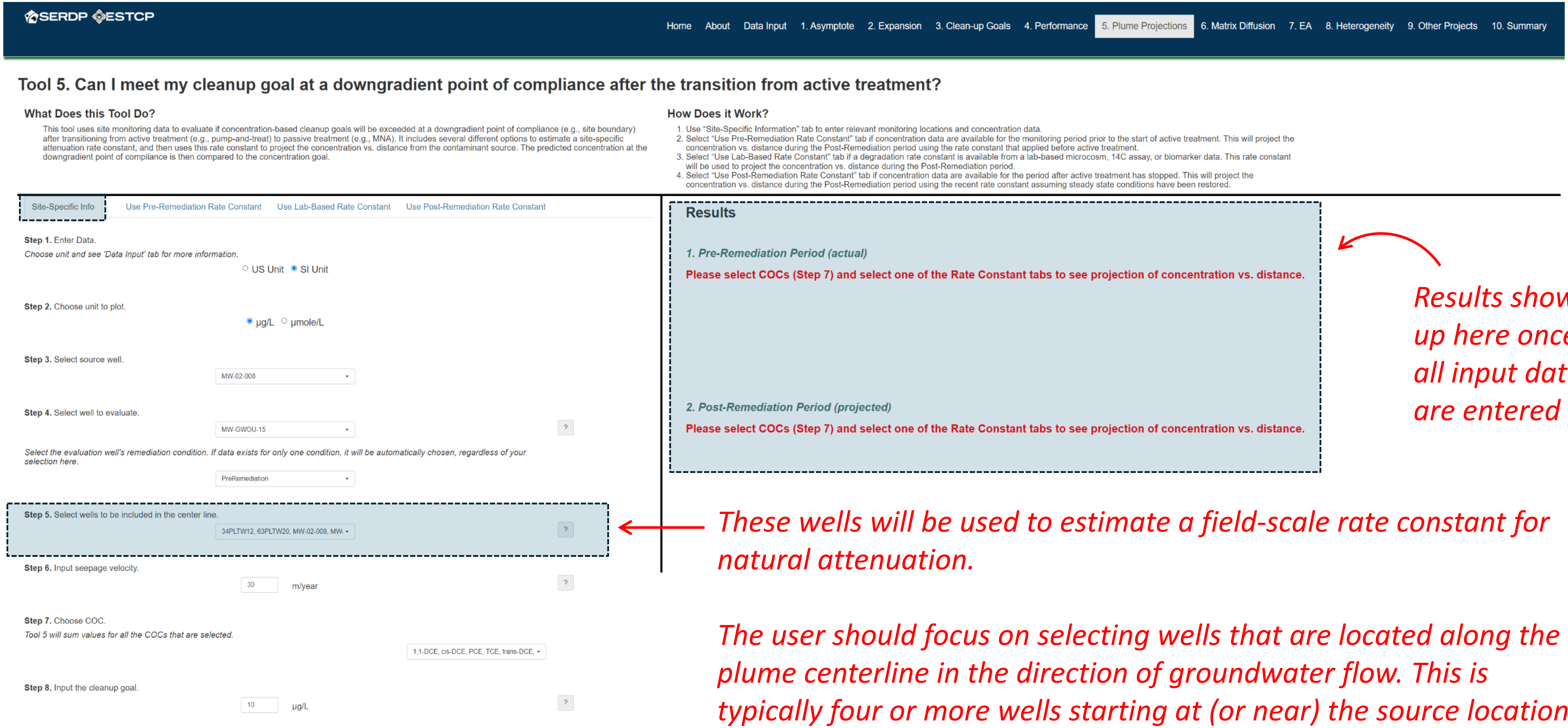
It will be used to estimate the rate constant, so it should be along the plume centerline



Results show up here once all input data are entered

The tool will project concentration vs. distance from this well.

The user can select any well that they wish to evaluate. It is typically a well that is critical for understanding if attenuation will reduce concentrations sufficiently to achieve the downgradient cleanup goal



Results show up here once all input data are entered

These wells will be used to estimate a field-scale rate constant for natural attenuation.

The user should focus on selecting wells that are located along the plume centerline in the direction of groundwater flow. This is typically four or more wells starting at (or near) the source location and proceeding downgradient towards the point of compliance.

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Tool 5. Can I meet my cleanup goal at a downgradient point of compliance after the transition from active treatment?

What Does this Tool Do?

This tool uses site monitoring data to evaluate if concentration-based cleanup goals will be exceeded at a downgradient point of compliance (e.g., site boundary) after transitioning from active treatment (e.g., pump-and-treat) to passive treatment (e.g., MNA). It includes several different options to estimate a site-specific attenuation rate constant, and then uses this rate constant to project the concentration vs. distance from the contaminant source. The predicted concentration at the downgradient point of compliance is then compared to the concentration goal.

How Does it Work?

1. Use "Site-Specific Information" tab to enter relevant monitoring locations and concentration data.
2. Select "Use Pre-Remediation Rate Constant" tab if concentration data are available for the monitoring period prior to the start of active treatment. This will project the concentration vs. distance during the Post-Remediation period using the rate constant that applied before active treatment.
3. Select "Use Lab-Based Rate Constant" tab if a degradation rate constant is available from a lab-based microcosm, 14C assay, or biomarker data. This rate constant will be used to project the concentration vs. distance during the Post-Remediation period.
4. Select "Use Post-Remediation Rate Constant" tab if concentration data are available for the period after active treatment has stopped. This will project the concentration vs. distance during the Post-Remediation period using the recent rate constant assuming steady state conditions have been restored.

Site-Specific Info | Use Pre-Remediation Rate Constant | Use Lab-Based Rate Constant | Use Post-Remediation Rate Constant

Step 1. Select confidence interval for one sided test.

○ 80% ● 90% ○ 95% ○ 99%

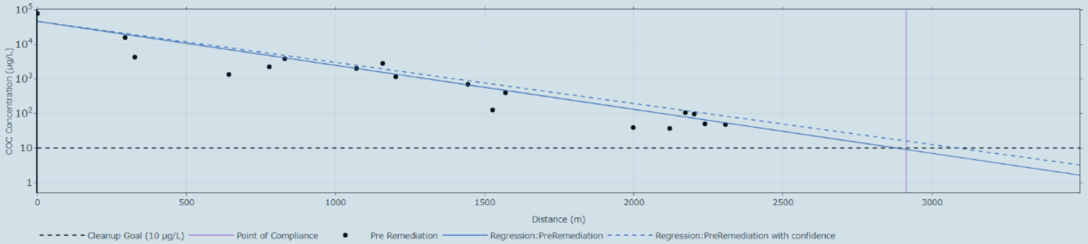
Select "Use Pre-Remediation Rate Constant" tab if concentration data are available for the monitoring period prior to the start of active treatment.

The tool will first plot the pre-remediation data and then use it to estimate the natural attenuation rate constant for this period (with a user-specified confidence limit).

Results

1. Pre-Remediation Period (actual)

Concentration of COC in Identified Wells Over Distance

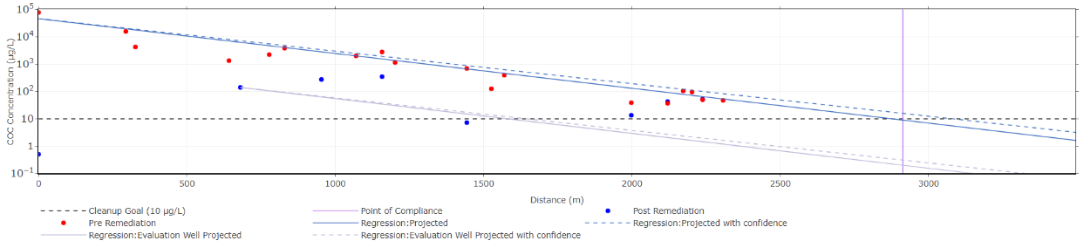


Estimated Attenuation Rate Constant (per meter)	Without Confidence Limit	With Confidence Limit
	0.0029	0.0027

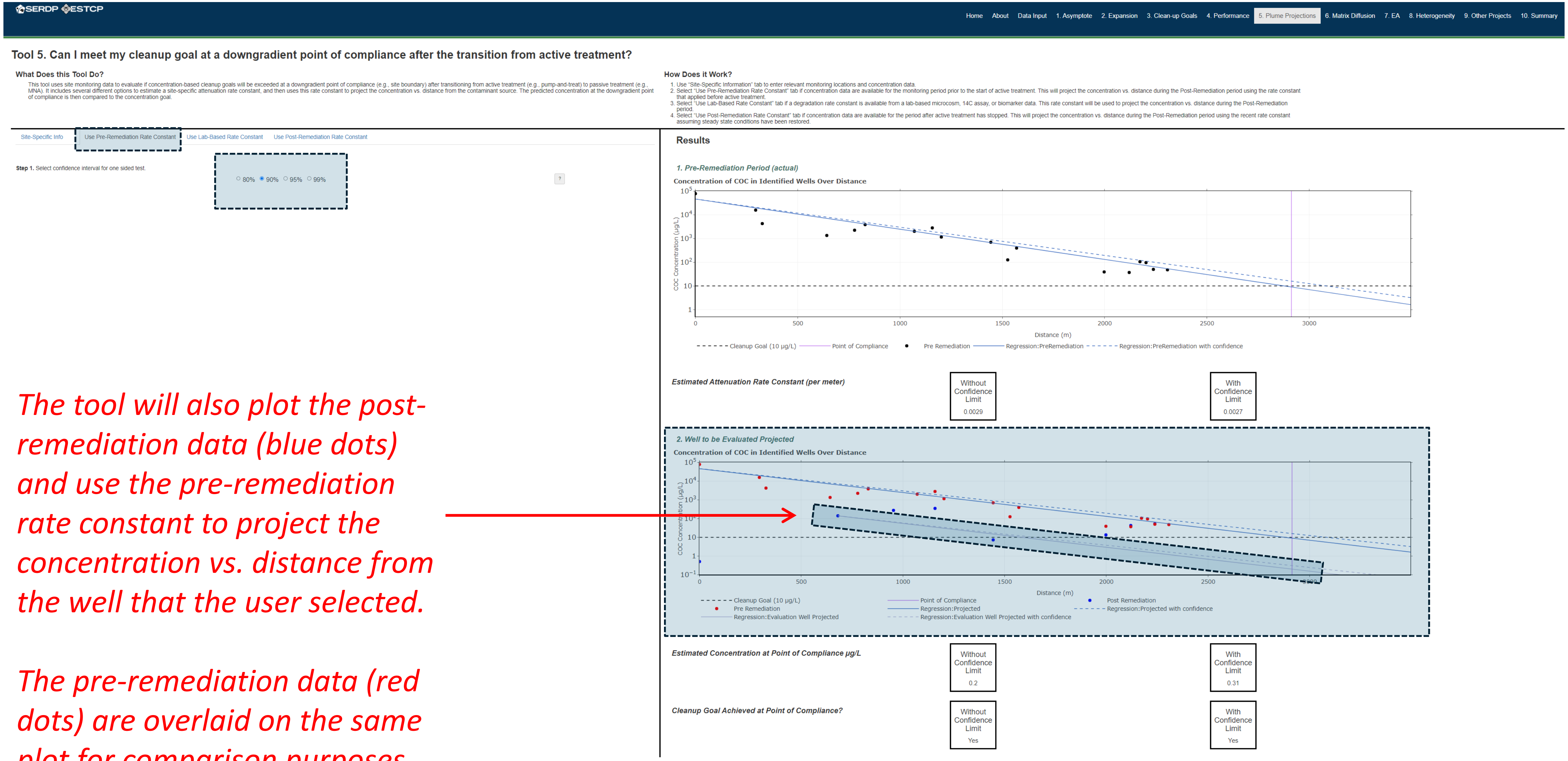
Estimated rate constant for pre-remediation period

2. Well to be Evaluated Projected

Concentration of COC in Identified Wells Over Distance



	Without Confidence Limit	With Confidence Limit
Estimated Concentration at Point of Compliance μg/L	0.2	0.31
Cleanup Goal Achieved at Point of Compliance?	Yes	Yes



The tool will also plot the post-remediation data (blue dots) and use the pre-remediation rate constant to project the concentration vs. distance from the well that the user selected.

The pre-remediation data (red dots) are overlaid on the same plot for comparison purposes.

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Tool 5. Can I meet my cleanup goal at a downgradient point of compliance after the transition from active treatment?

What Does this Tool Do?

This tool uses site monitoring data to evaluate if concentration-based cleanup goals will be exceeded at a downgradient point of compliance (e.g., site boundary) after transitioning from active treatment (e.g., pump-and-treat) to passive treatment (e.g., MNA). It includes several different options to estimate a site-specific attenuation rate constant, and then uses this rate constant to project the concentration vs. distance from the contaminant source. The predicted concentration at the downgradient point of compliance is then compared to the concentration goal.

How Does it Work?

1. Use "Site-Specific Information" tab to enter relevant monitoring locations and concentration data.
2. Select "Use Pre-Remediation Rate Constant" tab if concentration data are available for the monitoring period prior to the start of active treatment. This will project the concentration vs. distance during the Post-Remediation period using the rate constant that applied before active treatment.
3. Select "Use Lab-Based Rate Constant" tab if a degradation rate constant is available from a lab-based microcosm, 14C assay, or biomarker data. This rate constant will be used to project the concentration vs. distance during the Post-Remediation period.
4. Select "Use Post-Remediation Rate Constant" tab if concentration data are available for the period after active treatment has stopped. This will project the concentration vs. distance during the Post-Remediation period using the recent rate constant assuming steady state conditions have been restored.

Site-Specific Info | Use Pre-Remediation Rate Constant | Use Lab-Based Rate Constant | Use Post-Remediation Rate Constant

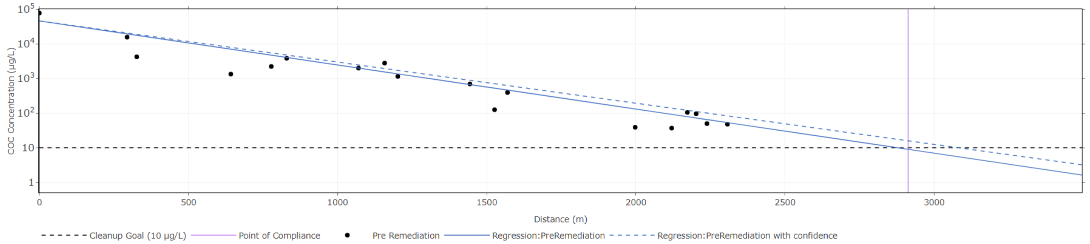
Step 1. Select confidence interval for one sided test.

○ 80% ● 90% ○ 95% ○ 99%

?

Results

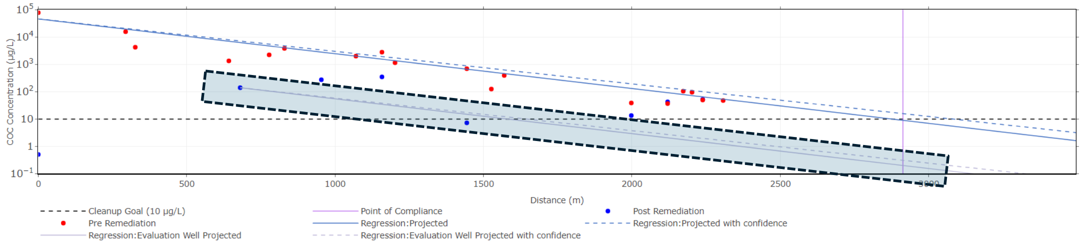
1. Pre-Remediation Period (actual)



Estimated Attenuation Rate Constant (per meter)	Without Confidence Limit	With Confidence Limit
	0.0029	0.0027

Point of compliance

2. Well to be Evaluated Projected



	Without Confidence Limit	With Confidence Limit
Estimated Concentration at Point of Compliance µg/L	0.2	0.31
Cleanup Goal Achieved at Point of Compliance?	Yes	Yes

The tool calculates the concentration at the point of compliance, and then says if it meets the cleanup goal (with a user-specified confidence level)

Tool 5. Can I meet my cleanup goal at a downgradient point of compliance after the transition from active treatment?

What Does this Tool Do?

This tool uses site monitoring data to evaluate if concentration-based cleanup goals will be exceeded at a downgradient point of compliance (e.g., site boundary) after transitioning from active treatment (e.g., pump-and-treat) to passive treatment (e.g., MNA). It includes several different options to estimate a site-specific attenuation rate constant, and then uses this rate constant to project the concentration vs. distance from the contaminant source. The predicted concentration at the downgradient point of compliance is then compared to the concentration goal.

How Does it Work?

1. Use "Site-Specific Information" tab to enter relevant monitoring locations and concentration data.
2. Select "Use Pre-Remediation Rate Constant" tab if concentration data are available for the monitoring period prior to the start of active treatment. This will project the concentration vs. distance during the Post-Remediation period using the rate constant that applied before active treatment.
3. Select "Use Lab-Based Rate Constant" tab if a degradation rate constant is available from a lab-based microcosm, 14C assay, or biomarker data. This rate constant will be used to project the concentration vs. distance during the Post-Remediation period.
4. Select "Use Post-Remediation Rate Constant" tab if concentration data are available for the period after active treatment has stopped. This will project the concentration vs. distance during the Post-Remediation period using the recent rate constant assuming steady state conditions have been restored.

Site-Specific Info | Use Pre-Remediation Rate Constant | Use Lab-Based Rate Constant | Use Post-Remediation Rate Constant

Step 1. Enter degradation rate constant for COC of interest.

0.05 per year ?

Step 2. Enter upper confidence limit for degradation rate constant (if known).

0.08 per year ?

Select "Use Lab-Based Rate Constant" tab if a degradation rate constant is available from a lab microcosm or similar type of test.

Results

1. Pre-Remediation Period (actual)

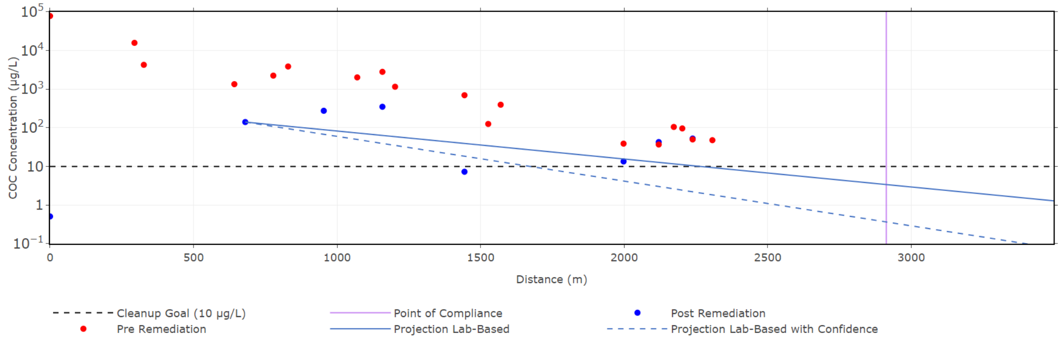
Data from Pre-Remediation Period is not used. Attenuation rate constant is estimated using user-entered degradation rate constant and groundwater seepage velocity

Pre-remediation data aren't used for the rate calculation in this case, so no plot is shown here

	Without Confidence Limit	With Confidence Limit
Estimated Attenuation Rate Constant (per meter)	0.0017	0.0027

2. Well to be Evaluated Projected

Concentration of COC in Identified Wells Over Distance



	Without Confidence Limit	With Confidence Limit
Estimated Concentration at Point of Compliance µg/L	3.4	0.37
Cleanup Goal Achieved at Point of Compliance?	Yes	Yes

Home | About | Data Input | 1. Asymptote | 2. Expansion | 3. Clean-up Goals | 4. Performance | 5. Plume Projections | 6. Matrix Diffusion | 7. EA | 8. Heterogeneity | 9. Other Projects | 10. Summary

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This tool uses site monitoring data to evaluate if concentration-based cleanup goals will be exceeded at a downgradient point of compliance (e.g., site boundary) after transitioning from active treatment (e.g., pump-and-treat) to passive treatment (e.g., MNA). It includes several different options to estimate a site-specific attenuation rate constant, and then uses this rate constant to project the concentration vs. distance from the contaminant source. The predicted concentration at the downgradient point of compliance is then compared to the concentration goal.

How Does it Work?

1. Use "Site-Specific Information" tab to enter relevant monitoring locations and concentration data.
2. Select "Use Pre-Remediation Rate Constant" tab if concentration data are available for the monitoring period prior to the start of active treatment. This will project the concentration vs. distance during the Post-Remediation period using the rate constant that applied before active treatment.
3. Select "Use Lab-Based Rate Constant" tab if a degradation rate constant is available from a lab-based microcosm, 14C assay, or biomarker data. This rate constant will be used to project the concentration vs. distance during the Post-Remediation period.
4. Select "Use Post-Remediation Rate Constant" tab if concentration data are available for the period after active treatment has stopped. This will project the concentration vs. distance during the Post-Remediation period using the recent rate constant assuming steady state conditions have been restored.

Site-Specific Info | Use Pre-Remediation Rate Constant | Use Lab-Based Rate Constant | Use Post-Remediation Rate Constant

Step 1. Enter degradation rate constant for COC of interest.

0.05 per year ?

Step 2. Enter upper confidence limit for degradation rate constant (if known).

0.08 per year ?

Results

1. Pre-Remediation Period (actual)

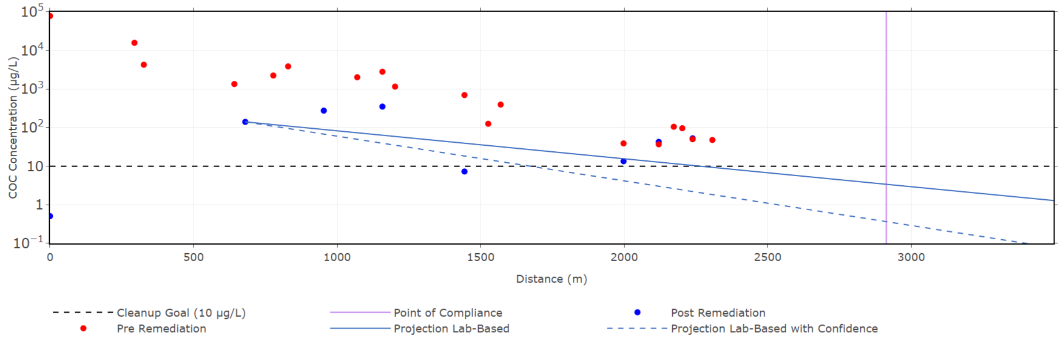
Data from Pre-Remediation Period is not used. Attenuation rate constant is estimated using user-entered degradation rate constant and groundwater seepage velocity

Estimated Attenuation Rate Constant (per meter)	Without Confidence Limit	With Confidence Limit
	0.0017	0.0027

Lab-based rate constant is converted into a "per meter" (concentration vs. distance) rate constant

2. Well to be Evaluated Projected

Concentration of COC in Identified Wells Over Distance



Estimated Concentration at Point of Compliance μg/L	Without Confidence Limit	With Confidence Limit
	3.4	0.37

Cleanup Goal Achieved at Point of Compliance?	Without Confidence Limit	With Confidence Limit
	Yes	Yes

SERDP ESTCP

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How Does it Work?

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4. Select “Use Post-Remediation Rate Constant” tab if concentration data are available for the period after active treatment has stopped. This will project the concentration vs. distance during the Post-Remediation period using the recent rate constant assuming steady state conditions have been restored.

Site-Specific Info | Use Pre-Remediation Rate Constant | Use Lab-Based Rate Constant | Use Post-Remediation Rate Constant

Step 1. Enter degradation rate constant for COC of interest.

0.05 per year

?

Step 2. Enter upper confidence limit for degradation rate constant (if known).

0.08 per year

?

The tool plots the post-remediation data (blue dots) and uses the lab-based rate constant to project the concentration vs. distance from the well that the user selected.

The pre-remediation data (red dots) are overlaid on the same plot for comparison purposes.

Results

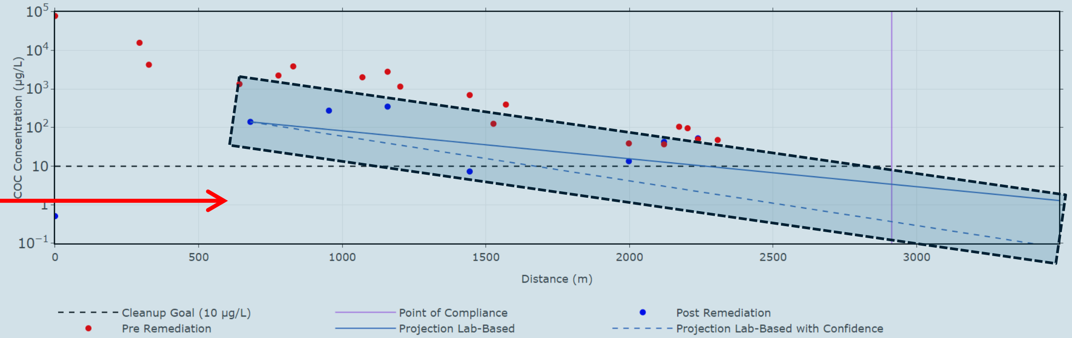
1. Pre-Remediation Period (actual)

Data from Pre-Remediation Period is not used. Attenuation rate constant is estimated using user-entered degradation rate constant and groundwater seepage velocity

	Without Confidence Limit	With Confidence Limit
Estimated Attenuation Rate Constant (per meter)	0.0017	0.0027

2. Well to be Evaluated Projected

Concentration of COC in Identified Wells Over Distance



	Without Confidence Limit	With Confidence Limit
Estimated Concentration at Point of Compliance µg/L	3.4	0.37
Cleanup Goal Achieved at Point of Compliance?	Yes	Yes

SERDP ESTCP

Home | About | Data Input | 1. Asymptote | 2. Expansion | 3. Clean-up Goals | 4. Performance | 5. Plume Projections | 6. Matrix Diffusion | 7. EA | 8. Heterogeneity | 9. Other Projects | 10. Summary

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How Does it Work?

1. Use "Site-Specific Information" tab to enter relevant monitoring locations and concentration data.
2. Select "Use Pre-Remediation Rate Constant" tab if concentration data are available for the monitoring period prior to the start of active treatment. This will project the concentration vs. distance during the Post-Remediation period using the rate constant that applied before active treatment.
3. Select "Use Lab-Based Rate Constant" tab if a degradation rate constant is available from a lab-based microcosm, 14C assay, or biomarker data. This rate constant will be used to project the concentration vs. distance during the Post-Remediation period.
4. Select "Use Post-Remediation Rate Constant" tab if concentration data are available for the period after active treatment has stopped. This will project the concentration vs. distance during the Post-Remediation period using the recent rate constant assuming steady state conditions have been restored.

Site-Specific Info | Use Pre-Remediation Rate Constant | Use Lab-Based Rate Constant | Use Post-Remediation Rate Constant

Step 1. Enter degradation rate constant for COC of interest.

0.05 per year ?

Step 2. Enter upper confidence limit for degradation rate constant (if known).

0.08 per year ?

The tool then calculates the concentration at the point of compliance, and then says if it meets the cleanup goal (with a user-specified confidence level)

Results

1. Pre-Remediation Period (actual)

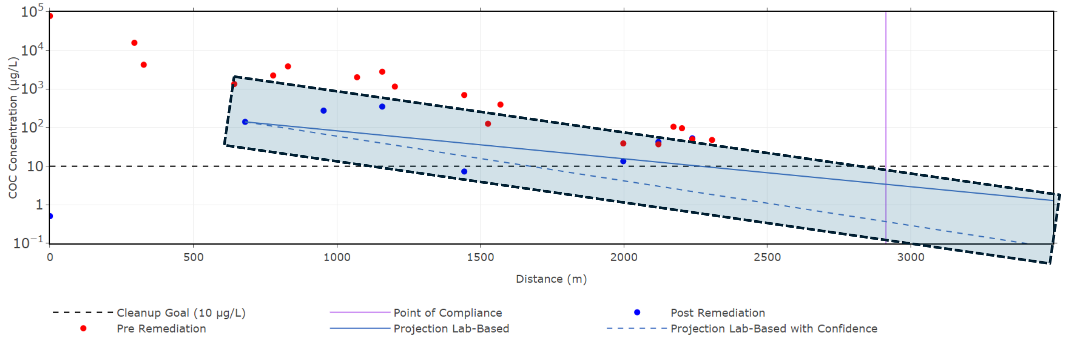
Data from Pre-Remediation Period is not used. Attenuation rate constant is estimated using user-entered degradation rate constant and groundwater seepage velocity

	Without Confidence Limit	With Confidence Limit
Estimated Attenuation Rate Constant (per meter)	0.0017	0.0027

2. Well to be Evaluated Projected

Concentration of COC in Identified Wells Over Distance

Point of compliance



	Without Confidence Limit	With Confidence Limit
Estimated Concentration at Point of Compliance µg/L	3.4	0.37
Cleanup Goal Achieved at Point of Compliance?	Yes	Yes

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Tool 5. Can I meet my cleanup goal at a downgradient point of compliance after the transition from active treatment?

What Does this Tool Do?

This tool uses site monitoring data to evaluate if concentration-based cleanup goals will be exceeded at a downgradient point of compliance (e.g., site boundary) after transitioning from active treatment (e.g., pump-and-treat) to passive treatment (e.g., MNA). It includes several different options to estimate a site-specific attenuation rate constant, and then uses this rate constant to project the concentration vs. distance from the contaminant source. The predicted concentration at the downgradient point of compliance is then compared to the concentration goal.

How Does it Work?

1. Use “Site-Specific Information” tab to enter relevant monitoring locations and concentration data.
2. Select “Use Pre-Remediation Rate Constant” tab if concentration data are available for the monitoring period prior to the start of active treatment. This will project the concentration vs. distance during the Post-Remediation period using the rate constant that applied before active treatment.
3. Select “Use Lab-Based Rate Constant” tab if a degradation rate constant is available from a lab-based microcosm, 14C assay, or biomarker data. This rate constant will be used to project the concentration vs. distance during the Post-Remediation period.
4. Select “Use Post-Remediation Rate Constant” tab if concentration data are available for the period after active treatment has stopped. This will project the concentration vs. distance during the Post-Remediation period using the recent rate constant assuming steady state conditions have been restored.

Site-Specific Info | Use Pre-Remediation Rate Constant | Use Lab-Based Rate Constant | Use Post-Remediation Rate Constant

Step 1. Select confidence interval for one sided test.

80% 90% 95% 99%

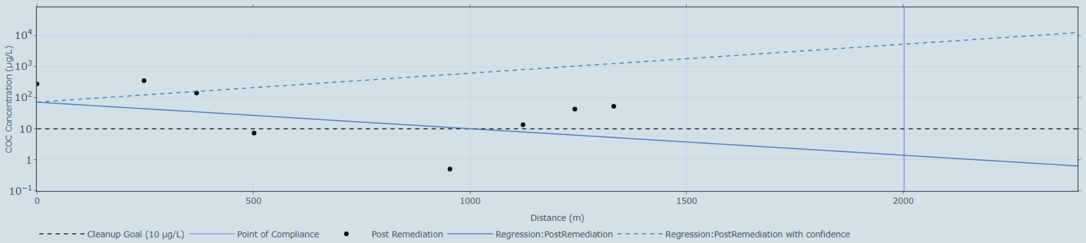
Select “Use Post-Remediation Rate Constant” tab if concentration data are only available for the monitoring period after the end of active treatment.

The tool will first plot the post-remediation data and then use it to estimate the natural attenuation rate constant for this period (with a user-specified confidence limit).

Results

1. Post-Remediation Period (actual)

Concentration of COC in Identified Wells Over Distance

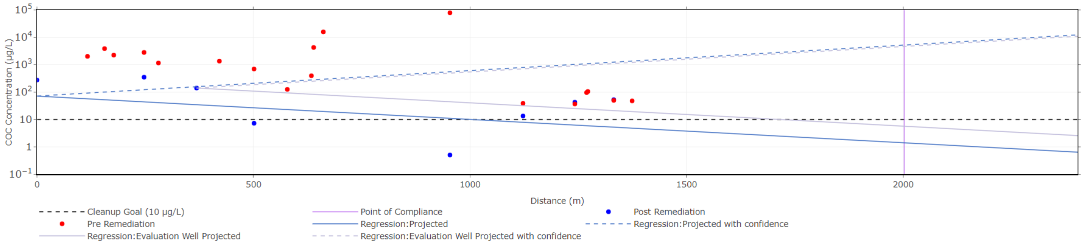


Estimated Attenuation Rate Constant (per meter)	Without Confidence Limit	With Confidence Limit
	0.002	-0.0021

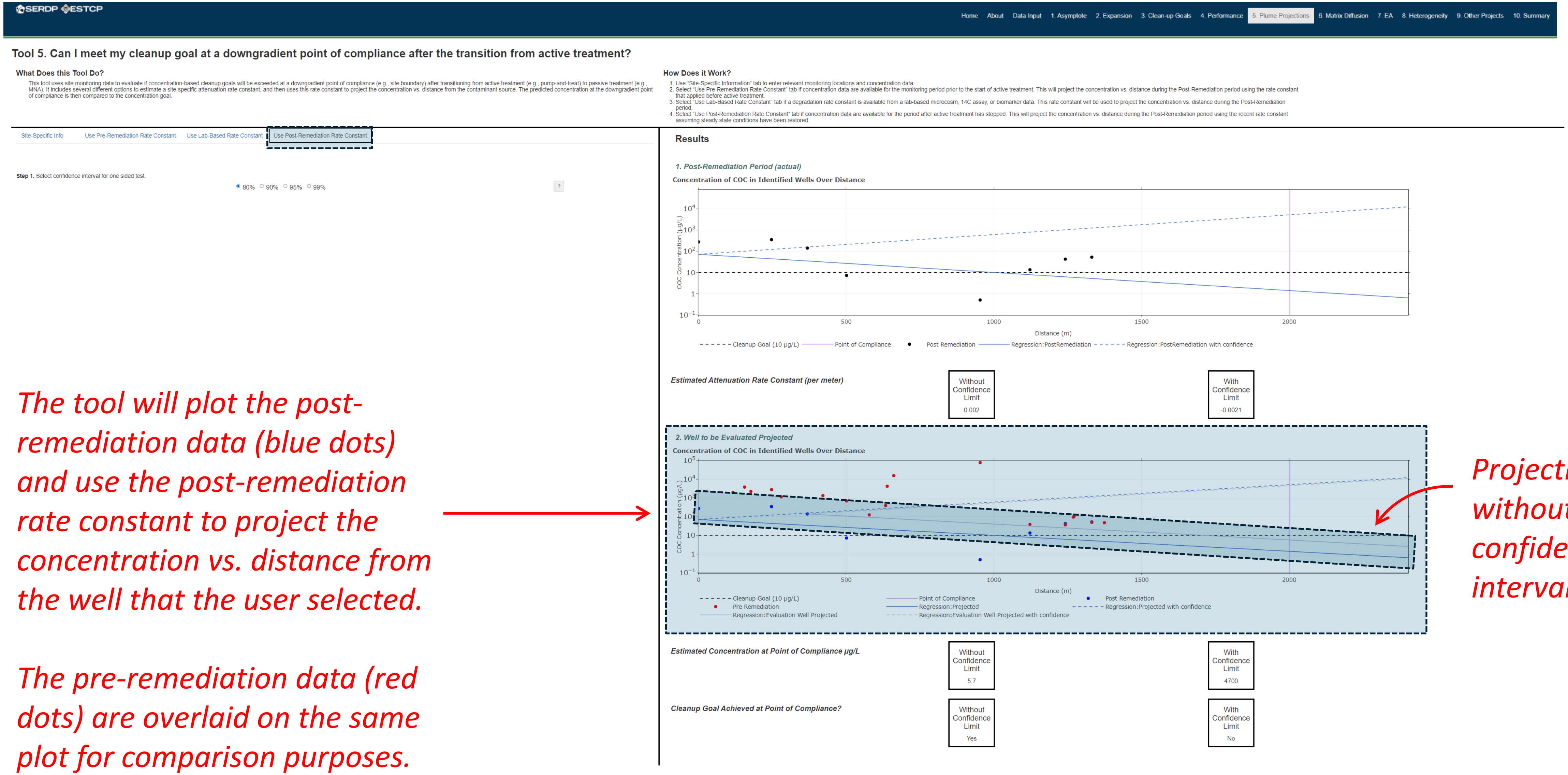
Estimated rate constant for post-remediation period

2. Well to be Evaluated Projected

Concentration of COC in Identified Wells Over Distance



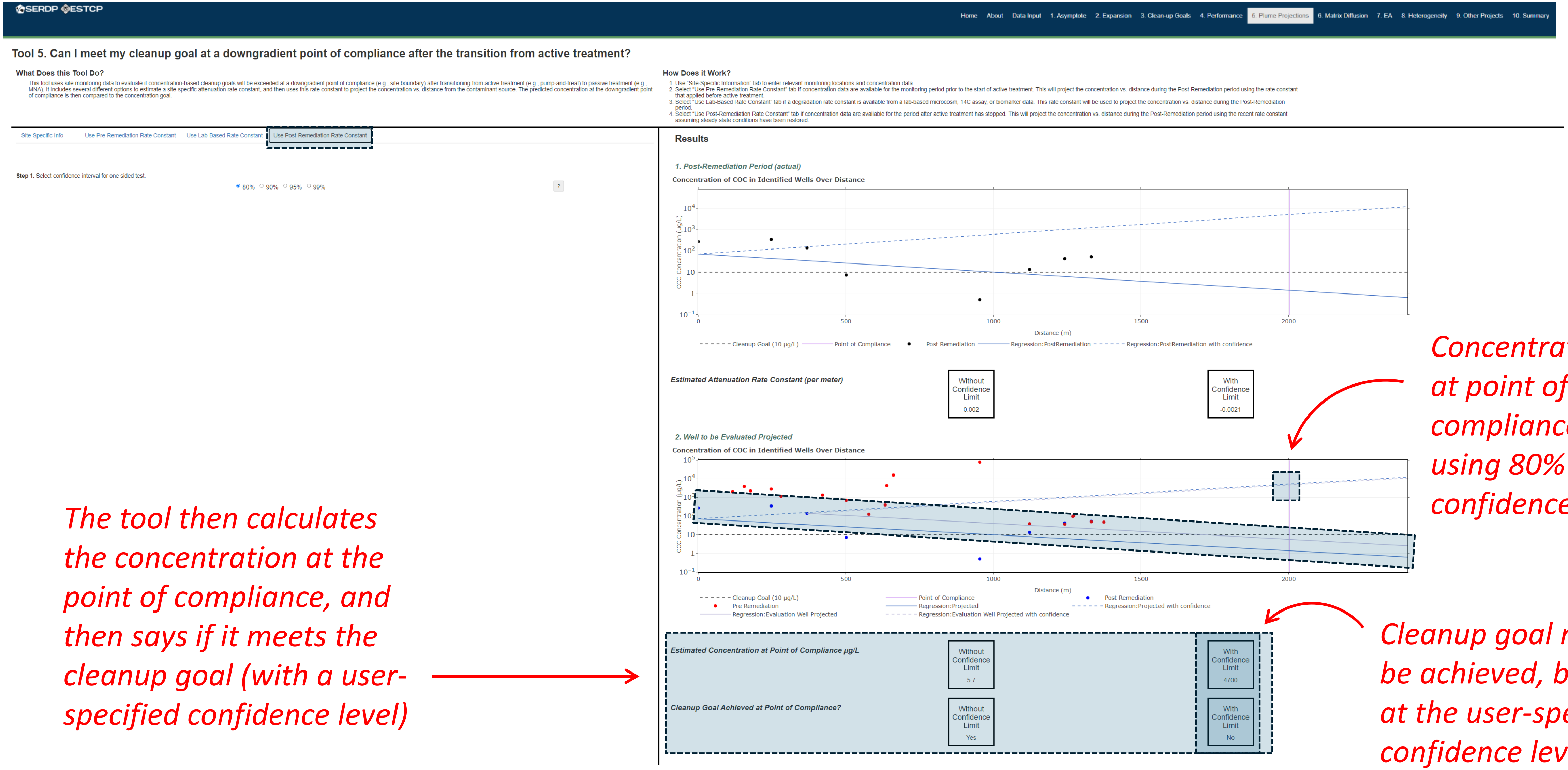
	Without Confidence Limit	With Confidence Limit
Estimated Concentration at Point of Compliance μg/L	5.7	4700
Cleanup Goal Achieved at Point of Compliance?	Yes	No



The tool will plot the post-remediation data (blue dots) and use the post-remediation rate constant to project the concentration vs. distance from the well that the user selected.

The pre-remediation data (red dots) are overlaid on the same plot for comparison purposes.

Projection without confidence interval



The tool then calculates the concentration at the point of compliance, and then says if it meets the cleanup goal (with a user-specified confidence level)

Concentration at point of compliance using 80% confidence level

Cleanup goal might be achieved, but not at the user-specified confidence level

Tool 6:

How do I model the effects of matrix diffusion in a groundwater plume for a Transition Assessment?

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6a History of TA | 6b MD Case Study | 6c Models for TA | 6d REMChlor-MD

Learning module that focuses on incorporating matrix diffusion modeling into a Transition Assessment

Tool 6a. History of Transition Assessments (TA)

Transition Assessments and Matrix Diffusion

As the Department of Defense (DoD) remediation portfolio ages, more and more active remediation projects appear to "hit a wall" in terms of being able to able to further decrease risk and/or close sites. The experience of many DoD remedial project managers is that remediation is a seemingly never-ending process exemplified by the excerpt in Figure 1 from the ESTCP's "Remediation Decision Guide" (Sale and Newell, 2011).

There are several reasons why concentrations may plateau at these sites, but a primary contributor is likely caused by contaminant mass in lower-permeability zones via a process called "**matrix diffusion**" (Figure 2). Specifically, a large portion of the remaining mass may be associated with contaminants trapped in soils with clays or silts due to diffusion and slow advection over the course of decades (i.e., after the initial release) (Sale et al., 2013).

Mass in the more accessible (transmissive) portions of the site may have already been removed through extensive treatment of the source or the plume, but the remaining portion of mass is slowly diffusing back out of the lower-permeability soils. Because of mass transfer limitations, concentrations can plateau at sites dominated by matrix diffusion, and the use of groundwater extraction to capture mass may not be a cost-effective approach for improving the remediation timeframe. In addition, these matrix diffusion effects make the remaining mass difficult to treat using more aggressive methods because amendments cannot be easily delivered to lower-permeability soils.

Furthermore, plume development can transport significant mass beyond the source area, where the potential interaction with low-permeability materials in downgradient areas may exacerbate the problem of matrix diffusion. In some mature sites, additional source and/or plume treatment may not be effective.

In 2013, a key National Research Council (NRC) report identified the need to "transition from active remediation to more passive strategies and provide more cost-effective and protective long-term management of complex sites," including conducting formal transition assessments.

Many DoD sites may be good candidates for less-intensive management strategies that focus on reducing mass discharge rates, stabilizing the plume, and protecting potential downgradient receptors rather than continuing a focus on mass removal. Given the treatment limitations at these sites, understanding and quantifying how natural attenuation processes are contributing to concentration trends is also critical.

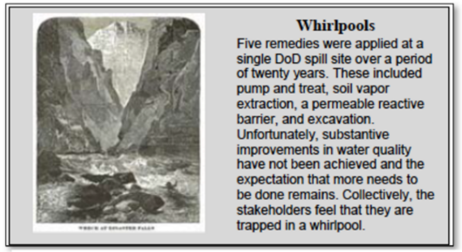

Figure 1. Excerpt ESTCP Decision Guide (Sale & Newell, 2011).

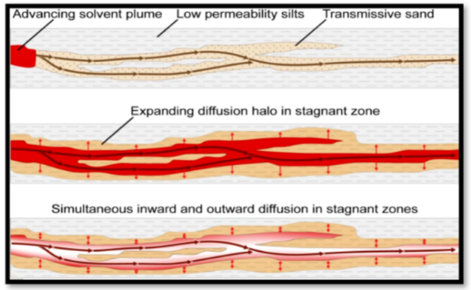

Figure 2. Matrix Diffusion process over several decades (NRC, 2005)

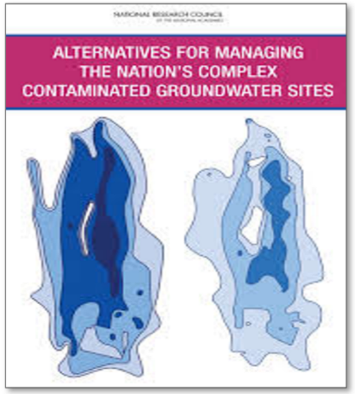

Figure 3. National Research Council Report recommending use of Transition Assessment concept (NRC, 2013)

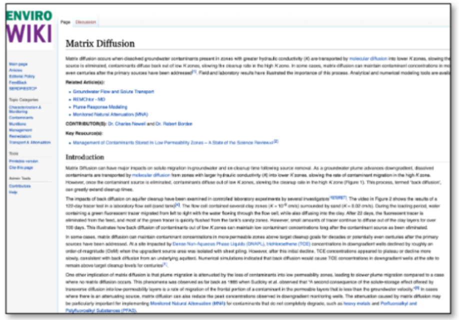

Figure 4. ESTCP EnviroWiki matrix diffusion article

Resources

Doner, L. and T. Sale, date unknown. Matrix Diffusion Visualization Video. ESTCP EnviroWiki, "Matrix Diffusion", Figure 2. http://www.enviro.wiki/index.php?title=Matrix_Diffusion

ESTCP EnviroWiki, 2020. Matrix Diffusion. http://www.enviro.wiki/index.php?title=Matrix_Diffusion

National Research Council. (2005). Contaminants in the Subsurface: Source Zone Assessment and Remediation. National Research Council. https://doi.org/10.17226/11146 https://www.nap.edu/catalog/11146/contaminants-in-the-subsurface-source-zone-assessment-and-remediation

Sale, T. C. and C. J. N. (2011). Decision Guide: A Guide for Selecting Remedies for Subsurface Releases of Chlorinated Solvents. https://www.serdp-estcp.org/Program-Areas/Environmental-Restoration/Contaminated-Groundwater/Persistent-Contamination/ER-200530

Sale, T., Parker, B., Newell, C., & Devlin, J. (2013). Management of Contaminants Stored in Low Permeability Zones. In SERDP: Vol. ER-1740. Strategic Environmental Research and Development Program (SERDP). https://www.serdp-estcp.org/Program-Areas/Environmental-Restoration/Contaminated-Groundwater/Persistent-Contamination/ER-1740

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Case study of a site where matrix diffusion was shown to influence P&T performance

Tool 6b. Matrix Diffusion Case Study: Pump and Treat Site

Case Study: Impact of Matrix Diffusion on Pump and Treat Systems

A large pump and treat site in California was evaluated for potential impacts of matrix diffusion (Figure 1). At 15 groundwater extraction wells, long term mass discharge (grams per day) data were compiled for the period 1997 to 2009 (McDade et al., 2013) and then updated by the authors in a 2020 study. Data from one well, REG-1A, is shown in Figure 2. Two groundwater transport models were applied to these data: 1) a conventional flushing/retardation model; and 2) a simple matrix diffusion model. As seen in Figure 2, the reduction in mass flux over time is relatively slow (about a 90% reduction over 24 years) and the dashed green line representing the flushing retardation model did not match the actual data measured at this well. However, as of 2019, lower but still significant mass was still being recovered by the Reg-1A extraction well, indicating that matrix diffusion processes were very active in this and 14 other pump and treat wells at this site. A simple matrix diffusion model based on the Matrix Diffusion Toolkit (Farhat et al., 2012) matched the recovery data much more closely (McDade et al,. 2013). A companion paper extended this same analysis at two additional pump and treat sites (Seyedabbasi et al., 2013).

Key point: These data provide an example of an operating remediation system hitting an asymptote, a key criteria that further mass removal in the source zones would not likely speed up remediation of this plume using pump and treat. At this particular site, the sources were managed using containment systems.

See more P&T wells from this site

See more P&T wells from other sites

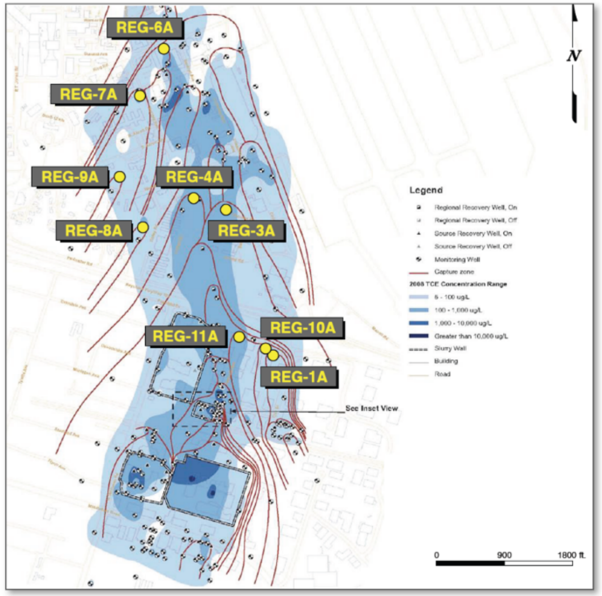

Figure 1: Pump and treat site with location and capture zone of selected pumping wells. Each of the wells shown did not have a capture zone where groundwater flowed through upgradient original source zones (so no contribution from the original contaminant sources once well pumping started) (McDade et al., 2013).

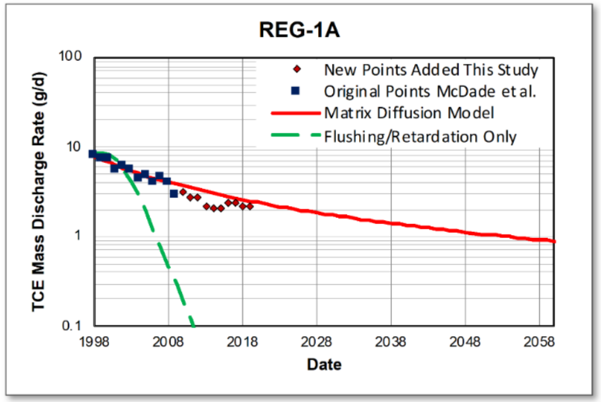

Figure 2: Mass discharge of pumping well REG-1A (McDade et al, 2013 with updates through 2019). REG-1A is located in the lower right of Figure 1. Two models are shown: A flushing/retardation model (green dashed line) and a simple matrix diffusion model (red solid line). The matrix diffusion model provided a much better explanation of the long tail expressed in these data (McDade et al., 2013).

References

Farhat, S. K., Newell, C. J., Sale, T. C., Dandy, D. S. Wahlberg, J. J., Seyedabbasi, M. A., McDade, J. M. and Mahler, N. T., 2012. Matrix Diffusion Toolkit, developed for the Environmental Security Technology Certification Program (ESTCP) by GSI Environmental Inc., Houston, Texas.

McDade, J. M., Kulkarni, P. R., Seyedabbasi, M. A., Newell, C. J., Gandhi, D., Gallinatti, J. D., Cocianni, V., & Ferguson, D. J., 2013. Matrix diffusion modeling applied to long-term pump-and-treat data: 1. Method development. Remediation, 23(2), 71–91. https://onlinelibrary.wiley.com/doi/10.1002/rem.21349

Seyedabbasi, M. A., Kulkarni, P. R., McDade, J. M., Newell, C. J., Gandhi, D., Gallinatti, J. D., Cocianni, V., & Ferguson, D. J., 2013. Matrix diffusion modeling applied to long-term pump-and-treat data: 2. results from three sites. Remediation, 23(2), 93–109. https://onlinelibrary.wiley.com/doi/10.1002/rem.21350

SERDP ESTCP

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6a History of TA | 6b MD Case Study | 6c Models for TA | 6d REMChlor-MD

Descriptions of eight different models for matrix diffusion, along with help on selecting options for your site and the level of effort

Tool 6c. Potential computer models for Transition Assessments (TA)

OVERVIEW

EIGHT WAYS TO SIMULATE MATRIX DIFFUSION AND REMEDIATION

Eight Ways to Simulate Matrix Diffusion and Remediation

As of 2022, there are eight general ways to model the impact of matrix diffusion on remediation for Transition Assessments (Table 1). Links to key resources (ESTCP project pages or key papers) are provided. A quick selection guide is provided below:

Use Model 1, SERDP Remediation Timeframe Tool in this web page (SERDP TA^2 Tool 3).

For a **quick screening** model approach:

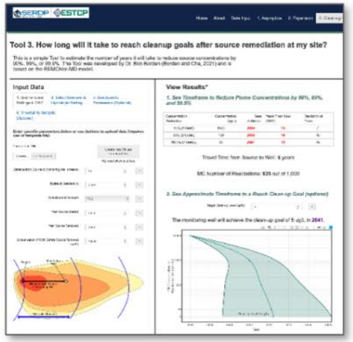
- Key Application: How long does it take to reach cleanup goals after a source is completely removed?
- Typical time required: 2-6 hours.
- Advantages: Simplest, quickest model. Provides uncertainty limit.
- Disadvantages: Only applicable to a subset of site data, cannot simulate partial source in-situ remediation projects*, assumes 1-D groundwater flow.

For a **mid-level model:** use Model 2, REMChlor-MD (Falta et al., 2018, Farhat et al., 2018). See the next tab for more detailed instructions on how to use REMChlor-MD for TAs.

- Key Application: How long does it take to reach cleanup goals after a source and/or plume remediation project?
- Typical time required: 2-4 days.
- Advantages: Detailed guidance, including the last tab in SERDP TA^2 Tool 6. Can simulate in-situ source remediation projects that typically don't remove all the contaminant mass.
- Disadvantages: Calibration can be time consuming. Assumes 1-D groundwater flow. Requires estimate of total contaminant mass released to the subsurface and initial source concentration when the release first started. Cannot simulate multiple source remediation projects.

For more **complex modeling**, use Model 3, MODFLOW 6 or MODFLOW-USG with the Matrix Diffusion Transport (MDT) Package.

- Key Application: How long does it take to reach cleanup goals after a source and/or plume remediation project?
- Typical time required: 2-4 weeks.
- Advantages: Existing MODFLOW / MT3D datasets can be used and augmented with matrix diffusion model input. Can simulate in-situ source remediation projects that typically don't remove all the mass. Can handle 3-D groundwater flow patterns and pumping wells. Best tool for modeling pump and treat systems.
- Disadvantages: More complex model setup, calibration. Source concentration / mass flux input data often need to develop externally outside the model. Only a beta version available now with no document. Complete version likely not available until Fall 2023.


Model 1

Model 2


Model 3

See next page for more

The other five models have different strengths and applicability.

- Model 4 (ESTCP Matrix Diffusion Toolkit) in Table 1 is a free ESTCP spreadsheet tool with two different matrix diffusion models are applicable to sites where a plume is in contact with a low-k aquitard overlying or underlying the plume. The "Square Root Model" in this toolkit is relatively easy to run.
- Models 5, 6, and 7 in Table 1 are all "fixes" or "hacks" to use existing MODFIOW/MT3D type finite differences so that they can more accurately account for matrix diffusion. As described above, current finite difference groundwater transport models can have problems modeling matrix diffusion unless relatively thin vertical layers are used. Note that Model 3 (MODFLOW with the Matrix Diffusion Transport Package (MDT)) will likely supersede Models 5, 6, and 7 when it is completed in the Fall of 2022.
- Model 8 is a note on one of the first models that approximated matrix diffusion effects, the original REMChlor model. It has now been superseded by Model 2, REMChlor-MD.

*(complete source remediation is unlikely in many cases, see SERDP TA^2 Tool 4)

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6a History of TA | 6b MD Case Study | 6c Models for TA | 6d REMChlor-MD

Tool 6c. Potential computer models for Transition Assessments (TA)

OVERVIEW

EIGHT WAYS TO SIMULATE MATRIX DIFFUSION AND REMEDIATION

Descriptions and help on selecting appropriate ones for your site

MODEL / MODELING APPROACH	DESCRIPTION	INPUT DATA	COMMENTS
1. SERDP Transition Assessment Assistant Tool 3 - Borden Remediation Timeframe Model (SERDP TA^2 Tool 3) (Borden and Cha, 2021)	A simple web-based model that estimates the number of years it will take to reduce source concentrations by 90%, 99%, or 99.9%. The Tool was developed by Dr. Bob Borden (Borden and Cha, 2021) and is based on the REMChlor-MD model.	Source release and source remediation dates. Hydrogeologic data to calculate seepage velocity. Transport data such as retardation factors. Distance to a point of compliance. Nature of geologic heterogeneity (aquitards or layers/lenses or both).	New model developed for this web tool. Includes an uncertainty calculation approach to describe the remediation timeframe results as a range of values.
2. ESTCP REMChlor-MD Model (ESTCP Project ER-201426) (Falta et al., 2018; Farhat et al., 2018)	As of 2022, perhaps the best balance of simplicity and power for transition assessment modeling. REMChlor-MD simulates matrix diffusion using a semi-analytical model based on heat transfer equations (Falta et al., 2018). However, it can only simulate 1-D flow fields	Groundwater flow, contaminant transport, and source information. The user describes if any thick aquitards overlie or underlie the plume, and the heterogeneity calculator in REMChlor-MD provides users with an option to enter boring logs to generate three key values: 1) transmissive zone volume fraction; 2) average diffusion length; and 3) surface area of low-k interfaces.	REMChlor-MD is first the model to specifically relate stratigraphic data to matrix diffusion input parameters. It assumes the entire plume is in contact with the same geologic heterogeneity and assumes 1-dimensional groundwater flow. Can simulate low-k layers, different configurations / density of low-k lenses based on boring logs. Can simulate source remediation, plume remediation or both.
3. MODFLOW with Matrix Diffusion Transport (MDT) Package (ESTCP ER-19-5028)	Commonly used numerical groundwater contaminant transport models (MODFLOW-USG and MODFLOW-6) with new Matrix Diffusion Transport (MDT) Package. This new package includes the matrix diffusion method that was developed for REMChlor-MD. It allows for much more efficient and accurate simulation of matrix diffusion.	3-D stratigraphic, hydrogeologic, plume, and source data for a groundwater plume. Unstructured grid array with many thin layers to represent site stratigraphy for plume.	In development as part of ESTCP Project ER-19-5028. A preliminary beta version for MODFLOW-USG was issued in 2021 This project will incorporate the semi-analytical matrix diffusion approach into open source, public domain, 3-D chemical transport codes for the unstructured grids (MODFLOW-USG and MODFLOW 6). These modified FORTRAN codes will then be incorporated into a widely used commercial groundwater modeling graphical user interface (Aquaveo Groundwater Modeling System [GMS]).
4. ESCTP Matrix Diffusion Toolkit (Farhat et al., 2012)	One of the first matrix diffusion focused modeling tools. Two separate analytical matrix diffusion models: 1) simpler "Square Root Model" and 2) more sophisticated "Dandy-Sale Model", both spreadsheet-based models.	Loading duration and time when transmissive zone is remediated; low-k unit properties; contaminant diffusion properties; transmissive zone properties.	Assumes two layers: a transmissive unit and a low-k unit. Cannot simulate low-k lenses or other stratigraphic scenarios. Assumes a constant source to groundwater, then assumes complete removal of the source.
5. MT3DMS / RT3D 3-D Model with Thin Layers (Chapman et al., 2012) (Carey et al., 2015) (Farhat et al., 2020)	Existing numerical groundwater contaminant transport model. However, as indicated in Chapman et al. 2012), Carey et al. (2015) and Farhat et al. (2020) finite difference groundwater models may need very thin layering (on the order of centimeters) to accurately model matrix diffusion.	Matrix diffusion can be modeled successfully if very thin layers are used (on centimeter scale). Carey et al. (2015): "Modeling vertical diffusion in a silt or clay lens may require the addition of dozens to hundreds of model layers, depending on the thickness and number of low-permeability lenses to be represented. This can be computationally prohibitive for a numerical model, particularly three-dimensional (3-D) models which already incorporate small horizontal grid spacing or multiple solutes."	It may be difficult to model large field sites if hundreds of thin vertical grids are used. For example, Muskus and Falta (2018) reported that a 3-D MT3D simulation of a DNAPL site (3400 ft x 2000 ft x 135 ft thickness required 2.8 million grid blocks (400 layers) and took "several days" for one simulation.
6. MT3DMS / RT3D 2-D "Bread Slices" (Rasa et al., 2011) (Farhat et al., 2020)	Commonly used numerical groundwater contaminant transport model, but modeled in a vertical, 2-dimensional form (X-Z), hence the term "bread slice". With this approach very fine vertical discretization can be employed but only over a portion of a field site (typically the centerline of the plume).	Centerline stratigraphic, hydrogeologic, plume, and source data for a groundwater plume but only for a 2-D slice through the zone of interest.	This approach has been applied successfully by Rasa et al. 2011 and Farhat et al., 2020. But 3-D groundwater flow (such as pumping wells or complex groundwater flow fields) cannot be simulated directly.
7. MT3DMS / RT3D 3-D Model with Dual Domain (GMS Tutorial)	Commonly used numerical groundwater contaminant transport model, but with a less commonly used dual-domain feature activated.	3-D stratigraphic, hydrogeologic, plume, and source data for a groundwater plume. In addition, the porosity of the immobile phase, initial concentration of the mobile phase, and a mass transfer coefficient are required.	The dual porosity mass transfer model typically requires calibration of the mass transfer coefficient, and the first-order representation of the matrix diffusion concentration gradient may be accurate only under a limited set of circumstances (Gaun et al., 2008).
8. Analytical "gamma" model for source zones such as the first version of REMChlor (Falta et al., 2005a, b; Falta et al., 2008) (USEPA)	A single parameter "gamma" is used to relate mass flux over time to source mass. A gamma of two or more will create a "long tail" representative of the persistent, slow decline in groundwater concentrations caused by matrix diffusion.	Gamma term. Is not directly linked to site stratigraphy, loading history, type of contaminant but is a general way to generate matrix diffusion effects in a source zone.	For source zone only, not plumes. Used in the first version of REMChlor (before the REMChlor-MD version) for the source zone, where near source wells indirectly reflect matrix diffusion effects in the source zone. Users now typically use REMChlor-MD which accounts for matrix diffusion in both the source and plume.

Detailed description of REMChlor-MD and its application for Transition Assessments

Tool 6d. How can I model a groundwater plume to support a Transition Assessment (TA)?

REMCHLOR-MD MODEL OVERVIEW

ESTCP's *REMChlor-MD* Model (Falta et al., 2018, Farhat et al., 2018) (Figure 1) was designed to help site managers, consultants, and regulators better understand matrix diffusion and help them determine if matrix diffusion processes are significant enough where a transition from an active remediation strategy to a more passive approach is merited. Having this information readily available before an active remedy is implemented, could assist site stakeholders select more appropriate remedies and improve effective risk communication with regulators and the public (Farhat et al., 2018). *REMChlor-MD's* key capabilities include:

- The ability to model matrix diffusion (Figure 2) in both the source zone and the plume, including remediation in both the source and the plume, and
- The ability to provide planning-level estimates of the concentration, mass, and mass discharge in the transmissive zone, concentration in an observation well, and mass in the low-k zone.

Links to videos and download pages

Figure 1. REMChlor-MD Splash Screen (Farhat et al., 2018)

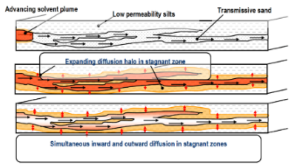

Figure 2. Conceptual Model of matrix diffusion effects as part of plume response. (Source: T. Sale, T. Illangasekare, AFCEE, 2007)

HOW TO USE REMChlor-MD FOR TRANSITION ASSESSMENTS

For a Transition Assessment, a key question is *"what benefits will a hypothetical remediation project provide?"* To answer this question, the REMChlor-MD model can be used to answer this question via a stepwise process such as:

Step 1: Calibrate the model to existing site data.

Step 2: Run the model into the future under a Monitored Natural Attenuation Scenario to determine two key metrics: 1) how long it will take to reach a cleanup goal at a point of compliance; and 2) how far the plume will migrate in the future, if any.

Step 3: Run the model with a potential *source* remediation scenario where you remove a certain percent of the mass in a certain year. (Because typical source remediation project only reduces source concentrations by about 90% (McGuire et al., 2016), a 90% source removal value is often used to simulate source removal in the model). Then obtain the data on the metrics 1 and 2 above.

Step 4: Compared metrics 1 and 2 from Step 2 to metrics 1 and 2 from Step 3.

Step 5: Repeat Steps 3 and 4 but with a *plume* remediation scenario by increasing degradation rates significantly over a certain period of plume remediation.

Step 6: If the active remediation metrics are not significantly better than the MNA metrics, and if no receptors are being exposed to unacceptable risks, then generally the modeling results do not support a continued active remediation approach to plume management. The costs and sustainability burden from the active remediation scenarios can also be used to weigh the costs and benefits of continued active remediation.

KEY PARAMETERS FOR REMChlor-MD

HOW TO CALIBRATE REMChlor-MD

REMCHLOR-MD ASSUMPTIONS AND LIMITATIONS

REMChlor-MD has the following assumptions and limitations (Farhat et al., 2018):

- Assumes the user is familiar with basic groundwater transport and mass balance concepts.
- Assumes a homogeneous and constant groundwater velocity field with flow in only one direction.
- The contaminant source mass balance assumes that the contaminant discharge is a power function of the remaining contaminant mass using an exponent Γ (gamma). As a simplistic model of a complicated heterogeneous multiphase transport system, the best value of gamma for a given site will be subject to a range of uncertainty. For this reason, it is probably a good idea to run the model with a range of gamma values.
- The model assumes that biodegradation reactions in the plume can be described by first order decay reactions. Biogeochemical conditions that control these reactions may not be well represented by first order reactions therefore, there is considerable uncertainty in values of field scale decay rates.
- First order decay rates are a function of time and distance from the source (x), but they do not depend on the y or z coordinates. This means that a specified reaction zone will extend over the entire model domain in the y and z directions.
- In the transmissive zone, the model uses a conventional advection-dispersion formulation. However, in the absence of matrix diffusion, this may not accurately represent the physical process at a site (e.g., see Hadley and Newell, 2014). There is a developing conceptual model that suggests that dispersion processes are much weaker than is commonly simulated, and that lower dispersion coefficients should be used in conventional advection dispersion models. By applying this model to a transmissive zone that only occupies part of the overall volume, and by including matrix diffusion, the transport can better fit the newer conceptual model.

REFERENCES

Tool 7:

What are the options for enhancing attenuation?

Introduction to the "Enhanced Attenuation" (EA) concept

Tool 7a. How to enhance Monitored Natural Attenuation processes

What if a Transition Assessment is appropriate, but MNA alone is not sufficient to manage a plume?

A Transition Assessment will identify if significant technical limitations exist that make achievement of site goals such as MCLs unlikely. If limitations are identified, then it makes sense to transition the site from an active mass removal phase to "more passive long-term management".

At some sites, Monitored Natural Attenuation (MNA) might be sufficient to manage the plume by itself. But in other cases, some additional remediation measures may be required to meet site objectives (e.g., limit future plume growth, keep with certain concentration goals at a point of compliance). For these Transition Assessments, Enhance Attenuation (EA) approaches may serve as a "bridge" between intensive source treatments for mass removal and MNA as shown in Figure 1:

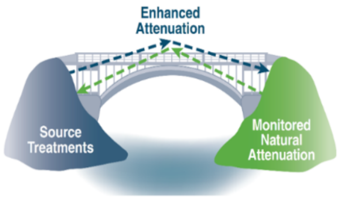

Figure.1 Concept of Enhanced Attenuation as a Bridge Between Source Treatment and MNA (ITRC, 2008)

What is Enhanced Attenuation (EA)?

A more detailed definition of EA is *"Any type of intervention that might be implemented in a source-plume system to increase the magnitude of attenuation by natural processes beyond that which occurs without intervention. Enhanced attenuation is the result of applying an enhancement that sustainably manipulates a natural process, leading to an increased reduction in mass flux of contaminants"* (ITRC, 2008).

What are Examples of EA?

At chlorinated solvent sites, three target areas for EA approaches were identified by the ITRC (ITRC, 2008):

- source enhancements (see Tab 7b);
- plume enhancements (see Tab 7c) and
- discharge zone enhancements (see Tab 7d) (ITRC, 2008).

Examples of EA for different groundwater contaminants classes are shown in Table 1.

Table 1. Examples of EA for Three Groundwater Contaminant Classes

	Reduce Contaminant Loading	Increase Attenuation Capacity
Chlorinated Solvents (Truex et al., 2007)	• Interception and Diversion of Surface Water • Cover/Cap Systems • Barriers or encapsulation methods • Drainage structures, plant-based methods, and combinations of the two • Diverting Electron Acceptors away from Contaminants • SVE	• Biostimulation • Bioaugmentation • Plant-Based Methods • Reactive barriers • Microbial benefits of in situ oxidation
Inorganics and Radionuclides (Truex et al., 2011)	• Infiltration control (cap/barrier system) • Reduce water flux in vadose (e.g., desiccation) • Intercept/diverge groundwater/surface water • Reactive barrier • Geochemical manipulation • Plant-based method hydraulic control	• Reactive barrier • Bioremediation • Geochemical manipulation • Phytoextraction
PFAS (Newell et al., 2021)	• Cover/cap system • Soil moisture management • Reducing oxygen influx • Sorbents and/or barriers • Trench • Intercept/diverge groundwater • Plant-based method hydraulic control (e.g., phytoremediation • Air-sparging	• Phytoremediation • Air-sparging

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Tabs describe different EA options depending on site objectives

Tool 7b. Source Enhacement Zone (ITRC, 2008)

Source enhancement includes a wide range of options for the unsaturated zone or the saturated zone that can reduce loading from the source to groundwater and/or increase attenuation capacity.

Reduce Loading

1. Cap/cover

Cap/cover systems work by reducing infiltration through the source zone and range from traditional Resource Conservation and Recovery Act (RCRA)-style caps, to alternative, vegetative covers,. The goal of the technology is to contain the contaminants in place by ensuring the rate of attenuation are greater than the loading rate to the underlying groundwater, ensuring a stable and then shrinking plume. This approach is most applicable for areas such as landfills or unsaturated source zones where reducing recharge helps to limit mass discharge. It is implemented by either reducing the permeability of soils overlying a source zone or manipulating the soil water balance to limit percolation (ITRC, 2008). The main benefit of a cap/cover is that it can be used for relatively large areas of contaminated soil. However, there is a long-term maintenance limitation because this approach leaves the contamination in place as opposed to removing it. Additionally, the cost of this method varies based on size of contaminated area and thickness of cap/cover required (EPA, 2012).

2. Containment barrier

Deployed upgradient of a contaminant source, containment barriers physically limit the discharge of contaminated groundwater from a source to downgradient receptors. Traditional barrier methods include slurry walls (cement/ bentonite) and sheet piling, while more recent approaches include impermeable membranes and bio-barriers. While different materials may be used, all containment barriers are aimed a reduction of mass loading. A primary benefit of containment barriers is the relatively low cost, especially if the containment area is large. However, there are long-term maintenance considerations since there is no removal of the contaminant (EPA, 2012).

3. Intercept surface water and storm flowContainment barrier

This method aims to maximize runoff and minimize infiltration through the source zone, with the overall goal of reducing the mass transfer rate of contaminants to groundwater and the mass flux feeding a plume. This can be achieved through configurations that include the minimal recontouring of local surface topography and/or lining drainage-pathways, as well as major changes including the surrounding topography recontouring and construction of lined drainage-ways (ITRC, 2008). These treatment methods can be specifically designed for a location, as opposed to a more generalized method like a cap/cover. The primary limitation of intercepting surface and storm water is that the cost can be greater when more significant changes of the land are required to intercept the surface water and stormwater flow (ITRC, 2008).

4. Intercept groundwater

The method of intercepting groundwater is used to divert water around the contaminant source, through methods such as containment with barriers or manipulating the hydraulic gradient. The aim of this method is to reduce the flow through the source to decrease the mass flux of contaminants to downgradient plumes (ITRC, 2008). One advantage of this method is that it is minimally invasive and can be used in areas where the surface may not be operated on. Conversely, the method does not remove the contaminants from the source zone, but instead it aims to stabilize and eventually shrink the plume, which may take time depending on the site conditions (ITRC, 2008).

5. SVE

Soil vapor extraction (SVE) is an in situ remedial technique that aims to remove volatile constituents present in the vadose zone and thereby reduce the mass loading to groundwater The method relies on applying a vacuum to change the barometric pressure gradient and promote movement of vapors toward extraction wells (ITRC, 2008). This method generally results in higher performance when applied to light petroleum products such as gasoline or chlorinated solvents. The primary benefits of this technology are its relatively low energy and cost, although this may not be the case for sites where a longer-term operating period is necessary. The main limitations are that its effectiveness depends on the soil type (particularly in low-permeability soils) and it may not be applicable for less volatile contaminants (EPA, 2017).

6. Plant-based method hydraulic control

Hydraulic control using plant-based methods relies on various types of vegetation to modify the flow of water and contaminants to reduce loading. By using the high rates of water uptake and evapotranspiration of certain plant species, this method is applicable to locations where the contaminants and/or water table are present are shallow. The aim is to promote direct plant uptake of contaminants and/or achieve a locally depressed water table by removing infiltration or groundwater at a rate quicker than its replenishment (ITRC, 2008). The main benefit of this process is that it is minimally invasive and may require little long-term maintenance once plantings are established. External factors that may interfere at some sites are extreme weather conditions and animals feeding on the vegetation.

Increase Attenuation Capacity

1. Inject nutrients

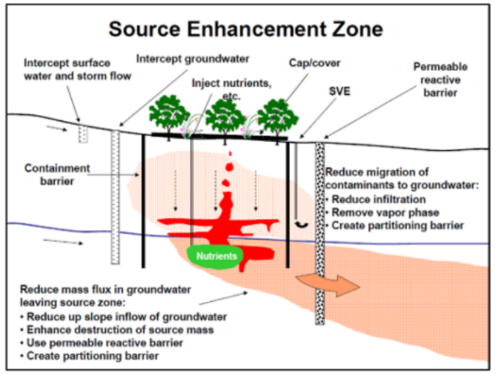
This remediation method utilizes injection points to deliver amendments that will enhance attenuation capacity. This may include the injection of specific nutrients, substrates, or electron acceptors (e.g., oxygen) to promote natural biological (or biogeochemical) activity. The key differences between this approach and conventional in situ bioremediation is that the amendment represents some element that is critical for stimulating natural attenuation and that it can be delivered in passive method that does not require multiple injection events. The main benefits of this method are that the contaminant is removed rather than contained in the groundwater, and that the nutrient or other amendment can be tailored ed to the target contaminant and site conditions.

2. Permeable reactive barrier

This method utilizes a permeable wall that is installed below the ground surface to remediate contaminated groundwater. The wall contains a reactive material such as iron, limestone, carbon or mulch which is selected based on its capacity to reduce the target contaminant through sorption, precipitation, chemical reactions, and/or biodegradation processes. The main benefit of this method is that it can be relatively inexpensive and low-effort remediation technique, with no energy required once it is in place. Additionally, once installed, no above-ground equipment is required during use (EPA, 2021). The width and depth of the barrier will depend on site-specific factors like contaminant concentration, plume size, and groundwater velocity. Total depths are typically 50 feet or less. The main limitation of this method is that the reactive material of the walls will eventually be depleted, such that the barrier will be less effective at treating groundwater. If this occurs before the site-specific remedial goals are achieved, then the reactive material will have to be replaced to ensure continued treatment (EPA, 2021).

3. Plant-based method (e.g., phytoextraction)

This remediation technique utilizes plants to promote the reduction of contaminant mass discharge in soil and groundwater through removal, degradation, or containment. This passive technique is most applicable to sites with shallow and low-to-moderate levels of contamination where uptake of contaminants by plants will readily occur through evapotranspiration. Plant-based methods have proven to be effective at removing a wide variety of contaminant types, including metals, explosives, pesticides, solvents, crude oil, landfill leachates, and hydrocarbons. One benefit of this method is that the cost of application is often lower than other physical or chemical techniques. Additionally, there are little long-term maintenance requirements (beyond occasional harvesting) if site conditions are favorable for continued growth of the planted species. In some settings, the performance of this approach may be impacted by extreme weather events (e.g., droughts) or animals feeding on the plants (EPA, 1999).



Ease of implementing EA options is estimated –
used later in Tool 10 to calculate the Remediation Transition Assessment Index (RTAI)

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7a Introduction | 7b EA for Sources | 7c EA for Plumes | 7d EA for Discharges | 7e EA Decision Chart

Tool 7e. EA Decision Chart

The purpose of this step is to establish the relative ease of implementing specific Enhanced Attenuation (EA) options. This is based on an assumption that if an EA technology can be easily implemented, it is generally a better candidate for a Transition Assessment (TA). In this case, the depth and width of a permeable reactive barrier (PRB) is used as a proxy of the estimated cost and ease of installation. This is summarized in the Decision Chart shown below.

The user can estimate the total depth of a PRB based on the depth interval of the plume or source area that is being targeted by the PRB. Similarly, the user can estimate the width of the PRB based on the width of the plume or source area (perpendicular to groundwater flow) that is being targeted by the PRB. The user then uses these depth and width values in the Decision Chart to select the Remediation Transition Assessment Index (RTAI) value for Tool 7 for the site. RTAI values range from 1 to 5, where higher RTAI values represent sites that are amendable to transitioning to a new technology included EA options. The RTAI value generated in Tool 7 is used to support an overall Transition Assessment for the site in Tool 10b.

	<30 ft (depth)	30-60 ft (depth)	>60 ft (depth)
< 100 ft (width)	RTAI = 5	RTAI = 4	RTAI = 3
100 - 500 ft (width)	RTAI = 4	RTAI = 3	RTAI = 2
> 500 ft (width)	RTAI = 3	RTAI = 2	RTAI =1

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Tool 8:

Understand how much geologic heterogeneity is present at a site

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Tool 8. Understand how much geologic heterogeneity there is at a site.

What Does this Tool Do?

This tool defines key site-specific features that contribute to matrix diffusion, including the presence of aquitards and the distribution of low-permeability layers and lenses within your plume. With this information, the impact of matrix diffusion on remediation performance and cleanup times can be categorized as Low, Moderate, or High.

How Does it Work?

In the "Select Aquifer Setting" tab, select the hydrogeologic setting that is most representative of the conditions for the plume at your site. Then, enter data from boring logs from your site to determine the distribution of low permeability layers/lenses that are in contact with the plume ("Enter Boring Logs" tab). The data from these two tabs are used to characterize the geologic heterogeneity at the site and the potential impact of matrix diffusion on remediation. This assessment is based on modeling simulations performed using the REMChlor-MD model (see Borden and Cha, 2021 and Farhat et al., 2018).

Input Data

Input tabs for documenting site-specific info

1. Introduction | 2. Select Aquifer Setting | 3. Enter Boring Logs

Learn how to distinguish between transmissive (T-Zone) and low-permeability zones (Low-k Zones).

What is the difference between transmissive and low-K media? A simple rule of thumb is that matrix diffusion effects are likely important when two geologic units in contact with each other have horizontal hydraulic conductivity values that differ by an order of magnitude (factor of 10) or more. The rationale behind this rule of thumb is that, with all else equal, the length of a plume entirely in a lower-K zone will be at least 10 times shorter than that of a plume entirely in the transmissive zone. For a more detailed explanation, click on the button below:

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See more detailed explanation

View Results

See how much heterogeneity your site has for purposes of a Remediation Transition Assessment.

The heterogeneity calculator provides the following information about how much matrix diffusion could impact remediation and remediation timeframes:

Help Box

How much heterogeneity is present at my site?
The effects of geologic heterogeneity on matrix diffusion at a site can be evaluated by examining the contact between geologic units with differences in hydraulic conductivity. Qualitative examples of geologic heterogeneity that can hinder in-situ remediation projects include:

1. Thick aquitards (a meter thick or more) that are below or above a transmissive zone with flowing groundwater; and
2. Multiple thick, low-conductivity lenses within a transmissive zone. The thickness is important because thin lenses (i.e., a few inches thick) would be expected to release most of their contamination back to groundwater within a few years

USCS Group	Description
GW	*Clean gravel- well graded*
GP	*Clean gravel- Poorly graded*
GM	*Silty gravel, gravel-sand-silt*
GC	*Clayey gravel, sand-clay-gravel*
SW	*Clean sand - well graded*
SP	*Clean sand - poorly graded*
SM	*Silty sands*
SC	*Clayey sands*
ML	*Low plasticity silt*
MH	*High plasticity silt*
CH	*High plasticity clay*
CL	*Low plasticity clay*

How can I tell the difference between transmissive and low-k geologic media?
The table below shows the estimated permeability contrast between different geologic media in the Universal Soil Classification System (USCS). The rule of thumb used here is that matrix diffusion effects become significant between geologic units where horizontal hydraulic conductivity differs by more than a factor of 10. Based on this rule of thumb and literature K values for different USCS soil types, matrix diffusion is likely to be important at soil type combinations represented by the green cells, where the hydraulic conductivity difference is greater than 10. Red cells represent soil type boundaries with a less substantial difference in hydraulic conductivity, meaning a lesser contribution to matrix diffusion.

The rows in the table represent the soil type of the low-k unit, while the columns represent the transmissive unit.

	Transmissive Unit	GW GP	SW coarse	GM	SW medium	SW fine	SP coarse	SW very fine	SP medium	SM	GC	SP fine	SC	SP very fine	ML	MH	CL
Low-k Unit	K (cm/s)	**1**	**3.5E-01**	**9.5E-02**	**6.8E-02**	**1.6E-02**	**1.5E-02**	**3.7E-03**	**1.9E-03**	**1.0E-03**	**3.0E-04**	**2.2E-04**	**1.2E-04**	**5.5E-05**	**1.4E-05**	**1.1E-06**	**1.0E-07**
GW GP	**1**																
SW coarse	**3.5E-01**	2.9															
GM	**9.5E-02**	11	3.7														
SW medium	**6.8E-02**	15	5.1	1.4													
SW fine	**1.6E-02**	62	22	5.9	4.3												
SP coarse	**1.5E-02**	67	23	6.3	4.5	1.1											
SW very fine	**3.7E-03**	270	95	26	18	4.3	4.1										
SP medium	**1.9E-03**	530	180	50	36	8.4	7.9	1.9									
SM	**1.0E-03**	1,000	350	95	68	16	15	3.7	1.9								
GC	**3.0E-04**	3,300	1,200	320	230	53	50	12	6.3	3.3							
SP fine	**2.2E-04**	4,500	1,600	430	310	73	68	17.0	8.6	4.5	1.4						
SC	**1.2E-04**	8,300	2,900	790	570	130	130	31	16	8.3	2.5	1.8					
SP very fine	**5.5E-05**	18,000	6,400	1,700	1,200	290	270	67	35	18	5.5	4.0	2.2				
ML	**1.4E-05**	71,000	25,000	6,800	4,900	1,100	1,100	260	140	71	21	16	8.6	3.9			
MH	**1.1E-06**	910,000	320,000	86,000	62,000	15,000	14,000	3,400	1,700	910	270	200	110	50	13		
CL	**1.0E-07**	10,000,000	3,500,000	950,000	680,000	160,000	150,000	37,000	19,000	10,000	3,000	2,200	1,200	550	140	11	
CH	**2.1E-08**	48,000,000	17,000,000	4,500,000	3,200,000	760,000	710,000	180,000	90,000	48,000	14,000	10,000	5,700	2,600	670	52	4.8

RESULTS: Lower k Material Less Likely to Act as Low-k Unit
Lower k Material Likely Acts as Low-k Unit

Help box for understanding how "transmissive" and "low-permeability" can be defined

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Tool 8. Understand how much geologic heterogeneity there is at a site.

What Does this Tool Do?

This tool defines key site-specific features that contribute to matrix diffusion, including the presence of aquitards and the distribution of low-permeability layers and lenses within your plume. With this information, the impact of matrix diffusion on remediation performance and cleanup times can be categorized as Low, Moderate, or High.

How Does it Work?

In the "Select Aquifer Setting" tab, select the hydrogeologic setting that is most representative of the conditions for the plume at your site. Then, enter data from boring logs from your site to determine the distribution of low permeability layers/lenses that are in contact with the plume ("Enter Boring Logs" tab). The data from these two tabs are used to characterize the geologic heterogeneity at the site and the potential impact of matrix diffusion on remediation. This assessment is based on modeling simulations performed using the REMChlor-MD model (see Borden and Cha, 2021 and Farhat et al., 2018).

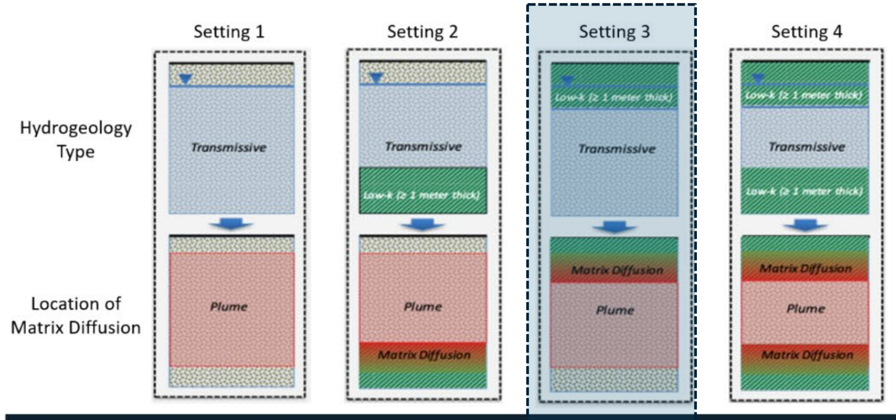
Input Data

1. Introduction | 2. Select Aquifer Setting | 3. Enter Boring Logs

Any aquitards in contact with plume?

Select which one of the four aquifer settings that is most representative of your site.

- ○ Setting 1: No Matrix Diffusion
- ○ Setting 2: Matrix Diffusion in Underlying Low-K Units
- ● Setting 3: Matrix Diffusion in Overlying Low-K Units
- ○ Setting 4: Matrix Diffusion in Under and Overlying Low-K Units



Select the aquifer setting that is most representative of the conditions for the plume at your site

View Results

See how much heterogeneity your site has for purposes of a Remediation Transition Assessment.

The heterogeneity calculator provides the following information about how much matrix diffusion could impact remediation and remediation timeframes:

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Tool 8. Understand how much geologic heterogeneity there is at a site.

What Does this Tool Do?

This tool defines key site-specific features that contribute to matrix diffusion, including the presence of aquitards and the distribution of low-permeability layers and lenses within your plume. With this information, the impact of matrix diffusion on remediation performance and cleanup times can be categorized as Low, Moderate, or High.

How Does it Work?

In the "Select Aquifer Setting" tab, select the hydrogeologic setting that is most representative of the conditions for the plume at your site. Then, enter data from boring logs from your site to determine the distribution of low permeability layers/lenses that are in contact with the plume ("Enter Boring Logs" tab). The data from these two tabs are used to characterize the geologic heterogeneity at the site and the potential impact of matrix diffusion on remediation. This assessment is based on modeling simulations performed using the REMChlor-MD model (see Borden and Cha, 2021 and Farhat et al., 2018).

Input Data

1. Introduction | 2. Select Aquifer Setting | 3. Enter Boring Logs

Enter data for layers/lenses within the plume.

Step 1. Enter typical depth of top of plume in transmissive media (e.g., gravels, sands) in meters below ground surface: 10

Step 2. Enter typical depth of bottom of plume in transmissive media (e.g., gravels, sands) in meters below ground surface: 21

Step 3. Enter low permeability ("Low-k") layer/lens data from one or more boring logs into the data entry screen below. For each low-K layer/lens within the plume zone enter thickness in meters. Do not include upper or lower aquitards. Press "See More Detailed Explanation" for a description of how to distinguish low-k and transmissive soils.

See more detailed explanation

More Details:
1. Enter layers/lens data for at least 3 and up to 10 representative boring logs in the plume.
2. Most boring logs will only have a few layers/lenses; leave all other entries blank
3. For detailed information: see Appendix 6 of REMChlor-MD User's Manual.

Logs	Low-K layer/len 1 (m thickness)	Low-K layer/len 2 (m thickness)	Low-K layer/len 3 (m thickness)	Low-K layer/len 4 (m thickness)
Boring Log 1	1.00			
Boring Log 2	0.50	0.60		
Boring Log 3	0.60	0.10	0.95	0.50
Boring Log 4	0.10	0.10		
Boring Log 5	1.60			
Boring Log 6	1.00			
Boring Log 7	0.50	0.60		
Boring Log 8	0.60	0.10	0.95	
Boring Log 9	0.10	0.10		
Boring Log 10	1.60			

Enter data from boring logs on the thickness of any low-k layers that are present

View Results

See how much heterogeneity your site has for purposes of a Remediation Transition Assessment.

The heterogeneity calculator provides the following information about how much matrix diffusion could impact remediation and remediation timeframes:

Key Matrix Diffusion Variable for Aquitard(s)	# of Aquitards	Impact on Matrix Diffusion
Number of Aquitard Interfaces	1	High

Key Matrix Diffusion Variable for Layers/Lenses	Values from Step 3	Impact on Matrix Diffusion
Percent of aquifer thickness (B) that is transmissive	89	Low
Number of layers	2	Low

Combining values from all steps,

the overall impact of heterogeneity on matrix diffusion is expected to be **High**.

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Tool 8. Understand how much geologic heterogeneity there is at a site.

What Does this Tool Do?

This tool defines key site-specific features that contribute to matrix diffusion, including the presence of aquitards and the distribution of low-permeability layers and lenses within your plume. With this information, the impact of matrix diffusion on remediation performance and cleanup times can be categorized as Low, Moderate, or High.

How Does it Work?

In the "Select Aquifer Setting" tab, select the hydrogeologic setting that is most representative of the conditions for the plume at your site. Then, enter data from boring logs from your site to determine the distribution of low permeability layers/lenses that are in contact with the plume ("Enter Boring Logs" tab). The data from these two tabs are used to characterize the geologic heterogeneity at the site and the potential impact of matrix diffusion on remediation. This assessment is based on modeling simulations performed using the REMChlor-MD model (see Borden and Cha, 2021 and Farhat et al., 2018).

Input Data

1. Introduction | 2. Select Aquifer Setting | 3. Enter Boring Logs

Enter data for layers/lenses within the plume.

Step 1. Enter typical depth of top of plume in transmissive media (e.g., gravels, sands) in meters below ground surface: 10

Step 2. Enter typical depth of bottom of plume in transmissive media (e.g., gravels, sands) in meters below ground surface: 21

Step 3. Enter low permeability ("Low-k") layer/lens data from one or more boring logs into the data entry screen below. For each low-K layer/lens within the plume zone enter thickness in meters. Do not include upper or lower aquitards. Press "See More Detailed Explanation" for a description of how to distinguish low-k and transmissive soils.

See more detailed explanation

More Details:
1. Enter layers/lens data for at least 3 and up to 10 representative boring logs in the plume.
2. Most boring logs will only have a few layers/lenses; leave all other entries blank
3. For detailed information: see Appendix 6 of REMChlor-MD User's Manual.

Logs	Low-K layer/len 1 (m thickness)	Low-K layer/len 2 (m thickness)	Low-K layer/len 3 (m thickness)	Low-K layer/len 4 (m thickness)
Boring Log 1	1.00			
Boring Log 2	0.50	0.60		
Boring Log 3	0.60	0.10	0.95	0.50
Boring Log 4	0.10	0.10		
Boring Log 5	1.60			
Boring Log 6	1.00			
Boring Log 7	0.50	0.60		
Boring Log 8	0.60	0.10	0.95	
Boring Log 9	0.10	0.10		
Boring Log 10	1.60			

View Results

See how much heterogeneity your site has for purposes of a Remediation Transition Assessment.

The heterogeneity calculator provides the following information about how much matrix diffusion could impact remediation and remediation timeframes:

Key Matrix Diffusion Variable for Aquitard(s)	# of Aquitards	Impact on Matrix Diffusion
Number of Aquitard Interfaces	1	High

Key Matrix Diffusion Variable for Layers/Lenses	Values from Step 3	Impact on Matrix Diffusion
Percent of aquifer thickness (B) that is transmissive	89	Low
Number of layers	2	Low

Combining values from all steps,
the overall impact of heterogeneity on matrix diffusion is expected to be **High**.

Tool will use input data to assess whether the impact of matrix diffusion on the performance of active remedies is expected to be high

Tool 9:

Incorporate insights from other SERDP transition assessment projects

Tool 9. Learn from other SERDP Transition Assessment Projects.

The TA^2 Tool was funded as part of a SERDP Statement of Need titled "Quantitative Groundwater Plume Characterization to Support Transition Assessments". Several other projects were funded under this Statement of Need, and these projects also aim to improve our ability to identify transition points from active to more passive remedial measures, and to allow us to better assess the impacts of interim remedial measures.

Links to the SERDP project pages are provided below for several of these projects. The information found at these pages—which will continue to be updated as these projects progress—include tools, guidance, reports, and other publications that highlight key findings and benefits to DoD and other interested parties.

Click on links to see project details, including reports and tech transfer products

SERDP Project Number	Title	Principal Investigator
ER20-1079	Development of Predictive Tools for Assessment of Natural Attenuation Capacity and Treatment Transition at Chlorinated Solvent Sites	Natalie Capiro (Cornell University) natalie.capiro@cornell.edu
ER20-1203	Quantifying the Distribution of Biotic and Abiotic Transformation Rate Constants in Low Permeability Clay Zones for Improved Assessment of TCE Impacts to Groundwater at DoD Field Sites	Charles Werth (University of Texas at Austin) werth@utexas.edu
ER20-1270	Quantitative Assessment of Long-term Abiotic Transformation Rates of Chlorinated Solvents	Weile Yan (University of Massachusetts Lowell) weile_yan@uml.edu
ER20-1357	Developing a Quantitative Framework for Predicting Abiotic Attenuation under Natural and Transitional Site Management Scenarios	Paul Tratnyek (Oregon Health & Science University) tratnyek@ohsu.edu
ER20-1368	Development of Protocols to Quantify Abiotic Transformation Rates and Mechanisms for Chlorinated Ethenes in Water Supply Aquifers	David Freedman (Clemson University) dfreedm@clemson.edu
ER20-1374	Field Deployable ORP Kit for Quantitative Assessment of Abiotic Monitored Natural Attenuation Rates	Dimin Fan (Geosyntec) dfan@geosyntec.com

Tool 10:

Summary Assessment

Flowchart for how the TA² Tool can be used to support a comprehensive Transition Assessment

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Tool 10a. Step-by-Step Guide for an MNA Transition Assessment

What Does this Tool Do?

This tool walks through the key steps that should be followed when conducting a site-specific transition assessment. In this case, the primary objective is to determine if transitioning to MNA is appropriate based on site conditions and/or the performance of on-going or prospective remedial measures. It integrates information from the other tools in this app, including a "Remediation Transition Assessment Index" (Tool 10b) that reflects the relative persistence of contamination at the site due to matrix diffusion effects.

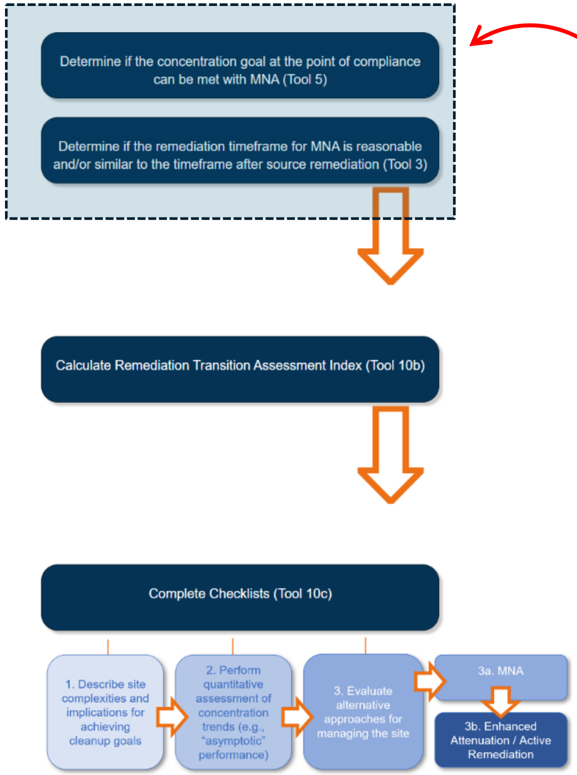
How Does it Work?

1. Go through Steps 1 - 3 in order to perform a comprehensive site transition assessment (*click on buttons below or use menu to navigate to each tool*).
2. Copy or transcribe the supporting information for each step so that it can be included in a site transition assessment report.

Step 1. Determine if the site meets the primary "bright line" criteria for transitioning to MNA

Step 2. Establish the "Remediation Transition Assessment Index" for the site

Step 3. Document the relevant info for the 3 key elements of a Transition Assessment



Step 1 is to determine if you can meet one or both "bright line" criteria that are often applicable for MNA sites

These can be done using Tool 5 (plume projections at point of compliance) and Tool 3 (remediation timeframe estimates after source remediation)

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Tool 10a. Step-by-Step Guide for an MNA Transition Assessment

What Does this Tool Do?

This tool walks through the key steps that should be followed when conducting a site-specific transition assessment. In this case, the primary objective is to determine if transitioning to MNA is appropriate based on site conditions and/or the performance of on-going or prospective remedial measures. It integrates information from the other tools in this app, including a "Remediation Transition Assessment Index" (Tool 10b) that reflects the relative persistence of contamination at the site due to matrix diffusion effects.

How Does it Work?

1. Go through Steps 1 - 3 in order to perform a comprehensive site transition assessment *(click on buttons below or use menu to navigate to each tool)*.
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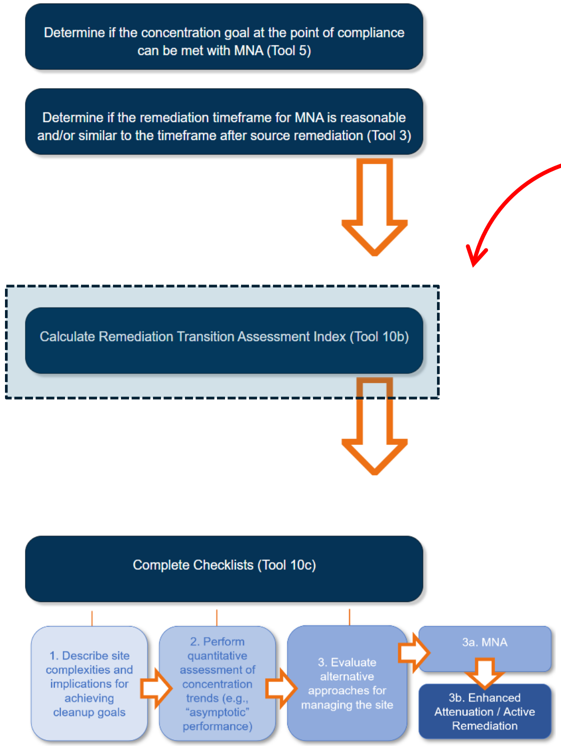
Step 1. Determine if the site meets the primary "bright line" criteria for transitioning to MNA

Step 2. Establish the "Remediation Transition Assessment Index" for the site

Step 3. Document the relevant info for the 3 key elements of a Transition Assessment



Step 2 is to determine the ***"Remediation Transition Assessment Index" (RTAI)*** *for your site*

It is automatically calculated using the results from several of the quantitative tools

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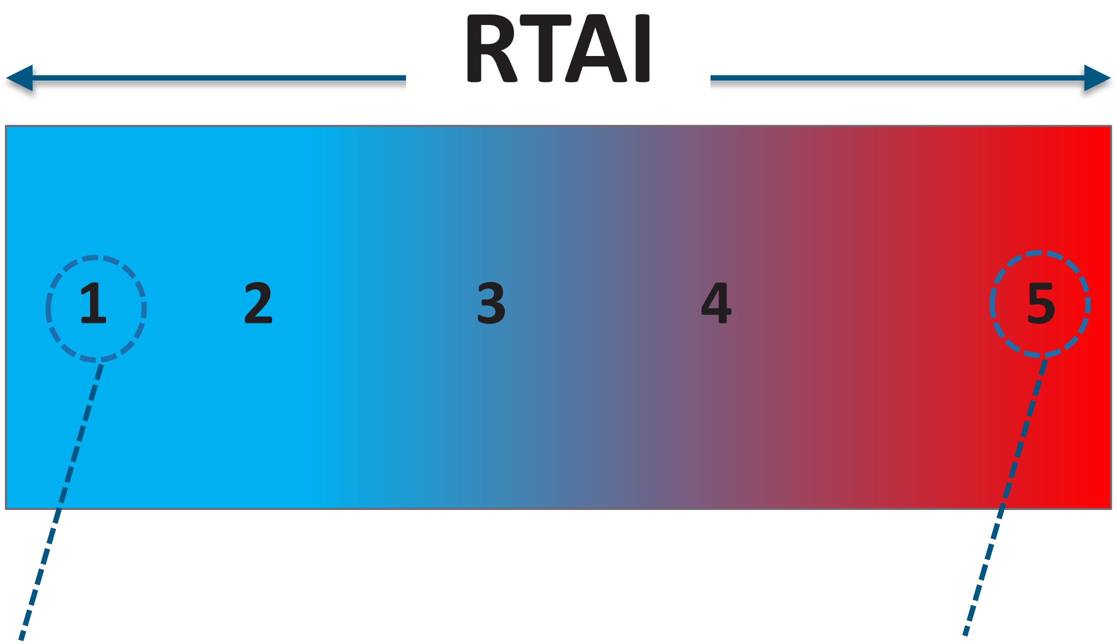
"Remediation Transition Assessment Index" (RTAI) *is a simple numerical indicator that reflects whether conditions support transitioning from active remediation*

RTAI = 1
Site is poor candidate for transition



RTAI = 5
Site is strong candidate for transition

EXAMPLE:
Site has low heterogeneity and performance of ongoing active treatment has not reached an asymptote

EXAMPLE:
Site has high heterogeneity and modeling results show that remediation timeframe will still be long after source remediation, so benefit of additional active treatment is limited

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Tool 10b. Remediation Transition Assessment Index (RTAI)

This portion of Tool 10 integrates information from several other tools in this app into a Remediation Transition Assessment Index 'RTAI'. This simple metric reflects the relative persistence of contamination at a site due to matrix diffusion and other site-specific considerations. It summarizes the results from each of the tools that have been completed by the user, and then assigns a RTAI value to each of those results. An RTAI of 5 indicates that the results suggest that the site is a strong candidate for transitioning to MNA or enhanced attenuation approaches, while an RTAI of 1 suggests that the site is a poor candidate. Note that a user can calculate an RTAI for their site without going through the other steps in Tool 10. However, a decision to transition to MNA will likely require that the "bright line" criteria described in Tool 10a have also been met, and that the relevant site information described in the Tool 10c checklists has been adequately documented.

Tool	RTAI					Rationale
	Poor Candidate RTAI = 1	Fair Candidate RTAI = 2	Typical Candidate RTAI = 3	Good Candidate RTAI = 4	Strong Candidate RTAI = 5	
1. Asymptote (Tool 1)	1	2	3	**4**	5	The RTAI is higher if there are more Lines of Evidence that concentrations at the site are asymptotic.
2. Is my Plume expanding? (Tool 2)	**I**	PI	ST	PD	D	The RTAI is higher if key downgradient/sentinal well(s) exhibit stable or declining concentration trends.
3. Expected performance (Tool 4)	<0.5	**0.5 to <0.75**	0.75 to <1.25	1.25 to <2	≥2	The RTAI is higher for sites where a higher concentration is needed and may not be achievable based on the expected level of performance of remediation technologies.
4. Remedial Potential (Tool 4)	**High**	High-Mod	Moderate	Mod-Low	Low	The RTAI is higher for sites with challenging cleanup goals and difficult conditions. It is based on a similar methodology developed by ITRC for evaluating remediation potential.
5. How long? (Tool 3)	<5	5 to <10	**10 to <25**	25 to <50	≥50	The RTAI is higher for sites where additional source remediation does not result in short remediation timeframes. It is based on the estimated number of years to reach the cleanup goal after source remediation.
6. Enhanced Attenuation (Tool 7)	-	-	✓	-	-	The RTAI is higher for sites where EA technologies or approaches can be easily implemented. It is based on the depth and width of the area being targeted, which are used as proxies for cost and ease of installation.
Metric	2	1	2	1	0	

RTAI of 4 from the Tool 1 asymptote analysis suggests the site is a good candidate for transitioning (because the performance of existing technology has plateaued)

Tool 10b. Remediation Transition Assessment Index (RTAI)

This portion of Tool 10 integrates information from several other tools in this app into a Remediation Transition Assessment Index 'RTAI'. This simple metric reflects the relative persistence of contamination at a site due to matrix diffusion and other site-specific considerations. It summarizes the results from each of the tools that have been completed by the user, and then assigns a RTAI value to each of those results. An RTAI of 5 indicates that the results suggest that the site is a strong candidate for transitioning to MNA or enhanced attenuation approaches, while an RTAI of 1 suggests that the site is a poor candidate. Note that a user can calculate an RTAI for their site without going through the other steps in Tool 10. However, a decision to transition to MNA will likely require that the "bright line" criteria described in Tool 10a have also been met, and that the relevant site information described in the Tool 10c checklists has been adequately documented.

Tool	RTAI					Rationale
	Poor Candidate RTAI = 1	Fair Candidate RTAI = 2	Typical Candidate RTAI = 3	Good Candidate RTAI = 4	Strong Candidate RTAI = 5	
1. Asymptote (Tool 1)	1	2	3	**4**	5	The RTAI is higher if there are more Lines of Evidence that concentrations at the site are asymptotic.
2. Is my Plume expanding? (Tool 2)	**I**	PI	ST	PD	D	The RTAI is higher if key downgradient/sentinal well(s) exhibit stable or declining concentration trends.
3. Expected performance (Tool 4)	<0.5	**0.5 to <0.75**	0.75 to <1.25	1.25 to <2	≥2	The RTAI is higher for sites where a higher concentration is needed and may not be achievable based on the expected level of performance of remediation technologies.
4. Remedial Potential (Tool 4)	**High**	High-Mod	Moderate	Mod-Low	Low	The RTAI is higher for sites with challenging cleanup goals and difficult conditions. It is based on a similar methodology developed by ITRC for evaluating remediation potential.
5. How long? (Tool 3)	<5	5 to <10	**10 to <25**	25 to <50	≥50	The RTAI is higher for sites where additional source remediation does not result in short remediation timeframes. It is based on the estimated number of years to reach the cleanup goal after source remediation.
6. Enhanced Attenuation (Tool 7)	-	-	✓	-	-	The RTAI is higher for sites where EA technologies or approaches can be easily implemented. It is based on the depth and width of the area being targeted, which are used as proxies for cost and ease of installation.
Metric	2	1	2	1	0	

RTAI values from the other tools ranged from 1 to 3, which are generally less favorable support for transitioning.

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Tool 10b. Remediation Transition Assessment Index (RTAI)

This portion of Tool 10 integrates information from several other tools in this app into a Remediation Transition Assessment Index 'RTAI'. This simple metric reflects the relative persistence of contamination at a site due to matrix diffusion and other site-specific considerations. It summarizes the results from each of the tools that have been completed by the user, and then assigns a RTAI value to each of those results. An RTAI of 5 indicates that the results suggest that the site is a strong candidate for transitioning to MNA or enhanced attenuation approaches, while an RTAI of 1 suggests that the site is a poor candidate. Note that a user can calculate an RTAI for their site without going through the other steps in Tool 10. However, a decision to transition to MNA will likely require that the "bright line" criteria described in Tool 10a have also been met, and that the relevant site information described in the Tool 10c checklists has been adequately documented.

Tool	RTAI					Rationale
	Poor Candidate RTAI = 1	**Fair Candidate RTAI = 2**	**Typical Candidate RTAI = 3**	**Good Candidate RTAI = 4**	**Strong Candidate RTAI = 5**	
1. Asymptote (Tool 1)	1	2	3	**4**	5	The RTAI is higher if there are more Lines of Evidence that concentrations at the site are asymptotic.
2. Is my Plume expanding? (Tool 2)	**I**	PI	ST	PD	D	The RTAI is higher if key downgradient/sentinal well(s) exhibit stable or declining concentration trends.
3. Expected performance (Tool 4)	<0.5	**0.5 to <0.75**	0.75 to <1.25	1.25 to <2	≥2	The RTAI is higher for sites where a higher concentration is needed and may not be achievable based on the expected level of performance of remediation technologies.
4. Remedial Potential (Tool 4)	**High**	High-Mod	Moderate	Mod-Low	Low	The RTAI is higher for sites with challenging cleanup goals and difficult conditions. It is based on a similar methodology developed by ITRC for evaluating remediation potential.
5. How long? (Tool 3)	<5	5 to <10	**10 to <25**	25 to <50	≥50	The RTAI is higher for sites where additional source remediation does not result in short remediation timeframes. It is based on the estimated number of years to reach the cleanup goal after source remediation.
6. Enhanced Attenuation (Tool 7)	-	-	✓	-	-	The RTAI is higher for sites where EA technologies or approaches can be easily implemented. It is based on the depth and width of the area being targeted, which are used as proxies for cost and ease of installation.
Metric	2	1	2	1	0	

There are two ways to use the RTAI.

The first is to average the results from each tool. The average in this case would be 2.3, which suggests the site is only a fair candidate for transitioning.

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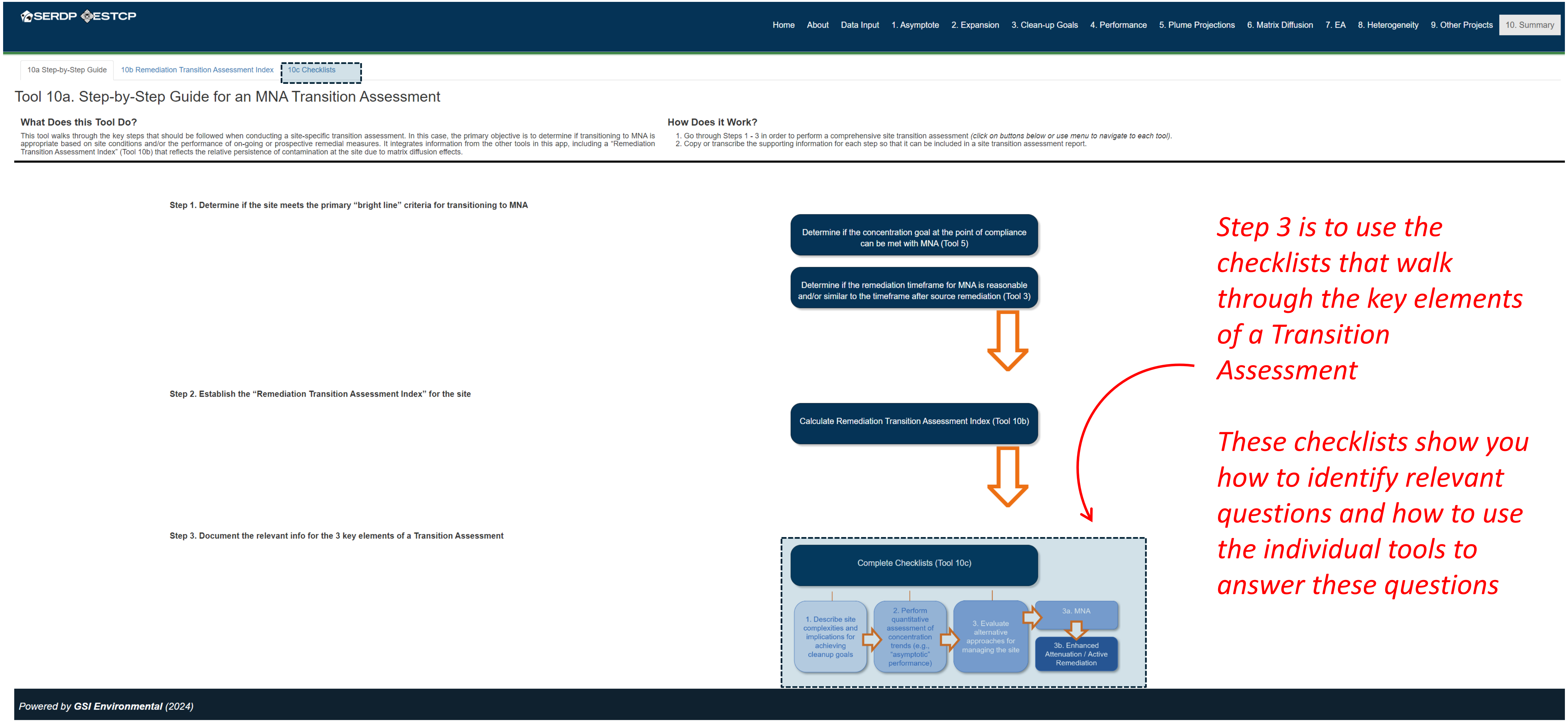
Tool 10b. Remediation Transition Assessment Index (RTAI)

This portion of Tool 10 integrates information from several other tools in this app into a Remediation Transition Assessment Index 'RTAI'. This simple metric reflects the relative persistence of contamination at a site due to matrix diffusion and other site-specific considerations. It summarizes the results from each of the tools that have been completed by the user, and then assigns a RTAI value to each of those results. An RTAI of 5 indicates that the results suggest that the site is a strong candidate for transitioning to MNA or enhanced attenuation approaches, while an RTAI of 1 suggests that the site is a poor candidate. Note that a user can calculate an RTAI for their site without going through the other steps in Tool 10. However, a decision to transition to MNA will likely require that the "bright line" criteria described in Tool 10a have also been met, and that the relevant site information described in the Tool 10c checklists has been adequately documented.

Tool	RTAI					Rationale
	Poor Candidate RTAI = 1	Fair Candidate RTAI = 2	Typical Candidate RTAI = 3	Good Candidate RTAI = 4	Strong Candidate RTAI = 5	
1. Asymptote (Tool 1)	1	2	3	**4**	5	The RTAI is higher if there are more Lines of Evidence that concentrations at the site are asymptotic.
2. Is my Plume expanding? (Tool 2)	**I**	PI	ST	PD	D	The RTAI is higher if key downgradient/sentinal well(s) exhibit stable or declining concentration trends.
3. Expected performance (Tool 4)	<0.5	**0.5 to <0.75**	0.75 to <1.25	1.25 to <2	≥2	The RTAI is higher for sites where a higher concentration is needed and may not be achievable based on the expected level of performance of remediation technologies.
4. Remedial Potential (Tool 4)	**High**	High-Mod	Moderate	Mod-Low	Low	The RTAI is higher for sites with challenging cleanup goals and difficult conditions. It is based on a similar methodology developed by ITRC for evaluating remediation potential.
5. How long? (Tool 3)	<5	5 to <10	**10 to <25**	25 to <50	≥50	The RTAI is higher for sites where additional source remediation does not result in short remediation timeframes. It is based on the estimated number of years to reach the cleanup goal after source remediation.
6. Enhanced Attenuation (Tool 7)	-	-	✓	-	-	The RTAI is higher for sites where EA technologies or approaches can be easily implemented. It is based on the depth and width of the area being targeted, which are used as proxies for cost and ease of installation.
Metric	2	1	2	1	0	

The second way is to use only the RTAI value(s) most relevant to the site-specific assessment. In this case, the asymptote analysis was most important because the site met other bright line criteria.



Step 3 is to use the checklists that walk through the key elements of a Transition Assessment

These checklists show you how to identify relevant questions and how to use the individual tools to answer these questions

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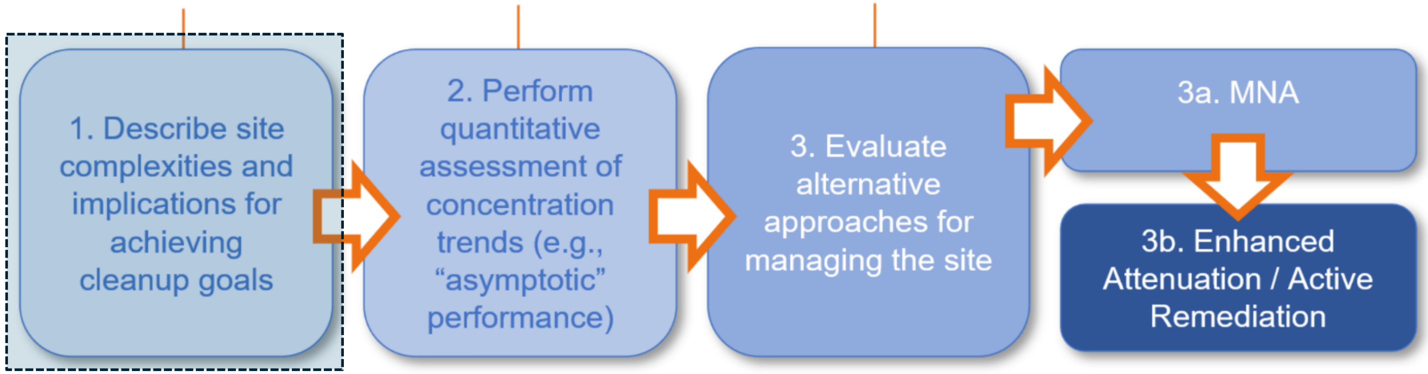
Tool 10c. Checklists

a. This portion of Tool 10 provides checklists to ensure that the user has gathered the necessary information to support a technically rigorous site-specific Transition Assessment. It also further maps out how each of the other tools in this app can be used to assist in the overall assessment. These checklists are based on three key site-specific elements shown in the graphic to the right. Note that the National Research Council (2012) has previously described the various elements that should be considered during a Transition Assessment, with a focus on an evaluation of alternative remedies or long-term management options after demonstrating that asymptotic conditions have occurred for the current remedy. For the purposes of this tool, we have included the initial steps of documenting site conditions and complexities, as well the quantitative assessment of asymptotic trends and plume stability, in the Transition Assessment.



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1. Describe site complexities and implications for achieving cleanup goals

- [ ] Do you have an existing CSM that identifies relevant site conditions, nature and extent of contamination, and relevant attenuation processes? ?
- [ ] Have you established the Geologic Heterogeneity at your site (Tool 8)? ?
- [ ] How does the performance of past source remediation efforts at your site compare to the typical performance at other sites (Tool 4)? ?
- [ ] Have you estimated the impact of additional source remediation on remediation timeframe (Tool 3)? ?
- [ ] Have you estimated the Remediation Transition Assessment Index (RTAI) for your site (Tool 10b)? ?

If a pump-and-treat system is in place:

- [ ] Has a rebound test been performed that suggests concentrations increase significantly after shutting off pump(s)? ?

Each of the key elements of a TA is broken down into a series of questions to be answered.

*The **first** key element involves describing site complexities and documenting the implications for achieving cleanup goals.*

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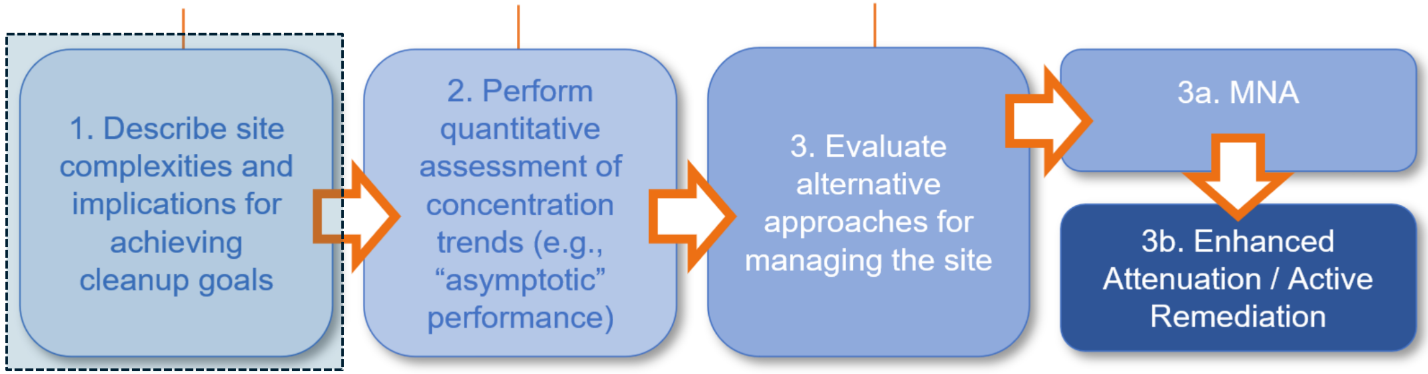

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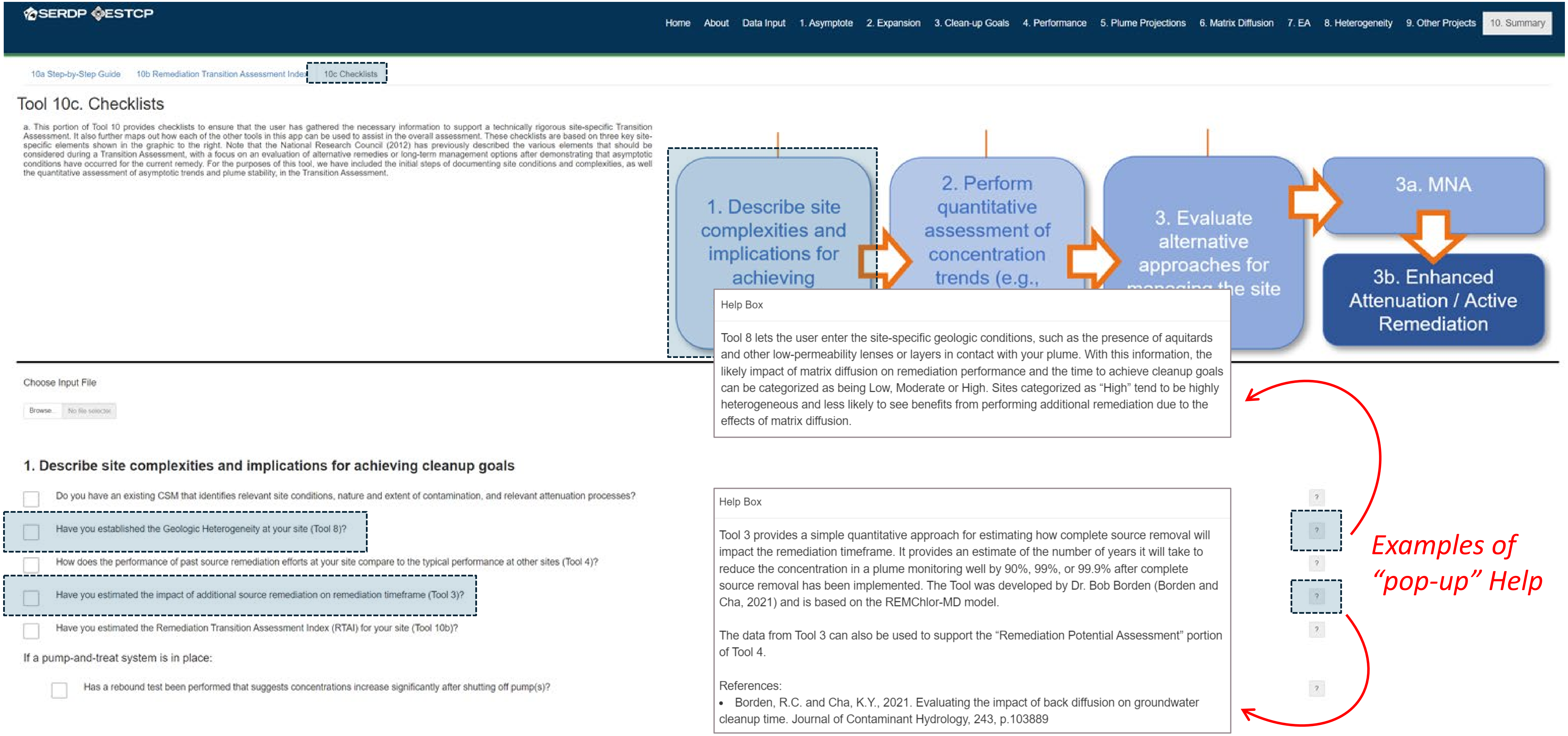
- [ ] Have you estimated the impact of additional source remediation on remediation timeframe (Tool 3)? ?
- [ ] Have you estimated the Remediation Transition Assessment Index (RTAI) for your site (Tool 10b)? ?

If a pump-and-treat system is in place:

- [ ] Has a rebound test been performed that suggests concentrations increase significantly after shutting off pump(s)? ?

*Click on "**Help**" buttons for additional explanations on how to answer each question, including how to use the TA^2 Tool modules to support your answer*



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1. Describe site complexities and implications for achieving
2. Perform quantitative assessment of concentration trends (e.g.,
3. Evaluate alternative approaches for
3a. MNA
3b. Enhanced Attenuation / Active Remediation
Help Box
Tool 8 lets the user enter the site-specific geologic conditions, such as the presence of aquitards and other low-permeability lenses or layers in contact with your plume. With this information, the likely impact of matrix diffusion on remediation performance and the time to achieve cleanup goals can be categorized as being Low, Moderate or High. Sites categorized as “High” tend to be highly heterogeneous and less likely to see benefits from performing additional remediation due to the effects of matrix diffusion.
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1. Describe site complexities and implications for achieving cleanup goals
Do you have an existing CSM that identifies relevant site conditions, nature and extent of contamination, and relevant attenuation processes?
Have you established the Geologic Heterogeneity at your site (Tool 8)?
How does the performance of past source remediation efforts at your site compare to the typical performance at other sites (Tool 4)?
Have you estimated the impact of additional source remediation on remediation timeframe (Tool 3)?
Have you estimated the Remediation Transition Assessment Index (RTAI) for your site (Tool 10b)?
If a pump-and-treat system is in place:
Has a rebound test been performed that suggests concentrations increase significantly after shutting off pump(s)?
Help Box
Tool 3 provides a simple quantitative approach for estimating how complete source removal will impact the remediation timeframe. It provides an estimate of the number of years it will take to reduce the concentration in a plume monitoring well by 90%, 99%, or 99.9% after complete source removal has been implemented. The Tool was developed by Dr. Bob Borden (Borden and Cha, 2021) and is based on the REMChlor-MD model.
The data from Tool 3 can also be used to support the “Remediation Potential Assessment” portion of Tool 4.
References:
• Borden, R.C. and Cha, K.Y., 2021. Evaluating the impact of back diffusion on groundwater cleanup time. Journal of Contaminant Hydrology, 243, p.103889
Examples of “pop-up” Help

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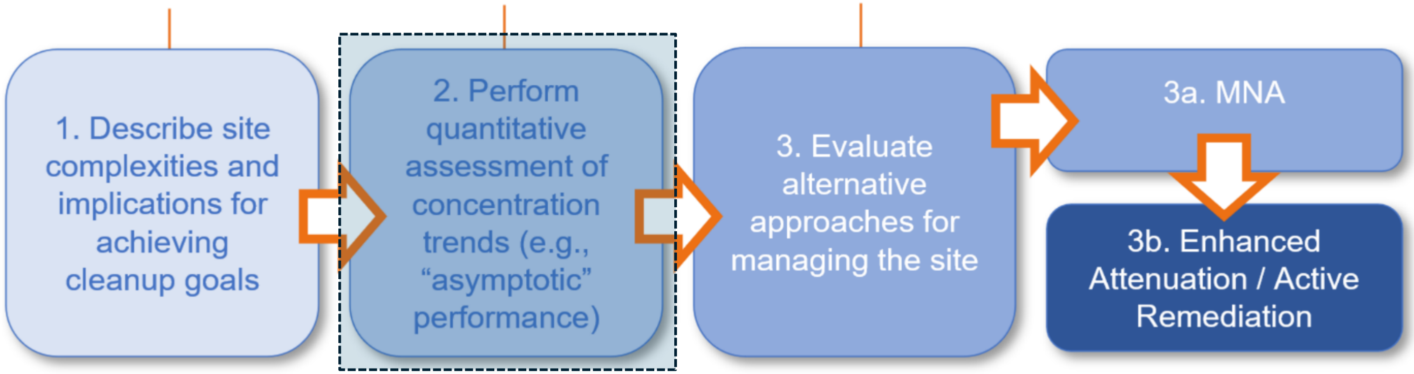

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2. Perform quantitative assessment of concentration trends (e.g., “asymptotic” performance).

- [ ] What is the current rate of source attenuation over time (based on max. concentration well or site-wide range) (Tool 1)? ?
- [ ] What is the projected remediation timeframe at the current rate of source attenuation (Tool 1)? ?
- [ ] Are there lines of evidence that the performance of current remedial measures (e.g., pump-and-treat system) is asymptotic (based on concentration vs. time) (Tool 1)? ?
- [ ] Are the plume concentrations stable or decreasing (based on a site-wide assessment of wells) (Tool 2)? ?
- [ ] Is the plume footprint stable or decreasing (based on an evaluation of downgradient wells) (Tool 2)? ?
- [ ] Is the site-wide mass decreasing over time (Tool 2)? ?

*The **second** key element of a TA requires quantitative assessments of concentration trends, including “asymptotic performance” of existing remedies*

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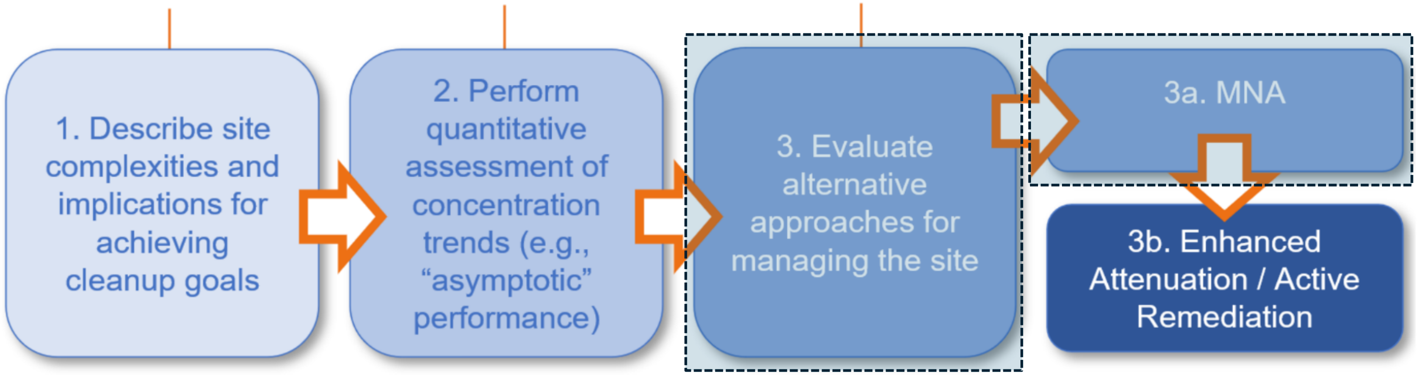

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3a. Evaluate alternative approaches for managing the site (MNA).

- [ ] Are the site cleanup objectives based on achieving a goal concentration within the source area and/or across the entire site?
- [ ] If the goal concentration must be met across the entire site, will this concentration be achieved within a reasonable timeframe with natural attenuation (Tool 1)?
- [ ] Can you establish the bulk natural attenuation rate within the plume using concentration vs. distance data from the plume centerline during the pre-remediation period (Tool 5, tab “Use Pre-Remediation Rate Constant”)?
- [ ] Can you establish the natural attenuation rate within the plume using degradation rates from lab assays or other site-specific data (Tool 5, tab “Use Lab-Based Rate Constant)?
- [ ] Can you establish the current bulk natural attenuation rate within the plume using concentration vs. distance data from the plume centerline during the post-remediation period (Tool 5, tab “Use Post-Remediation Rate Constant)?
    - [ ] Has this attenuation rate been consistent over time (i.e., compare rates using concentration vs. distance data from different events) (Tool 5, tab “Use Post-Remediation Rate Constant)?
    - [ ] Is this rate comparable to the attenuation rate constant estimated using the Pre-Remediation data?
    - [ ] Is this rate comparable to the attenuation rate estimated using lab-based studies?
    - [ ] If data are not available, can you install additional monitoring wells along the plume centerline to generate the necessary data?

*The **third** key element of a TA requires evaluating alternative approaches for site management, starting with assessing natural attenuation rates*

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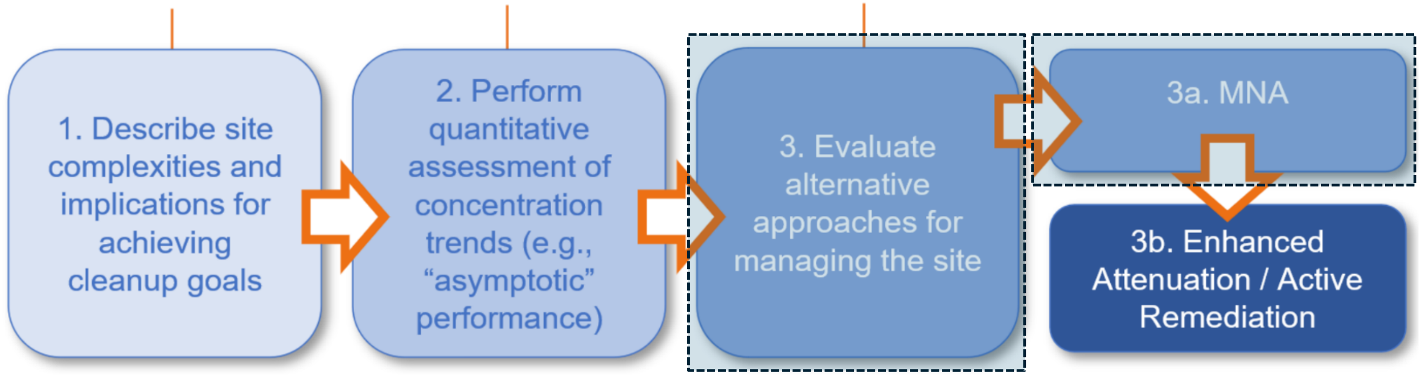

If a treatment is active at the site (e.g., a pump-and-treat system is in place) and the goal is to shut it off and transition to MNA:

- [ ] Has the downgradient point of compliance been established (e.g., the property boundary or other regulatory-based location)?
- [ ] Can the plume be allowed to migrate beyond its current footprint?
- [ ] Does the bulk attenuation rate constant within the plume indicate that the goal concentration will be met at the downgradient point of compliance?
- [ ] Has a rebound test has been performed?
- [ ] Did concentrations increase in the relevant extraction well(s) during the rebound test?
- [ ] If the maximum concentration after rebound is used to recalculate the bulk attenuation rate within the plume, does this new rate still indicate that the goal concentration will be met at the downgradient point of compliance?
- [ ] Is the rate of contaminant capture at the extraction well(s) (based on concentration vs. time) similar to the rate of attenuation observed in monitoring wells prior to pumping (Tool 1)?

The next set of questions evaluates whether MNA is appropriate alternative to ongoing active remedies (like pump-and-treat systems) for managing the site

If a pump-and-treat system (or other active treatment system) is not in place:

- [ ] Is the plume stable (Tool 2)?
- [ ] Is there evidence to suggest that processes contributing to plume stability are sustainable over a long period of time?
- [ ] Does the potential for risk to receptors require implementing remediation or other measures that would preclude the use of MNA?
- [ ] Is the estimated remediation timeframe for the site (based on applicable standards) using MNA considered reasonable (Tool 1)?

MNA can be also evaluated for sites there is no ongoing active remedy - relies on the estimated attenuation rates and plume stability

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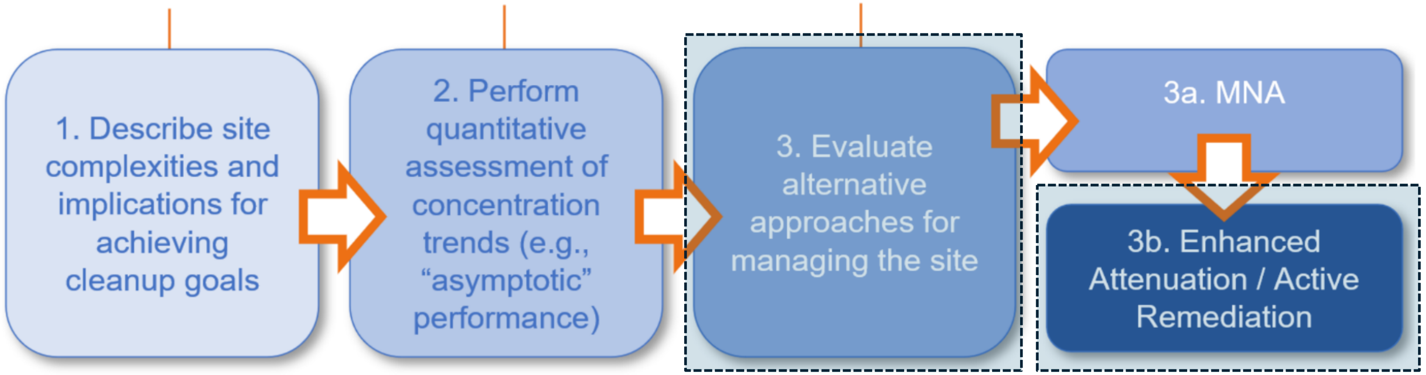

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3b. Evaluate alternative approaches for managing the site (Enhanced Attenuation / Active Remediation)

- [ ] Are the site cleanup objectives based on achieving a goal concentration within the source area and/or across the entire site?
  - [ ] Is source remediation predicted to achieve the goal concentration in the source area within a reasonable timeframe (Tool 3)?
  - [ ] What amount of source attenuation would be needed such the source remediation would be needed to reach the goal concentration within a reasonable timeframe (Tool 3 – enter new value for starting concentration)?
  - [ ] When would this source concentration be reached based on the current source attenuation rates (Tool 1)?
  - [ ] Have you evaluated enhanced attenuation processes for the source area that are potentially feasible for the site (Tool 7)?
    - [ ] Have you identified options for reducing contaminant loading (Tool 7b)?
    - [ ] Have you identified options for increasing attenuation capacity (Tool 7b)?

For sites where MNA is not sufficient, then other alternatives are evaluated, including "enhanced attenuation" options

*The first set of questions focuses on **sites where cleanup objectives must be achieved across the site***

Tool 10c. Checklists

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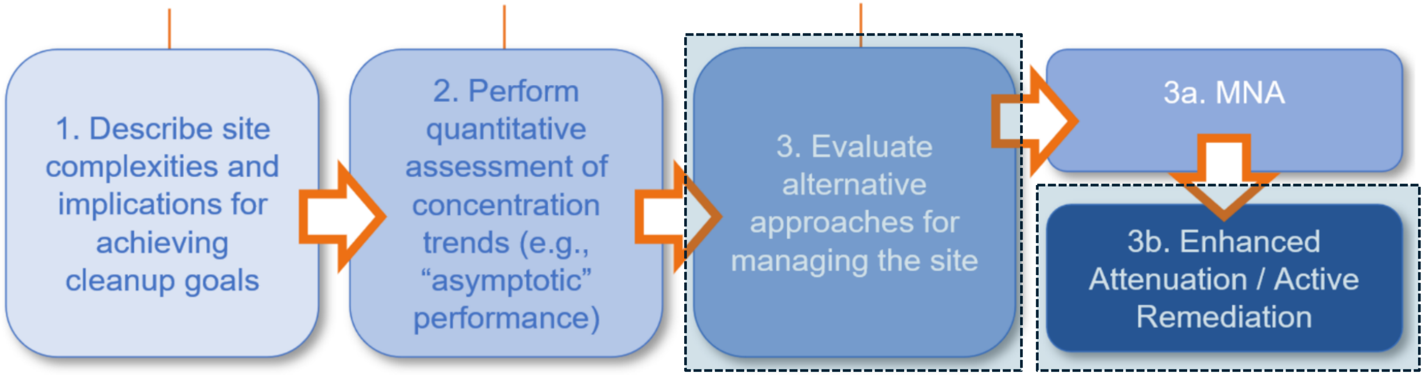

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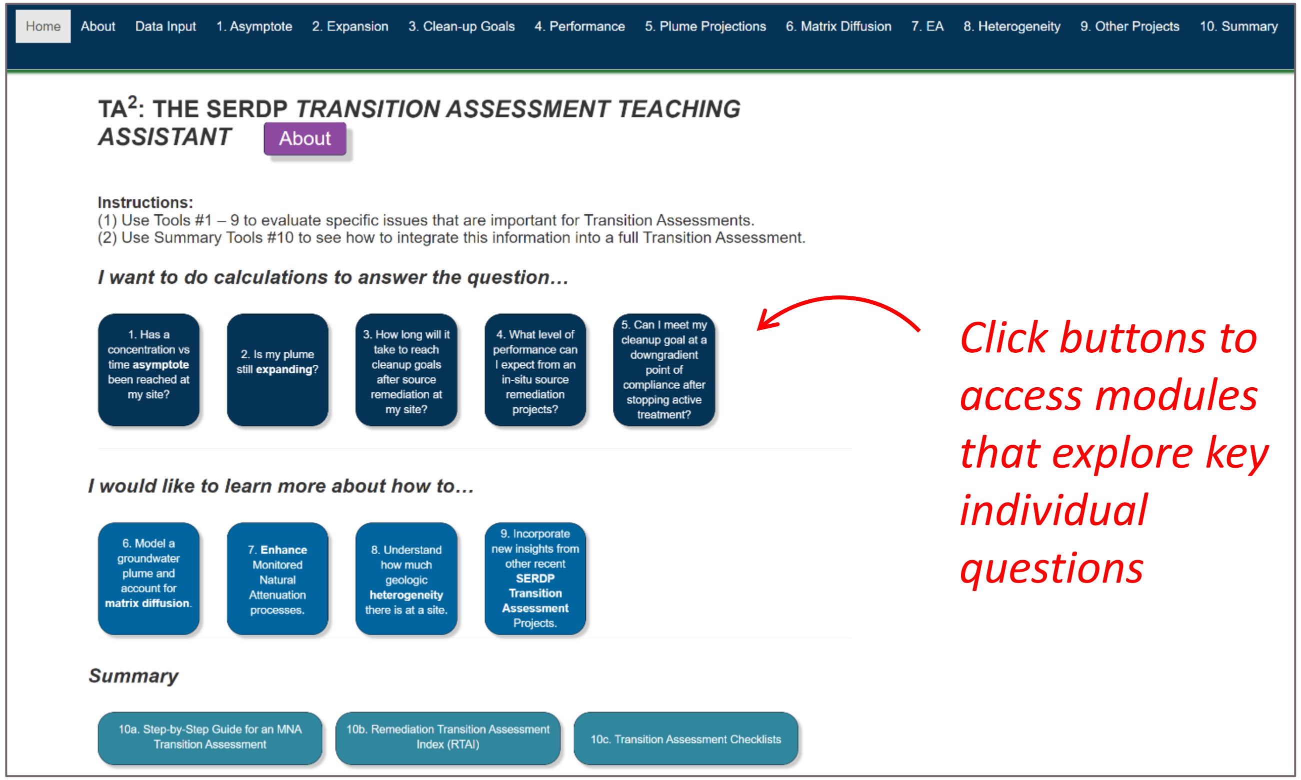
3b. Evaluate alternative approaches for managing the site (Enhanced Attenuation / Active Remediation)

- [ ] Are the site cleanup objectives based on achieving a goal concentration at a downgradient point of compliance?
  - [ ] Is the plume already stable or shrinking? (Tool 2)
  - [ ] Is the concentration in source area wells decreasing over time (Tool 1 or Tool 2)?
  - [ ] What reduction in the source concentration would need to be achieved to allow natural attenuation in the plume to reach the goal concentration at the downgradient point of compliance (absent any further source attenuation) (Tool 5)?
    - [ ] When would this source concentration be reached based on the current source attenuation rates (Tool 1)?
  - [ ] Have you evaluated enhanced attenuation processes for the source, plume, or discharge area that are potentially feasible for the site (Tool 7)
    - [ ] Have you identified options for reducing contaminant loading (Tool 7b, 7c, Tool 7d)?
    - [ ] Have you identified options for increasing attenuation capacity (Tool 7b, Tool 7c, Tool 7d)?

The next set of questions evaluates alternatives at ***sites where cleanup objectives must be achieved at a downgradient point of compliance***

Conclusion



Click buttons to access modules that explore key individual questions

TA^2:

Transition Assessment Teaching Assistant

- Can be accessed at the project webpage
- Assessments can used in project reporting (screenshots) or shared with team members directly through the tool
- For technical support contact:
  - Hiroko Hort (hmori@gsienv.com)
  - Dave Adamson (dtadamson@gsienv.com)