PNDEP CEM Work Shop: Tools for Showing Plume Stability/Trends

"It is far better to have an approximate answer to the right question than a precise answer to the wrong question…" — John Hauser

1. VISUAL ANALYSIS

Overview

Using industry standard data analysis tools (i.e., Excell), plot data (groundwater level, concentration) vs time. This allows for visual identification of trends over time. These types of plots are commonly referred to as time-series plots.

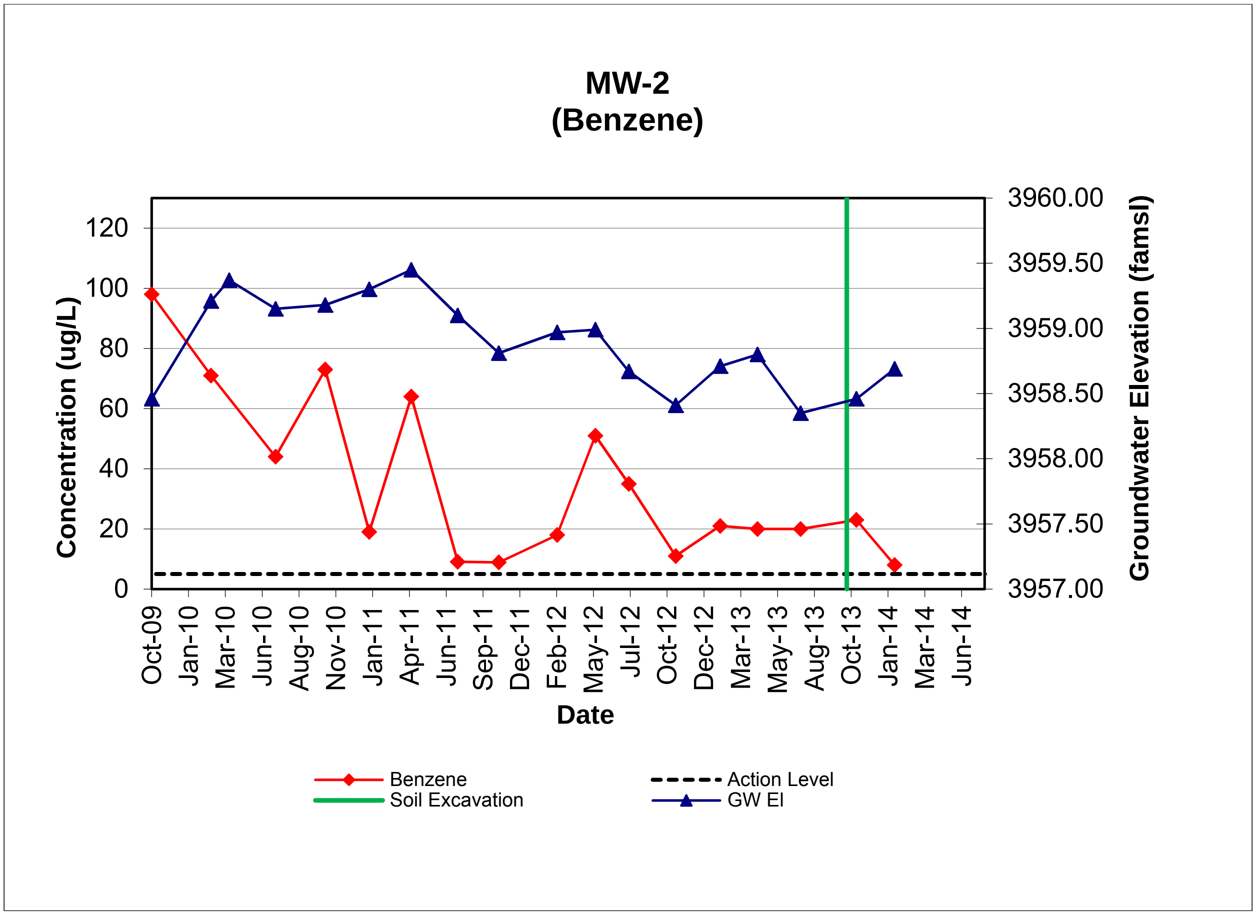
Advantages

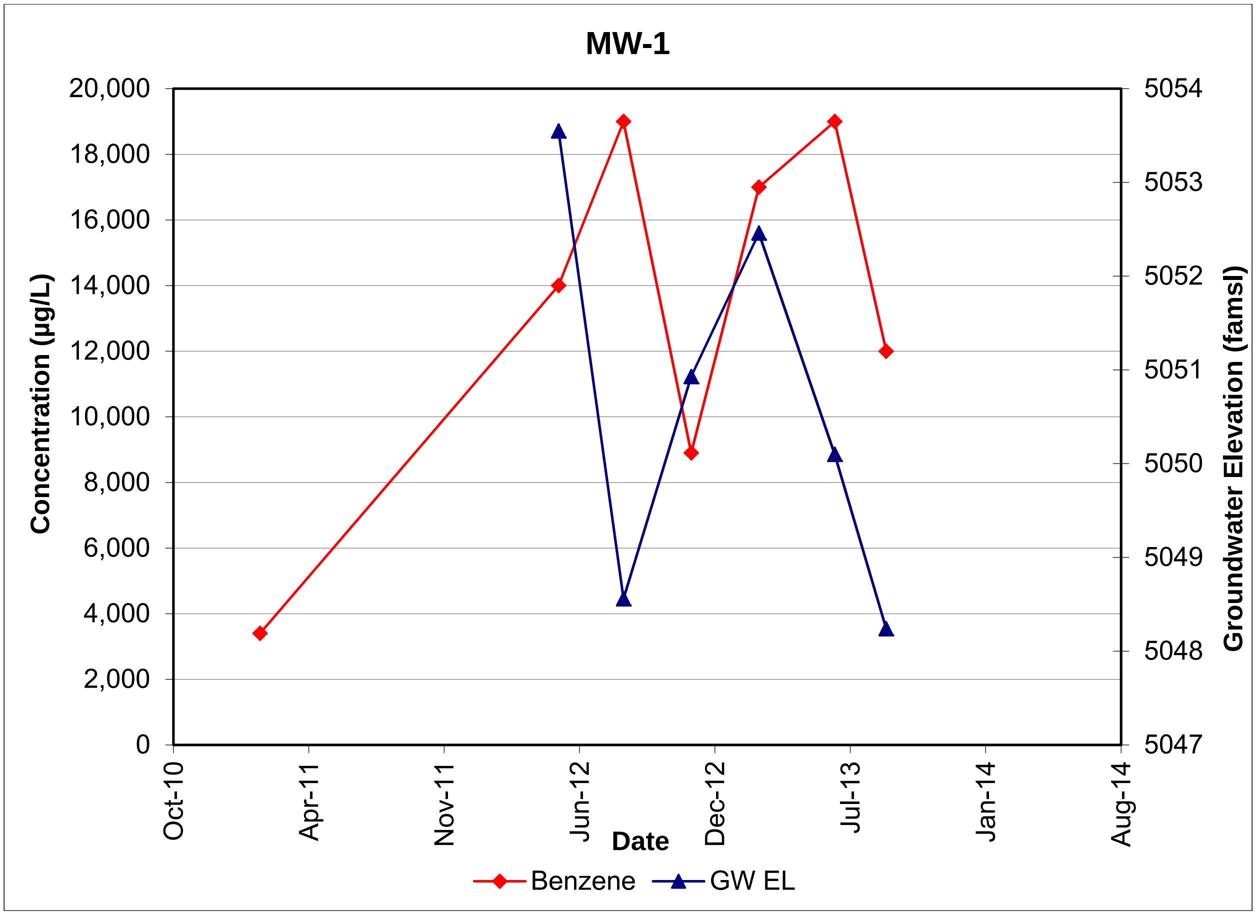
- Easily created.
- Minimal data requirements (can be as little as two data points, although more are preferred).
- Can show different components of project (VE system turned on, VE system turned off, etc.) to aid in evaluating trends.

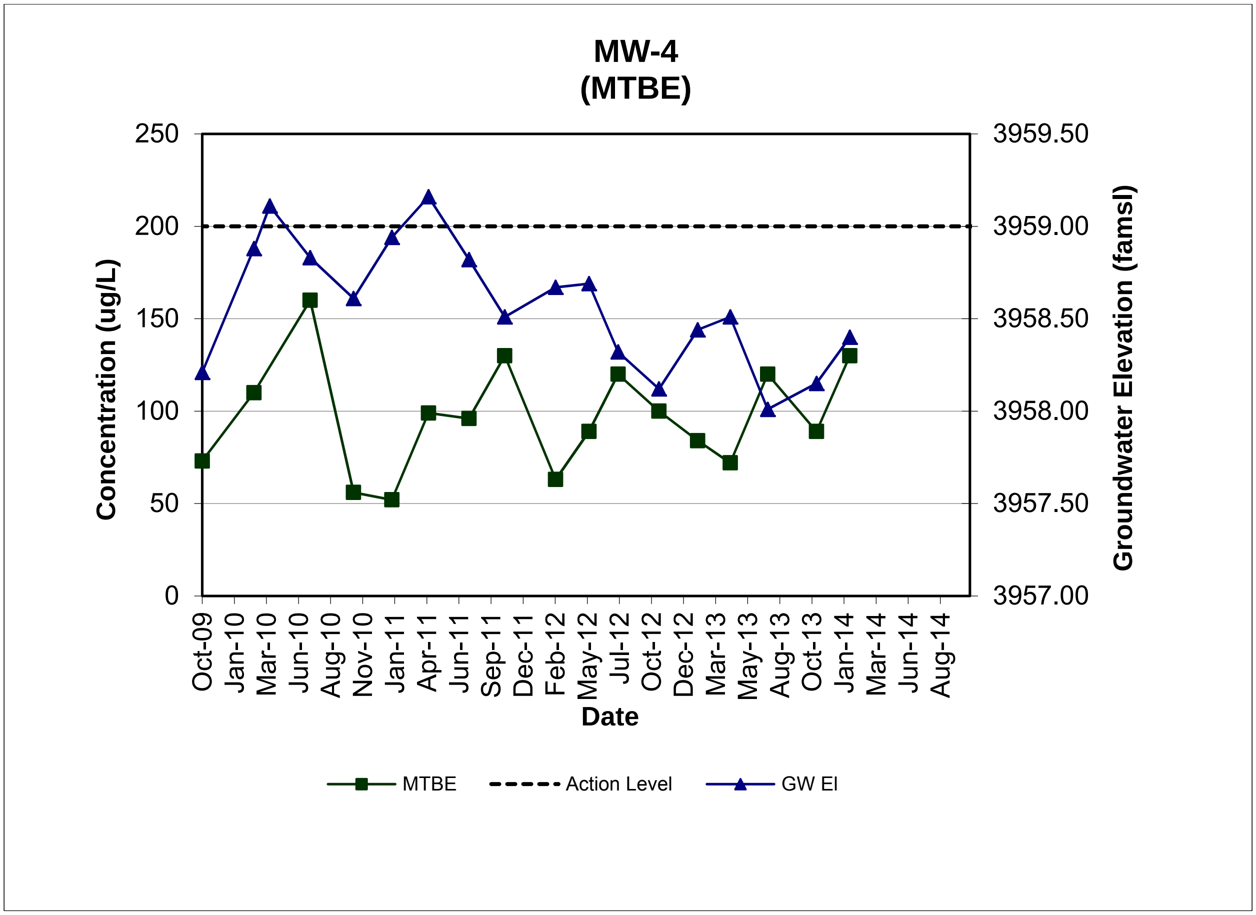
Disadvantages

- Data outliers can inadvertently influence "trend."
- Does not account for variability in seasonal groundwater fluctuations.
- Trends identified can be

Example Output


MW-2
(Benzene)
Concentration (ug/L)
Groundwater Elevation (famsl)
120
100
80
60
40
20
0
3960.00
3959.50
3959.00
3958.50
3958.00
3957.50
3957.00
Oct-09
Jan-10
Mar-10
Jun-10
Aug-10
Nov-10
Jan-11
Apr-11
Jun-11
Sep-11
Dec-11
Feb-12
May-12
Jul-12
Oct-12
Dec-12
Mar-13
May-13
Aug-13
Oct-13
Jan-14
Mar-14
Jun-14
Date
Benzene
Action Level
Soil Excavation
GW El


MW-1
Concentration (µg/L)
20,000
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
Groundwater Elevation (famsl)
5054
5053
5052
5051
5050
5049
5048
5047
Oct-10
Apr-11
Nov-11
Jun-12
Dec-12
Jul-13
Jan-14
Aug-14
Date
Benzene
GW EL



2. LINEAR REGRESSION

Overview

A parametric statistical technique used to estimate a trend via a linear relationship between multiple data points (sample analytical results). A line with a positive slope indicates an increasing trend, whereas a negative slope is indicative of a decreasing trend. Assumptions of linear regression are as follows:

1. The difference between each concentration measurement and its predicted value from the regression equation (residuals) are approximately normal in distribution.
2. Missing data and ND's are not part of data set.

The following conditions should be met prior to concluding a resulting trend:

1. The residuals (R) are approximately normal/reasonably symmetric in distribution.
2. A scatter plot of residuals vs concentrations yields a scatter cloud of generally uniform thickness.
3. A scatter plot of residuals vs time yields a scatter cloud of generally uniform thickness.
4. A minimum of eight measurements.

If the above conditions are met, the following can generally be applied with respect to trend interpretation:

- Where y=mx+b represents the trend line, and m=slope, if m is negative, the trend (slope) is decreasing.
- Conversely, if m is positive, the trend is increasing.
- A higher m value (steeper slope) indicates a more rapid rate of degradation/contamination.
- When the above items cannot be met in an approximate sense, a non-parametric trend method should be utilized (Mann-Kendall).
- A smaller R^2 value indicates a less accurate trend line (if $R^2 = 0$, then the trend line would have no linear relationship). The larger the R^2 value, the less the amount of variation/deviation in the dataset from the trend line, and the more reliable the trend line is (If $R^2=1$, the dataset is defined as linear).

Advantages

- Least squares regression is the most commonly used regression method. Calculates a best fit line for the observed data by minimizing the sum of the squares of vertical deviations from each data point to the line.
- Can be used site-wide or for individual wells, but is best suited for individual well analysis.
- Principles can be applied to site-wide plume characteristics for site wide analysis
- Relatively simple trend analysis/data requirements.

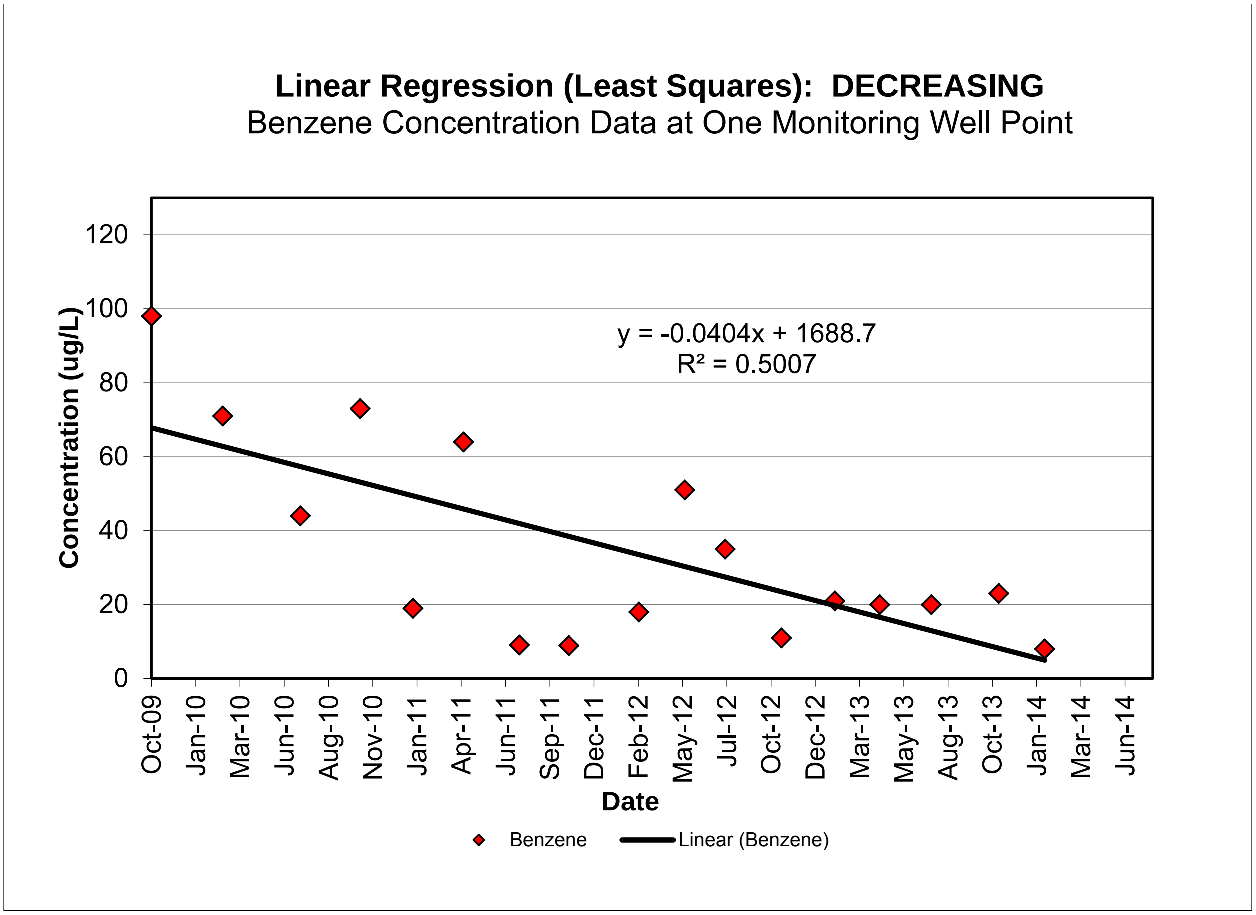
Disadvantages

- Data outliers can inadvertently influence "trend." Data input/output must be QA/QC'd prior to determining accuracy of trend (i.e., checking the residuals and/or visual).
- Extrapolation of data is not recommended in support of project decision making, yet can be useful as a general forecasting tool.
- Trends are dependent on data quality and user interpretation.
- Does not account for ND or missing data.

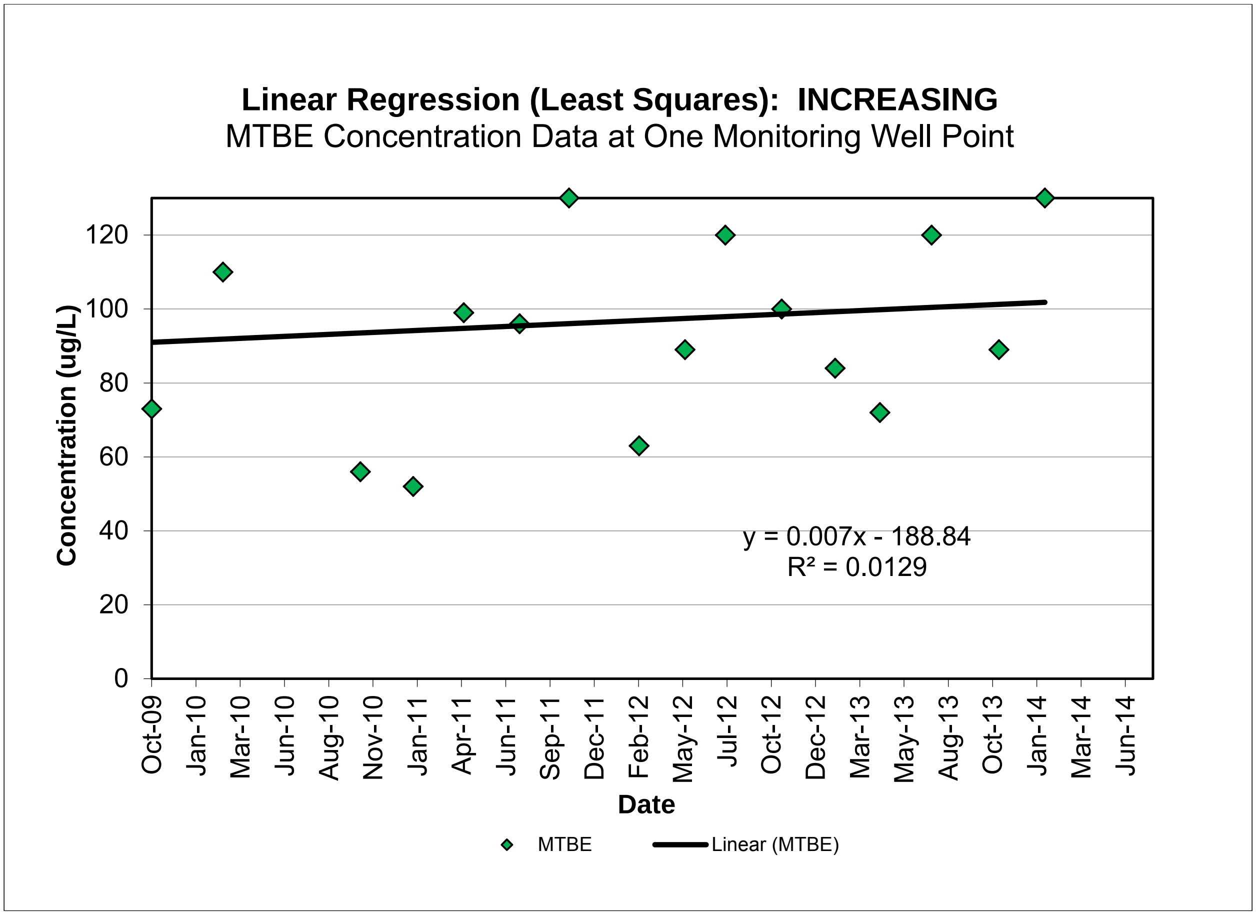
Online/Free-ware availability

Regression calculators and/or freeware are readily available online. Much of the freeware discussed in the following slides are equipped with regression analysis tools. It is also easily set up using Microsoft's Excel program.

Example Output



Linear Regression (Least Squares): DECREASING
Benzene Concentration Data at One Monitoring Well Point
y = -0.0404x + 1688.7
R² = 0.5007
Concentration (ug/L)
120
100
80
60
40
20
0
Oct-09
Jan-10
Mar-10
Jun-10
Aug-10
Nov-10
Jan-11
Apr-11
Jun-11
Sep-11
Dec-11
Feb-12
May-12
Jul-12
Oct-12
Dec-12
Mar-13
May-13
Aug-13
Oct-13
Jan-14
Mar-14
Jun-14
Date
Benzene
Linear (Benzene)



Sources

Peter J. Brockwell, Richard A. Davis , *Time Series: Theory and Methods, Second Edition*
Springer, 2009

Environmental Protection Agency, Office of Resource Conservation and Recovery, *Statistical Analysis of Groundwater Monitoring Data at RCRA Facilities – Unified Guidance*, March, 2009

http://www.stat.yale.edu/Courses/1997-98/101/linreg.htm

3. MANN-KENDALL (M-K)

Overview

M-K analysis is a non-parametric test for identifying trends in time-series data. In short, the analysis compares relative magnitudes of sample data (not the data values themselves). If an increasing trend exists, the sample taken first from any randomly selected pair of measurements should on average, have a lower concentration than the measurement collected at a later time.

The M-K statistic (S) is given by examining all possible pairs of data points (concentrations) and scoring each pair by assigning a value (identical values = 0, earlier value > later value = -1, earlier value < later value = 1). Summing the total of the assigned values gives S. A positive S suggests an upward trend, while a negative S suggests a negative trend. The larger the value of S (+/-), the stronger the level of confidence that the trend is legitimate.

Assumptions are as follows:

1. Only relative magnitudes are required (not actual concentrations) to rank the data.
2. ND should be treated as a common value lower than any detected values.
3. At least four data points must be analyzed.

Advantages

- Relatively simple data requirements.
- User friendly.
- Quantifies confidence level in trends based on data.
- Enables quick identification of trends, historic and/or recent.

Disadvantages

- Does not account for site specific characteristics such as seepage velocity or well location.
- Analyzes only a single data point (monitoring well).
- Seasonal effects are not accounted for which can incorrectly influence trend (groundwater fluctuation through “smear zone”).
- Must address ND values…they need to be the same.

Online/Free-ware availability

Mann-Kendall free-ware is available online. Two good options are:

1. GSI Mann-Kendall Toolkit
   http://www.gsi-net.com/en/software/free-software/gsi-mann-kendall-toolkit.html
2. Washington State Department of Ecology (Package A)
   http://www.ecy.wa.gov/programs/tcp/policies/pol_main.html

Mann-Kendall analysis tools are also provided in the freeware packages discussed in the following slides.

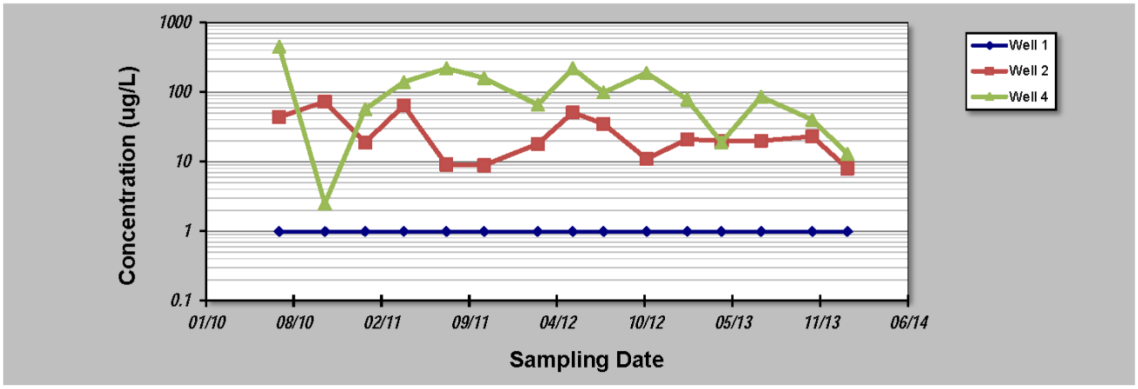
Example Output

1. **(GSI)**

GSI MANN-KENDALL TOOLKIT
for Constituent Trend Analysis

Evaluation Date:	16-Jun-14	Job ID:	9999
Facility Name:	ABC Corporation	Constituent:	Benzene
Conducted By:	Jerry Garcia	Concentration Units:	ug/L

Sampling Point ID:		Well 1	Well 2	Well 4				
Sampling Event	Sampling Date	BENZENE CONCENTRATION (ug/L)						
1	2-Apr-10							
2	8-Jul-10	0.99	44	450				
3	20-Oct-10	0.99	73	2.5				
4	20-Jan-11	0.99	19	57				
5	18-Apr-11	0.99	64	140				
6	24-Jul-11	0.99	9.1	220				
7	18-Oct-11	0.99	8.9	160				
8	17-Feb-12	0.99	18	66				
9	7-May-12	0.99	51	220				
10	16-Jul-12	0.99	35	99				
11	22-Oct-12	0.99	11	190				
12	23-Jan-13	0.99	21	78				
13	11-Apr-13	0.99	20	19				
14	10-Jul-13	0.99	20	86				
15	4-Nov-13	0.99	23	40				
16	23-Jan-14	0.99	8.0	13				
17								
18								
19								
20								
Coefficient of Variation:		0.00	0.73	0.94				
Mann-Kendall Statistic (S):		0	-26	-30				
Confidence Factor:		48.0%	89.0%	92.3%				
Concentration Trend:		Stable	Stable	Prob. Decreasing				



Notes:

1. At least four independent sampling events per well are required for calculating the trend. *Methodology is valid for 4 to 40 samples.*
2. Confidence in Trend = Confidence (in percent) that constituent concentration is increasing (S>0) or decreasing (S<0): >95% = Increasing or Decreasing; ≥ 90% = Probably Increasing or Probably Decreasing; < 90% and S>0 = No Trend; < 90%, S≤0, and COV ≥ 1 = No Trend; < 90% and COV < 1 = Stable.
3. Methodology based on "MAROS: A Decision Support System for Optimizing Monitoring Plans", J.J. Aziz, M. Ling, H.S. Rifai, C.J. Newell, and J.R. Gonzales, *Ground Water*, 41(3):355-367, 2003.

2. (WSDE)

Module1: Mann-Kendall Trend Test for Plume Stability (Non-parametric Statistical Test)

Site Name:	*ABC Corporation*
Site Address:	*Reno, NV*
Additional Description:	

Well (Sampling) Location?	**Well 2**
Level of Confidence (Decision Criteria)?	**85%**

Monitoring Well Information: Contaminant Concentration at a well: Quarterly sampling recommended.

Clear all dates

Sampling Event	Date Sampled	Hazardous Substances (unit is ug/L) Benzene	MTBE				
#1	2-Apr-10						
#2	8-Jul-10	44	110				
#3	20-Oct-10	73	80				
#4	20-Jan-11	19	18				
#5	18-Apr-11	64	11				
#6	24-Jul-11	9.10	5				
#7	18-Oct-11	8.90	5				
#8	17-Feb-12	18	3				
#9	7-May-12	51	3				
#10	16-Jul-12	35	2				
#11	22-Oct-12	11	2				
#12	23-Jan-13	21	1				
#13	11-Apr-13	20	2				
#14	10-Jul-13	20	2				
#15	4-Nov-13	23	2				
#16	23-Jan-14	8.0	1				

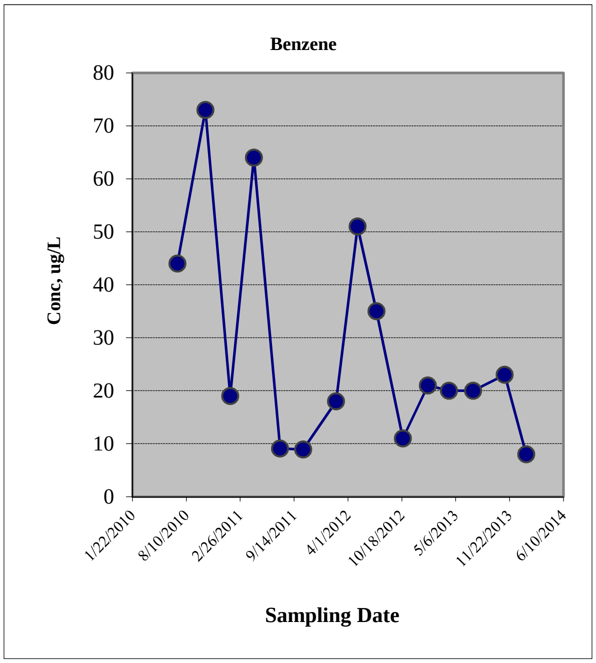
Mann-Kendall Non-parametric Statistical Test Results

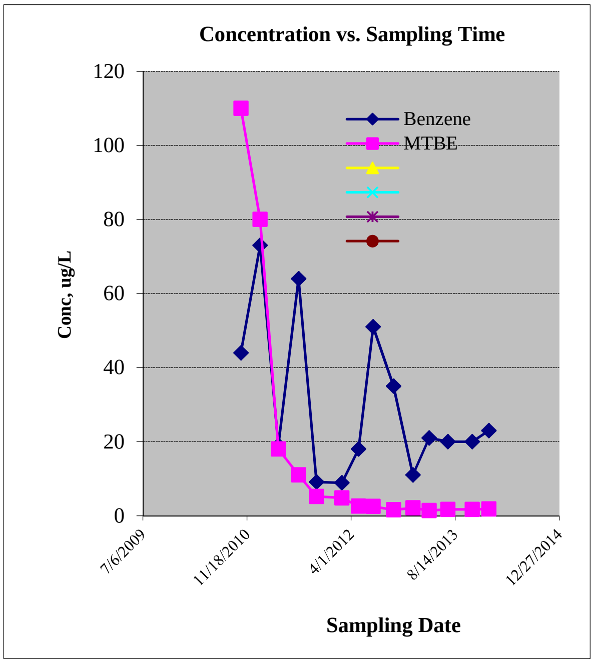
Hazardous Substance?	**Benzene**	**MTBE**				
Confidence Level Calculated?	88.00%	100.00%	NA	NA	NA	
Plume Stability?	Shrinking	Shrinking	NA	NA	NA	
Coefficient of Variation?			n<4	n<4	n<4	
Mann-Kendall Statistic "S" value?	-26	-86	0	0	0	
Number of Sampling Rounds?	15	15	0	0	0	
Average Concentration?	28.33	16.36	NA	NA	NA	
Standard Deviation?	20.61	32.75	NA	NA	NA	
Coefficient of Variation?	0.73	2.00	NA	NA	NA	
Blank if No Errors found			n<4	n<4	n<4	

Temporal Trend: Plot of Concentration vs. Sampling Time

Hazardous substance? **Benzene**

Plume Stability? **Shrinking**





Sources

Environmental Protection Agency, Office of Resource Conservation and Recovery, *Statistical Analysis of Groundwater Monitoring Data at RCRA Facilities – Unified Guidance*, March, 2009

GSI Environmental, Inc., *GSI Mann-Kendall Toolkit for Constituent Trend Analysis, User's Manual, Version 1.0*, November, 2012

Washington State Department of Ecology, *User's Manual: Natural Attenuation Analysis Tool Package for Petroleum-Contaminated Ground Water*, July, 2005

4. WASHINGTON STATE DEPARTMENT OF ECOLOGY: NATURAL ATTENUATION ANALYSIS TOOL PACKAGE FOR PETROLEUM-CONTAMINATED GROUND WATER

Overview

Comprehensive site evaluation tool based on statistical methods applied to site-specific data that accounts for historical and current data as well as hydrogeologic factors (e.g., wells, seepage velocity), and potential receptors. Analyzes individual wells, plume with respect to temporal/spatial indicators and stability. Using statistical trend analysis, helps identify temporal trends, plume characteristics (shrinking/expanding), time until target concentrations are met, influence of groundwater, evaluation of geochemical indicators, and graphical presentation of historical groundwater data. The program is divided into two packages, A and B.

Package A (Modules 1, 2, and 3) analysis tool will conduct the following:

- Non-parametric statistical tests for plume stability at each well.
  - Mann-Kendall test (previously discussed)
  - Mann-Whitney U-test
- Graphical presentation of historical ground water data.
  - Plot of temporal ground water analytical and elevation data vs. time to assess the plume status and the impact of ground water elevation fluctuation on contaminant concentrations at each well
  - Plot of spatial ground water analytical data vs. distance (for multiple wells) to assess the overall plume status
- Evaluation of geochemical indicators.
  - Estimate of expressed assimilative capacity at multiple wells
  - Simultaneous plot of concentrations of contaminant and geochemical indicators vs. distance (at multiple wells) to demonstrate biodegradation clearly
- Temporal trend (regression) analysis at each well.
  - Estimate of an average and a range of (kpoint) point decay rate (1st-order) constant for both the best-fit and a given one-tailed confidence level at each well
  - Temporal prediction at each well location under a given confidence level
  - Estimate of an average and a range (under a given confidence level) of restoration time to reach the cleanup goal at each well
  - Calculation of the correlation coefficient and confidence level (with the Pearson's correlation coefficient) of log-linear regression analysis (for a plot of concentration vs. time at each well)

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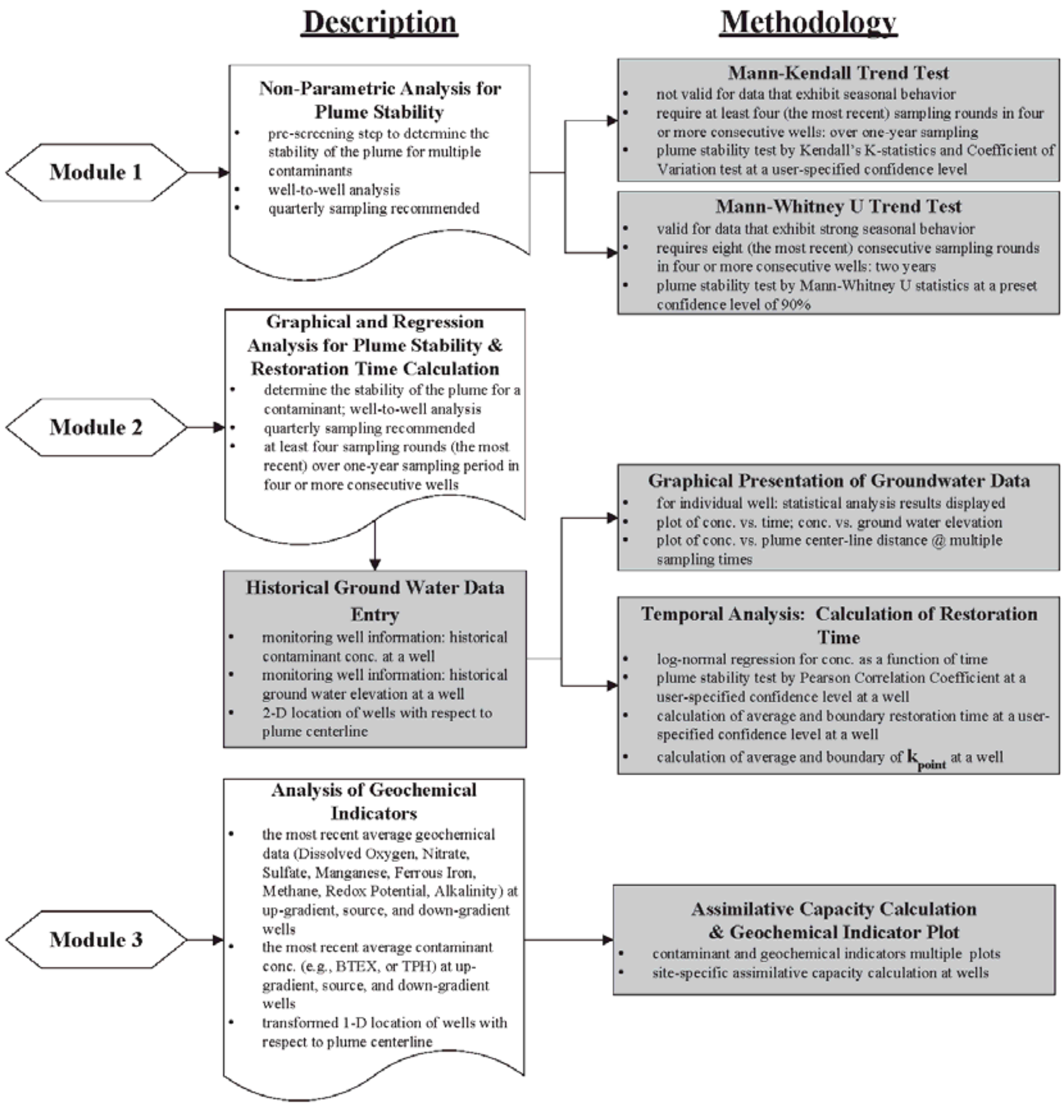
Figure A.1. Calculation Module for Natural Attenuation Analysis Package A

Note: Modules are not linked each other.



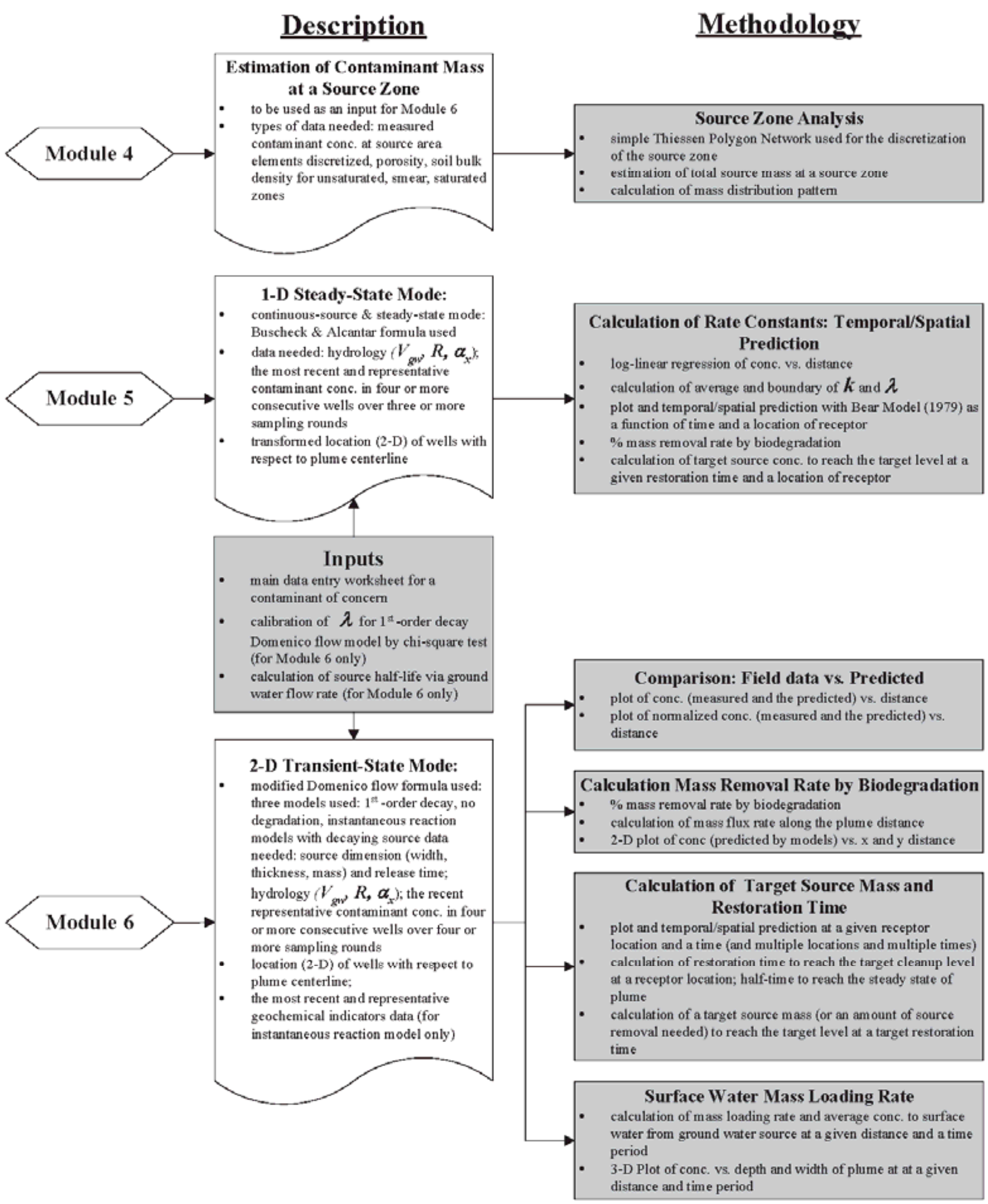
7/2005: Version 1.0; User's Manual: Natural Attenuation Analysis Tool Package for Petroleum-Contaminated Ground Water

Package B (Modules 4, 5, and 6) analysis tool will conduct the following calculations:

- Estimate of source mass from sampling data: for unsaturated, smear, and dissolved zones.
- Under 1-D (transformed from 2-D): steady state/continuous source assumption for only stable.
  - plume (with Buscheck and Alcantar model: see footnote on page 33 of this User's Manual)
  - Plot of the concentration vs. distance
  - Estimate of an average and a range of (λ) biodegradation rate constant
  - Estimate of an average and a range of (k) bulk attenuation rate (1st-order) constant under steady state (stable plume)
  - Estimate of a percent mass removal rate by biodegradation alone
  - Temporal and spatial prediction as a function of time and well location
  - Estimate of a target source concentration in order to reach a target level at a receptor location under given restoration time
- Under 2-D; transient state (with modified Domenico model) for shrinking and stable (or any type) plumes:
  - Estimate of a biodegradation rate constant (λ) by calibration via chi-square statistics for best-fit to the normalized concentration of consecutive multiple wells by 1st-order decay model
  - Estimate of a percent mass removal rate by biodegradation alone with 1st-order decay model and instantaneous reaction model (via the calculation of mass flux)
  - Estimate of a temporal/spatial prediction at a receptor location by 1st-order decay model and instantaneous reaction model
  - Estimate of a plume stabilization time (half time to reach the steady state) at a receptor location
  - Estimate of a restoration time to reach a target level at a receptor location by 1st-order decay model and instantaneous reaction model
  - Estimate of a target source mass amount (amount of mass that should be removed from the current source zone) in order to reach a target level at a receptor location under a given restoration time by 1st-order decay model and instantaneous reaction model
  - Estimate of a contaminant mass loading rate (as a function of x-distance and time) to the adjacent surface water body by 1st-order decay model

Figure A.2. Calculation Module for Natural Attenuation Analysis
Package B

Note: Modules 5 and 6 share the same input worksheet.



7/2005: Version 1.0; User's Manual: Natural Attenuation Analysis Tool Package for Petroleum-Contaminated Ground Water

Advantages

- User friendly
- Quantifies confidence level in trends based on data
- Enables quick identification of trends, historic and/or recent
- Comprehensive site analysis
- Incorporates hydrogeologic site data and potential receptors in analysis
- Geochemical/Biodegradation assessment/modeling capability
- 2-D Modeling capability

Disadvantages

- Complex data requirements (depending on module)
- Time intensive (depending on module)
- Does not use real world coordinates in 2-D modeling components
- Does not provide site optimization recommendations

Online/Freeware availability

Free-ware is available online:

http://www.ecy.wa.gov/programs/tcp/policies/pol_main.html

Example Output

Module 5: Calculation of Rate Constants: Temporal/Spatial Prediction
by 1-D (transformed) Steady State/Continuous Source Assumption

Site Name: Dummy XYZ site
Site Address: 1234, Olympia, WA 98501

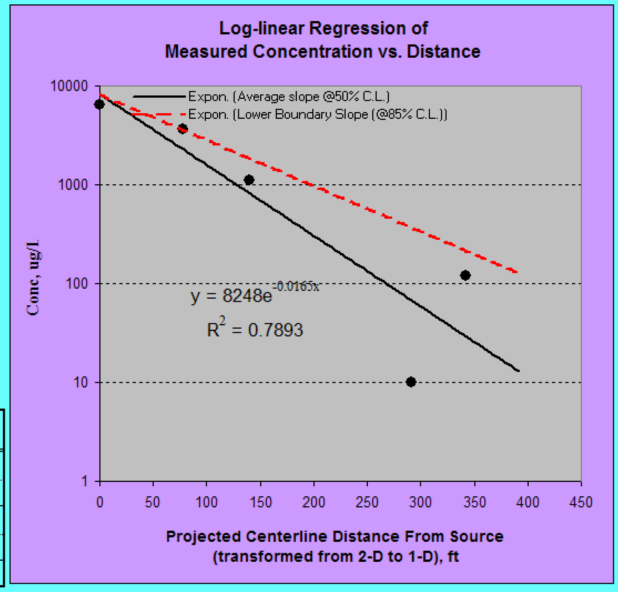
Main | Print View | End

1. Input data used for this module

Hazardous Substance:	Benzene
Seepage Velocity (Average), v_{gw}, ft/yr	113.8
Longitudinal Dispersivity, α_x, ft	13.45
Retardation Factor, R	2.05
Current Continuous Source Concentration, ug/L	6500

2. Enter Decision Criteria

Level of Confidence (Decision Criteria used) 85%



3. 1-D Steady-state analytical result for estimating contaminant degradation rates: Buscheck and Alcantar (1995)

Log-Linear Regression Results:

Average Slope	ft^{-1}	1.65E-02
Lower Boundary Slope (@85% C.L.)	ft^{-1}	1.06E-02
Intercept	ug/L	8248.0
Coefficient of Determination, r^2		0.789
Correlation Coefficient, r		-0.888
Number of Data Point, n		5
t-statistics		3.35
Level of Significance calculated for the slope		95.6%

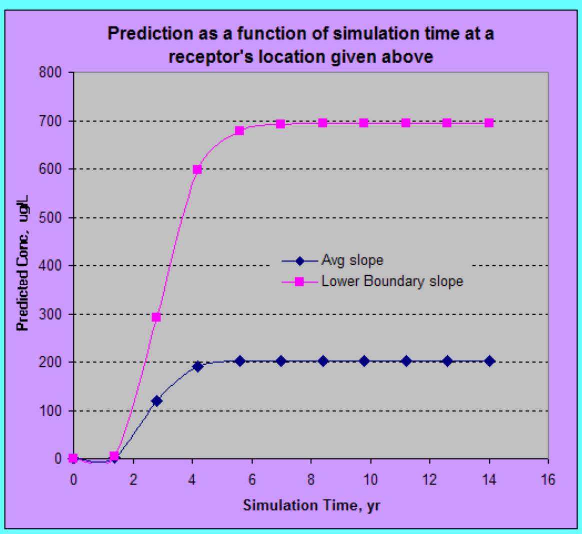
Rates Calculated:

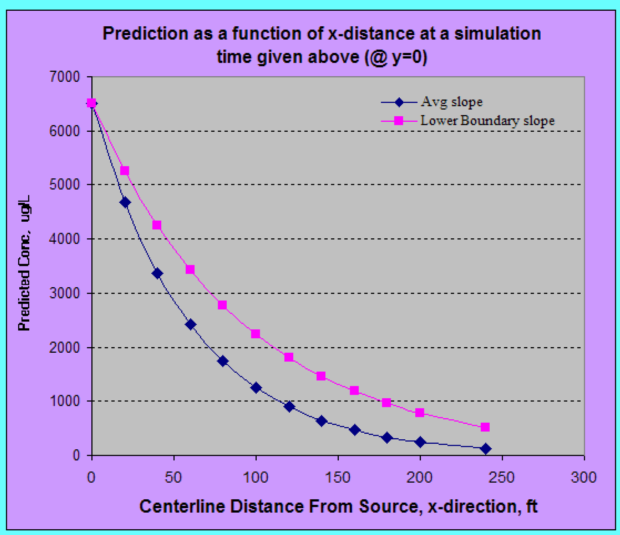
	unit	@ Avg Slope	@Lower Boundary Slope (85% C.L.)
Bulk Attenuation Rate Constant, k	yr^{-1}	1.88	1.21
Half Life of k	yr	0.37	0.57
Biodegradation Rate Constant, λ	yr^{-1}	1.12	0.67
Half-Life of λ	yr	0.62	1.03
Ratio of λ/k	%	59%	56%

4. 1-D Temporal/Spatial Prediction with Bear Equation (1979): Transient Plug-flow model with a longitudinal dispersion

Temporal/Spatial Prediction		Predicted Concentration, ug/L		Calculation of Target Source Concentration	
Location of a Receptor		@ Avg Slope	@Lower Boundary Slope (85% C.L.)	Target Groundwater Level at a receptor, ug/L @Avg slope	10
x-direction, ft	200	202.8	694.2		
y-direction, ft	15				
Simulation Time, yr	14				

Calculate Target Source concentration





Module 6: Calculation of Mass Removal Rate by Biodegradation

Main | Print View | End

Site Name: *Dummy XYZ site*
Site Address: *1234, Olympia, WA 98501*
Hazardous Substance: *Benzene*

Transverse Distance, y-direction (ft) — **Ground water Concentrations in Plume (ug/L at z=0)** — **Distance from Source, x-direction (ft)**

↓	0.0	55.0	110.0	165.0	220.0	275.0	330.0	385.0	440.0	495.0	550.0
100.0	36.3	39.6	48.8	37.2	23.9	14.1	8.0	4.3	2.3	1.2	0.6
50.0	4669.0	1681.7	789.4	372.3	176.8	84.3	40.4	19.4	9.3	4.5	2.1
0.0	4669.0	2272.0	1103.6	533.2	256.3	122.8	58.7	28.1	13.4	6.4	3.0
-50.0	4669.0	1681.7	789.4	372.3	176.8	84.3	40.4	19.4	9.3	4.5	2.1
-100.0	36.3	39.6	48.8	37.2	23.9	14.1	8.0	4.3	2.3	1.2	0.6
MASS FLUX (mg/day)	3.00E+4	7.56E+3	3.68E+3	1.79E+3	8.71E+2	4.23E+2	2.06E+2	9.99E+1	4.85E+1	2.35E+1	1.14E+1

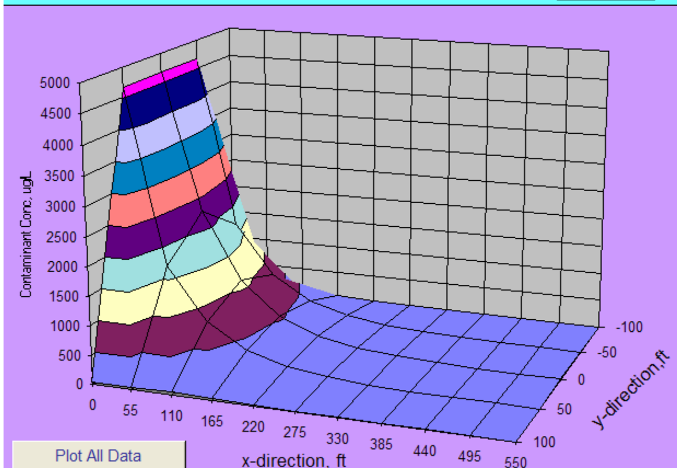
Target Ground water Conc, ug/L : 5.0
Modeled Area Length (L), ft : 550.0
Modeled Area Width (W), ft : 200.0
Enter Simulation Time, yr: 12

L W

****Displayed Model is 1st-order Decay.***

Choose a Model below to Display:

No Degradation Model
1st Order Decay Model
Instantaneous Reaction Model



Plot All Data
Plot Data > Target

Plume and Source Masses (Order-of-Magnitude Accuracy)

Plume Mass if No Biodegradation:	96.2	*kg*
- Actual Plume Mass:	5.3	*kg*
= Plume Mass Removed by Biodegradation:	**90.9**	*kg* (94 %)

Change in Electron Acceptor/Byproduct Mass, kg:

Oxygen	Nitrate	Ferrous Iron	Sulfate	Methane	Manganese
na	na	na	na	na	na

Contam. Mass in Source (t=0 years):	200.0	*kg*
Contam. Mass in Source Now (t=12 years):	103.8	*kg*
Current Volume of Groundwater in Plume:	10.4	*ac-ft*
Flowrate of Water Through Source Zone:	1.960	*ac-ft/yr*

Module 5: Calculation of Rate Constants: Temporal/Spatial Prediction

by 1-D (transformed) Steady State/Continuous Source Assumption

Site Name: Dummy XYZ site

Site Address: 1234, Olympia, WA 98501

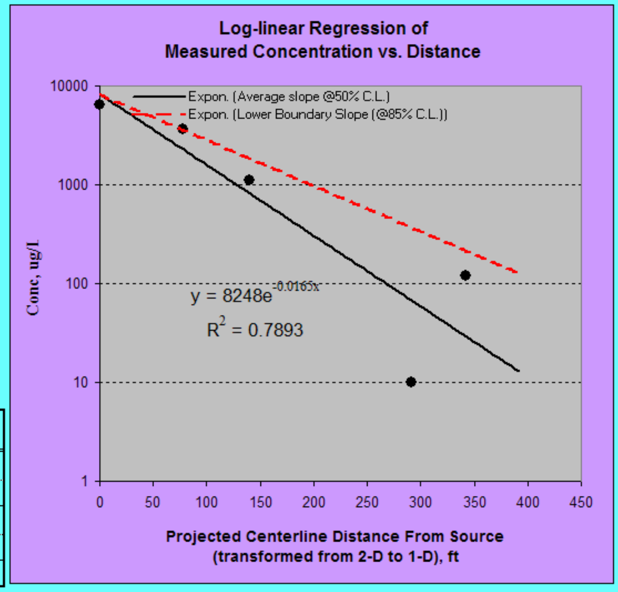
1. Input data used for this module

Main | Print View | End

Hazardous Substance:	Benzene
Seepage Velocity (Average), v_{gw}, ft/yr	113.8
Longitudinal Dispersivity, α_x, ft	13.45
Retardation Factor, R	2.05
Current Continuous Source Concentration, ug/L	6500

2. Enter Decision Criteria

Level of Confidence (Decision Criteria used): 85%



3. 1-D Steady-state analytical result for estimating contaminant degradation rates: Buscheck and Alcantar (1995)

Log-Linear Regression Results:

Average Slope	ft^{-1}	1.65E-02
Lower Boundary Slope (@85% C.L.)	ft^{-1}	1.06E-02
Intercept	ug/L	8248.0
Coefficient of Determination, r^2		0.789
Correlation Coefficient, r		-0.888
Number of Data Point, n		5
t-statistics		3.35
Level of Significance calculated for the slope		95.6%

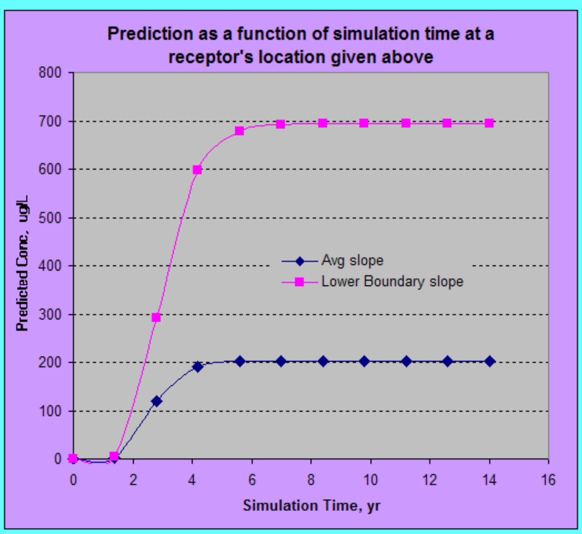
Rates Calculated:

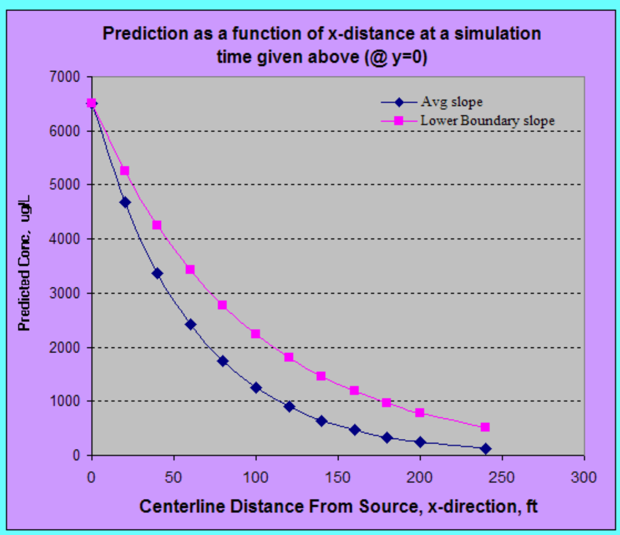
	unit	@ Avg Slope	@Lower Boundary Slope (85% C.L.)
Bulk Attenuation Rate Constant, k	yr^{-1}	1.88	1.21
Half Life of k	yr	0.37	0.57
Biodegradation Rate Constant, λ	yr^{-1}	1.12	0.67
Half-Life of λ	yr	0.62	1.03
Ratio of λ/k	%	59%	56%

4. 1-D Temporal/Spatial Prediction with Bear Equation (1979): Transient Plug-flow model with a longitudinal dispersion

Temporal/Spatial Prediction		Predicted Concentration, ug/L		Calculation of Target Source Concentration	
Location of a Receptor		@ Avg Slope	@Lower Boundary Slope (85% C.L.)	Target Groundwater Level at a receptor, ug/L @Avg slope	10
x-direction, ft	200	202.8	694.2		
y-direction, ft	15				
Simulation Time, yr	14				

Calculate Target Source concentration





Module 6: Calculation of Target Source Mass and Restoration

Site Name: Dummy XYZ site
Site Address: 1234, Olympia, WA 98501

1. Input data used for this Module

Hazardous Substance:	Benzene
Current Source Mass, kg	100
Source Release time, yr	3
Seepage Velocity, V_{gw}, ft/yr	113.81
Longitudinal Dispersivity, α_x, ft	13.45
Transverse Dispersivity, α_y, ft	1.35
Retardation Factor, R	2.054
Biodegradation Rate Constant, λ, yr^{-1}	0.627

Main | Print View | End

2. Enter Decision Criteria

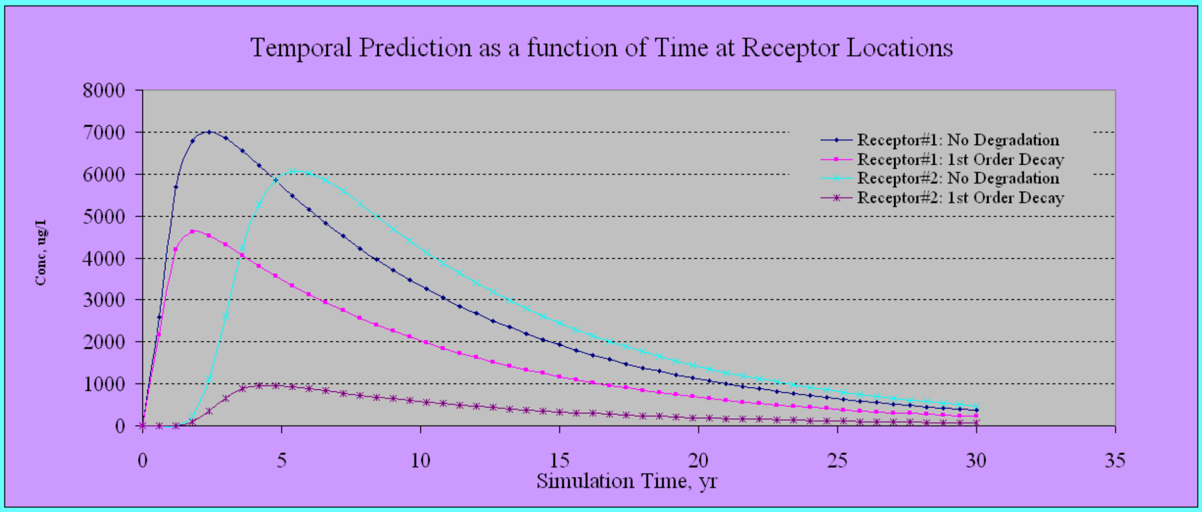
Simulation Start time, yr	0.001
Simulation End time, yr	30
Target Level at receptors, ug/L	100

Calculate Restoration Time | Calculate Target Source Mass

3. Temporal Prediction at a Receptor (at z=0)

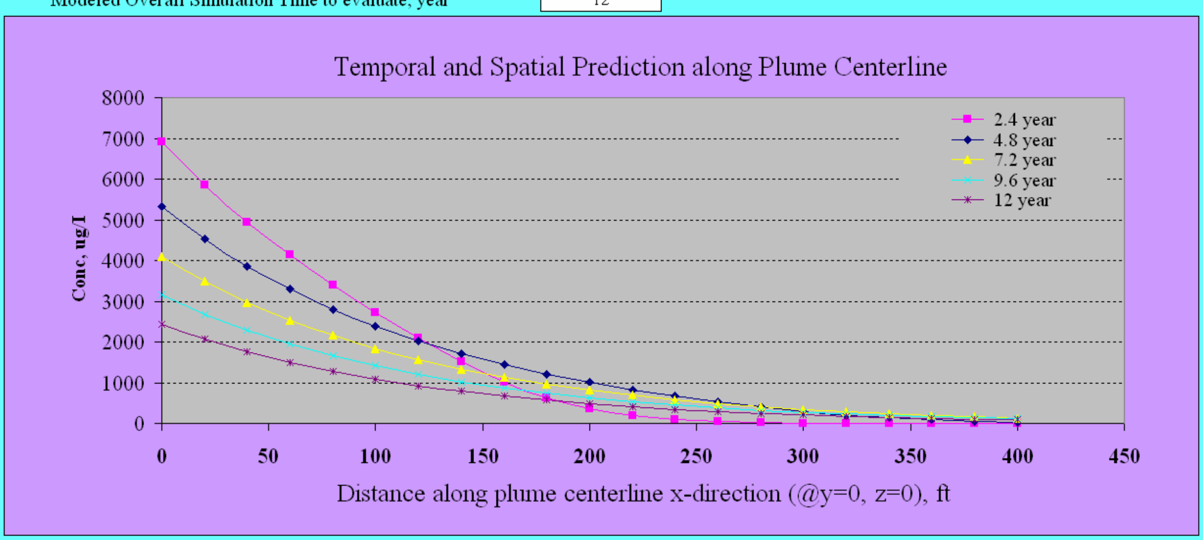
Location of Receptors		Type of Model Used	Half-Time to reach the steady-state, yr	Predicted Concentration, ug/L @Simulation Time, yr		Time to reach the Target level without source Removal, yr	Target Source information to reach target level (@100ug/L) and at Simulation End Time (@30yr)	
				15.0	30.0		Target mass	Removal needed
Receptor #1								
x-direction, ft	50	No degradation	1.2	1925.2	373.2	42.0	70.7	29.3
y-direction, ft	10	1st Order Decay	1.0	1169.4	226.7	37.5	79.5	20.5
		Inst. Reaction	NA	0.0	0.0	NA	NA	NA
Receptor #2								
x-direction, ft	200	No degradation	3.9	2449.2	474.8	44.2	65.0	35.0
y-direction, ft	20	1st Order Decay	3.1	333.4	64.6	26.0	NA	NA
		Inst. Reaction	NA	0.0	0.0	NA	NA	NA

Location of Receptor #1 is 50ft x-direction & 10ft y-direction; Location of Receptor #2 is 200ft x-direction & 20ft y-direction



4. Temporal/Spatial Prediction along Plume Centerline (@ y & z = 0) with 1st-order Decay Model

Modeled Overall Plume Centerline Distance to evaluate, ft	400
Modeled Overall Simulation Time to evaluate, year	12



Sources

Washington State Department of Ecology, User's Manual: Natural Attenuation Analysis Tool Package for Petroleum-Contaminated Ground Water, July, 2005

5. MONITORING AND REMEDIATION OPTIMIZATION SYSTEM (MAROS)

Overview

Developed by GSI for the Air Force Center for Environmental Excellence (AFCEE), in accordance with the AFCEE Long Term Monitoring Optimization Guide.

Comprehensive site evaluation tool based on statistical methods applied to site-specific data that accounts for historical and current data as well as hydrogeologic factors (e.g., wells, seepage velocity), and potential receptors. Analyzes individual wells, plume with respect to spatial indicators and stability, and site optimization. Using database trend analysis, helps identify constituents of concern (CoC), significance of temporal trends, redundancy of data points (monitoring wells), adequate sampling frequency, and data gaps.

MAROS will conduct the following calculations:

- Summary Statistics for Individual Wells
  - Calculates the detection frequency, date range of data, maximum concentration, range of concentrations, and date of maximum result for up to 5 COCs for all wells
  - Summary Statistics using Kaplan-Meier Method: Mean, median standard deviation and percentiles for individual well data are calculated using the Kaplan-Meier method to account for datasets with a higher percentage of non-detect (ND) data
  - Outliers for Individual Wells: uses Dixon's method to identify high or low outliers in a dataset
  - Data Distribution: MAROS Uses the Shapiro-Wilk method to identify individual well datasets that do not have Normal or Log-normal data distributions

- Trend Analysis for Individual Wells
  - Mann Kendall
  - Linear Regression

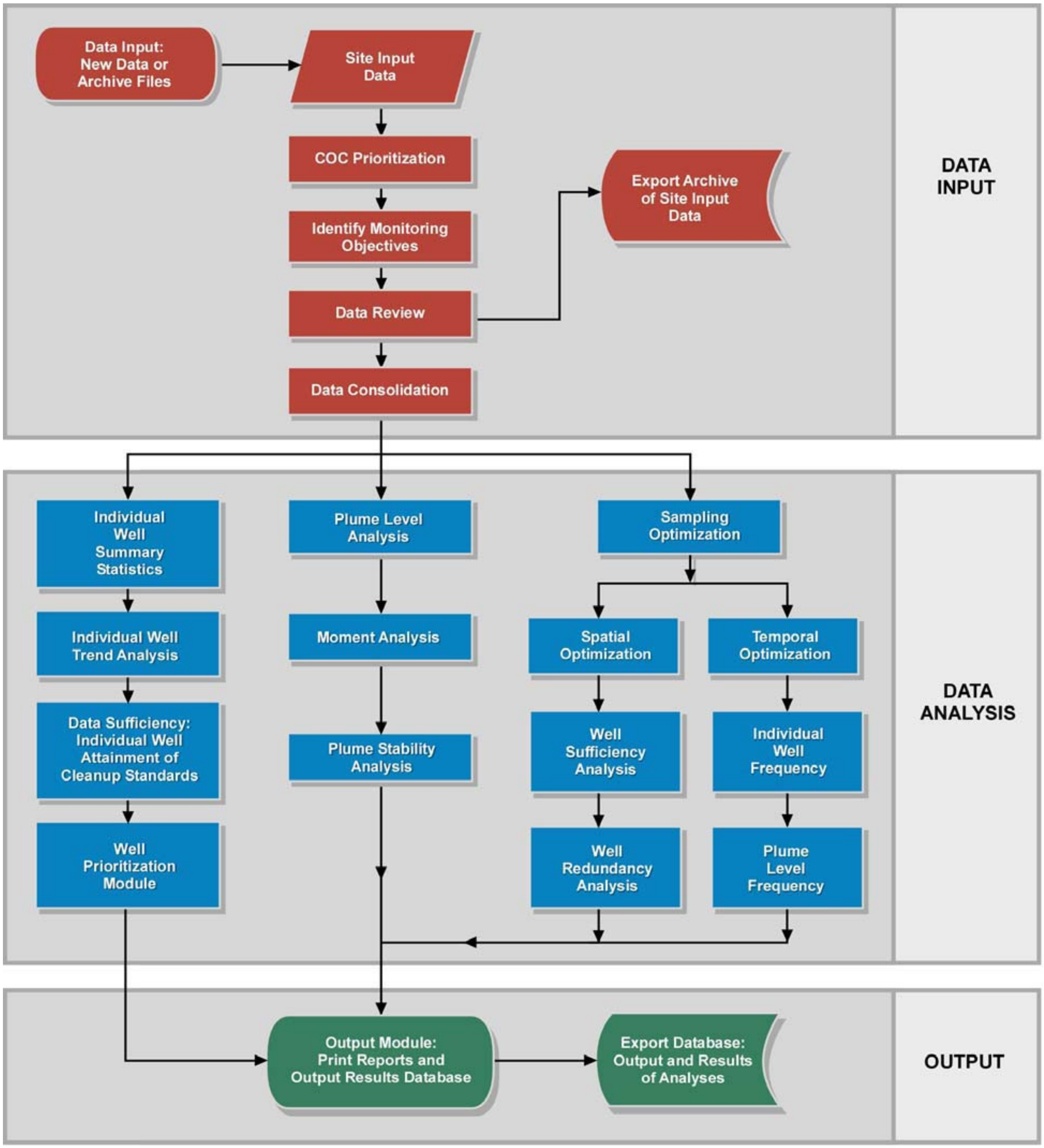
- Data Sufficiency for Individual Wells
  - Cleanup Status: Sequential T-Test and Student's T-Test are used to determine if concentrations are statistically below the cleanup goal
  - Power Analysis: Estimates how many more samples may be required to demonstrate location is statistically below the cleanup level
  - Prioritizes well importance using a qualitative method based on individual well statistics and well monitoring objectives

- Moment Analysis

- Uses the full dataset to estimate moments and the Mann-Kendall trends of each metric.
- Total dissolved mass in the plume
- Center of mass: Coordinates of the center of mass
- Spread of mass about the center of the plume

- Evaluation of aggregate concentration trends for source area, tail and User-defined well groups

- Spatial/Temporal Optimization
    - Provides several qualitative and quantitative metrics for identifying redundant monitoring locations and for identifying areas of high uncertainty that may require more monitoring locations
    - Provides several qualitative and quantitative metrics for assessing appropriate sampling frequency for well networks


Data Input: New Data or Archive Files
Site Input Data
COC Prioritization
Identify Monitoring Objectives
Data Review
Data Consolidation
Export Archive of Site Input Data
DATA INPUT
Individual Well Summary Statistics
Individual Well Trend Analysis
Data Sufficiency: Individual Well Attainment of Cleanup Standards
Well Prioritization Module
Plume Level Analysis
Moment Analysis
Plume Stability Analysis
Sampling Optimization
Spatial Optimization
Temporal Optimization
Well Sufficiency Analysis
Individual Well Frequency
Well Redundancy Analysis
Plume Level Frequency
DATA ANALYSIS
Output Module: Print Reports and Output Results Database
Export Database: Output and Results of Analyses
OUTPUT

Advantages

- Comprehensive site analysis
- Incorporates hydrogeologic site data and potential receptors in analysis
- Recommendations for sampling optimization (potential for cost reduction)
- Recommendations for potential well locations (data gaps)
- EPA accepted data analysis tool for project decision support
- Uses real world coordinates in 2-D modeling components

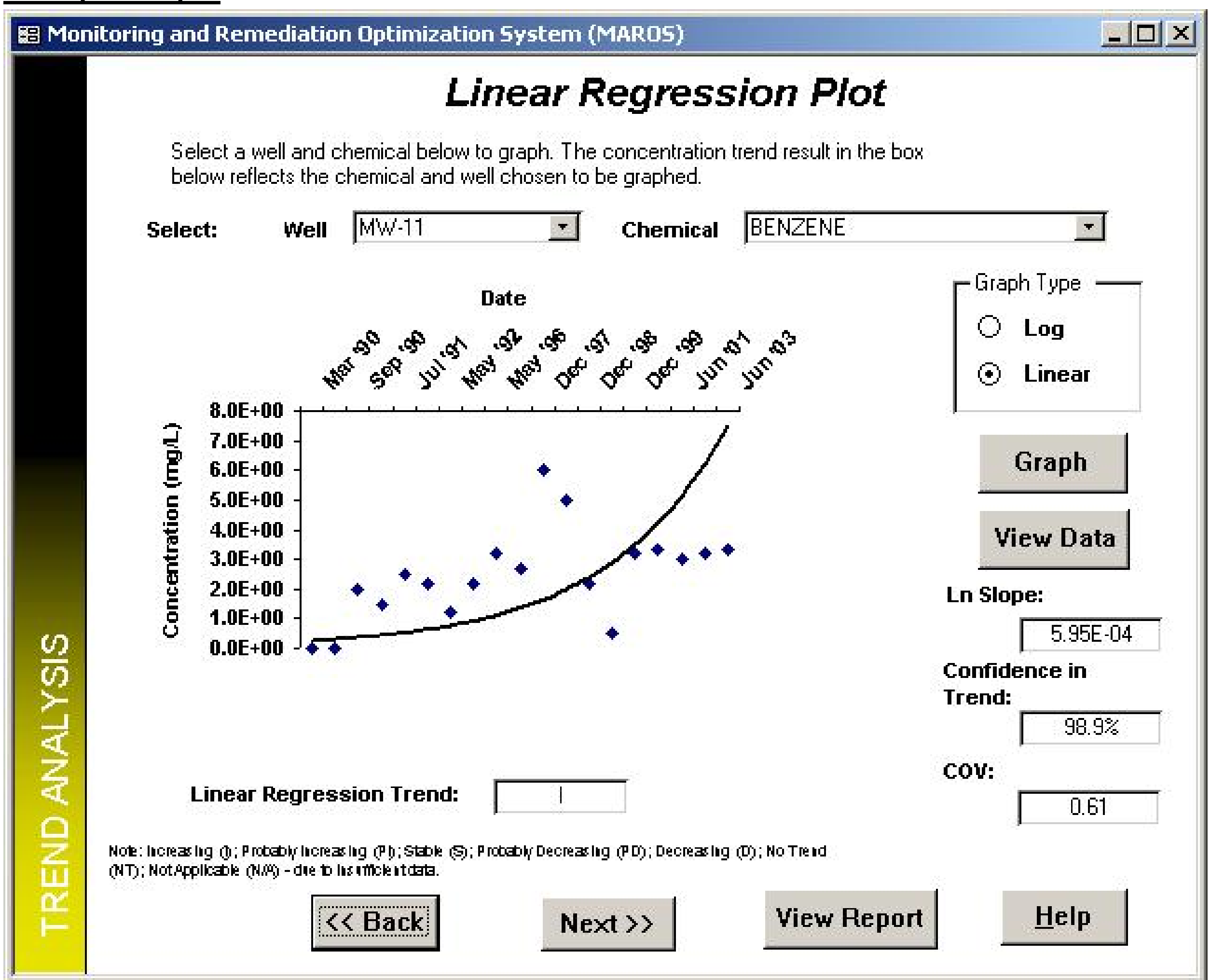
Disadvantages

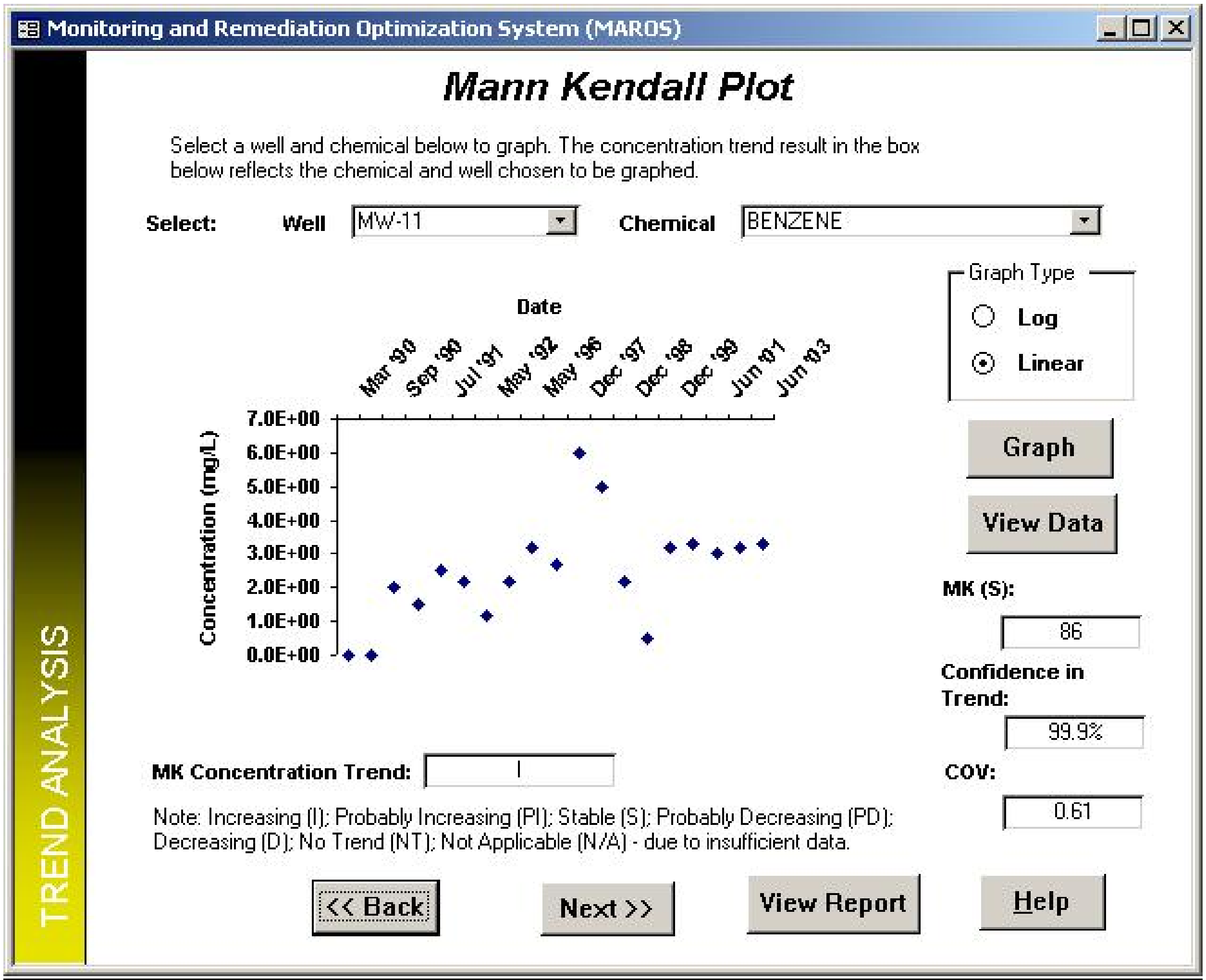
- Complex data requirements
- Time intensive
- Does not analyze geochemical/biodegradation components (work-around required)

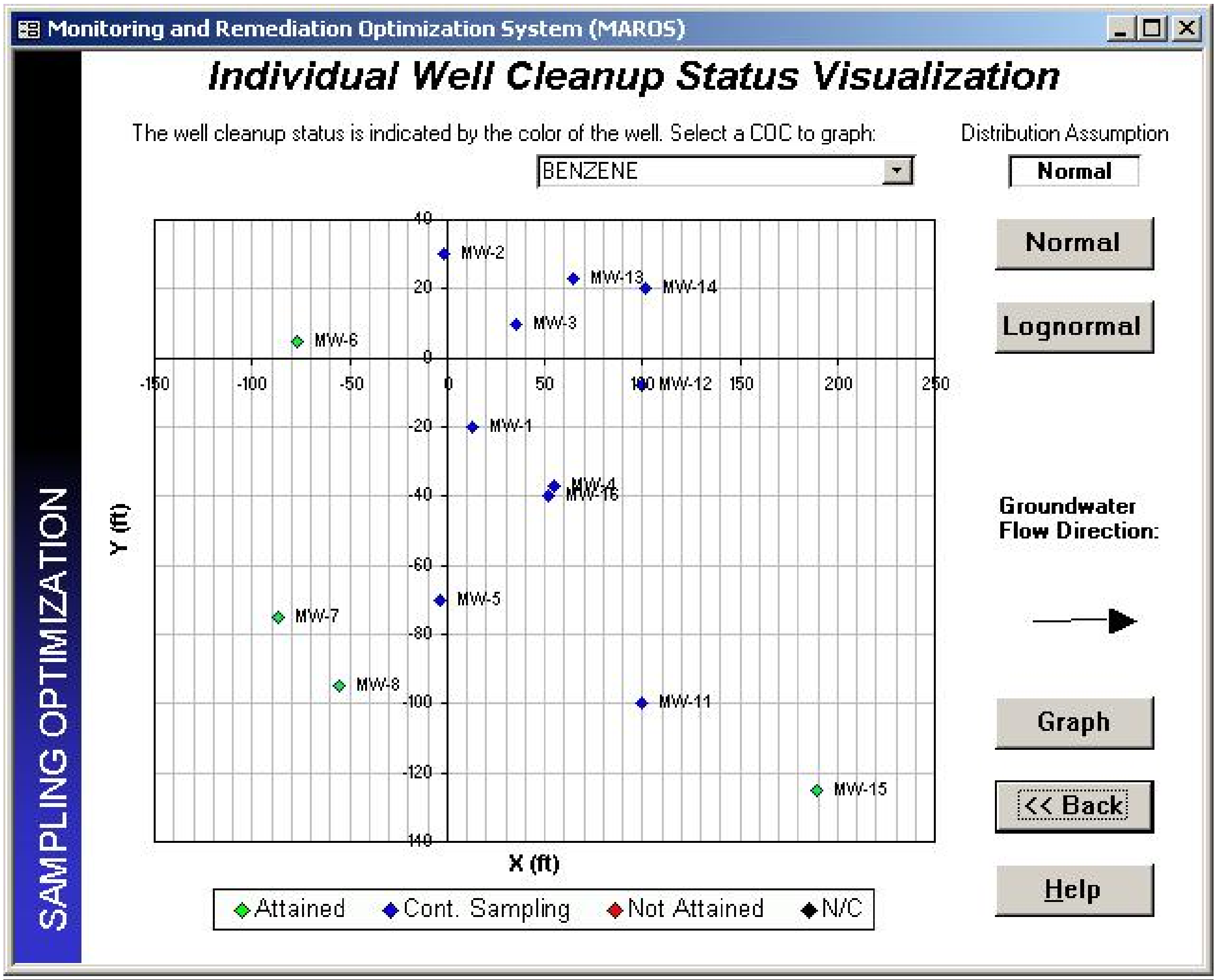
Online/Freeware availability

http://www.gsi-net.com/en/software/free-software/maros.html

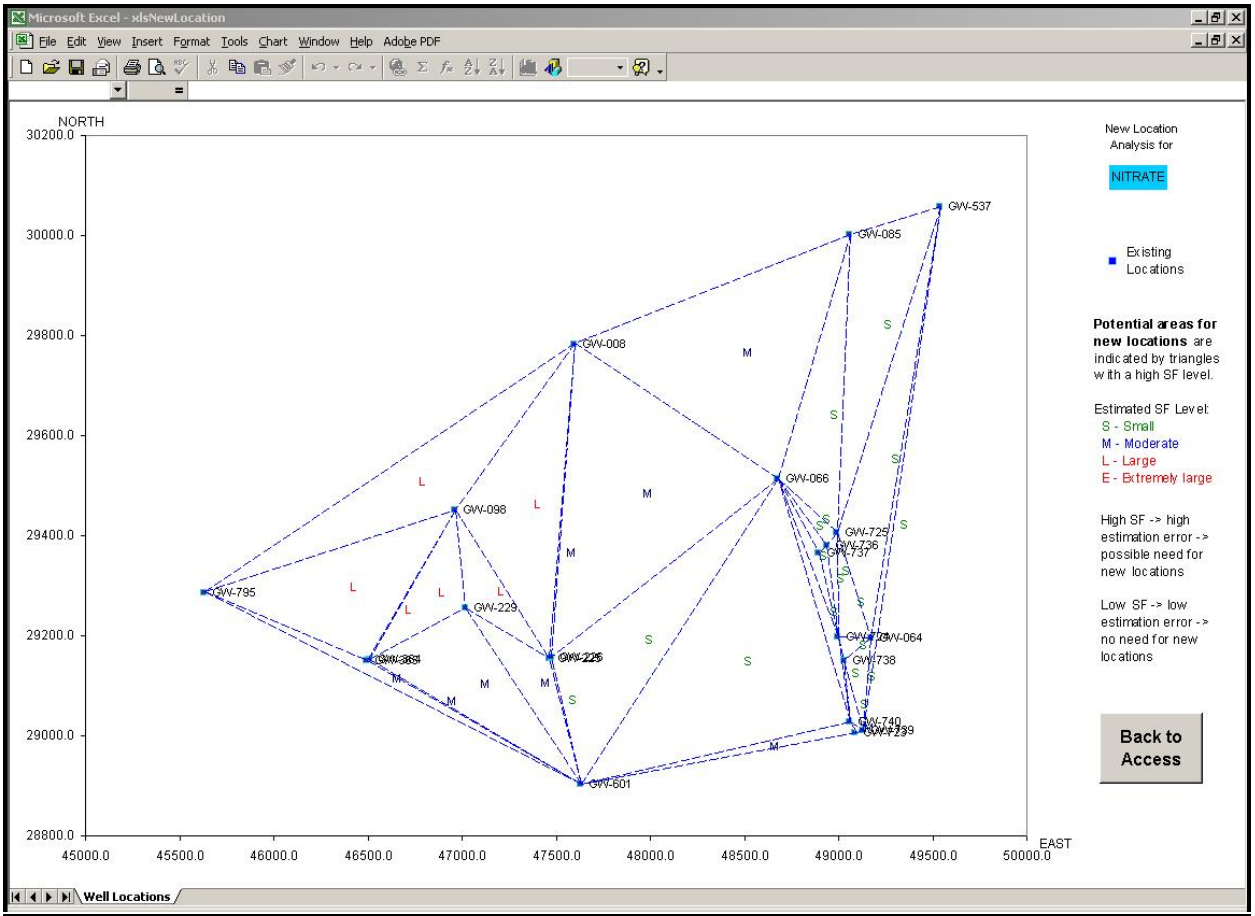
Example Output




Monitoring and Remediation Optimization System (MAROS)
TREND ANALYSIS
Mann Kendall Plot
Select a well and chemical below to graph. The concentration trend result in the box below reflects the chemical and well chosen to be graphed.
Select:
Well
MW-11
Chemical
BENZENE
Graph Type
Log
Linear
Date
Mar '90
Sep '90
Jul '91
May '92
May '96
Dec '97
Dec '98
Dec '99
Jun '01
Jun '03
Concentration (mg/L)
7.0E+00
6.0E+00
5.0E+00
4.0E+00
3.0E+00
2.0E+00
1.0E+00
0.0E+00
Graph
View Data
MK (S):
86
Confidence in Trend:
99.9%
MK Concentration Trend:
I
COV:
0.61
Note: Increasing (I); Probably Increasing (PI); Stable (S); Probably Decreasing (PD); Decreasing (D); No Trend (NT); Not Applicable (N/A) - due to insufficient data.
<< Back
Next >>
View Report
Help



Monitoring and Remediation Optimization System (MAROS)
Individual Well Cleanup Status Visualization
The well cleanup status is indicated by the color of the well. Select a COC to graph:
BENZENE
Distribution Assumption
Normal
Normal
Lognormal
Groundwater Flow Direction:
Graph
<< Back
Help
SAMPLING OPTIMIZATION
Y (ft)
X (ft)
MW-2
MW-13
MW-14
MW-3
MW-6
MW-12
MW-1
MW-4
MW-16
MW-5
MW-7
MW-8
MW-11
MW-15
Attained
Cont. Sampling
Not Attained
N/C



Sources

GSI Environmental, Inc., Air Force Center for Engineering and the Environment, Monitoring and Remediations System (MAROS), User's Guide and Technical Manual, September, 2012